2006 Stream EC trends for inland New South Wales

Department of Environment & Climate Change NSW

Acknowledgments

Dr. Greg Summerell for advice on the use of catchment characteristics. Mark Mitchell for advice on the hydrogeology of the Murrumbidgee Valley. Geoff Beale for general advice throughout the project.

The previous work on the application of Generalised Additive Models to trend estimation by Richard Morton is acknowledged. Hugh Jones (DECC) and Dr Amrit Kathuria (since moved to work for NSW DPI) gave of their time and statistical expertise via discussions on formulating the key statistical steps and methodology for this analysis, and its implementation within the S-PLUS software package.

Prepared by:

Frank Harvey, Wagga Wagga Research Centre
Terry Koen, Cowra Research Centre
Michelle L Miller, Wagga Wagga Research Centre
Sarah J McGeoch, Wagga Wagga Research Centre

Published by:

Department of Environment and Climate Change NSW
59–61 Goulburn Street
PO Box A290
Sydney South 1232

Phone: (02) 9995 5000 (switchboard)
Phone: 131 555 (environment information and publications requests)
Phone: 1300 361 967 (national parks information and publications requests)
Fax: (02) 9995 5999
TTY: (02) 9211 4723

Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

In April 2007 the Department of Natural Resources became part of the Department of Environment and Climate Change NSW.

ISBN 978 1 74122 870 0
DECC 2009/55
February 2009

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Abstract

This study was undertaken to quantify electrical conductivity (EC) trends in 92 river tributaries in inland NSW. The statistical approach used is a variation of the methods detailed in Jolly *et al.* (1997) and Morton (2002), and examined a number of models of varying complexity which attempted to quantify EC trend. Most successful was a Generalised Additive Model that proposed the natural logarithm of EC as a function of the combined effects of a spline function of the logarithm of instantaneous flow, a seasonality term within years and a spline function of time.

Two trend indicators were used: a linear trend (on $\log_e$ scale) and a cyclical component that quantified the amplitude of the trend cycle. As well as aiding in the prediction of EC behaviour, these 2 factors were linked to a number of catchment characteristics to explain EC processes.

Foreword

This report has evolved from a draft report entitled ‘Stream EC Trend Analysis for Six Valleys in New South Wales’, which was reviewed in September 2005 by Associate Professor Rodger Grayson, Professor David Fox, both of Melbourne University, and Peter Evans, of Environmental Hydrology Associates. We gratefully acknowledge the reviewers’ advice.

This report has been expanded to include most of the reviewers’ recommendations. A notable exception is an investigation into the early years of the data collection program, which was outside our capacity. Since the review, the report has been expanded to include a number of additional catchments in the Upper Murrumbidgee, Castlereagh and Macquarie valleys, prompting a renaming of the report. We gratefully acknowledged David Hohnberg and Chris Burton (senior natural resource officers) for editing the data from the additional sites and using it to produce outputs for the S-PLUS models. Chris also provided useful background information on the Macquarie Valley and made several suggestions that have been incorporated.

Sandy Grant provided the maps.

1 Introduction

One approach to assessing the health of landscapes involves evaluation of the quality of the stream networks that drain them. Gauging stations near catchment outlets are convenient locations to monitor processes occurring within a catchment. In theory, the outlet data—flow and electrical conductivity (EC)—can flag salinisation due to changes in land use and water table levels, as well as the impacts of remediation.

1.1 Previous work

In recent decades, a number of reports have alluded to the growing salinisation crisis within the Murray–Darling Basin (MDB) and have used EC data collected at catchment outlets as an indicator of landscape health. The overall conclusion is that there were generally rising trends across the basin, and in some places these trends were substantial (Williamson *et al.* 1997). At some locations, there was an indication that the trends were cyclic in behaviour (Jolly *et al.* 1997).

Many of the long-term gauging stations used in previous studies are located on larger catchments (>10 000 km^2). Consequently, their analyses may reflect wider regional groundwater salinity responses, and thus mask localised water table responses. Many of the long-term sites are located on regulated streams, whereby any EC trends analysis is potentially complicated by EC retardation within dam storages.

Despite the pessimistic outlook on salinity, 4 recent investigations raise questions about the spatial extent and magnitude of the rising trend.

Jolly *et al.* (2001) applied a flow-weighted trend analysis to 87 sites in the MDB. This took the form of a statistical model which included spline functions of flow and time. The authors categorised these sites into 4 zones. In Zones 1 and 4 (in the north and west of the basin), they found no evidence of a significant rising trend. However, they noted that other studies had predicted future problems of rising water tables and accompanying salinisation in these zones. In Zone 2, the Southern and Eastern Dryland Region (>500 mm/y), half of the catchments showed a significant rising stream salinity trend, whereas only 3 showed a fall. Impacts were minimal in catchments where the rainfall exceeded 800 mm/y, but rising trends were in the 500–800 mm/y band. Zone 3, the Irrigation Region (<500 mm/y), in the lower reaches of river systems, showed significantly rising trends at 44% of sites. Jolly *et al.* also proposed an idealised concept, whereby catchment EC might achieve a new equilibrium (albeit increased) with the passing of time. How quickly this occurs depends on the amount of catchment rainfall.

Harvey and Jones (2001) investigated EC – instantaneous flow relationships using discrete EC samples taken from 4 gauging stations in the mid Murrumbidgee Valley. Using a flow spline technique, they noted that the rising trend in stream salinity at these sites appeared to have paused in the early 1990s. Cresswell *et al.* (2003) investigated salinisation of the Kyeamba Valley, in the southern rangelands of NSW. In weighing up the evidence, they concluded that the groundwater table was in ‘dynamic equilibrium’. Beale *et al.* (2001) calculated noticeable negative trends in several of the catchments that they analysed in the Hunter Valley.

The above works and their conclusions have substantially influenced the statistical approaches, as well as the choice of sites, in this study. Further, Jolly *et al.*’s (2001) concept of dividing the basin into zones prompted us to investigate the link between stream EC behaviour and catchment characteristics. We did this to expand the zone concept. A number of works have looked at the link between geography and catchment health. One of these (Dowling *et al.* 1998) has been used as the basis for generating several of the catchment characteristics used in this study.

1.2 General approach of this report

In developing a strategy, we decided that the scope of the investigation was much wider than the calculation of EC trends. This work consequently incorporates an evaluation of the various data systems, as outlined in Annexure A.

1.2.1 Investigation criteria

Jolly *et al.* (1997, 2001), Beale *et al.* (2001), Harvey and Jones (2001) and Cresswell *et al.* (2003) either suggest a respite in the previously estimated rising EC trend, or identify geographic areas that are not experiencing a rising trend. The purpose of this work is to build on the existing knowledge, evaluate the readily available information, and identify possible causes of salinity trends.

Possible explanations for the previously identified salinity trends are:

- changes in data collection procedures
- changes in archiving procedures
- climate changes
- land use changes.

1.2.2 Site criteria

The report confines itself to inland NSW (Figure 1). Some study catchments are contained within others.

In attempting to quantify EC trends in NSW (from the late 1960s to the present), we decided to focus on unregulated tributary streams with instantaneous flow records. Where possible, these monitoring sites were chosen to represent a wide range of catchment conditions, such as annual rainfall, elevation and vegetation. There were 92 sites from 8 inland valleys (Figures 2, 3).

1.2.3 Data criteria

EC data in the form of discrete EC samples were downloaded from the Department of Water and Energy's (DWE)[1] TRITON archive and underwent a rigorous review. (The term 'discrete' is used here to describe grab samples sent to the laboratory for analysis, as well as automatic and rising stage sampling and portable meter readings.)

The EC data in TRITON were collected under several programs using a variety of collection and measuring techniques. The earlier record (late 1960s to early 1990s) was collected as part of a hydrographic program, with occasional independent check measurements. The data quality assurance process flagged likely systematic errors in the earlier TRITON records. The matter has been investigated and is reported in Annexure A. Only after extensive editing were the discrete sample data sets used to quantify the trends.

Time-series EC data, collected using *in situ* probes, was reviewed but not used in this report. We concluded that for this study, time-series data could be used only qualitatively in its present form. There were difficulties associated with using time-series EC data quantitatively, not the least being that the data was unedited. These matters are described in Harvey 2006 (in preparation).

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[1] Previously Department of Natural Resources (DNR); Department of Infrastructure, Planning and Natural Resources (DIPNR); Department of Land and Water Conservation (DLWC); Department of Water Resources (DWR).

Figure 1. NSW map showing the 8 valleys investigated in this report.

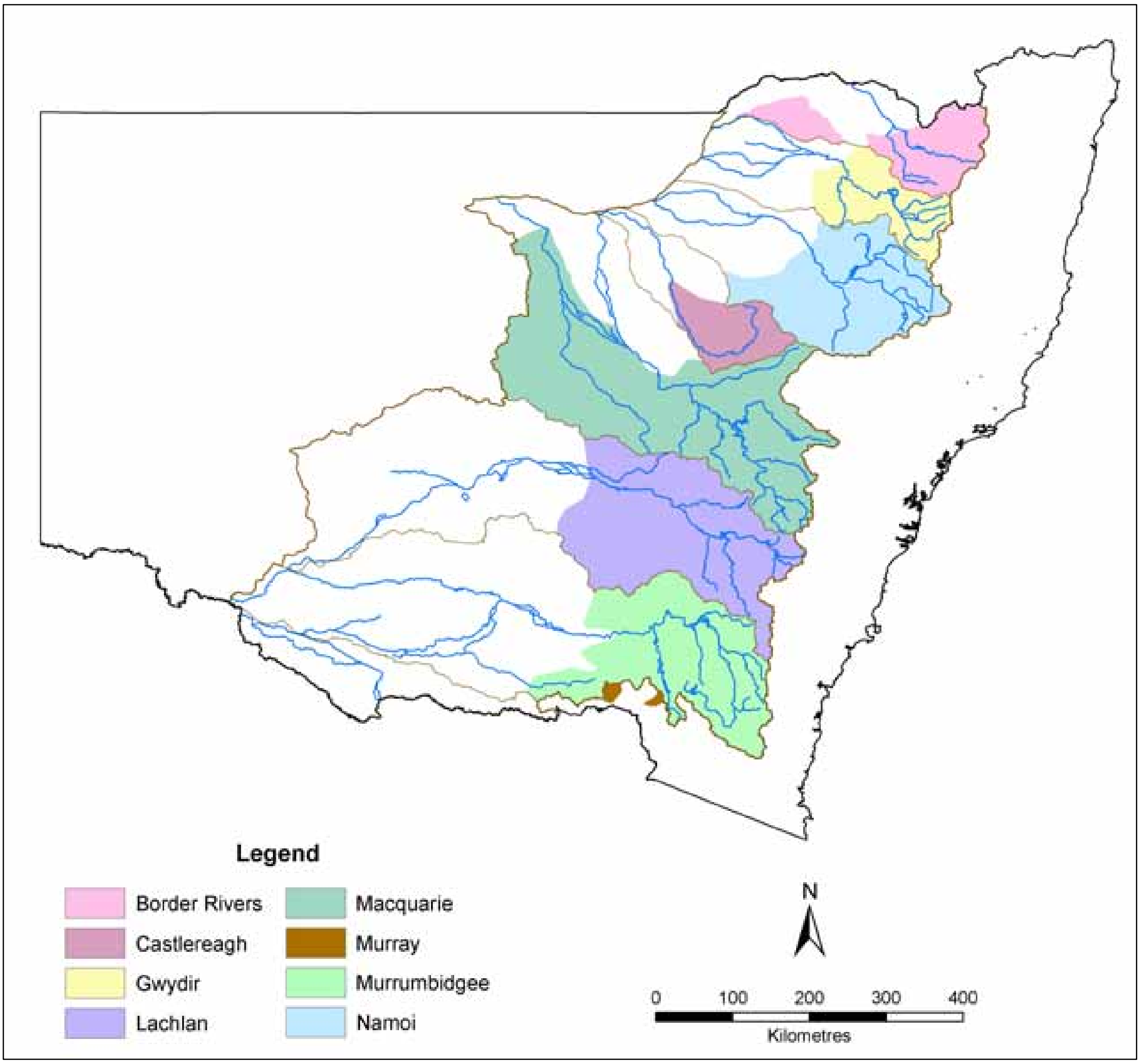


Figure 2. The 49 catchments that comprise the study sites in the southern half of NSW.

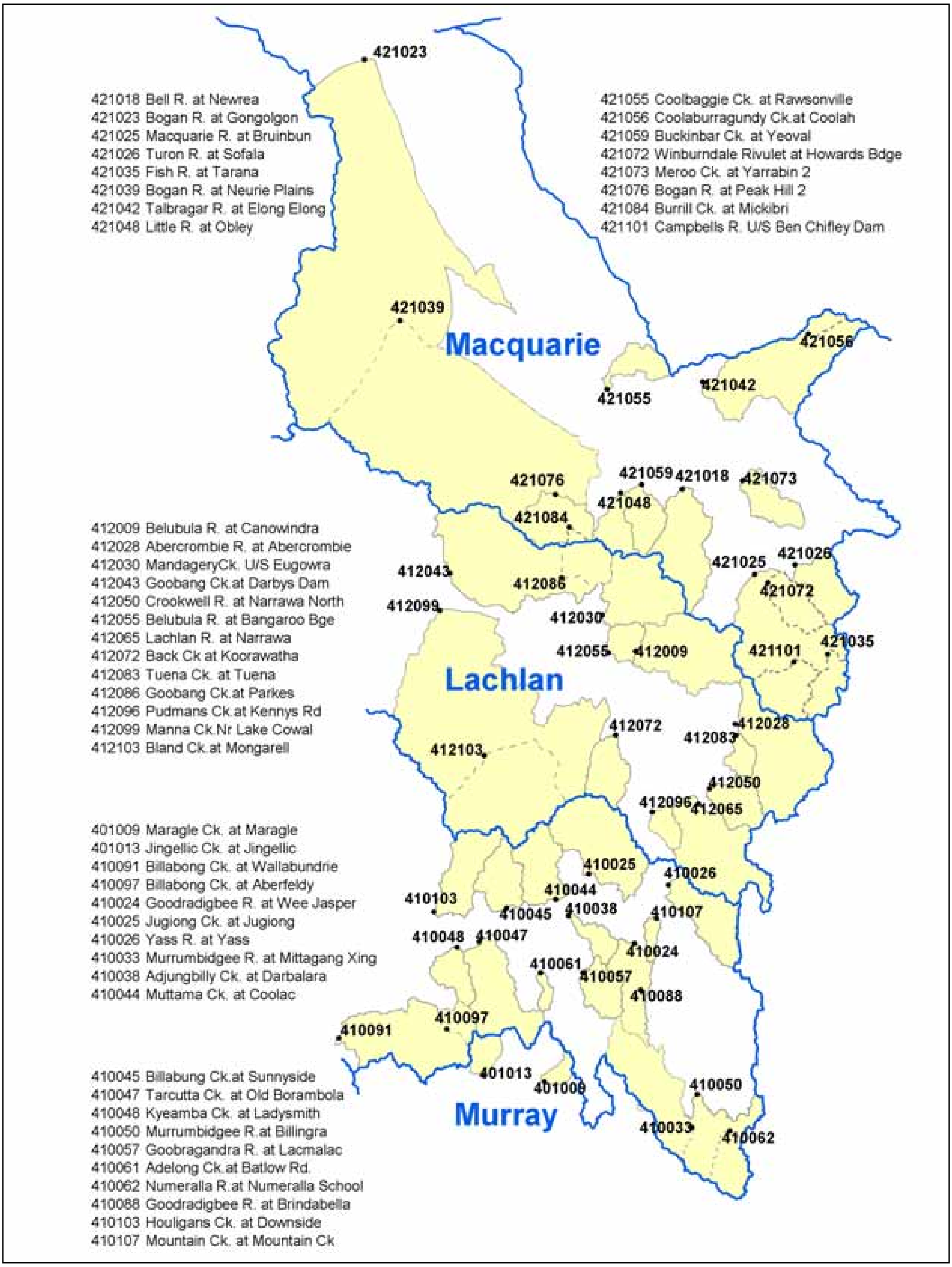
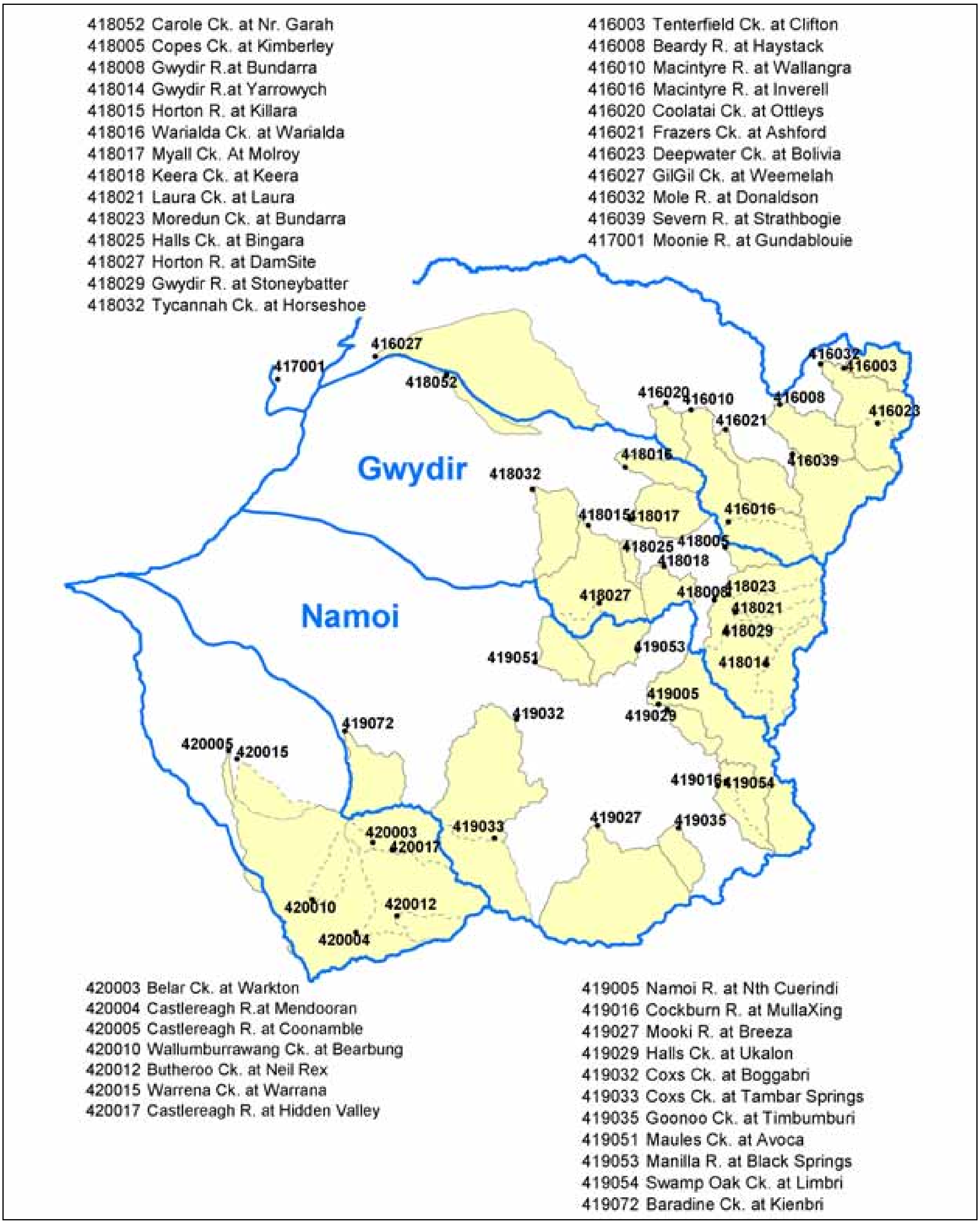


Figure 3. The 43 catchments that comprise the study sites in the northern half of NSW.

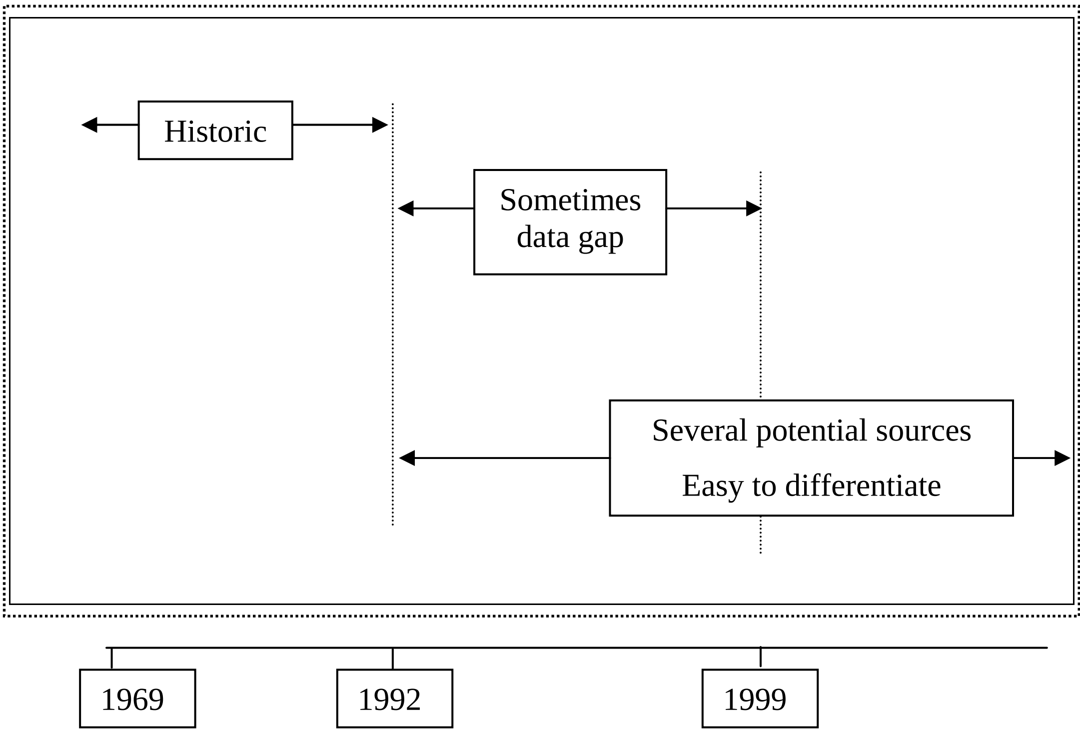


2 Data

2.1 Background

As a starting point to identifying the causes of salinity trends, the EC data-gathering and archiving process needs to be confirmed as reliable. The DWE data archives have been collected sporadically under a number of different programs. It is possible that our decisions taken as part of the data vetting process could influence the trend calculations. In that context, the editing process is considered just as important as the choice of the statistical methods. To undertake the editing effectively, we reviewed the archive as several separate collection systems (Figure 4).

Figure 4. Schematic diagram of discrete sample collection program.



The first EC data collection system is called ‘historical’ in this document. It generally covers the period from the late 1960s to 1992–93. It coincides with a period identified in many studies as having a pronounced rising EC. In most cases, the data originated from samples collected by departmental hydrographic teams during routine gauging station visits. The historical sampling program was under the control of 3 district offices—northern (Armidale), central (Sydney), and southern (Tumut).

The early data collection methods, analysis, and archiving procedures evolved in slightly different ways at each office. This report deals with the evolution of the Tumut and Armidale data, and covers 6 valleys—Border Rivers (Macintyre), Gwydir, Lachlan, Murray, Murrumbidgee and Namoi. The Macquarie and Castlereagh data were not investigated for systematic errors by us.

From 1993 onwards, the management of EC sampling changed. At many sites, sampling ceased until the late 1990s. A few stations were sampled relatively intensely by grab sampling, rising stage sampling, automatic sampling and portable meter readings over a 2-year period. From 1999, most of the sites used in the study were being monitored by at least 1 sampling program.

The sporadic evolution of the program and diversity of collection approaches have raised questions in this study. For example, is it worthwhile to include marginal data of doubtful quality in order to extend the dataset by several years? We examined each valley as a unique data collection system, and then each station in turn. There was an opportunity to evaluate ‘systems’, but there was insufficient time available to evaluate the work practices of individual staff members.

2.2 Historical EC dataset—(late 1960s to early 1990s)

Routine hydrographic visits to gauging stations usually occurred every 6 weeks or 3 months, with the occasional extra visit to gauge high flows. This means that the historical data set follows a regular pattern. From time to time, gaps appear in the historical record, but in the south of NSW, this is the exception rather than the rule. At the sites used in the Murrumbidgee and Murray valleys, the historical data set generally started in 1969 and finished in the early 1990s. However, at some of the Lachlan Valley sites, it starts a year earlier but cuts out as early as 1987.

A close examination of the historical EC records in TRITON revealed curiosities. In some instances, there was more than one EC value registered on a particular date. The database provided no clarification, flagging the source of the sample analysis as unknown. A preliminary investigation suggested that most of the EC data points during 1969 to 1975 may have been underestimated. This in turn suggests that any rising trend calculations based on the TRITON database might be overestimated. The evidence supporting the existence of the bias is included in Annexure A. It was outside the scope of this study to entirely resolve the database issues, but the implications are discussed in Annexure A.

We planned to examine the Castlereagh and Macquarie sites in a similar way. However, the old hardcopy records could not be easily found. Also, we understood that there was no dual measuring program, because the samples were all transported back to the Sydney laboratory, which was the only measurement location for the 2 valleys.

2.3 Recent EC dataset (1993 to present)

2.3.1 Discrete sampling

After the historical collection program terminated, EC measurements ceased at many gauging sites for about 6 years. There were several exceptions (particularly in the mid Murrumbidgee Valley, where sampling intensified). When regular discrete sampling re-emerged in the late 1990s, the management system had proliferated to a much larger number of locations. This in turn resulted in a variety of sampling methods, frequencies and data quality. For simplicity, the new program is tagged as ‘recent’ in this report. This period of record in the TRITON database has proved the most difficult to review. The quality of the portable meters for measuring EC, the rigour of the meter testing process and the maintenance of standard test solutions vary from office to office. A variety of collection techniques (discussed next) have produced data of varying accuracy.

2.3.2 TRITON (laboratory)

The data in the TRITON database that have been flagged as being ‘laboratory’ analysed are automatically considered suitable for this study. We assume that there are rigorous standards in the collection and analysis of these data.

2.3.3 TRITON (field)

The data flagged as ‘Field’ in TRITON are measured with portable meters in the field, and their accuracy depends on local office protocols. In some instances, the procedure entails adjusting the instrument as part of the checking process. It is difficult to track the impact or significance of the changes.

2.3.4 Instrument hydrographer (Tumut)

Data were obtained from the DWE's HYDSYS database and Tumut office calibration sheets. The instrument hydrographer is an officer based at Tumut and is responsible for the calibration and accurate deployment of *in situ* EC probes used to provide time-series data. He has extensively evaluated the behaviour of instruments and has a number of accurate instruments at his disposal for comparison. We assume that the measurements he takes during field tests are accurate. Time did not permit an investigation of the equivalent database at Armidale.

2.3.5 Hydrographer portable meters

Data were obtained from the HYDSYS database. The study stations were chosen because they provide flow as well as EC data. Such sites involve routine hydrographic visits. If time-series EC data are collected, then check measurements are undertaken, and these data are available on the HYDSYS database. The instruments used are specifically purchased to measure EC. The disadvantage of this particular system is that not all instruments have calibration documentation.

2.3.6 Rising stage and automatic sample sequences

Over 1992 to 1994, intensive sequence sampling and grab sampling occurred at 4 sites in the Murrumbidgee Valley: 410025 Jugiong at Jugiong, 410044 Muttama at Coolac, 410047 Tarcutta at Old Borambola and 410048 Kyeamba at Ladysmith. All of the samples were analysed in the laboratory. We decided to use the individual grab samples, and to use only 1 sample from each sequence. In the case of automatic sample sequences, this was usually the mid-sequence sample. For the rising stage samples, we adopted the EC value associated with the highest flow.

2.4 Time-series

The time-series data stored in the HYDSYS database are mainly unedited. Their suitability for use in a trend analysis is unknown. We carried out a number of checks to see whether we could quickly edit the data. The data from 10 southern sites are reviewed in Harvey 2006 (in prep.). We concluded that the process of editing would be too time-consuming if the study deadlines were to be achieved. The time-series could be used qualitatively (if needed) to examine the EC characteristics of individual catchments.

2.5 Amalgamation of various EC data systems

The strategy for prioritising the suitability of data since 1992 is as follows:

- Time-series EC (Section 2.4) was not used quantitatively because it was not sufficiently edited (Harvey 2006, in prep.).
- To match the historical record collection frequency, we set a target of 8 to 12 discrete samples a year from the 'recent' record. In most situations, this meant that there was seldom more than 1 data point each month. (For the purpose of comparison with an earlier study, this rule was overlooked at 4 of the sites.)
- Use rising stage and automatic sample sequence data, but cull as per Section 2.3.6.
- Use all laboratory-analysed data as highest priority.
- Use the Tumut instrument hydrographer's data where available, as priority 2.
- Consider hydrographer portable meter reading (if calibration documentation is available).

- Lower priority—data classified ‘field’ in TRITON.
- Lower priority—hydrographic portable meters without calibration documentation.

At some sites, the recent record has 1 source only, for example 410061 Adelong at Batlow Road. At other sites, choice is not an issue. For example, at 410091 Billabong at Walbundrie, there is sufficient laboratory data to fulfil frequency requirements, and the other data types were not required for the analysis. At many sites in the north of the State, ‘field’ was conveniently accompanied by laboratory analyses. In such cases, the ‘field’ sample was dropped.

Others undertook the editing and program runs for the Castlereagh, Macquarie and Upper Murrumbidgee and supplied the results to us. The editing procedures are listed in Section 12.

2.6 Groundwater data

We considered including groundwater information in the statistical analysis. In the early stages, it was decided not to, because the process would involve extensive evaluation of numerous bores as a prelude to any editing. At most sites, bore depth measurement frequencies were generally monthly or longer. At a later stage of the study, a method of interpolating these data was developed. Interpolated ground water levels could then be synchronised with the stream EC measurements. The interpolation technique did not reflect short-term fluctuations, but it reflected long-term water table trends.

Another factor worked against the use of bore data. Efficient comparison of the gauging station and groundwater data depends on both being surveyed to a common datum. Without the surveyed information, it is difficult to assess when the deep groundwater tables begins to affect the stream network. Without a common datum, it is difficult to assess the water table gradient between bores.

As a pathfinder investigation, we tried to link the bore data with the stream EC analysis from 8 gauging stations, 4 in the mid Murrumbidgee and 4 in the Namoi. The details are described at the end of the Results section (Section 7.2).

2.7 Catchment characteristics

Jolly *et al.* (2001) divided the basin into zones. Their concept prompted us to wonder whether the stream EC behaviour could be linked to various catchment parameters. We generated several different characteristics listed below from various geographic information system databases with a view to linking them to catchment EC behaviour.

2.7.1 Elevation at the gauge

The elevation (in m) at the gauging station was measured from a 25-m raster-based digital elevation model (DEM) derived from contour mapping. The numbers produced by this method were used as the default. However, at many sites the gauges had been surveyed to the Australian Height Datum (AHD), and the value of the gauge zero could be used as the stream elevation. If the difference between the DEM and surveyed results was large, then we used the AHD value.

2.7.2 Mean annual rainfall

Mean annual rainfall (mm) was calculated from the Queensland Department of Natural Resources and Mines’ SILO dataset (www.nrm.qld.gov.au/silo), in which daily climatic data from 1956 to 2002 have been interpolated over a 5-km grid. The data in SILO were originally sourced from the Australian Bureau of Meteorology. The mean annual rainfall in each catchment was derived from the rainfall values at a number of grid points within the catchment boundaries.

2.7.3 Catchment forested (as a percentage)

The Australian Land Cover Change dataset (BRS 2000) was used to indicate the percentage of catchment covered by ‘plantation’ and ‘other woody’ species in 1995.because it contained the most recent data that covered all of NSW.

2.7.4 UPNESS midpoint

‘UPNESS’ is derived from digital elevation data, and is defined as the accumulation of upslope area at any given point’ (Summerell *et al.* 2005). The ‘midpoint’ is derived objectively from the first inflection point in the normalised cumulative distribution curve of the FLAG UPNESS index (Summerell *et al.* 2005). In this study, the midpoint value has been used to classify the catchment according to the dominant landforms of steep, even, and flat. The UPNESS value at the midpoint will be lower for steep catchments and greater for open and undulating catchments.

2.7.5 Average slope

The average slope of the catchment was calculated as part of the hypsometric program (Dowling *et al.* 1998) using contour information from the 25-m DEM. The units are angular degrees.

2.7.6 Hypsometric integral

There were several steps as a prelude to the calculation of the hypsometric integral:

(a) Collation of average slope (Section 2.7.5).

(b) Selection of the elevation contour interval for hypsometric analysis: the smaller the contour interval, the more detailed the analysis. We used 10 m in all catchments, following the methodology of Dowling *et al.* (1998).

(c) Calculation of minimum and maximum elevation as a prelude to the hypsometric program (Dowling *et al.* 1998) from the 25-m DEM of the catchment.

Hypsometric (area–altitude) analysis gives a dimensionless parameter that relates the horizontal cross-sectional area of the drainage basin to the relative elevation above the basin mouth. It is said to measure the erosional state or geomorphic age of the catchment (Strahler 1952, Dowling *et al.* 1998), and has been used in this report as an indicator of catchment verticality. The hypsometric integral allows comparison of catchments regardless of area, and is independent of the absolute height of the catchment above sea level. Mathematically, the integral is the area under the hypsometric curve drawn on axes of relative height and relative catchment area. Its values range from 0 to 1, where lower values have been interpreted by Strahler (1952) to represent older eroded landscapes and higher values to represent young, less eroded landscapes.

2.7.7 Mean EC

This value represents the arithmetic mean of the EC sample data set. Not being flow-weighted, it was vulnerable to bias, but was considered useful as a possible indicator of trend.

3 Input Dataset

3.1 Final preparation of data

3.1.1 Low flows

The instantaneous flow data used in the study came from the DWE HYDSYS database. Sometimes this information had not been generated in HYDSYS, and it was necessary to go back through the hardcopy record to view the gauging measurement data. If the gauged flow was estimated and was very low, we considered excluding it.

3.1.2 Typographic errors

In preparing data sets, we compared the hardcopy record with the TRITON data. Some of the contradictory data were typographic errors.

3.1.3 Outliers

The dataset from each station was prepared in Microsoft Excel before the S-PLUS script (Appendix 6) was run. By plotting the natural logs ($\log_e$) of EC against flow, we could easily identify potential anomalous points. These plots were quickly reviewed, and any anomalies were checked against the data set. On the rare occasions that different sources gave contradictory information, we used the option that plotted better. Otherwise, the outlier was included in the analysis.

3.1.4 Dual data sets

As discussed in Section 2.2, we identified a possible bias in the historical EC record. The details are covered in Annexure A. In the Macquarie and Castlereagh, there was no evidence of a bias. In the Murray, Murrumbidgee and Lachlan, there was insufficient evidence to warrant the use of an altered data set, although it was likely that the EC data for the first few years may have been underestimates. In the Macintyre, Gwydir and Namoi, sufficient evidence existed to warrant an adjustment of +10% to the EC data from the start of the record to 1977 inclusive (Annexure A). *These changes have implications for the study conclusions, because they decrease the trend slopes at all sites in these 3 valleys.*

Despite having made the definitive decision about data adjustment, we decided to run both data sets through the statistical package (S-PLUS) for all valleys except the Macquarie and Castlereagh. One set was based on the original data, and the other was corrected in the earlier years of record as per Annexure A. This dual run was not time-consuming, but was necessary because the implications of the adjustment could not be assessed until the outputs could be compared.

3.2 Characteristics of input data

We analysed data from 92 gauging stations (Figures 2, 3). With the exception of the 2 sites on the Belubula River, the sites were unregulated. Thirteen of the study sites were subcatchments of larger sites. The sampling frequency was low, and the data points might not be sufficiently representative of the flow range at each station.

Table 1 provides some perspective as to whether the EC samples are taken from a representative flow range at a particular site. It also provides information on the flow behaviour at a particular site.

The instantaneous flows associated with a specific percentile have been calculated using HYDSYS, and have been generated using hourly instantaneous flow.

Two percentile values are presented. The **time-weighted** percentile is the percentage of time that a particular flow is exceeded. The **flow-weighted** percentile is the percentage of total volume that has been recorded whenever a particular instantaneous flow has been exceeded. It is based on the total volume of flow that has passed the site throughout its life. For example, at station 401009, the instantaneous flow of 672 ML/d is exceeded **2% of the time** (Column 9). Flows above 2480 ML/d represent **2% of the total volume** that passes through the site.

Table 1 provides useful background information on flow behaviour. Columns 3 and 6 list the minimum and maximum instantaneous flows (ML/d). As can be seen from Column 3, flows at many of the sites stop. Column 8 gives a guide to the ephemeral nature of some streams: a zero indicates that there is no flow for at least 50% of the time. Although the time-weighted percentile is a good ephemerality indicator, much of the range may be represented as zero flow. The flow-weighted percentiles are a more sensitive guide because the periods of zero flow are not considered in the calculation.

Table 1 has been used to indicate how representative the EC sampling has been over the site flow range. Column 11 lists the lowest flow associated with an EC sample. Column 12 is the flow-weighted percentile associated with Column 11. It describes where the lowest sample flow fits into the low flow regime. A small number is an indicator of good coverage; in most cases, the Column 12 value encompasses the lower end of the flow regime.

Columns 13 to 15 demonstrate the statistics of the highest flow associated with an EC sample. Column 15 indicates how often the flow is above the sample data set. For example, at site 401009, the highest flow associated with an EC sample is exceeded 2% of the time. On superficial examination at least, the sample data set encompasses the station flow regime most of the time. This suggests that the data set might be a good guide for assessing EC thresholds, where the 'number of days exceeded' is the appropriate indicator.

From the perspective of salt-load calculations, the coverage is not as good. Column 14 represents the percentage of the flow distribution not covered by the data set. The higher the percentile, the smaller the flow range encompassed by the EC sampling. At site 401009, 12% of the flows exceed the sample range.

Table 1. Flow duration data (ML/d) showing the extent to which EC sampling represents flows.

Column 1	Column 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14	Col.15
StationNo.	Station Name	Flow - Weighted Percentile				Time - Weighted Percentile				ML/d	%ile	ML/d	%ile	%ile
Flow Duration Table		100 %ile	50 %ile	2 %ile	0 %ile	100 %ile	50 %ile	2 %ile	0 %ile	Lowest Flow	Flow Weighted	Highest Flow	Flow Weighted	Time Weighted
401009	Maragle Ck. at Maragle	0.00	255	2480	18810	0.00	45.5	672	18810	0.76	100	978	12	2
401013	Jingellic Ck. at Jingellic	0.04	480	7680	16770	0.04	50.0	1150	16770	1.30	100	3550	8	2
410091	Billabong Ck. at Walbundrie	0.47	2200	24400	38370	0.47	80.0	3840	38370	2.26	100	3750	37	2
410097	Billabong Ck. at Aberfeldy	0.14	387	6610	11630	0.14	6.9	489	11640	0.41	100	1450	23	2
410024	Gooradigbee R. at Wee Jasper	7.40	1570	14350	41870	8.17	412.0	4210	41870	20.00	100	4460	16	2
410025	Jugiong Ck. at Jugiong	0.00	875	20840	56200	0.00	49.0	1540	56200	0.01	100	12280	5	1
410026	Yass R. at Yass	0.00	2640	40980	72430	0.00	23.7	2080	72430	0.01	100	41040	2	1
410033	Murrumbidgee R. at Mittagang Xing	*	*	*	*	*	*	*	*	13.00	*	6890	*	*
410038	Adjungbilly Ck. at Darbalara	0.18	495	5760	14250	0.18	101.0	1530	14250	0.36	100	4420	4	1
410044	Muttama Ck. at Coolac	0.00	895	16700	37160	0.00	14.0	1110	37160	0.10	100	5120	14	1
410045	Billabung Ck. at Sunnyside	0.00	955	24220	28960	0.00	0.0	513	28960	0.01	100	6330	20	1
410047	Tarcutta Ck. at Old Borambola	0.00	1430	19110	34960	0.00	151.0	3330	34960	2.10	100	25210	1	0
410048	Kyeamba Ck. at Ladysmith	0.00	817	10500	19300	0.00	1.9	835	19300	0.04	100	16070	1	0
410050	Murrumbidgee R. at Billilingra	0.00	3170	133200	209770	0.00	333.5	6240	209770	1.00	100	18040	19	2
410057	Goobarragandra R. at Lacmalac	10.50	1260	8800	26350	10.50	443.0	3340	26350	15.00	99	4230	9	2
410061	Adelong Ck. at Batlow Rd.	0.00	185	6280	18280	0.00	59.0	589	18280	4.00	100	649	25	2
410062	Numeralla R. at Numeralla School	0.00	3100	63080	75030	0.00	37.9	1920	75030	0.00	100	6900	38	1

*: No or insufficient flow data for the percentile assessment.

Column 1	Column 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14	Col.15
StationNo.	Station Name	Flow - Weighted Percentile				Time - Weighted Percentile				ML/d	%ile	ML/d	%ile	%ile
Flow Duration Table		100 %ile	50 %ile	2 %ile	0 %ile	100 %ile	50 %ile	2 %ile	0 %ile	Lowest Flow	Flow Weighted	Highest Flow	Flow Weighted	Time Weighted
410088	Goodradigbee R. at Brindabella	24.40	771	8220	21340	24.60	242.9	2090	21340	28.00	100	7562	2	2
410103	Houlaghans Ck. at Downside	0.00	674	9570	10000	0.00	0.0	54	10000	0.00	100	10000	0	0
410107	Mountain Ck.at Mountain Ck	0.00	553	8080	20230	0.00	8.0	800	20230	0.20	100	1260	32	2
412009	Belubula R. at Canowindra	14.00	2420	28180	46360	14.00	176.0	5020	46360	7.20	100	14100	15	1
412028	Abercrombie R. at Abercrombie	0.00	3510	88570	218000	0.00	173.0	6280	218000	0.33	100	19980	14	1
412030	Mandagery Ck. at U/S Eugowra	0.00	1140	22100	37400	0.00	31.0	1530	37400	1.10	100	1910	40	2
412043	Goobang Ck. at Darbys Dam	*	*	*	*	*	*	*	*	0.17	*	2830	*	*
412050	Crookwell R. at Narrawa North	0.00	1310	54000	112000	0.00	54.0	2100	112000	0.36	100	12000	12	1
412055	Belubula R. at Bangaroo Bridge	*	*	*	*	*	*	*	*	0.03	*	3110	*	*
412065	Lachlan R. at Narrawa	0.00	2730	69200	103400	0.00	93.0	3750	103400	0.20	100	36600	8	1
412072	Back Ck at Koorawatha	0.00	682	6960	7140	0.00	3.0	312	7140	0.01	100	3900	11	1
412083	Tuena Ck. at Tuena	0.00	694	26320	57400	0.00	11.0	796	57400	0.02	100	3550	20	1
412086	Goobang Ck. at Parkes	0.00	201	4840	5240	0.00	1.8	173	5240	0.02	100	1030	19	1
412096	Pudmans Ck. at Kennys Rd	0.00	714	12700	27600	0.00	8.3	570	27600	0.02	100	9210	6	1
412099	Manna Ck. near Lake Cowal	0.00	11430	23500	23500	0.00	0.0	1770	23500	0.01	100	19800	15	1
412103	Bland Ck. at Morangarell	0.00	2970	18000	20000	0.00	0.0	1330	20000	0.70	100	7200	23	1
416003	Tenterfield Ck.at Clifton	0.00	977	21900	28500	0.00	12.0	859	28500	0.01	100	2740	31	1
416008	Beardy R. at Haystack	0.00	2250	46400	61500	0.00	12.0	1540	61500	0.01	100	5520	33	2
416010	Macintyre R. at Wallangra	0.00	5590	122000	150700	0.00	54.0	2750	150700	0.30	100	6210	48	2
416016	Macintyre R. at Inverell	0.00	1580	68300	133100	0.00	30.0	1110	133100	0.10	100	1840	48	2
416020	Ottleys Ck. at Coolatai	0.02	2650	37700	45100	0.03	4.9	181	45100	0.16	100	1460	60	1
416021	Frazer Ck. at Ashford	0.00	3870	71900	78500	0.00	6.2	1710	78500	0.03	100	2040	62	2
416023	Deepwater Ck. at Bolivia	0.00	425	12400	13700	0.00	25.5	774	13700	0.01	100	1420	30	1
416027	GilGil Ck. at Weemelah	0.00	4840	32050	34000	0.00	50.0	3040	34000	0.10	100	6010	47	1
416032	Mole R. at Donaldson	0.00	1620	63800	143000	0.00	71.0	2593	143000	0.06	100	22800	8	1
416039	Severn R. at Strathbogie	0.00	3350	46500	71400	0.00	66.0	3590	71400	0.42	100	5360	40	2
417001	Moonie R. at Gundablouie	0.00	8190	41000	44700	0.00	0.0	5440	44700	0.06	100	16600	27	1
418005	Copes Ck. at Kimberley	0.00	672	21940	35520	0.00	8.5	534	35520	0.05	100	1340	38	1
418008	Gwydir R. at Bundarra	0.00	26200	247400	400000	0.00	93.0	10550	400000	0.01	100	26600	40	1
418014	Gwydir R. at Yarrowych	0.00	2580	80700	139000	0.00	18.5	1600	139000	0.11	100	9920	30	2
418015	Horton R. at Rider	0.00	8710	199000	242000	0.00	69.4	3660	242000	0.30	100	6180	55	1
418016	Warialda Ck. at Warialda	0.00	1670	18400	23300	0.00	2.7	382	23300	0.01	100	5020	27	1
418017	Myall R. at Molroy with 4/1980	0.08	1720	60000	102500	0.08	10.6	538	102500	0.30	100	834	60	1
418018	Keera Ck. at Keera	0.00	569	37460	65360	0.00	10.7	705	65360	0.16	100	910	41	1
418021	Laura Ck. at Laura	0.00	650	19900	33300	0.00	7.6	632	33300	0.04	100	935	43	1
418023	Moredun Ck. at Bundarra	0.00	1670	28580	30010	0.00	16.6	1360	30010	0.10	100	3630	36	1
418025	Halls Ck. at Bingara	0.06	52	19980	37100	0.06	7.7	73	37100	1.80	99	72	44	2
418027	Horton R. at Dam Site	0.00	2460	66730	95700	0.00	5.1	840	95700	0.01	100	10180	22	1
418029	Gwydir R. at Stoneybatter	0.00	1670	100700	112600	0.00	69.5	2455	112600	0.37	100	4700	31	1
418032	Tycannah Ck. at Horseshoe Lagoon	0.00	4830	55560	57100	0.00	3.2	485	57100	0.10	100	10000	36	1
418052	Carole Ck. near Garah	0.00	580	8260	9940	0.00	62.0	1370	9940	0.10	100	2490	17	1
419005	Namoi R. at Nth Cuerindi	0.00	2430	71800	130000	0.00	161.0	71800	130000	1.10	100	11300	22	1
419016	Cockburn R. at Mulla Crossing	0.00	1960	32900	64500	0.00	24.0	1760	64500	0.02	100	6249	28	1
419027	Mooki R. at Breeza	0.00	16600	144000	158000	0.00	9.5	2710	158000	0.03	100	90600	14	1
419029	Halls Ck. At Ukalon	0.00	324	15200	21140	0.00	6.9	391	21140	0.57	100	1070	25	1
419032	Coxs R. at Boggabri	0.00	17000	111300	115000	0.00	0.0	1320	115000	0.07	100	4890	74	1
419033	Coxs R. at Tambar Springs	0.00	6670	45400	48000	0.00	6.1	307	0	0.30	100	624	74	1
419035	Goonoo Goonoo Ck. at Timbumburi	0.00	1390	33940	43700	0.00	7.9	387	43700	0.12	100	3310	40	1
419051	Maules Ck. at Avoca	*	*	*	*	*	*	*	*	*	*	*	*	*
419053	Manilla R. at Black Springs	0.00	1440	79500	116000	0.00	18.0	580	116000	0.70	100	7280	31	1
419054	Swamp Ck. At Limbri	0.00	743	28320	56900	0.00	7.1	699	56900	0.07	100	1230	39	1
419072	Baradine Ck. at Kienbri	0.00	1270	18500	24340	0.00	0.0	307	24340	0.16	100	2960	35	1
420003	Belar Ck. at Warkton	0.01	255	5720	12920	0.01	4.3	205	12920	0.38	100	4200	5	1
420004	Castlereagh R. at Mendooran	0.00	4980	65290	82730	0.00	26.9	1527	82730	0.03	100	31640	17	1
420005	Castlereagh R. at Coonamble	0.00	5640	57400	61330	0.00	7.8	3380	61330	0.11	100	61160	0	0
420010	Wallumburrawang Ck. at Bearbung	0.00	652	7400	20610	0.00	0.0	238	20610	0.01	100	1750	28	1
420012	Butheroo Ck. at Neilrex	0.00	1580	22000	25840	0.00	0.2	130	25840	0.00	100	622	67	1
420015	Warrena Ck. At Warrana	0.00	1860	6870	7410	0.00	0.0	356	7410	0.00	100	3690	30	1
420017	Castlereagh R. at Hidden Valley	0.00	2415	75380	98450	0.00	12.0	833	98450	0.02	100	3865	43	1
421018	Bell R. at Newrea	0.00	1754	79150	104300	0.00	61.0	2090	104300	0.20	100	17780	15	1
421023	Bogan R. at Gongolgon	0.00	8080	144200	220000	0.00	50.5	8660	220000	0.38	100	46930	63	1
421025	Macquarie R. at Bruinbun	0.00	3970	154400	232200	0.00	249.2	7390	23200	1.58	100	14820	22	2
421026	Turon R. at Sofala	0.00	2040	104900	154200	0.00	36.3	1630	154200	0.03	100	63020	6	1
421035	Fish R. at Tarana	0.00	724	33440	55860	0.00	106.5	1670	55860	0.41	100	2160	21	2
421039	Bogan R. at Neurie	0.00	9080	49600	58200	0.00	0.0	3180	58200	0.02	100	2750	74	2
421042	Talbragar R. at Elong	0.00	2100	42630	65130	0.00	16.0	1170	65130	0.12	100	14640	16	1
421048	Little R. at Obley	0.00	1460	42780	48080	0.00	6.1	840	48080	0.10	100	4080	99	1
421055	Coolbaggie Ck. at Rawsonville	0.00	3830	19510	20670	0.00	0.0	431	20670	0.02	100	15960	4	1
421056	Coolaburragundy R.at Coolah	0.00	181	12400	32100	0.00	8.1	166	32100	0.17	100	617	39	1
421059	Buckinbah Ck. at Yeoval	0.22	14.9	640	1260	0.22	7.4	43	1260	0.08	100	478	3	1
421072	Winburndale Rivulet at Howards Bge	0.00	1275	66210	70350	0.00	43.0	1600	70350	0.40	100	66270	2	0
421073	Meroo Ck. At Yarrabin2	*	*	*	*	*	*	*	*	0.17	*	6680	*	*
421076	Bogan R. at Peak Hill	0.00	2770	28740	29470	0.00	0.0	619	29470	0.93	100	6100	31	1
421084	Burrill Ck. At Mickibri	0.00	327	6630	6380	0.00	0.0	109	8380	0.06	100	310	51	2
421101	Campbells R. atU/S BenChifley Dam	0.00	861	37100	67200	0.00	45.6	1480	67200	0.04	100	4170	21	1

In general, the flow-weighted percentile column (14) suggests that the coverage of the sampling might extend into the high flow range at some sites. This is particularly the case for the data sets from southern NSW. On first view, this might be seen as cause for optimism, because comprehensive representation across the flow range might point to robustness in the development of any mathematical equations. Unfortunately, the following information offsets any illusion that the high flow EC is well represented.

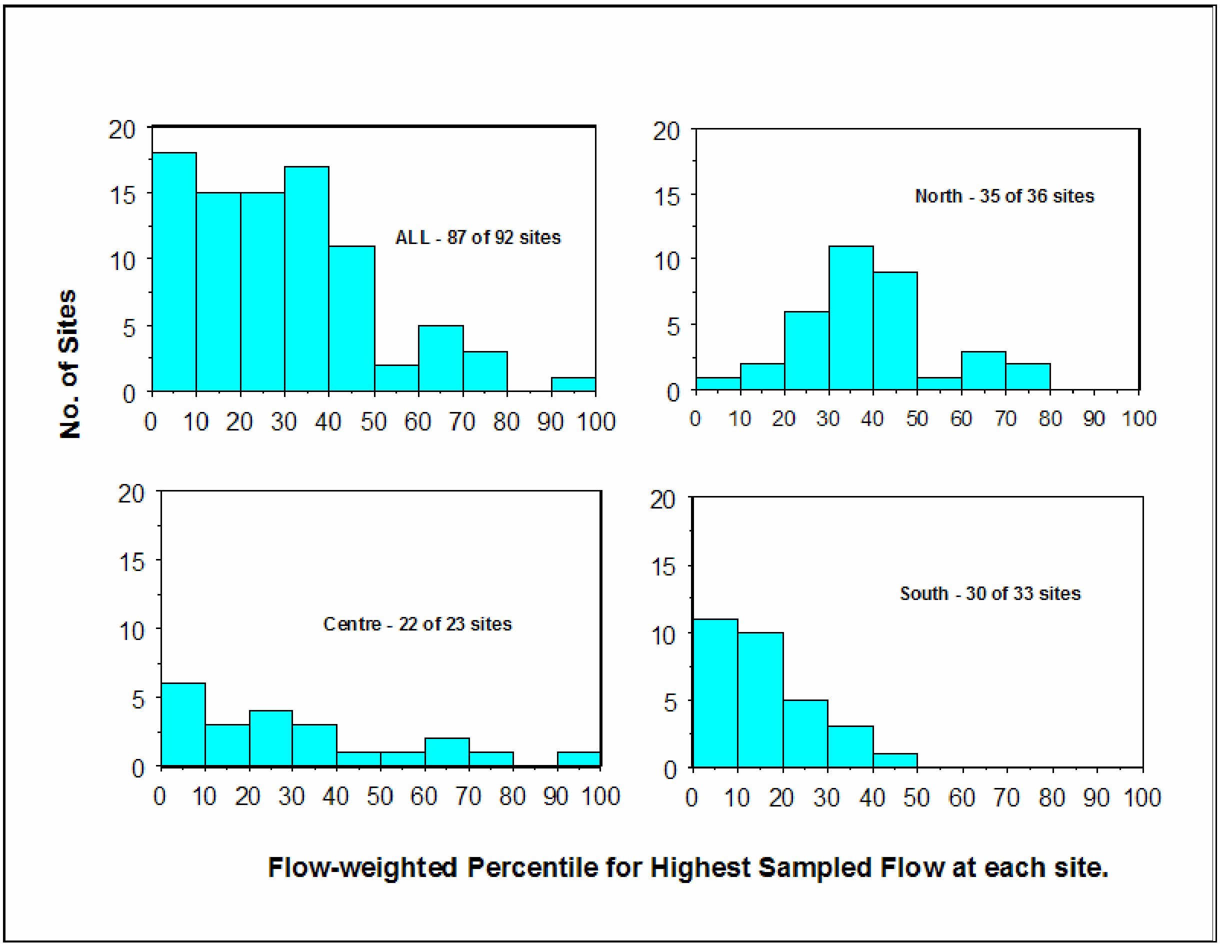
In the early part of this investigation, we hoped to run the trend analysis models for event and base flow separately. As a consequence, the sample sets for 12 of the southern sites were separated into event and base flow, using the separation method described in Harvey and Jones (2001). The percentages of runoff event samples were low, varying from 13% to 34% of the data set at each site. At most sites the event sampling ratio was as low as 1 in 5. It is not clear whether these small percentages are sufficient to adequately extend the EC–flow relationship into the high flow ranges. There must be some optimism that the subsequent trend analysis extends beyond base flow conditions. Base flow data sets have been modelled, and the results are provided in Section 7.1.

To understand how well the high flows were represented in the EC sampling across NSW, we developed histograms showing where the highest sample sat in each flow range. The data are drawn from Column 14. Four bar charts are presented in Figure 5. A small percentile value (on the *X* axis) is an indication of a high flow. The first quadrant covers the whole State, where 87 of the 92 sites have flow duration information. The State has been divided arbitrarily into north, centre and south. The partitioning is based on the old DWR management structure and on the assumption that different strategies may have been used for data collection in each district.

Two aspects of Figure 5 are of interest. If the highest sample flow is in the 0 to 20 percentile range, then there might be a case for claiming an understanding of EC behaviour for high flows at a particular site. A high proportion of the southern sites fall in the 0 to 20 percentile range, whereas few of the northern sites have a high flow coverage.

We also wanted to identify sites with a poor representation of high flow range. The 50 to 100 percentile range indicates no incorporation of higher flows' EC in the trend calculations. There can be little confidence in any results from 11 such sites (none in southern NSW).

Figure 5. Distribution of highest sampled flow as flow-weighted percentiles.



4 Statistical Methodology

4.1 Aim

The aim of this data analysis is to obtain estimates of stream salinity trends that are independent of season of observation and fluctuations in river flow rates and, hence, indicate the impacts of catchment salinisation on stream EC.

4.2 Background

Much of the technical details of the statistical trend analysis performed in this report originate from work developed by Richard Morton, a biometrician in the Mathematical and Information Sciences unit of CSIRO in Canberra.

Early work by Morton (Cunningham and Morton 1983; Morton and Cunningham 1985) concentrated on using time-series analysis to model the salinity trend at stations on the River Murray. Cunningham and Morton (1983) worked on 43 years (517 monthly readings) of chloride data from Morgan, SA. They proposed a model that had deterministic components that included a time trend, together with seasonality and flow measurements. The random component of their model was formed as a first-order autoregressive process. Morton and Cunningham (1985) extended this work when analysing 16 years of monthly EC data from 8 stations on the Murray. Instead of analysing each station in isolation, they developed a predictive model for a downstream station by including data from an upstream station, which effectively accounted for spatial correlation between stations.

Later work (Morton 1997a, b) introduced semi-parametric models for the estimation of trends in stream salinity. The method combined elements of Generalised Additive Models (GAMs) and time-series analysis to account for serial correlation over time. Application of this method can be found in Jolly *et al.* (1997, 2001), Walker *et al.* (1998), Nathan *et al.* (1999) and Smitt *et al.* (2002).

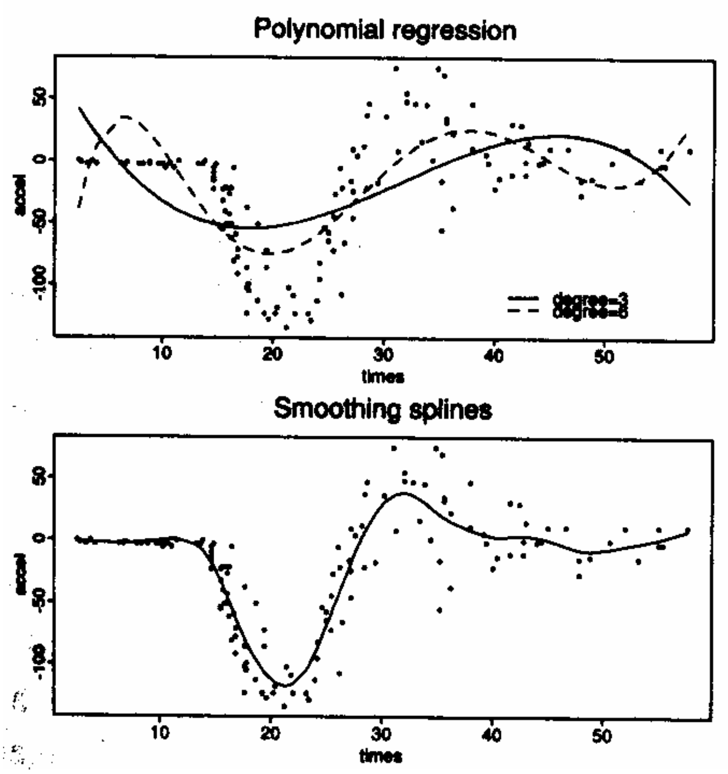
More recently, Morton (2002) provided the NSW Department of Land and Water Conservation (now DWE) with a review of potential statistical methods for the detection and estimation of trends in water quality. They concluded that GAMs are preferable when the trend is non-linear and autocorrelation is present. Morton and Henderson (2002) applied these methods to data originating from DWE's 'Key Sites' project (Preece 1998).

4.3 Formulation of the model

The statistical methods used in the trend analysis exploit semi-parametric regression models. In semi-parametric models, arbitrary smooth curves are fitted in place of parametrically defined curves such as straight lines or polynomials (Figure 6). Models using these curves are commonly referred to as GAMs. The smooth curves are 'non-parametric' in the true sense of the term, in that the smooth function does not have a parametric form. 'Semi' implies that some regression terms may be represented parametrically. Unlike polynomials, spline curves are usually suitable for short-term prediction because they are often straight near the extremes.

Harvey and Jones (2001) reported an example of a flat spline at the EC versus flow extremity. They observed that the low flow regime was not the major driver of EC. Rather, time elapsed after the peak (in days) seemed to have greater affinity with EC.

Figure 6. Comparison of polynomial and smoothing spline curves on irregularly shaped data.



Graphic is copied from Venables and Ripley (1994).

Smooth curves can be estimated by various methods, including splines, kernels and locally weighted regression (LOWESS). Hastie and Tibshirani (1990) give an excellent account of such methods.

Weaknesses with previous approaches to trend analysis were that the methods generally assumed the starting date for a temporal trend to be the beginning of the time-series and, more often than not, that trends were linear over time. They also had no effective way of modelling non-linear fluctuations with time other than by fitting higher-order polynomials. In addition, the relationship between salinity and flow is often marked by an absence of any correlation in low flows. A GAM, however, can not only fit the *time* trend as an arbitrary smooth spline, but it can also fit the *flow* term as an arbitrary smooth curve, thereby allowing a flexible method of correcting for flow effects (often called a nuisance variable in the statistical literature). Other additive terms can be incorporated into the regression model, and season can be represented as a sinusoidal curve. Thus, there is considerable flexibility in using this modelling approach.

The regression methodology fitted the GAMs using an ordinary least squares algorithm, assuming errors to be independent and normally distributed.

The analyses were carried out with S-PLUS (Insightful Corp. 2003) v. 6.2 statistical software, and were based on the natural logarithms of flow and EC. Log-transformation was used for 3 main reasons. Firstly, we found that flow effects acted proportionately on EC and hence additively on the $\log_e$ scale. Secondly, the log-transform stabilised the variance. Thirdly, the transformation reduced the right skewness and so was likely to make the error distribution more symmetrical. Moreover, we found that the relation of $\log_e$EC to $\log_e$flow was approximately linear in most of the data sets, which simplified the adjustment of EC for flow. Also, as described in Section 4.5, the linear trend is easily estimated from the $\log_e$ transformation as a percentage change in trend (compounded).

A copy of the S-PLUS script file is given in Appendix 6. Users are advised to apply the script file at their own risk, as the process requires considerable statistical experience and understanding. The analysis should never be considered to be an ‘automatic’ or a ‘robotic’ process. An annotated output from running this script file on one data set is given in Appendix 7.

The mathematical form of the regression model used was:

$$\log_e EC = \alpha + S_1(\log_e flow; df_f) + \beta \sin(2\pi\, Yday / 365) + \gamma \cos(2\pi\, Yday / 365) + S_2(time; df_t) + \varepsilon, \quad (1)$$

where:

- $\log_e EC$ is the natural logarithm of EC
- $\log_e flow$ is the natural logarithm of flow
- *Yday* is the numeric day of the year (1 … 365), e.g. 2 October 1988 = 276
- *time* is a decimal variate of date of observation, e.g. 2 October 1988 = 1988 + (276 / 365) = 1988.756
- $S_1(\log_e flow; df_f)$ is a smoothing spline of $\log_e EC$ vs $\log_e flow$ with df_f degrees of freedom
- $S_2(time; df_t)$ is a smoothing spline of $\log_e EC$ vs *time* with df_t degrees of freedom
- α, β, γ are linear regression coefficients to be estimated
- ε is the normally distributed residual error, which may or may not possess serial correlation.

The terms df_f and df_t are smoothing parameters that determine the shape of the splines fitted to the data. We have adopted Morton’s (1997b) recommendation of smoothing parameters set at 2 for $\log_e flow$ and 4 for *time* trend. In heuristic terms, the amount of non-linearity accommodated in the model is roughly similar to that found in a polynomial of degree 2 or 4 (quadratic or quartic), although the shape of the fitted curve is not constrained to that of a polynomial. As assumed by Morton and Henderson (2002), the form of the $\log_e flow$ effect is considered to be very smooth, hence $df_f = 2$. The trend in *time* is expected to be less regular, with $df_t = 4$ allowing for a non-linear curve of reasonable complexity. We agree with Morton and Henderson (2002) that ‘where data exist for less than 8 years, the spline with $df_t = 4$ may be undersmoothing the *time* trend’. Since the data used in the study are at times half as regular as Morton and Henderson’s monthly data, sites with less than 16 years of data may require using $df_t = 2$ rather than 4. Thus, *time* trend and $\log_e flow$ followed non-parametric curves, whereas season had a parametric form.

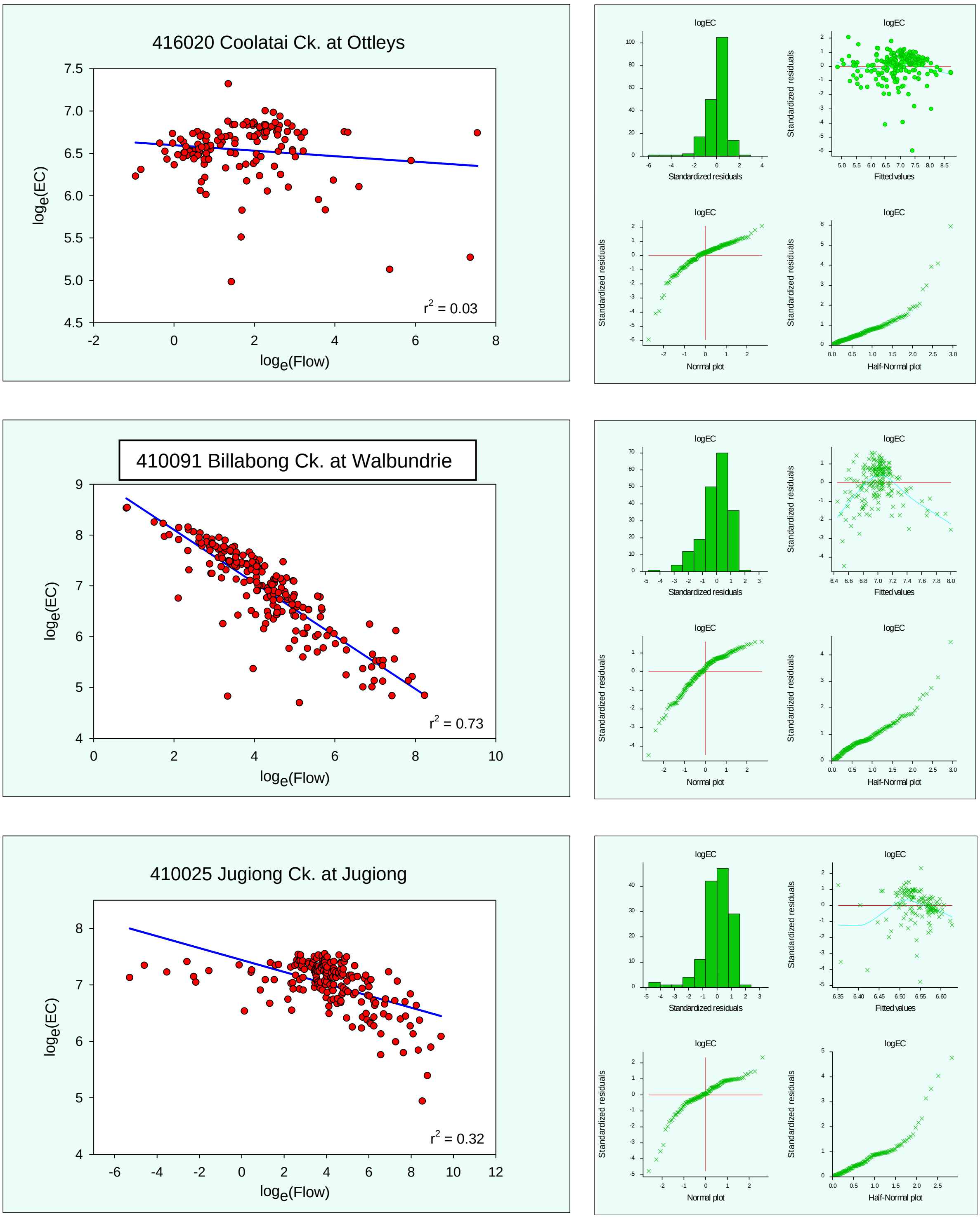
4.4 Graphical insight into model structure

Equation 1 embodies a complex but necessarily flexible formula of explanatory variables that may affect stream EC. Essentially, the formula needs to be adaptable in order to maximise its chances of suitably fitting the 100+ individual sites that make up the stream EC study.

This section has been written to help the reader develop an understanding of the influence of each component of the GAM on stream EC by graphically examining different elements of the model.

To obtain estimates of stream salinity trends that are independent of season of observation and of fluctuations in river flow rates, various relationships need to be quantified for each site. Initially, we focus on the relationship between $\log_e EC$ and $\log_e flow$. Figure 7 shows the extent to which the EC–flow relationship can differ between sites.

Figure 7. Differing degrees of linearity in log$_e$EC and log$_e$flow relationships (standard residual diagnostic plots in right panel)

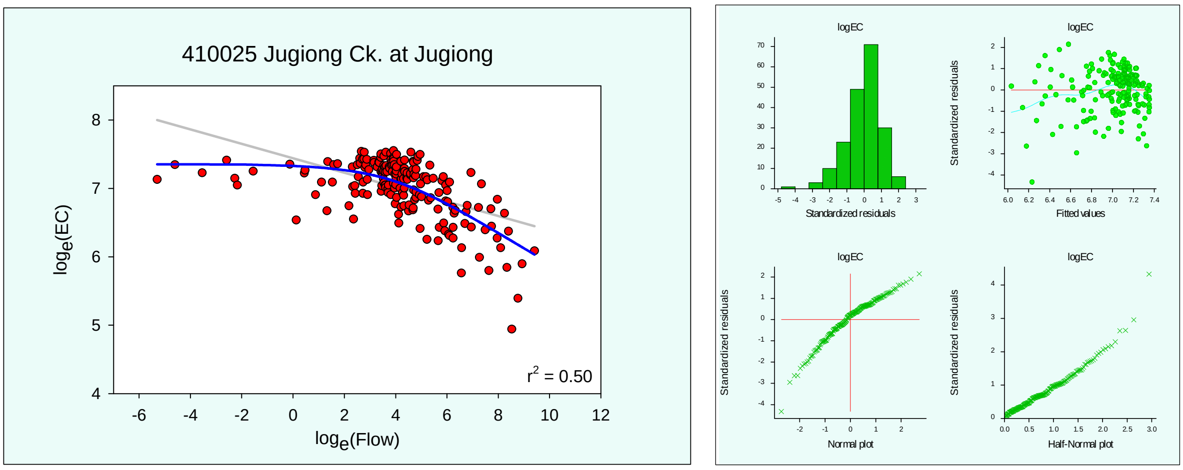


Coolatai Creek shows a very poor EC–flow association. Billabong Creek shows a statistically strong *linear* relationship. Jugiong Creek shows a strong EC–flow association; however, the obvious lack of fit about the linear response and the arched shape of the diagnostic graphic of ‘residuals vs fitted values’ suggest that a curvilinear function would be more appropriate.

Figure 8 shows that mathematically, a cubic spline of log$_e$flow is a better predictor of log$_e$EC at Jugiong Creek than a simple linear relationship. Thus, it is evident that the term S_1(log$_e$flow; df_f)

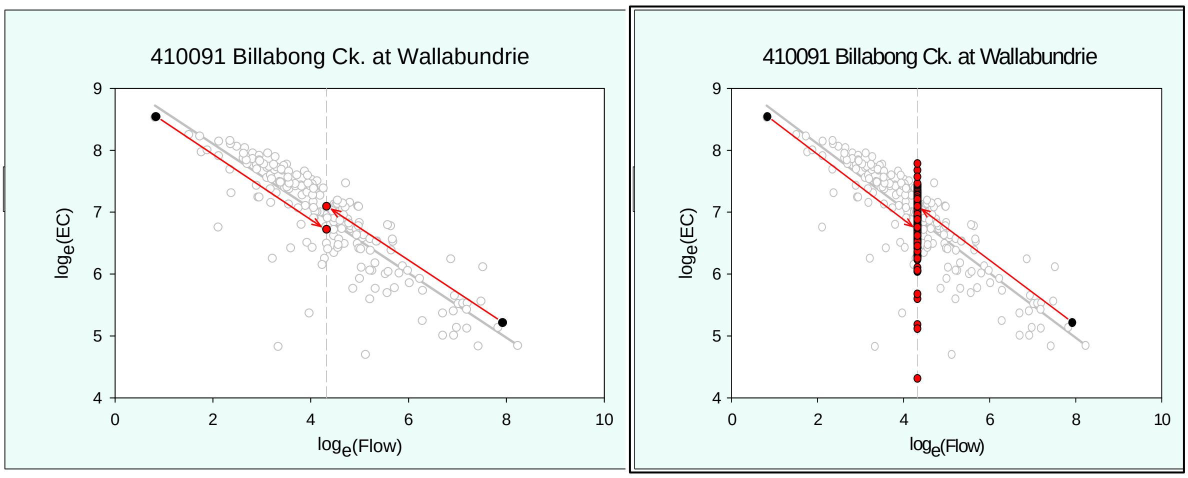
within Equation 1 is capable of suitably fitting such non-linear relationships. In situations where this curvature is absent, the spline function would default back to a simpler linear response function.

Figure 8. Fitting a spline function of $\log_e$flow to $\log_e$EC (standard residual diagnostic plots in right panel)



The formula obtained for the EC–flow relationship is now used to derive an estimate of EC that has been adjusted for differences caused by stream flow. This adjustment process is depicted in Figure 9. Using the linear relationship for Billabong Creek as an example, observed $\log_e$EC values are numerically 'walked' up and down imaginary lines (which run parallel to the linear regression line) to the point of average $\log_e$flow. The average $\log_e$flow is shown by a vertical line at an equivalent $\log_e$flow of 4.32. The left panel of Figure 9 shows that a *high* reading for $\log_e$EC may be primarily due to the fact that this record was taken at a time of *low* $\log_e$flow. Similarly, a *low* $\log_e$EC reading may be due to the existence of a *high* $\log_e$flow. The right panel of Figure 9 shows the full corrected EC dataset for Billabong Creek, having been adjusted to the mean $\log_e$flow.

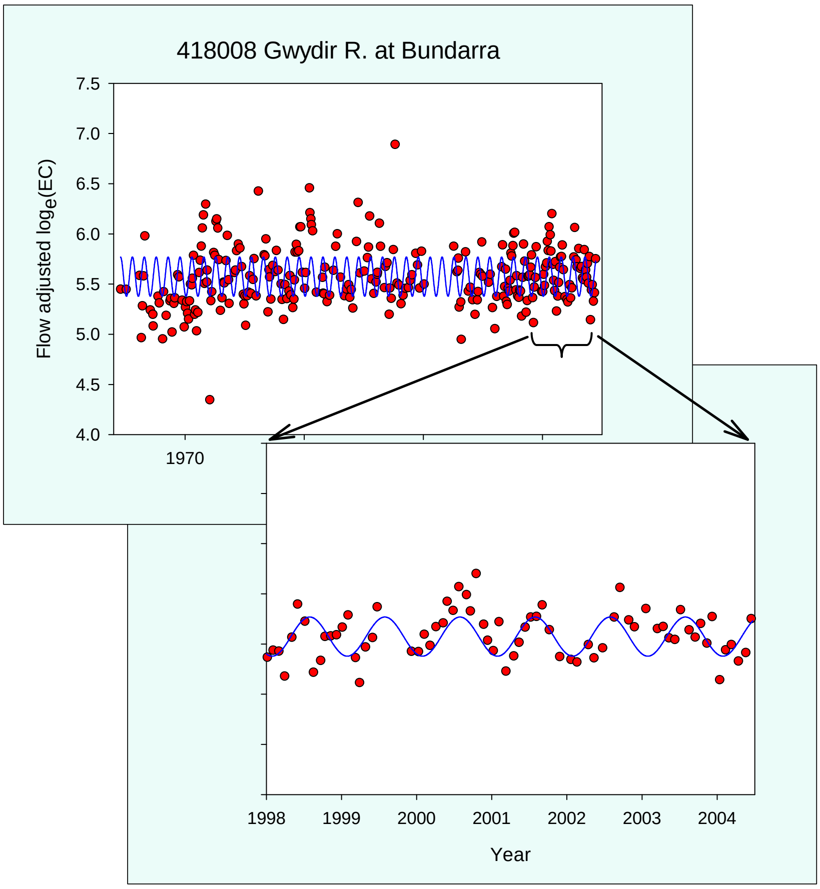
Figure 9. Calculation of 'EC adjusted for flow'.



Grey symbols: unadjusted EC; red symbols: flow-adjusted EC values.

Another variable which may add 'unwanted noise' to the efficient estimation of long-term stream salinity trends is periodicity of EC levels. For the Gwydir River at Bundarra, Figure 10 shows the effect of fitting the seasonality terms $\beta \sin(2\pi\, Yday / 365) + \gamma \cos(2\pi\, Yday / 365)$ (Equation 1) to the flow-adjusted $\log_e$EC data. Although the compressed time scale axis makes it difficult to immediately appreciate the positive benefits of including these terms (Figure 10, top panel), magnification of part of the time axis (Figure 10, bottom panel) reveals a sinusoidal pattern within the flow-adjusted EC data.

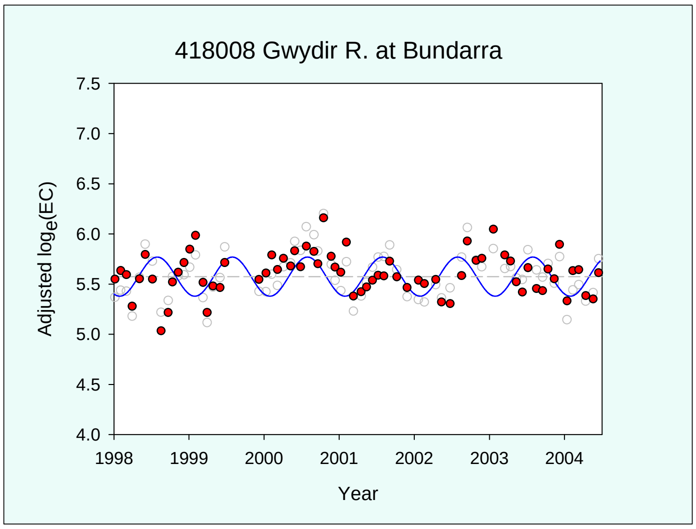
Figure 10. Modelling seasonality within EC trends.



In a manner similar to that described for adjusting for differences in flow, EC data are further adjusted for common periodic patterns within each year. Figure 11 illustrates how data that follow the 'high' side of the fitted sinusoidal curve are adjusted downwards, and data that follow the 'low' side of the curve are adjusted upwards.

Figure 11. Calculation of EC adjusted for flow and seasonality.

Grey symbols: flow-adjusted EC; red symbols: flow- and seasonally adjusted EC values.

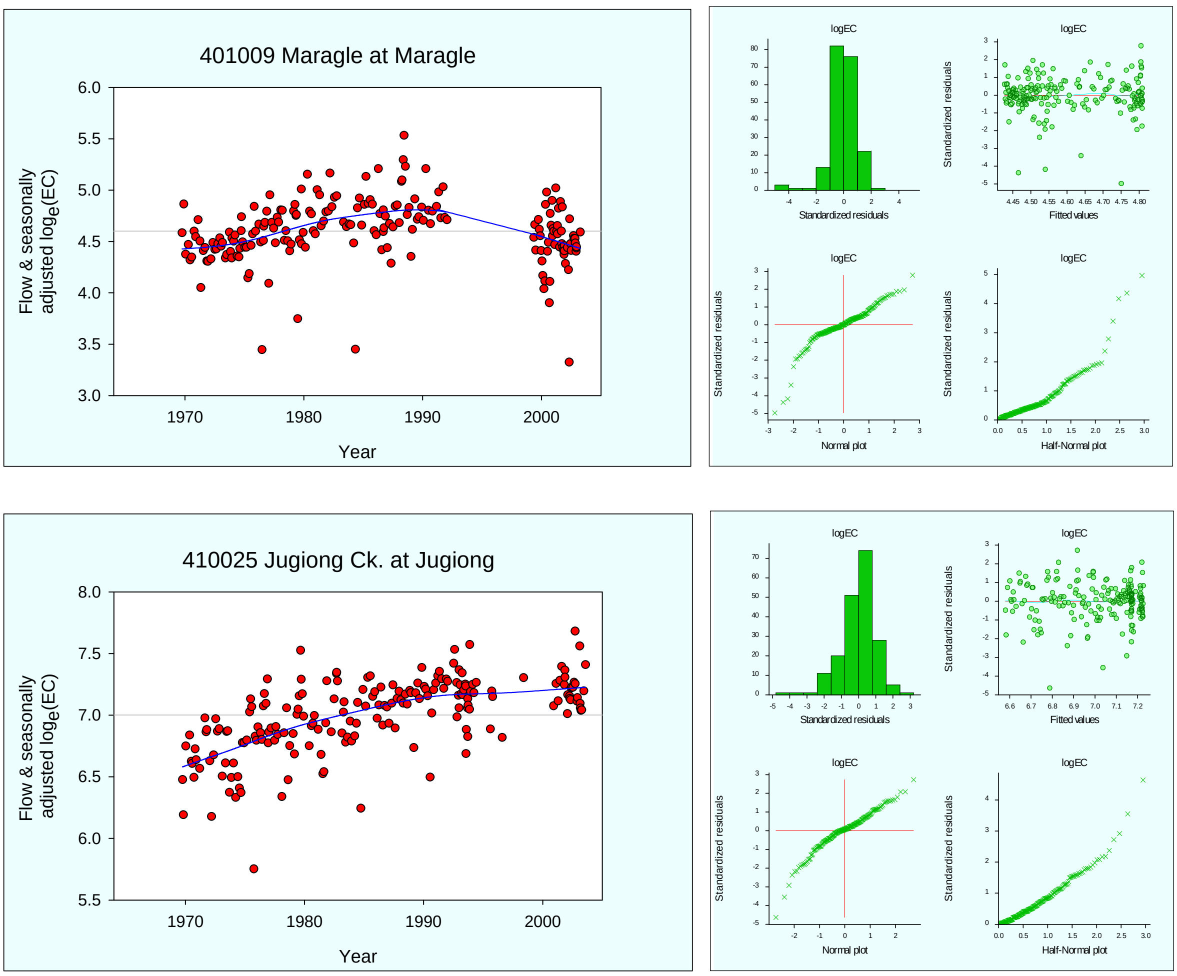


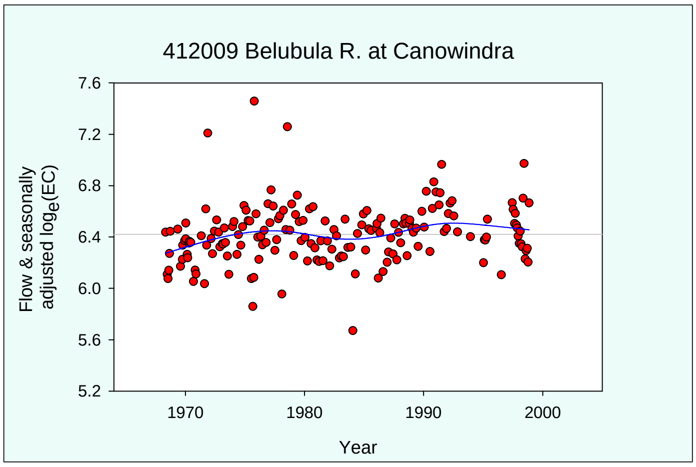
Once these ‘corrections’ to the $\log_e$EC data have been completed, a more accurate view of the trend of $\log_e$EC over time can be made. The 3 panels in Figure 12 indicate the range of trends of $\log_e$EC over time. These plots indicate that the flexibility of the spline term for *time* (Equation 1) was essential to adequately model the variety of time responses evident in this project.

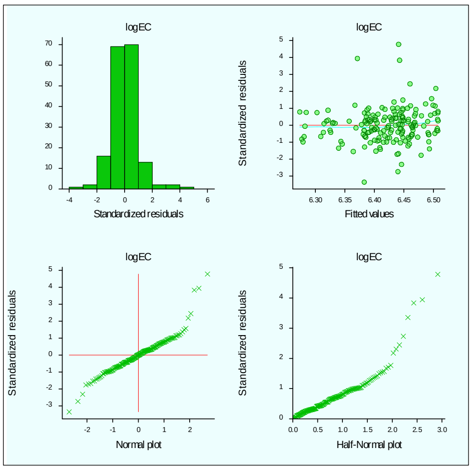
The plot for Maragle suggests that up until the mid 1990s, $\log_e$EC was tending to increase. However, a relative decline is evident from 2000. The panel for Jugiong Creek implies that $\log_e$EC was also increasing to the mid 1990s, and has flattened somewhat throughout the early 2000s. The third panel shows that the Belubula River trend has remained almost negligible over the period of observation.

These changing trends have significant impacts on the ability and confidence with which future predictions of $\log_e$EC can be made, as is discussed in Section 4.5.

Figure 12. Differing degrees of curvature of adjusted EC over time.







4.5 Interpretation of analysis

It is important to note that each term of the form $S(x; m)$ is the sum of the linear component (of the form $a + b{\cdot}x$) and the non-linear component (which has a mean of zero and no linear trend) of the trend. By separating the linear and non-linear components of the spline function, we can expand the spline terms in Equation 1 to:

$$\log_e EC = \alpha + S_1(\log_e flow;\ df_f) + \beta \sin(2\pi\ Yday / 365) + \gamma \cos(2\pi\ Yday / 365) + S_2(time;\ df_t) + \varepsilon,$$

$$S_1(\log_e flow;\ df_f) \downarrow\ \chi \log_e flow + C_{logeFlow} \qquad S_2(time;\ df_t) \downarrow\ \eta\ time + C_{time}$$

where χ and η are the linear coefficients of $\log_e$flow and *time* respectively, and $C_{logeFlow}$ and C_{time} are the non-linear components of $S_1(\log_e flow;\ df_f)$ and $S_2(time;\ df_t)$.

When we are most interested in the overall **linear** trend in EC per year over the period of observation, the linear coefficient of *time*, η, is relevant; η was used to calculate the percentage change in EC per annum (compounded) using the formula:

$$100 \times (e^{\eta} - 1). \qquad (2)$$

Derivation of this formula is explained in Appendix 8.

As was shown by Cunningham and Morton (1983), estimates of the standard error (SE) of η can be used with compound interest formulae to derive confidence limits (CLs) for the net percentage increase (or decrease) over the full period of observation:

- linear coefficient = lc = η (from printout of analysis of $\log_e$EC)
- upper limit = ul = $\eta + 1.969 \times SE$
- lower limit = ll = $\eta - 1.969 \times SE$
- proportional change in EC p.a. = pc = $(e^{\eta} - 1)$
- upper limit = pu = $(e^{ul} - 1)$
- lower limit = pl = $(e^{ll} - 1)$
- % change over period = %c = $100 \times \{pc \times (1 + pc)^{years} - pc\} / pc$
- upper limit = %u = $100 \times \{pu \times (1 + pu)^{years} - pu\} / pu$
- lower limit = %l = $100 \times \{pl \times (1 + pl)^{years} - pl\} / pl$

As an example of using these formulae, a typical site may have, say, 43 years of data, a linear trend coefficient on the $\log_e$ scale of 0.0018, with an SE of 0.00058. This equates to a percentage change per annum (compound) of 1.43%, with 95% CLs of (0.0409%, 2.84%). For the period spanned by the data, namely 43 years, the percentage is compounded, giving the estimated increase as 84.2% with CLs (1.8%, 233.4%).

This example serves as a warning of the potential inaccuracies that may occur from data such as these in the estimation of trend parameters and in forming future predictions.

Another warning needs to be given to those who may mistakenly consider that the linear trend is the only statistic of interest. Morton (2002) reminds us that the trend may be markedly non-linear, in which case the linear trend component does not give an adequate summary of the trend. When interpreting this type of trend analysis, note must be taken of the significance of the non-linear component C_{time}. It should be obvious to all readers that extrapolation or prediction of such trends into the future is fraught with danger, and especially so in the presence of a significant non-linear *time* component.

The linear trend is not to be taken as suitable for extrapolation, as it becomes exponential on the original scale, and there is no guarantee that it remains linear on the logarithmic scale. Plotting the form of the non-linear trend over time after removing the influences of flow and season by including a LOWESS smoother is a useful exploratory tool.

4.6 Correlated residual terms

It is commonly found that data recorded over time possess serial correlation. The strength of serial correlation will depend on the degree of contribution of all processes generating these data, relative to random noise; the correlation will also be influenced by the physical time lag between successive observations. Thus, it may be expected that the degree of serial correlation exhibited by data examined by Morton and Henderson (2002) could be somewhat higher than that found in the present study. This expectation occurs because Morton and Henderson used monthly data observations collected largely from regulated rivers with ‘more uniform’ flow patterns. In small streams with characteristically peaky flows, autocorrelation is often not an issue. This report uses data collected approximately every 2 months, and originates from third-order unregulated rivers and streams.

Notwithstanding this, a positive serial correlation within the residual terms will influence the interpretation of output from this analysis. Morton and Henderson (2002) clearly state that the regression estimates given by this method are generally accurate in themselves, but the formal SEs and CLs formed around the estimates are misleadingly small. That is, a positive autocorrelation has the effect of reducing the formal statistical significance of estimated time trends. This results in estimates of trend that appear to have greater precision than they deserve.

Morton and Henderson (2002) generalised this model even further for a ‘complete’ dataset (that is, when <20% of the monthly data are missing). They accommodate serial correlation in the residuals by fitting the regression as a time-series model, assuming that the residuals follow a first-order autoregressive process with autocorrelation coefficient ρ. They suggest a threshold of $\rho > 0.2$ as being sufficiently high to invalidate SEs and confidence intervals (CIs).

Morton has suggested a workaround for datasets that have >20% of monthly values missing, as is common in the present analysis. Under Morton’s biometrical guidance, Jolly *et al.* (1997) provide a formula to calculate an adjustment factor used to increase the otherwise misleadingly small SEs of estimates. In this case, the SEs from the statistical output are adjusted for the magnitude of the autocorrelation and amount of missing data by multiplying by the following factor:

$$\sqrt{\left[1+\frac{2*P*ACF}{1-ACF}\right]} \qquad (3)$$

where

- *P* is the proportion of available data
- *ACF* is the first-order autocorrelation coefficient.

Morton and Henderson (2002) remind us of Morton's (1997a) approximation to this multiplier, formed when there are no missing data (*P* is assumed to be unity). This approximation is:

$$\sqrt{\left[\frac{1+ACF}{1-ACF}\right]} \qquad (4)$$

Morton and Henderson have found reasonable agreement between the SE of a linear trend component derived either by the adjustment of ordinary least squares estimates of error or by applying a 'proper' time-series method.

We acknowledge that the estimate of the (lag 1) autocorrelation coefficient used here is approximate, as the data have not been recorded at regular time intervals. Nevertheless, we have adopted a conservative approach to the estimation of the precision of the linear trend, and our analysis includes the derivation (and tabulation) of a first-order autocorrelation coefficient, and uses the approximate multiplying factor from Equation 4 when deriving SEs and CLs of trend estimates. The whole process of estimation and prediction is therefore an approximation.

4.7 Model hierarchy

Equation 1 represents a reasonably sophisticated model that has been fitted in a single operation by previous workers. For this analysis, we have fitted it in incremental steps, initially to better monitor and understand the progress of the individual components of the model (Figure 13). The incremental fitting procedure also allowed investigation of the contribution of each additional term in a hierarchical sense, and allowed the exploration of other potential explanatory variates, such as groundwater, to be included in future trend analyses.

Models 1 to 3 (Figure 13) examined $\log_e$EC versus $\log_e$flow, with a seasonality component added. Models 4 and 5 examined flow-adjusted EC as a function of time. Models 6 and 7 fitted EC as a function of all explanatory variables, namely instantaneous flow, seasonality and time.

Model 7 fits a GAM, with spline terms for flow and time. We considered Models 3, 5 and 7 to be of most interest, since each represents a more sophisticated equation for, respectively, $\log_e$EC vs $\log_e$flow, flow-adjusted $\log_e$EC vs time, and $\log_e$EC as a function of $\log_e$flow, seasonality and time.

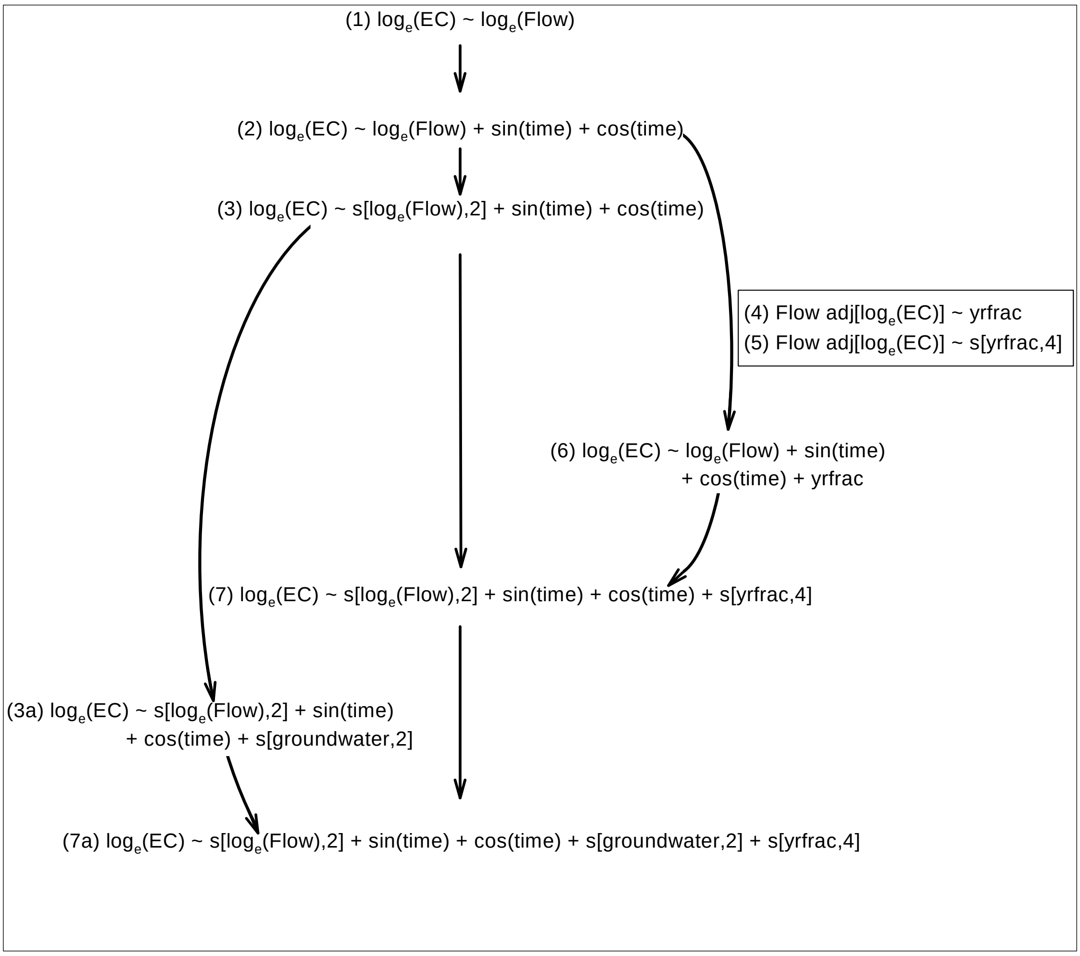
The mean of the observed $\log_e$flow was calculated for each sample data set. Model 7 was then solved to predict $\log_e$EC over the time period of observation, using average $\log_e$flow and seasonality effects. The average $\log_e$flow at each site is tabulated in Appendix 1.

Results from these analyses were summarised using statistics and plots. The relevant statistics are presented in a number of tables throughout this report. S-PLUS was used to generate graphical representations of many steps of the analyses. The final plot generated a $\log_e$EC spline curve fitted at the mean $\log_e$flow and seasonality over the period of observation. These plots are presented in Appendix 2.

Figure 13 also indicates that groundwater was used as an additional explanatory variable in a pilot study of 8 gauging stations. We postulated that a groundwater smoothing spline accounted for additional variation in $\log_e$EC not explained by other variables in the model (Models 3a and 7a).

Figure 13. Flow chart of hierarchical model sequence.

Model 7 was of primary interest. The benefits of including groundwater data were explored in Models 3a and 7a.



4.8 Trend indicators

Jolly *et al.* (2001) represented EC trend as linear on a $\log_e$ scale. The various curves in Jolly *et al.* (1997) implied cyclic behaviour at some sites. Harvey and Jones (2001) noted a decrease in the rising EC trend at some of their sites. As one of our study goals was to quantify trends, it was essential to have a classification or quantification that considered cyclicity (non-linearity). As the project evolved, the non-linear component of the GAM graphs became increasingly important in the interpretation of the processes.

4.8.1 Statistical linearity

The first method used to indicate trend was based on the statistical approach of Jolly *et al.* (1997). Statistical routines were used to:

- quantify the linear trend on $\log_e$ scale
- determine whether this linear trend was statistically significant
- determine whether the non-linear component of the trend was statistically significant.

4.8.2 Cyclicity

The second method attempted to flag the salinity behaviour of the catchment by quantifying the extent of the cyclicity (non-linearity) of the Model 7 trend. This process generated 2 measures of the cyclicity of the catchment. The first measure was the ratio of the $\log_e$EC at the peak of the smoothed cycle to $\log_e$EC at the trough of the smoothed cycle. This measure has been termed 'cycle ratio'; it did not receive major use within the report. The second measured the real-scale difference between peak and trough expressed as a percentage of the mean. This has been termed 'percentage of cycle' throughout this report, and is used in any quantification of cyclicity. The higher the percentage, the more extreme is the cycle.

4.8.3 Recovery factor

The recovery factor was calculated as the ratio of the EC at the start of the record to the EC at the end of the record. A value of 1 meant that the EC was the same at the end of record as at the beginning. A value much greater than 1 meant that the catchment EC had fallen below the initial levels (and was resilient). A value much less than 1 meant that the catchment EC had not fallen sufficiently (and was not resilient). This factor was used only as a 'safety check' of the calculations in Section 4.8.1.

4.9 Comparison with catchment characteristics

Attempts were made to link the various model outputs with catchment characteristics. We compared model performance as measured by the R^2 from Model 7, together with trend indicators (Section 4.8), with the catchment characteristics described in Section 2.7. Comparisons were initially undertaken by the examination of matrix plots.

4.10 Groundwater pilot study

As outlined in Section 4.7, our modelling process allowed other potential explanatory variates, such as groundwater, to be included in future trend analyses. This led to the creation of 2 additional models: Models 3a and 7a (Figure 13).

5 Results

Unless otherwise stated, all references to EC and Flow are in the $\log_e$ scale.

5.1 Performance of models

Occasionally, the analysis of individual sites is based on few or sparse data, with an average of less than 2 observations per year. Table 2 shows the years of record, the number of samples, and the maximum and minimum EC at each of the 92 sites. It also includes a general indication of the goodness of fit of the successive models as the R^2 for each model. As described in Section 4.7, Models 1 to 3 do not include a time component, and deal with various relationships between EC and the combination of instantaneous flow and seasonality; Models 4 and 5 relate flow-adjusted EC to time (i.e. trend); and Models 6 and 7 relate EC to flow, seasonality and time.

5.1.1 Flow and seasonality as descriptors of EC (Models 1 and 2)

As can be seen in Table 2, flow (as per Models 1, 2 and particularly 3) plays a substantial role in describing EC behaviour at some sites. This appears to be more the case at sites in southern NSW. At a few sites (e.g. 410038), the application of more sophisticated models (2 to 7) provides little improvement over the results produced by the simple linear EC–flow relationship of Model 1.

Model 2 adds a seasonality component. By comparing the results of Models 1 and 2 in Table 2, it can be seen that the southern and central sites generally registered little response to seasonality. At the northern sites, Model 2 gave a better fit, and the seasonality was marginally significant ($P < 0.10$) for 416039 (Severn River at Strathbogie) and 418008 (Gwydir River at Bundarra). See Table 3 ,Column 7. The seasonal Model 2 gave a good fit (although not statistically significant) at number of sites in the upper Gwydir and upper Border Rivers.

5.1.2 Spline (Flow 2) as a descriptor of EC (Model 3)

At other sites, the non-linear spline function of flow appeared to give a poor explanation of variation in EC. Using a criterion of $R^2 \leq 0.15$ (for Model 3), a foundational relationship between EC and flow does not seem to exist at some sites (Figures 14 and 15):

- 410033 Murrumbidgee River at Mittagang Crossing
- 410045 Billabung at Sunnyside
- 410050 Murrumbidgee River at Billilingra
- 418025 Halls Creek at Bingara
- 419032 Coxs Creek at Boggabri
- 421039 Bogan River at Neurie Plains
- 421055 Coolbaggie Creek at Rawsonville
- 421076 Bogan River at Peak Hill 2

Of the 3 flow and seasonality models, the more complex Model 3 generally gave the best fit. It represented the relationship between EC and flow using a spline with 2 df, plus a seasonality component. Figure 14 shows the catchments where Model 3 gave a good or bad fit. A number of sites showed a strong interrelationship between EC and instantaneous flow. These were scattered throughout the Murrumbidgee, but otherwise tended to congregate in the upper (south-eastern) Macquarie and upper Lachlan. In the northern half of NSW, the relationship was not as good

(Figure 15). The upper Gwydir and parts of the upper Namoi showed some degree of fit. Interestingly, some sites in the mid Castlereagh showed a good fit.

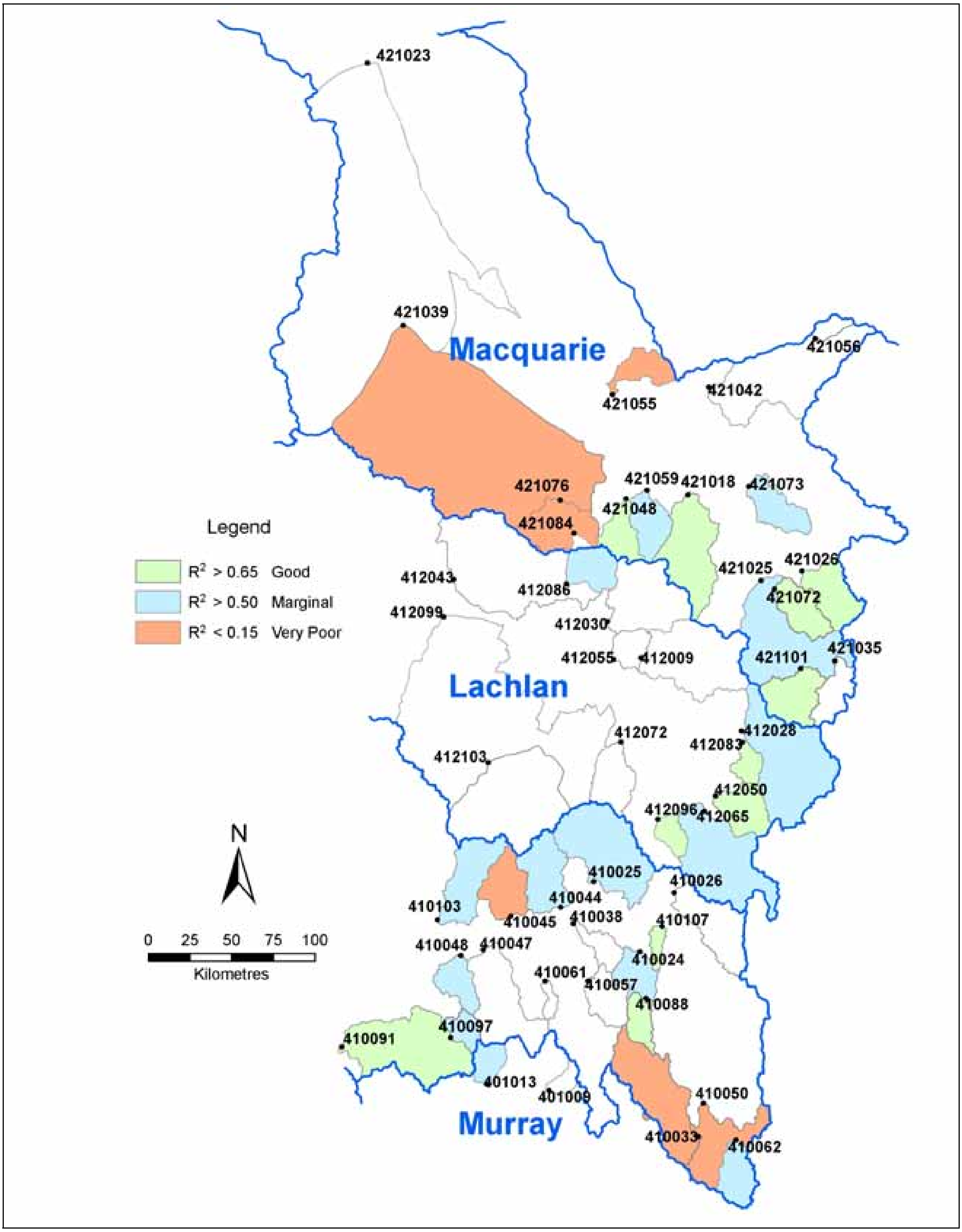
The distribution of the R^2 for Model 3 is shown in Figure 16. This figure indicates the number of sites that responded well or poorly to a flow (Spline 2) relationship. It suggests that the EC behaviour at many of the central (Macquarie and Castlereagh) and northern (Border, Gwydir and Namoi) sites was not well explained by flow. The central sites seemed to fall into 2 distinct groups. At the southern sites (Murray, Murrumbidgee and Lachlan), a higher proportion of sites seemed responsive to flow.

Table 2. Data set statistics and coefficients of determination (R^2) for various models.

StationNo.	Name	**First Year**	**Last Year**	**Number of Samples.**	Min EC Observed	Max EC Observed	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
401009	Maragle Ck. at Maragle	1969	2003	198	34	350	0.43	0.45	0.45	0.00	0.21	0.44	0.56
401013	Jingellic Ck. at Jingellic	1969	2003	217	50	186	0.57	0.57	0.59	0.00	0.14	0.57	0.65
410091	Billabong Ck. at Walbundrie	1969	2003	192	110	5130	0.73	0.73	0.73	0.22	0.27	0.79	0.81
410097	Billabong Ck. at Aberfeldy	1969	2003	183	115	2316	0.51	0.54	0.55	0.15	0.18	0.60	0.63
410024	Goodradigbee R. at Wee Jasper	1969	2004	190	33	245	0.59	0.61	0.63	0.04	0.20	0.63	0.71
410025	Jugiong Ck. at Jugiong	1969	2003	193	140	1900	0.30	0.33	0.52	0.39	0.42	0.49	0.74
410026	Yass R. at Yass	1969	2004	193	22	1260	0.23	0.29	0.36	0.03	0.03	0.30	0.37
410033	Murrumbidgee at Mittagang Xing	1969	2004	177	30	486	0.03	0.09	0.08	0.08	0.14	0.15	0.22
410038	Adjungbilly Ck. at Darbalara	1969	2003	149	27	690	0.46	0.46	0.46	0.00	0.04	0.46	0.49
410044	Muttama Ck. at Coolac	1969	2003	178	214	3420	0.51	0.51	0.59	0.08	0.18	0.53	0.68
410045	Billabung Ck. at Sunnyside	1969	1984	35	104	800	0.00	0.09	0.13	0.08	0.12	0.11	0.29
410047	Tarcutta Ck. at Old Borambola	1967	2003	222	52	783	0.38	0.37	0.42	0.26	0.39	0.52	0.65
410048	Kyeamba Ck. at Ladysmith	1970	2003	140	90	1932	0.48	0.47	0.54	0.29	0.31	0.59	0.70
410050	Murrumbidgee R. at Billilingra	1968	2004	217	35	312	0.05	0.09	0.09	0.07	0.18	0.15	0.27
410057	Goobarragandra R. at Lacmalac	1969	2003	170	24	212	0.22	0.21	0.22	0.00	0.04	0.21	0.25
410061	Adelong Ck. at Batlow Rd.	1969	2003	169	53	280	0.45	0.45	0.46	0.00	0.05	0.45	0.49
410062	Numeralla R.at Numeralla School	1969	2004	200	29	345	0.56	0.55	0.56	0.06	0.16	0.58	0.63
410088	Goodradigbee R. at Brindabella	1969	2004	154	29	430	0.62	0.65	0.66	0.00	0.10	0.65	0.69
410103	Houlaghans Ck. at Downside	1974	2002	28	79	12600	0.60	0.56	0.59	0.43	0.37	0.92	0.95
410107	Mountain Ck at Mountain Ck	1972	2004	141	52	409	0.68	0.68	0.69	0.09	0.13	0.71	0.73
412009	Belubula R. at Canowindra	1968	1998	176	184	1110	0.43	0.44	0.48	0.03	0.08	0.45	0.52
412028	Abercrombie R. at Abercrombie	1967	2002	198	85	780	0.42	0.50	0.58	0.01	0.01	0.50	0.58
412030	Mandagery Ck. at U/S Eugowra	1968	2002	132	110	3300	0.35	0.37	0.42	0.11	0.18	0.42	0.57
412043	Goobang Ck. at Darbys Dam	1968	1982	61	115	705	0.24	0.36	0.43	0.14	0.14	0.42	0.51
412050	Crookwell R. at Narrawa North	1969	2004	140	73	1039	0.55	0.58	0.66	0.00	0.00	0.58	0.65
412055	Belubula R. at Bangaroo Bridge	1968	1989	116	140	1000	0.31	0.35	0.40	0.02	0.12	0.36	0.48
412065	Lachlan R. at Narrawa	1968	2003	147	166	2023	0.36	0.40	0.56	0.03	0.06	0.40	0.59
412072	Back Ck at Koorawatha	1968	1989	82	190	4700	0.35	0.35	0.38	0.05	0.05	0.37	0.41
412083	Tuena Ck. at Tuena	1968	2002	132	107	938	0.54	0.55	0.68	0.00	0.01	0.55	0.69
412086	Goobang Ck. at Parkes	1968	1989	108	67	1830	0.58	0.59	0.60	0.04	0.08	0.60	0.63
412096	Pudmans Ck. at Kennys Rd	1975	2003	97	160	2100	0.58	0.61	0.71	0.01	0.00	0.60	0.71
412099	Manna Ck. near Lake Cowal	1975	1992	36	220	889	0.29	0.31	0.29	0.17	0.38	0.42	0.57
412103	Bland Ck. at Morangarell	1976	1991	33	64	1450	0.04	0.17	0.26	0.41	0.46	0.53	0.61
416003	Tenterfield Ck. at Clifton	1969	2004	234	85	786	0.45	0.57	0.63	0.00	0.02	0.57	0.64
416008	Beardy R. at Haystack	1969	2004	233	62	1200	0.25	0.30	0.37	0.08	0.22	0.35	0.51
416010	Macintyre R. at Wallangra	1969	2004	155	146	960	0.14	0.28	0.37	0.01	0.06	0.28	0.41
416016	Macintyre R. at Inverell	1970	2004	150	138	858	0.08	0.16	0.25	0.01	0.05	0.16	0.28
416020	Ottleys Ck. at Coolatai	1969	2004	139	146	1510	0.03	0.06	0.22	0.00	0.04	0.06	0.25
416021	Frazers Ck. at Ashford	1969	2004	122	122	660	0.33	0.35	0.45	0.07	0.26	0.39	0.59
416023	Deepwater Ck. at Bolivia	1969	2004	156	64	391	0.42	0.46	0.46	0.00	0.07	0.45	0.49
416027	Gil Gil Ck. at Weemelah	1969	2004	127	42	1380	0.45	0.53	0.54	0.00	0.01	0.53	0.54
416032	Mole R. at Donaldson	1969	2004	251	49	320	0.62	0.66	0.69	0.01	0.05	0.66	0.70

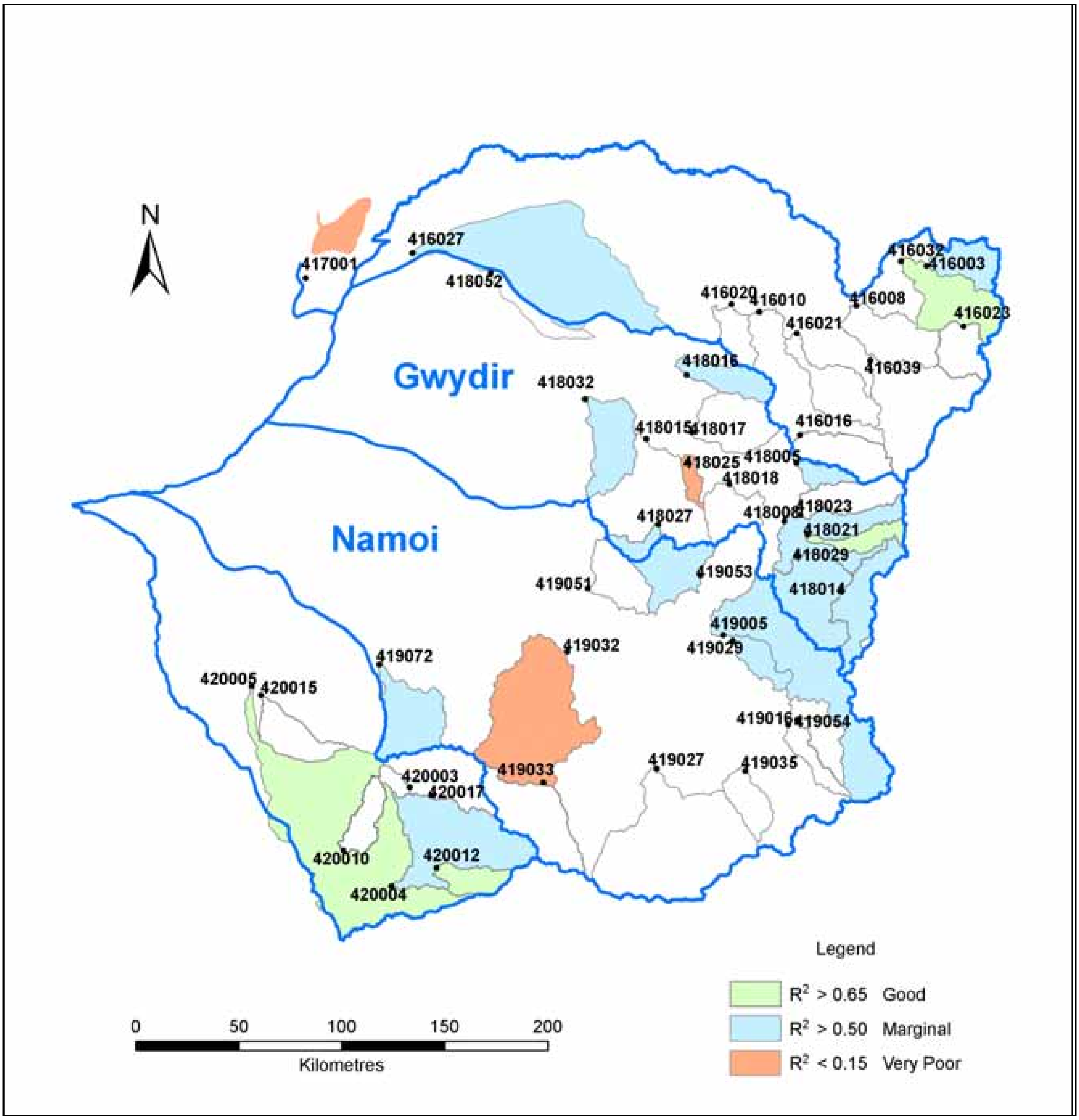
StationNo.	Name	First Year	Last Year	Number of Samples.	Min EC Observed	Max EC Observed	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
416039	Severn R. at Strathbogie	1975	2004	206	89	940	0.13	0.29	0.29	0.03	0.07	0.31	0.34
417001	Moonie R. at Gundablouie	1969	2004	67	51	340	0.01	0.03	0.03	0.00	0.06	0.01	0.08
418052	Carole Ck. near Garah	1980	2004	93	145	865	0.22	0.28	0.30	0.01	0.14	0.28	0.40
418005	Copes Ck. at Kimberley	1970	2004	156	51	790	0.50	0.49	0.51	0.05	0.05	0.51	0.54
418008	Gwydir R. at Bundarra	1964	2004	279	68	943	0.40	0.53	0.58	0.02	0.08	0.53	0.61
418014	Gwydir R. at Yarrowych	1969	2004	152	83	685	0.50	0.62	0.63	0.04	0.03	0.63	0.65
418015	Horton R. at Killara	1968	2004	246	160	1040	0.41	0.45	0.48	0.00	0.21	0.45	0.59
418016	Warialda Ck. at Warialda	1972	2004	115	226	1250	0.32	0.39	0.54	0.00	0.03	0.39	0.56
418017	Myall Ck. At Molroy	1969	2004	176	280	3700	0.24	0.28	0.36	0.00	0.09	0.27	0.42
418018	Keera Ck. at Keera	1969	1989	122	134	1370	0.24	0.28	0.31	0.01	0.09	0.28	0.37
418021	Laura Ck. at Laura	1969	2003	128	72	675	0.68	0.73	0.79	0.00	0.00	0.73	0.78
418023	Moredun Ck. at Bundarra	1970	1988	106	83	750	0.35	0.48	0.48	0.00	0.05	0.47	0.50
418025	Halls Ck. at Bingara	1969	2004	158	330	1985	0.00	-0.01	0.02	0.06	0.12	0.05	0.14
418027	Horton R. at Dam Site	1969	2004	141	82	1203	0.56	0.56	0.64	0.18	0.22	0.65	0.72
418029	Gwydir R. at Stoneybatter	1969	1988	93	94	570	0.44	0.57	0.60	0.00	0.19	0.56	0.68
418032	Tycannah Ck. at Horseshoe Lagoon	1971	2004	135	142	1630	0.43	0.46	0.52	0.00	0.09	0.45	0.56
419005	Namoi R. at North Cuerindi	1970	2004	136	59	1125	0.46	0.50	0.55	0.06	0.08	0.53	0.59
419016	Cockburn R. at Mulla Crossing	1969	2004	172	150	1540	0.21	0.20	0.27	0.11	0.11	0.30	0.36
419027	Mooki R. at Breeza	1970	2004	183	269	3000	0.19	0.19	0.23	0.12	0.24	0.29	0.42
419029	Halls Ck. at Ukalon	1970	2004	142	191	1100	0.54	0.55	0.58	0.04	0.14	0.57	0.64
419032	Coxs Ck. at Boggabri	1969	2004	91	91	1390	0.12	0.13	0.14	0.02	0.08	0.13	0.21
419033	Coxs Ck. at Tambar Springs	1969	2004	153	298	1920	0.46	0.48	0.48	0.00	0.03	0.48	0.49
419035	Goonoo Goonoo Ck. at Timbumburi	1970	2004	141	119	3310	0.31	0.30	0.38	0.00	0.01	0.30	0.38
419051	Maules Ck. At Avoca	1972	2004	163	120	1010	0.15	0.13	0.29	0.00	0.07	0.15	0.35
419053	Manilla R. at Black Springs	1972	2004	150	200	1244	0.48	0.52	0.58	0.00	0.10	0.52	0.63
419054	Swamp Oak Ck. at Limbri	1974	2004	107	159	1830	0.29	0.33	0.42	0.01	0.09	0.33	0.48
419072	Baradine Ck. at Kienbri	1981	2004	40	101	500	0.40	0.53	0.60	0.02	0.20	0.53	0.70
420003	Belar Ck. at Warkton	1968	1991	160	72	910	0.14	0.19	0.21	0.08	0.07	0.24	0.27
420004	Castlereagh R. at Mendooran	1968	2002	290	105	2332	0.50	0.51	0.59	0.00	0.10	0.51	0.63
420005	Castlereagh R. at Coonamble	1968	2001	91	107	941	0.66	0.68	0.74	0.00	0.18	0.67	0.79
420010	Wallumburrawang Ck. at Bearbung	1969	1998	56	120	1310	0.25	0.31	0.36	0.01	0.07	0.31	0.41
420012	Butheroo Ck. at Neilrex	1969	2001	83	180	14400	0.78	0.78	0.79	0.00	0.15	0.78	0.82
420015	Warrena Ck. at Warrana	1970	2001	71	56	705	0.32	0.38	0.38	0.00	0.14	0.37	0.47
420017	Castlereagh R. at Hidden Valley	1980	2004	95	82	1060	0.09	0.10	0.31	0.03	0.11	0.13	0.38
421018	Bell R. at Newrea	1967	2004	165	180	999	0.56	0.57	0.65	0.03	0.09	0.58	0.68
421023	Bogan R. at Gongolgon	1968	2004	224	83	1234	0.26	0.31	0.32	0.01	0.11	0.31	0.39
421025	Macquarie R. at Bruinbun	1968	2004	236	139	1140	0.47	0.51	0.53	0.01	0.03	0.52	0.55
421026	Turon R. at Sofala	1968	2004	146	66	690	0.56	0.56	0.66	0.01	0.03	0.56	0.67
421035	Fish R. at Tarana	1969	1996	83	54	953	0.20	0.21	0.21	0.00	0.00	0.20	0.21
421039	Bogan R. at Neurie Plains	1968	2003	53	64	740	0.06	0.08	0.09	0.00	0.00	0.07	0.05
421042	Talbragar R. at Elong Elong	1968	2002	198	110	3525	0.31	0.31	0.34	0.03	0.12	0.33	0.42
421048	Little R. at Obley	1969	2004	163	83	1854	0.62	0.62	0.65	0.29	0.30	0.73	0.76
421055	Coolbaggie C. at Rawsonville	1969	2004	72	42	864	0.12	0.08	0.10	0.00	0.07	0.07	0.16
421056	Coolaburragundy Ck. at Coolah	1968	1998	123	337	1193	0.19	0.19	0.32	0.00	0.04	0.18	0.34
421059	Buckinbar Ck. at Yeoval	1969	2004	97	240	2240	0.38	0.43	0.53	0.01	0.07	0.43	0.56
421072	Winburndale Rivt.at Howards Bdge	1968	1978	59	114	629	0.65	0.63	0.67	0.02	0.20	0.63	0.73
421073	Meroo Ck. at Yarrabin 2	1968	1983	58	122	690	0.50	0.52	0.59	0.00	0.00	0.52	0.57
421076	Bogan R. at Peak Hill 2	1969	2002	40	58	348	0.06	0.15	0.14	0.01	0.11	0.13	0.23
421084	Burrill Ck. at Mickibri	1973	1990	37	73	484	0.39	0.34	0.32	0.01	0.01	0.32	0.34
421101	Campbells R. at U/S BenChifleyDam	1978	2003	83	126	985	0.61	0.72	0.78	0.02	0.00	0.73	0.78

Figure 14. Map showing performance of Model 3, southern NSW.



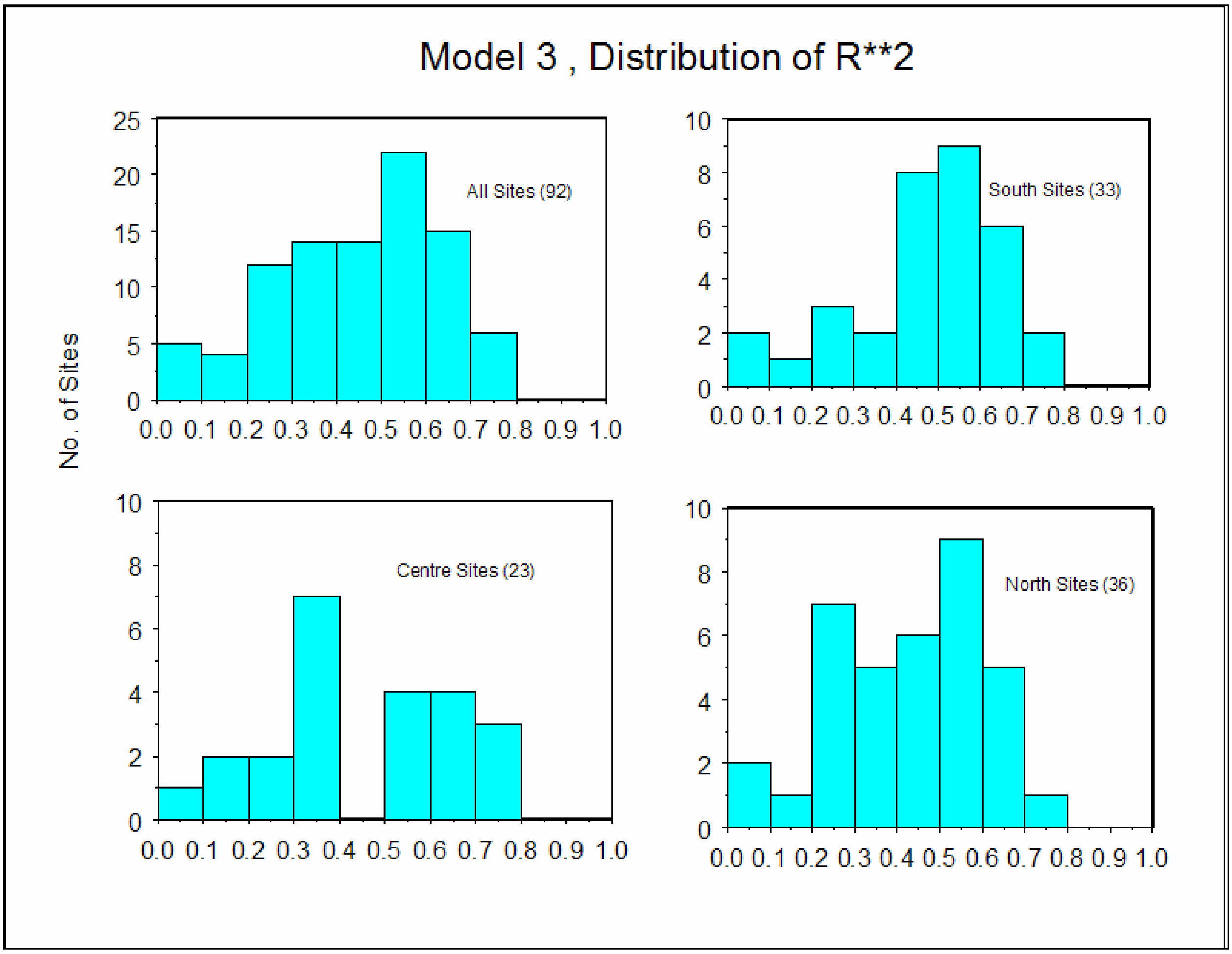
EC as modelled by 'short-term' influences (flow spline and seasonality).

Figure 15. Map showing performance of Model 3, northern NSW.



EC as modelled by 'short-term' influences (flow spline and seasonality).

Figure 16. Model 3, distribution of R^2 across NSW.

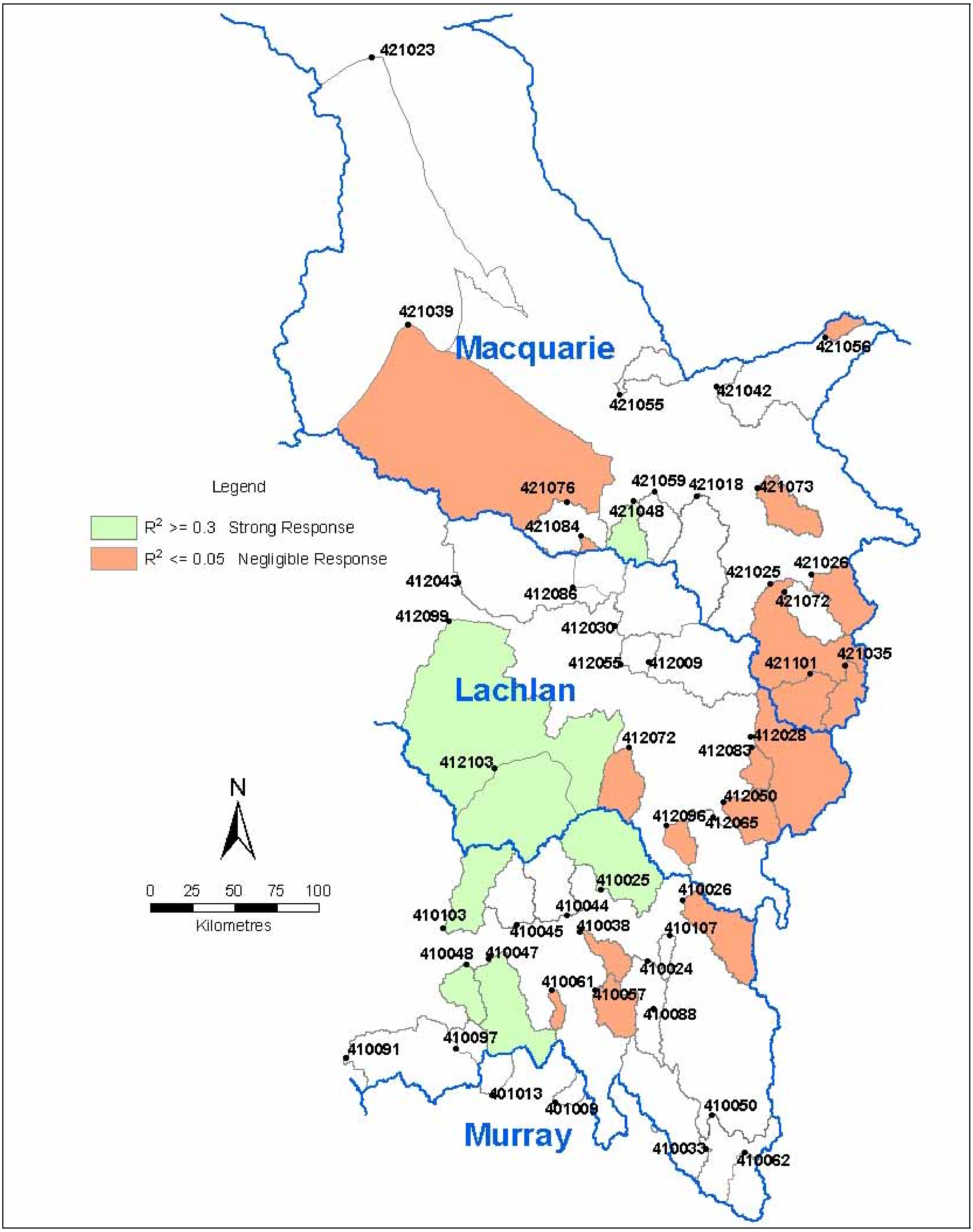


5.1.3 Time as a descriptor of EC (Model 5)

Of the 2 models that attempted to fit time to flow-adjusted EC, the spline function of time (Model 5) showed the highest degree of predictive power. Its purpose was to evaluate whether the flow-adjusted EC data set showed any non-linear time trend. At some sites (mainly in the south), the spline time component (Model 5) had a substantial effect (Figures 17 and 18). R^2 was ≥ 0.3 and was considered a substantial response for Model 5, and occurred at the following sites:

- 410025 Jugiong Creek at Jugiong
- 410047 Tarcutta Creek at Old Borambola
- 410048 Kyeamba Creek at Ladysmith
- 410103 Houlaghans Creek at Downside
- 412099 Manna Creek Nr Lake Cowal
- 412103 Bland Creek at Morangarell
- 421048 Little River at Obley

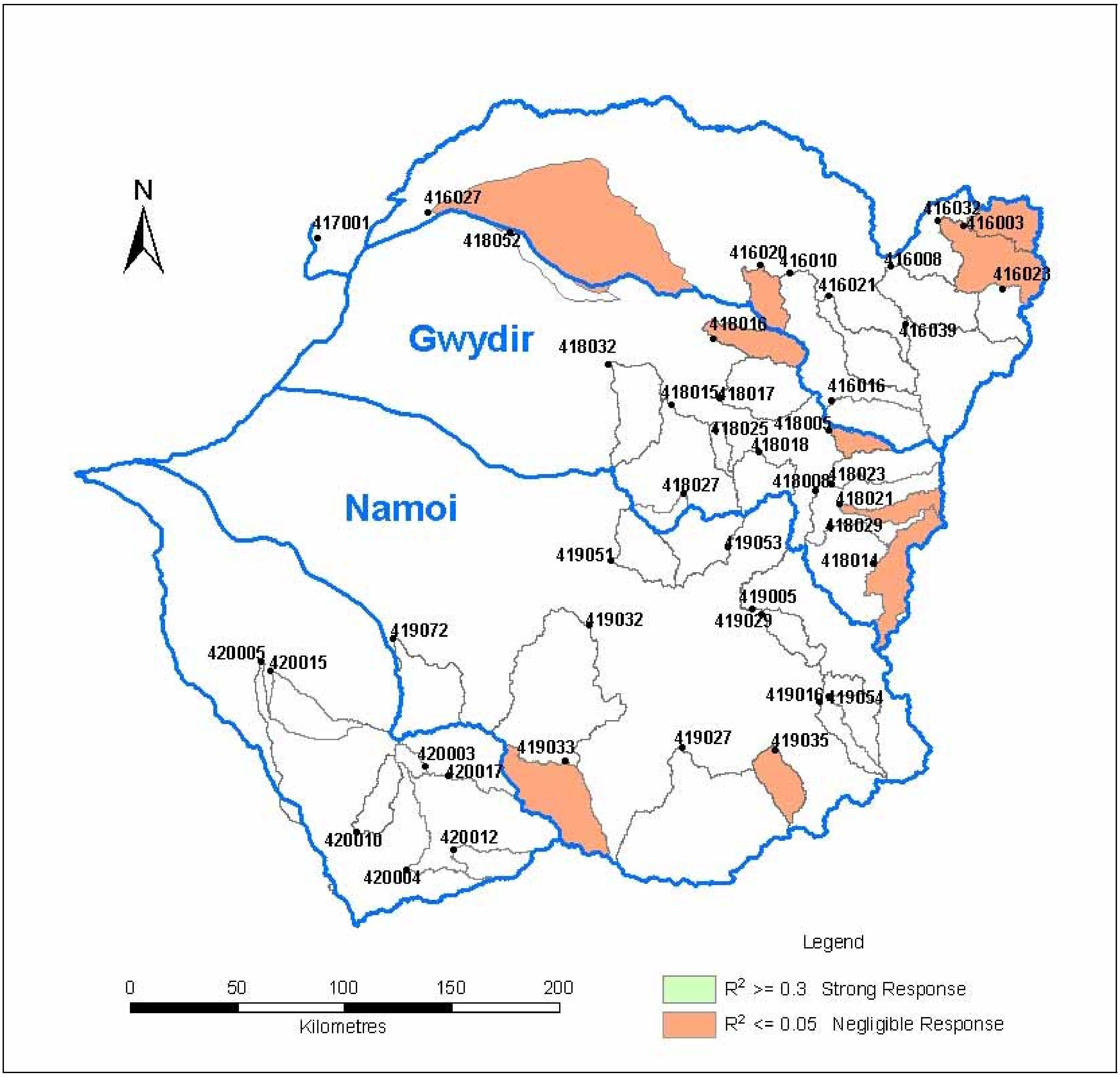
Figure 17. Map showing performance of Model 5, southern NSW.



Flow-adjusted EC as modelled by 'longer-term' influences (spline of time).

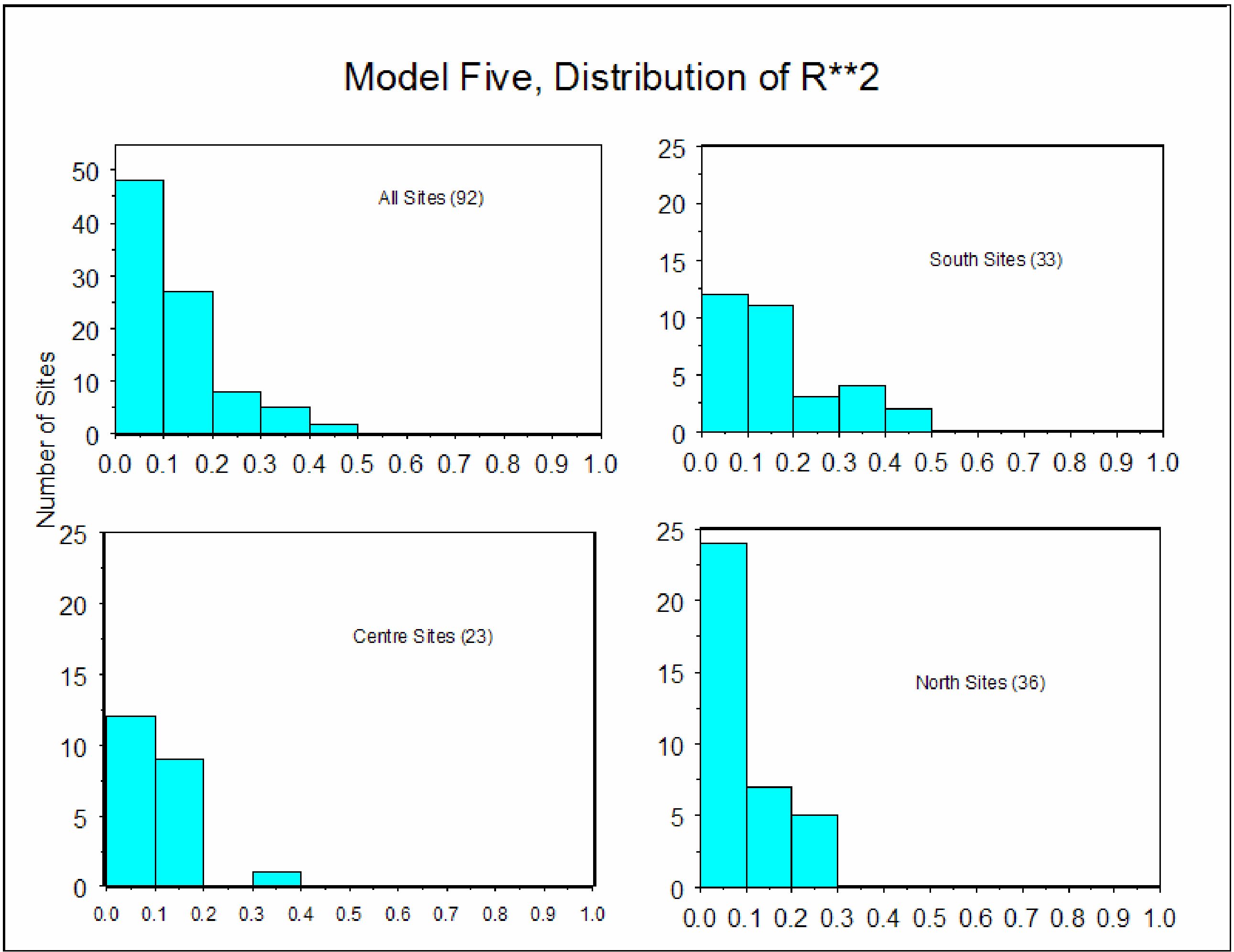
All sites except 421048 are located in the central Murrumbidgee–Lachlan. At most other sites, the additional effect of time as an explanatory variable was far less marked. At 27 of the 92 sites, Table 2 suggests that EC trends are small or negligible over time (Model 5, $R^2 \leq 0.05$). Figure 17 and (to a much lesser extent) Figure 18 suggests that the catchments where Model 5 showed some significance had low-elevation outlets. The catchments where Model 5 had little influence were generally of a high elevation, i.e. at the top of the valleys. Figure 19 shows the distribution of the Model 5 performance across NSW, and suggests that the 3 northern valleys have a large proportion of the 'non-respondents' to Model 5.

Figure 18. Map showing performance of Model 5, northern NSW.



Flow-adjusted EC as modelled by 'longer-term' influences (spline of time).

Figure 19. Model 5, distribution of R^2 across NSW.

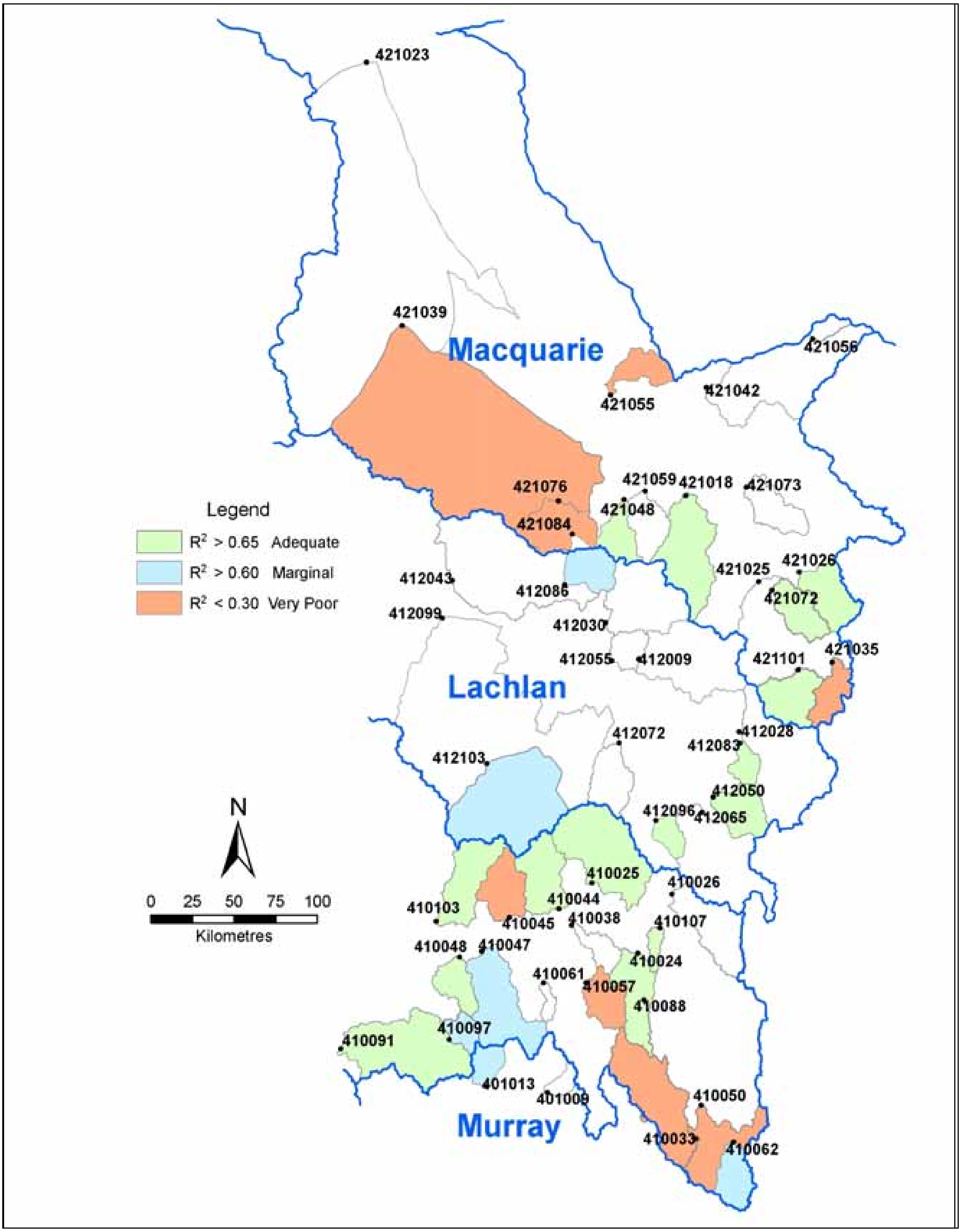


5.1.4 Performance of the full GAM (Model 7)

Interest focused on the full and more complex Model 7, since it generally provided the best fit to the EC data (Table 2). However, R^2 can be misleading if used as the sole indicator of a model's performance. For example, 410103 Houlaghans Creek at Downside, with just 28 data values spanning 28 years, shows a high final R^2 of 0.95. In fact, the deviations from the fitted curve are large, but small when compared with the huge influence of the trend component (Model 5) at the site. At some other sites, such as 410038 Adjungbilly Creek at Darbalara, the trend component is minor, but R^2 is as low as 0.49. Here, the limitations of data collection instruments are likely to have a much larger impact than any fitted trend. Thus, we have much more confidence in the Adjungbilly Creek trend results than in the Houlaghans Creek results.

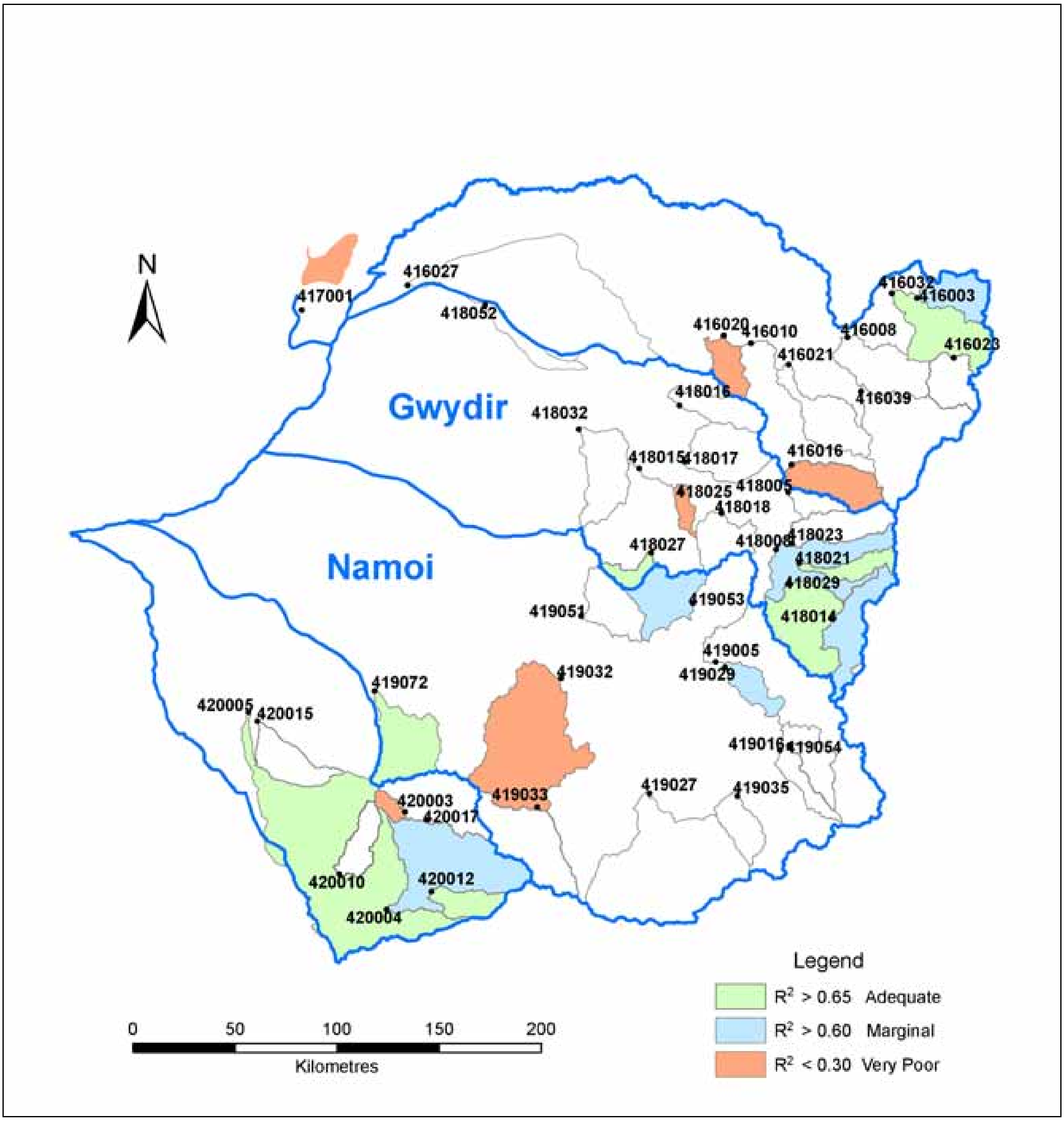
Despite those reservations, the distribution of the set of Model 7 R^2 values is presented spatially (Figures 20 and 21) and as histograms (Figure 22).

Figure 20. Map showing performance of Model 7, southern half of NSW.



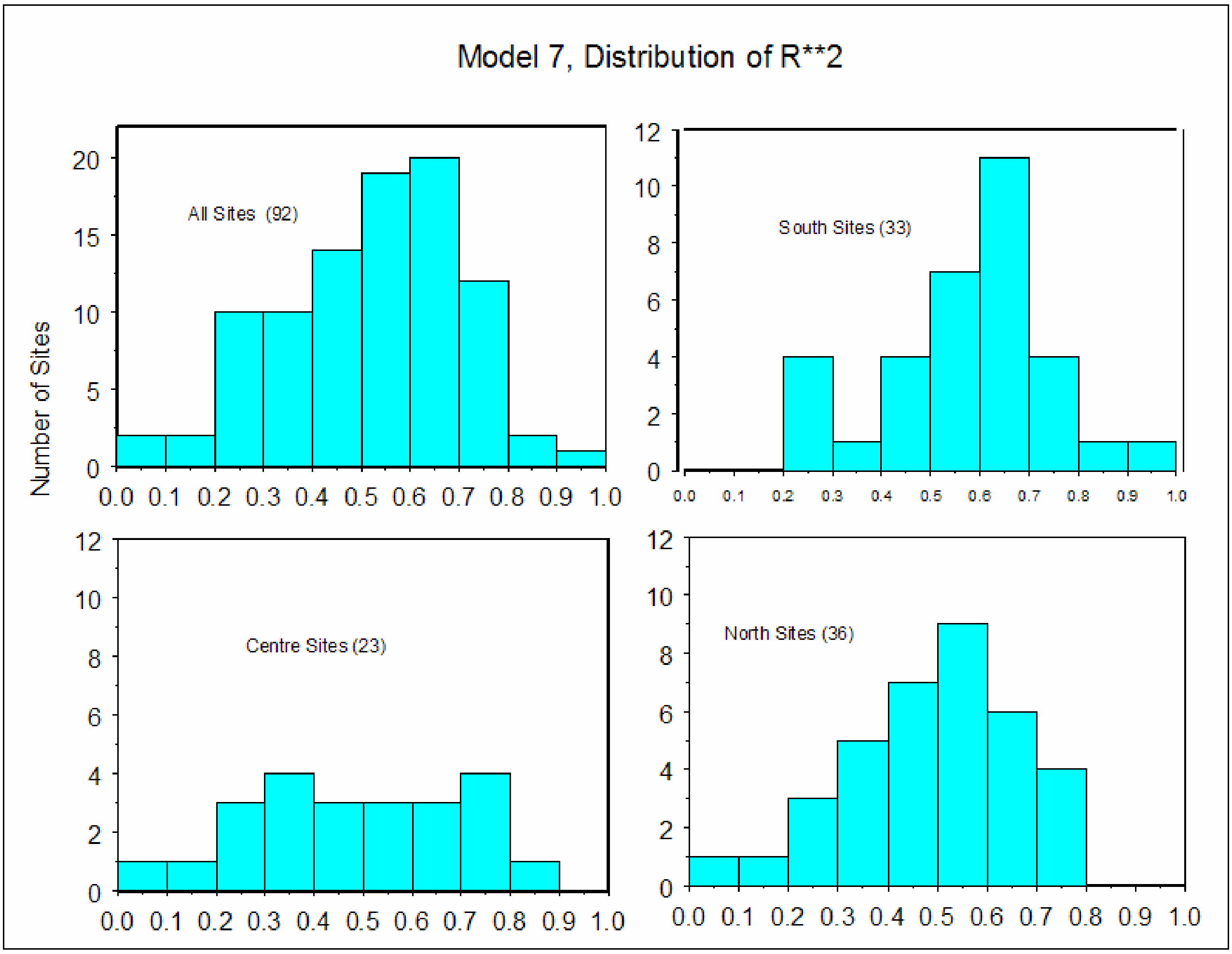
EC as modelled by combining 'short-term' and 'longer-term' influences.

Figure 21. Map showing performance of Model 7, northern half of NSW.



EC as modelled by combining 'short-term' and 'longer-term' influences.

Figure 22. Model 7, distribution of R^2 across NSW.



An arbitrary decision was made to use $R^2 \geq 0.65$ as indicating a successful Model 7 fit. Under this criterion, a site was considered adequately modelled if 2/3 of the variance in EC could be explained by Model 7. There were 25 sites in this category, 13 of them in the 3 southern-most valleys. The R^2 values for a further 8 sites fell between 0.6 and 0.65 and were categorised as 'marginal'. Model 7 generated a larger number of high R^2 values in the south of the State than in the north. This success was probably driven by the comparatively large trend component (Model 5) at a number of the southern sites (Figures 17, 19). Also worthy of note was the spatial grouping of the Macquarie Valley, in which the better Model 7 performers clustered in the south-east of the valley. In summary, the better results of Model 7 were obtained in the upper valleys of the Gwydir, Macquarie, Lachlan and generally scattered throughout the Murrumbidgee.

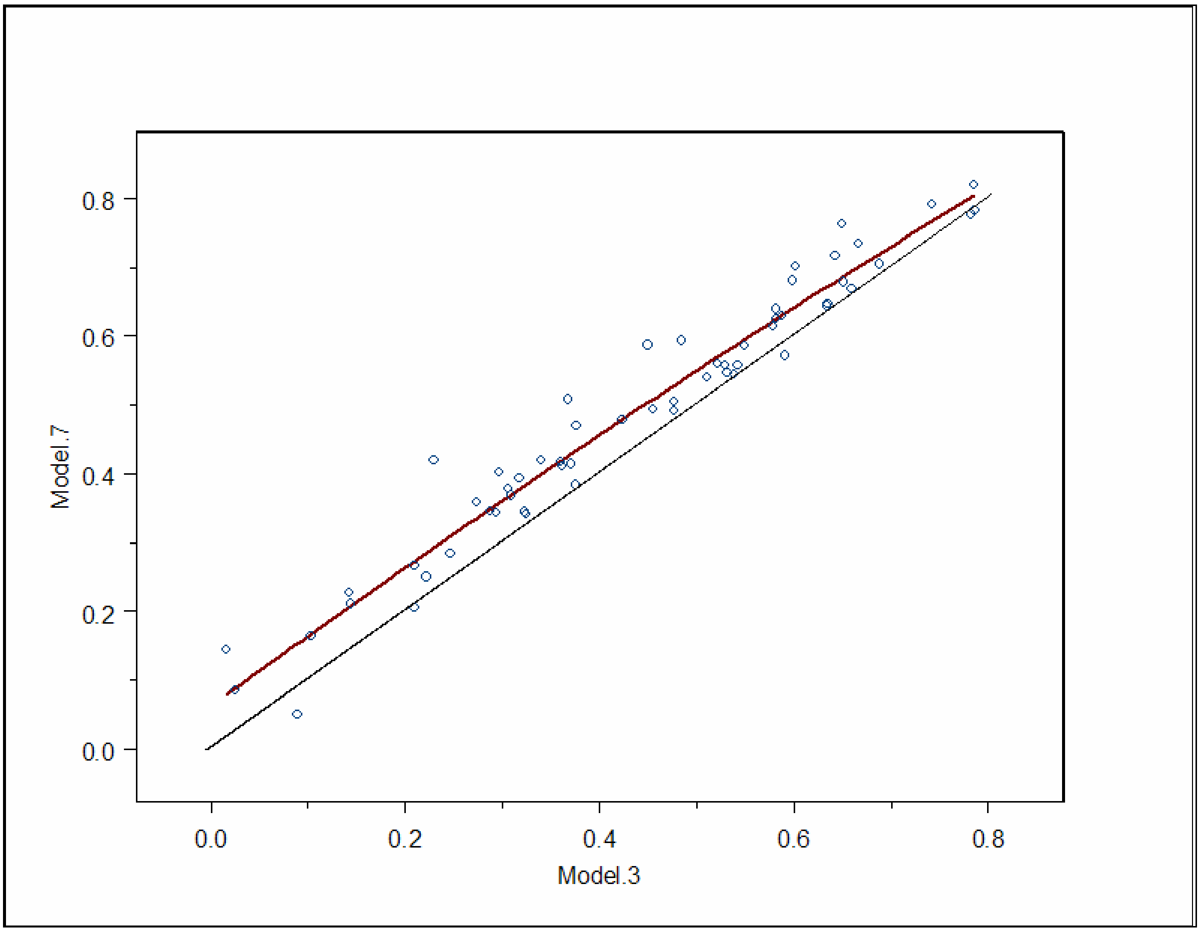
A 'very poor' category was established for sites with Model 7 $R^2 < 0.3$. For these, we concluded that the combination of flow and time trend components was poor at explaining the variation in EC data. There were 14 such sites throughout the State.

5.1.5 Link between Model 3 and Model 7

Model 7 combined flow and time components to predict EC. It was of interest to note the difference in magnitude of the R^2 values between Models 7 and 3, as the models differ in the inclusion of the spline time component (Model 5). Only at the few sites listed in Section 5.1.3 did the time spline function (as calculated in Model 5) appear to contribute beneficially to Model 7. Of flow and time, flow appears to be a stronger contributor to Model 7 performance. To explore this link, the R^2 of

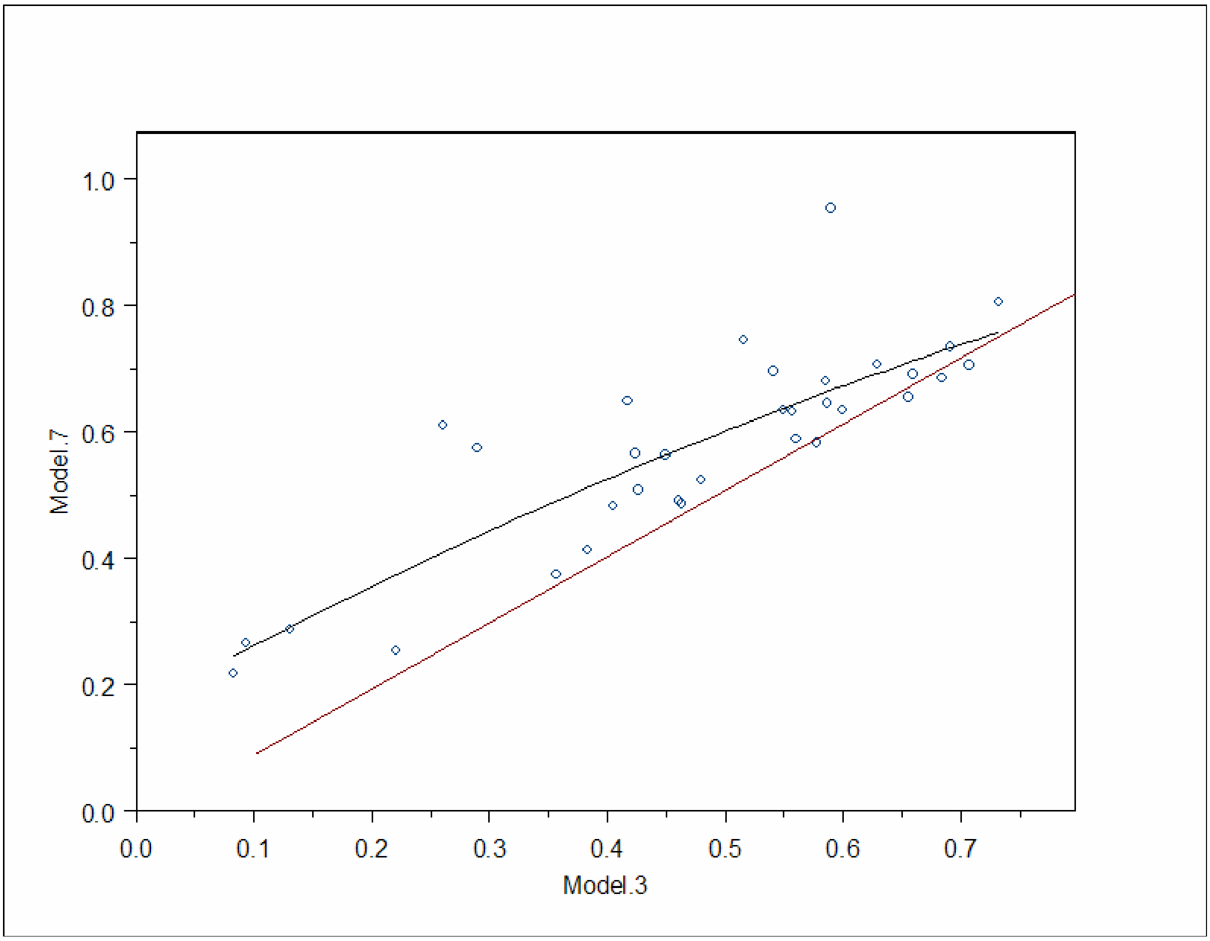
Model 3 is plotted against the Model 7 R^2 (Figures 23, 24). The red line is a smoothed line of best fit and the blue is a one-to-one line.

Figure 23. Plot of Model 3 R^2 vs Model 7 final R^2 in all central and northern valleys.



Figures 23 and 24 indicate that the performance of the more complex Model 7 seems to be only marginally better than that of Model 3 in the north of the State. This should be seen in the context that, generally, the models did not perform as well in the north and centre of the State. In the south, there appeared to be much less of a clear link (less duplication) between Models 3 and 7, i.e. Model 7 is an improvement over Model 3 owing to the added time spline. As flagged in Section 5.1.3 and Table 2, the time component plays an additional influential role (over and above that of flow) at the listed sites. This is borne out by some of the relatively high R^2 values for Model 5 (already discussed in Section 5.1.3).

Figure 24. Plot of Model 3 R^2 vs Model 7 final R^2 in Murray–Murrumbidgee–Lachlan valleys.



5.2 EC trend indicators

5.2.1 Description of Table 3

The trend indicators developed as per Section 4.8 are tabulated in Table 3. After the station identification number and name, the next 8 columns of statistics contain results generated using Jolly *et al.*'s (1997) statistical method of estimating trends. Although many sites have a statistically significant linear trend of $\log_e$EC over time, there is also a significant non-linear component to this overall trend. As the investigation proceeded, it became increasingly evident that relying on linear trend alone limited the potential for a fuller understanding of EC behaviour at any particular site. Often, the non-linear trend revealed as much, if not more, about the catchment behaviour. In this context, the cyclicity indicators become an important guide.

Columns 9 to 11 attempt to supplement the non-linear statistics of the regression used in Model 7. These indicate the cyclical behaviour of the EC trend derived for the mean flow of the observations. (The details of that specific flow are tabulated in Appendix 1. The Model 7 curves are plotted in Appendix 2.) Specifically:

- Column 9 is the ratio of the logs of the maximum and minimum values of the Model 7 curve
- Column 10 is the percentage difference between the maximum and minimum values (in real scale)
- Column 11 is the recovery factor, as described in Section 4.8.3.

The large percentages (in Column 10) at some of the sites indicate large cyclic fluctuations. The magnitudes of these cycles stress the danger of calculating EC trends or attempting to provide forecasts for 2020.

The graphs in Appendix 2 show that the recovery factor method (Section 4.8.3) was a good indicator of the trend in the Murrumbidgee–Murray (station numbers 409--- and 410---). At many sites in these valleys, the EC had been steadily rising since the start of the record, and showed signs of stabilising only in the mid 1990s. The recovery factor (section 4.8.3) was not a useful tool in the north, where many of the stations showed completely different behaviour, starting with a falling trend and then beginning to rise. When applied to the northern valleys, it ignored the trough. Consequently, the calculation could not effectively indicate the catchment's capacity to drop back to low EC levels.

Table 3. Summary statistics from fitting the GAM shown as Equation 1.

The columns of Table 3 indicate the …

- station number
- station name
- (1) linear coefficient η of *time* from the spline term in Equation 1
- (2) standard error of the linear coefficient (η)
- (3) probability that the linear slope (η) is equal to zero
- (4) first-order autocorrelation coefficient (ACF) of residuals from Equation 1
- (5) significance probability of non-linear portion C_{time} of Eq. 1
- (6) significance *P* of the non-linear portion $C_{logeFlow}$ of Eq. 1
- (7) significance *P* of the seasonality term
- (8) coefficient of determination (R^2) for the full model
- (9) ratio of logs of max and min from Model 7
- (10) difference between max and min from Model 7 as %
- (11) recovery (Section 4.8.3)

Station No.	Station name	1 Linear coeff.	2 SE	3 *P*(slope) = 0	4 Lag 1 ACF	5 Pr(F) C_{time}	6 Pr(F) $C_{logeFlow}$	7 Pr(chi) season	8 Adj. R^2	9 Cycle ratio	10 % of cycle	11 Recovery
401009	Maragle Creek at Maragle	0.0007	0.002	Nil	0.203	0.01	Nil	Nil	0.56	1.08	37.0	0.96
401013	Jingellic Creek at Jingellic	–0.0007	0.001	Nil	0.054	0.01	0.01	Nil	0.65	1.03	12.9	0.98
410091	Billabong Creek at Walbundrie	0.0195	0.003	0.01	0.121	0.01	0.10	Nil	0.81	1.11	65.5	0.52
410097	Billabong Creek at Aberfeldy	0.0109	0.002	0.01	–0.027	0.05	0.01	Nil	0.63	1.06	37.4	0.72
410024	Goodradigbee River at Wee Jasper	–0.0043	0.001	0.01	0.154	0.01	0.01	Nil	0.71	1.06	25.8	1.12
410025	Jugiong Creek at Jugiong	0.0195	0.002	0.01	0.200	0.01	0.01	Nil	0.74	1.08	55.0	0.57
410026	Yass River at Yass	0.0080	0.004	0.05	0.184	Nil	0.01	Nil	0.37	1.04	25.6	0.83
410033	Murrumbidgee River Mittagang Xing	–0.0100	0.003	0.01	0.178	0.01	Nil	Nil	0.22	1.10	37.8	1.79
410038	Adjungbilly Creek at Darbalara	–0.0015	0.003	Nil	0.026	0.05	0.10	Nil	0.49	1.04	21.3	1.11
410044	Muttama Creek at Coolac	0.0112	0.002	0.01	0.036	0.01	0.01	Nil	0.68	1.06	42.0	0.90
410045	Billabung Creek at Sunnyside	0.0269	0.013	0.10	–0.199	Nil	0.05	Nil	0.29	1.09	46.3	0.62
410047	Tarcutta Creek at Old Borambola	0.0127	0.001	0.01	0.047	0.01	0.01	Nil	0.65	1.08	41.3	0.79
410048	Kyeamba Creek at Ladysmith	0.0213	0.003	0.01	0.168	0.05	0.01	Nil	0.70	1.12	70.5	0.55
410050	Murrumbidgee River at Billilingra	–0.0087	0.002	0.01	0.378	0.01	Nil	Nil	0.27	1.08	35.1	1.29
410057	Goobarragandra River at Lacmalac	0.0015	0.002	Nil	0.006	0.05	Nil	Nil	0.25	1.04	16.7	1.00
410061	Adelong Creek at Batlow Rd	–0.0008	0.002	Nil	0.091	0.01	Nil	Nil	0.49	1.03	16.3	1.10
410062	Numeralla River at Numeralla School	–0.0074	0.002	0.01	0.022	0.01	Nil	Nil	0.63	1.07	34.2	1.24
410088	Goodradigbee River at Brindabella	0.0007	0.002	Nil	0.135	0.01	0.05	Nil	0.69	1.04	17.6	1.00
410103	Houlaghans Creek at Downside	0.1852	0.012	0.01	–0.291	0.01	Nil	Nil	0.95	1.90	195.0	0.01
410107	Mountain Creek at Mountain Creek	0.0101	0.003	0.01	0.096	0.05	0.01	Nil	0.73	1.09	43.6	0.70
412009	Belubula River at Canowindra	0.0045	0.002	0.05	0.103	0.01	0.01	Nil	0.52	1.02	13.5	0.86

Station No.	Station name	1 Linear coeff.	2 SE	3 *P*(slope) = 0	4 Lag 1 ACF	5 Pr(F) C_{time}	6 Pr(F) $C_{logeFlow}$	7 Pr(chi) season	8 Adj. R^2	9 Cycle ratio	10 % of cycle	11 Recovery
412028	Abercrombie River at Abercrombie	–0.0023	0.002	Nil	0.102	Nil	0.01	Nil	0.58	1.01	4.0	1.08
412030	Mandagery Creek u/s Eugowra	0.0138	0.003	0.01	0.154	0.01	0.01	Nil	0.57	1.04	30.1	0.61
412043	Goobang Creek at Darbys Dam	0.0284	0.009	0.01	–0.018	Nil	0.01	Nil	0.51	1.04	21.9	0.69
412050	Crookwell River at Narrawa North	–0.0008	0.002	Nil	0.244	Nil	0.01	Nil	0.65	1.01	5.5	1.11
412055	Belubula River at Bangaroo Bridge	0.0056	0.004	Nil	–0.213	0.01	0.01	Nil	0.48	1.03	18.1	0.76
412065	Lachlan River at Narrawa	0.0044	0.002	0.05	0.040	0.05	0.01	Nil	0.59	1.03	17.3	0.87
412072	Back Creek at Koorawatha	0.0162	0.008	0.05	0.059	Nil	0.05	Nil	0.41	1.02	15.9	0.74
412083	Tuena Creek at Tuena	–0.0100	0.003	Nil	0.161	Nil	0.01	Nil	0.69	1.01	9.1	1.03
412086	Goobang Creek at Parkes	–0.0146	0.006	0.05	–0.115	0.05	0.05	Nil	0.63	1.06	32.7	1.15
412096	Pudmans Creek at Kennys Rd	0.0028	0.004	Nil	–0.086	Nil	0.01	Nil	0.71	1.02	10.8	0.84
412099	Manna Creek nr Lake Cowal	0.0223	0.007	0.01	0.144	0.01	Nil	Nil	0.57	1.12	64.5	0.67
412103	Bland Creek at Morangarell	0.0871	0.018	0.01	–0.053	Nil	0.10	Nil	0.61	1.23	106.0	0.35
416003	Tenterfield Creek at Clifton	–0.0007	0.002	Nil	0.240	0.05	0.01	Nil	0.64	1.02	9.7	0.97
416008	Beardy River at Haystack	–0.0098	0.002	0.01	0.282	0.01	0.01	Nil	0.51	1.09	32.3	1.13
416010	Macintyre River at Wallangra	–0.0033	0.002	Nil	0.343	0.01	0.01	Nil	0.41	1.03	17.5	1.04
416016	Macintyre River at Inverell	–0.0027	0.003	Nil	0.200	0.05	0.01	Nil	0.28	1.04	23.4	1.00
416020	Ottleys Creek At Coolatai	0.0014	0.003	Nil	0.080	0.05	0.01	Nil	0.25	1.03	21.8	0.89
416021	Frazers Creek at Ashford	0.0081	0.002	0.01	0.325	0.01	0.01	Nil	0.59	1.08	45.2	0.72
416023	Deepwater Creek at Bolivia	–0.0007	0.003	Nil	0.144	0.01	Nil	Nil	0.49	1.03	15.5	0.96
416027	Gil Gil Creek at Weemelah	0.0027	0.003	Nil	0.038	Nil	Nil	Nil	0.54	1.03	14.7	0.90
416032	Mole River at Donaldson	–0.0022	0.001	0.10	0.155	0.01	0.01	Nil	0.70	1.01	6.6	1.03
416039	Severn River at Strathbogie	0.0058	0.002	0.05	0.357	0.01	Nil	0.10	0.34	1.04	20.5	0.72
417001	Moonie River at Gundablouie	0.0004	0.004	Nil	–0.152	0.10	Nil	Nil	0.08	1.06	30.2	1.05
418005	Copes Creek at Kimberley	–0.0066	0.002	0.01	0.088	Nil	0.01	Nil	0.54	1.03	15.2	1.17
418008	Gwydir at Bundarra	0.0028	0.001	0.05	0.272	0.01	0.01	0.10	0.61	1.02	8.8	0.93
418014	Gwydir at Yarrowyck	–0.0044	0.002	0.01	0.111	Nil	0.01	Nil	0.65	1.02	12.0	1.12
418015	Horton River at Rider (Killara)	–0.0010	0.001	Nil	0.484	0.01	0.01	Nil	0.59	1.03	19.4	1.00
418016	Warialda Creek at Warialda	–0.0008	0.002	Nil	0.349	0.10	0.01	Nil	0.56	1.01	6.2	0.92
418017	Myall Creek at Molroy	–0.0018	0.002	Nil	0.188	0.01	0.01	Nil	0.42	1.04	24.7	0.98
418018	Keera Creek at Keera	–0.0069	0.006	Nil	0.108	0.01	0.10	Nil	0.37	1.06	35.8	
418021	Laura Creek at Laura	0.0007	0.002	Nil	0.008	Nil	0.01	Nil	0.78	1.01	4.5	0.97
418023	Moredun Creek at Bundarra	0.0034	0.005	Nil	0.058	0.05	Nil	Nil	0.50	1.04	22.3	
418025	Halls Creek at Bingara	–0.0045	0.001	0.01	0.158	0.01	0.10	Nil	0.14	1.02	16.9	1.10
418027	Horton River at Dam Site	–0.0183	0.003	0.01	0.349	0.05	0.01	Nil	0.72	1.10	53.7	1.69
418029	Gwydir River at Stoneybatter	0.0009	0.004	Nil	0.253	0.01	0.01	Nil	0.68	1.07	38.6	
418032	Tycannah Ck at Horseshoe Lagoon	–0.0010	0.002	Nil	0.219	0.01	0.01	Nil	0.56	1.04	22.6	0.97
418052	Carole Creek near Garah	–0.0055	0.005	Nil	0.067	0.01	0.05	Nil	0.40	1.05	30.6	1.05
419005	Namoi River at North Cuerindi	–0.0116	0.004	0.01	0.234	0.10	0.01	Nil	0.59	1.07	33.1	1.44
419016	Cockburn River at Mulla Xing	–0.0100	0.002	0.01	0.270	Nil	0.01	Nil	0.36	1.03	16.8	1.34
419027	Mooki River at Breeza	0.0127	0.002	0.01	0.385	0.01	0.01	Nil	0.42	1.08	52.7	0.70

Station No.	Station name	1 Linear coeff.	2 SE	3 *P*(slope) = 0	4 Lag 1 ACF	5 Pr(F) C_{time}	6 Pr(F) $C_{logeFlow}$	7 Pr(chi) season	8 Adj. R^2	9 Cycle ratio	10 % of cycle	11 Recovery
419029	Halls Creek at Ukalon	–0.0065	0.003	0.05	0.111	0.01	0.01	Nil	0.64	1.04	25.5	1.08
419032	Coxs Creek at Boggabri	–0.0071	0.006	Nil	0.298	0.05	0.10	Nil	0.21	1.09	52.3	1.33
419033	Coxs Creek at Tambar Springs	–0.0017	0.002	Nil	0.162	0.10	Nil	Nil	0.49	1.02	13.6	1.05
419035	Goonoo Goonoo Ck at Timbumburi	–0.0023	0.004	Nil	0.086	Nil	0.01	Nil	0.38	1.03	17.5	0.97
419051	Maules Creek at Avoca	–0.0011	0.002	Nil	0.007	0.01	0.01	Nil	0.35	1.04	22.2	1.10
419053	Manilla River at Black Springs	–0.0014	0.002	Nil	0.295	0.01	0.01	Nil	0.63	1.03	18.4	0.94
419054	SwampOak Creek at Limbri	–0.0048	0.004	Nil	0.185	0.01	0.01	Nil	0.48	1.03	19.8	0.71
419072	Baradine Creek at Kienbri	0.0056	0.005	Nil	–0.022	0.01	0.01	Nil	0.70	1.06	33.5	0.78
420003	Belar Creek at Warkton	–0.0124	0.003	0.01	–0.073	Nil	0.05	Nil	0.27	1.04	21.2	1.16
420004	Castlereagh River at Mendooran	0.0018	0.002	Nil	0.274	0.01	0.01	Nil	0.63	1.03	16.7	0.83
420005	Castlereagh River at Coonamble	–0.0009	0.003	Nil	0.105	0.01	0.01	Nil	0.79	1.04	26.2	0.92
420010	Wallumburrawang Ck at Bearbung	0.0076	0.008	Nil	0.304	0.10	0.05	Nil	0.41	1.04	26.0	0.80
420012	Butheroo Creek at Neilrex	0.0035	0.007	Nil	0.121	0.01	0.10	Nil	0.82	1.08	62.5	0.85
420015	Warrena Creek at Warrana	0.0039	0.008	Nil	0.261	0.01	Nil	Nil	0.47	1.19	87.3	0.57
420017	Castlereagh River at Hidden Valley	0.0095	0.006	0.10	0.030	0.01	0.01	Nil	0.38	1.06	37.1	
421018	Bell River at Newrea	0.0027	0.001	0.05	0.050	0.01	0.01	Nil	0.68	1.01	9.2	0.92
421023	Bogan River at Gongolgon	0.0033	0.003	Nil	0.431	0.01	0.05	Nil	0.39	1.05	30.7	0.82
421025	Macquarie River at Bruinbun	0.0024	0.002	Nil	0.018	0.05	0.01	Nil	0.55	1.03	15.5	0.90
421026	Turon River at Sofala	–0.0025	0.002	Nil	0.032	0.10	0.01	Nil	0.67	1.03	19.1	0.94
421035	Fish River at Tarana	0.0012	0.009	Nil	–0.074	Nil	Nil	Nil	0.21	1.05	21.9	0.88
421039	Bogan River at Neurie Plains	0.0014	0.005	Nil	–0.061	Nil	Nil	Nil	0.05	1.04	19.8	1.01
421042	Talbragar River at Elong Elong	0.0083	0.003	0.01	0.387	0.01	0.01	Nil	0.42	1.08	51.0	0.73
421048	Little River at Obley	0.0223	0.003	0.01	0.205	0.10	0.01	Nil	0.76	1.12	66.3	0.50
421055	Coolbaggie Creek at Rawsonville	0.0025	0.006	Nil	0.113	0.05	Nil	Nil	0.16	1.13	56.7	1.05
421056	Coolaburragundy Creek at Coolah	0.0005	0.003	Nil	0.181	0.05	0.01	Nil	0.34	1.01	8.7	0.95
421059	Buckinbar Creek at Yeoval	0.0018	0.002	Nil	0.091	0.05	0.01	Nil	0.56	1.04	27.0	0.90
421072	Winburndale Rivulet Howards Bridge	0.0119	0.010	Nil	0.197	0.01	0.01	Nil	0.73	1.04	23.0	
421073	Meroo Creek at Yarrabin 2	–0.0008	0.008	Nil	–0.157	Nil	0.01	Nil	0.57	1.00	1.9	1.02
421076	Bogan River at Peak Hill 2	0.0045	0.007	Nil	0.239	0.10	Nil	Nil	0.23	1.06	28.2	0.84
421084	Burrill Creek at Mickibri	0.0076	0.011	Nil	–0.242	Nil	Nil	Nil	0.34	1.08	39.4	
421101	Campbells R. u/s Ben Chifley Dam	0.0027	0.003	Nil	–0.110	Nil	0.01	Nil	0.78	1.01	8.3	0.94

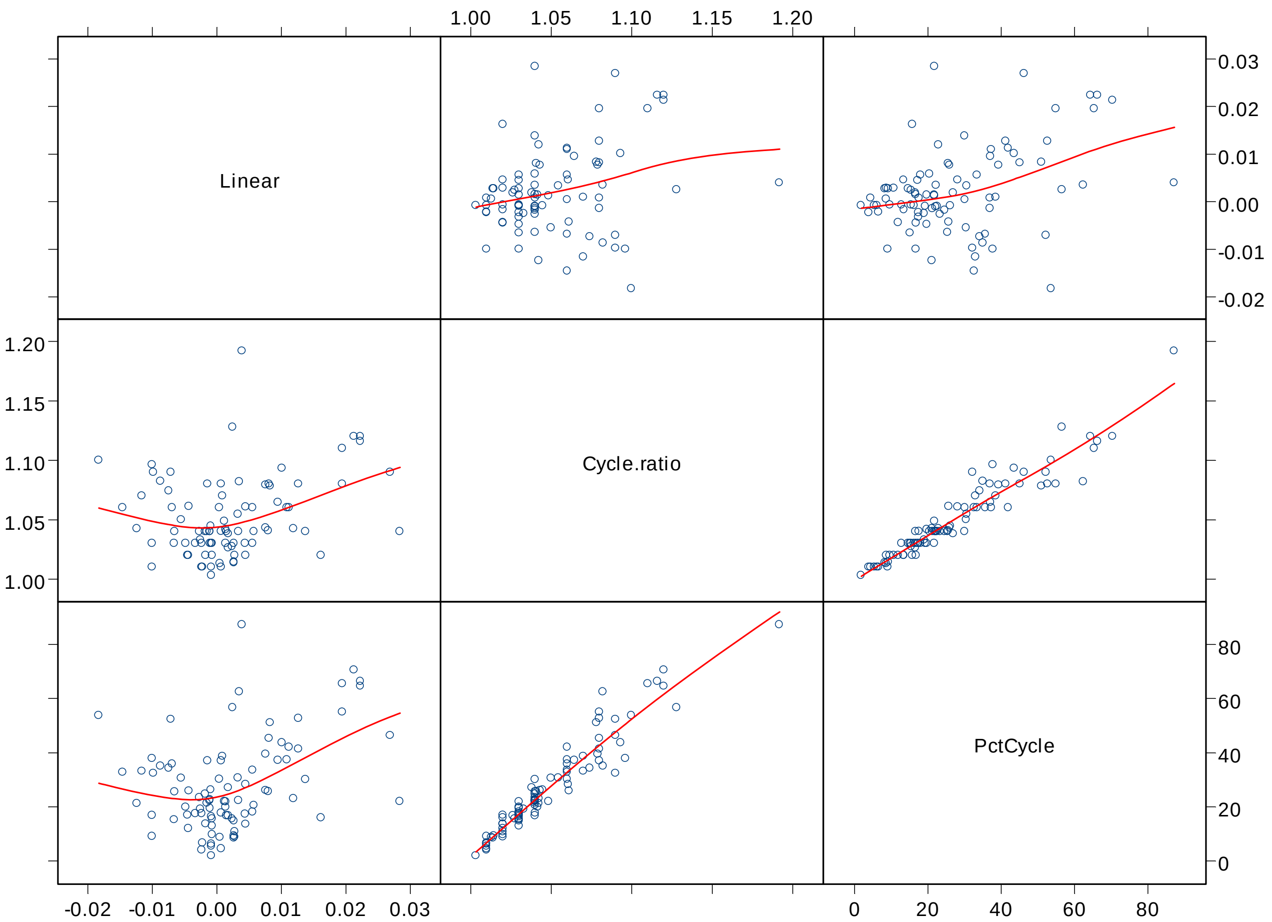
Shaded results based on adjusted data sets (Sections 2.2 and 3.1.3).

5.2.2 Comparison of indicators

Three of the trend indicators described in Section 4.8 (statistical linearity, cycle ratio and percentage of cycle) have been plotted in Figure 25, using 90 of the 92 sites. Two sample points have been removed because we consider them to be outliers with an extreme influence on the projection of the fitted line. The sites, 410103 Houlaghans at Downside and 412103 Bland at Morangarell, are 2 of the more western catchments in the study area.

As might be expected, the cycle ratio and the percentage of cycle seem to be strongly linked (Figure 25). However, the 2 indicators based on cycle have no strong relationship with linear trend. There is a weak suggestion that the 2 cycle indicators increase as the magnitude of the linear trend increases (particularly when the linear trend is positive).

Figure 25. Matrix plot of 3 measures of trend.



5.2.3 Other statistical measures of trend

Table 4 lists the significance of the linear (η) and non-linear (C_{time}) time coefficients from Section 4.5. Over the period of observation, most sites exhibit non-linear curvature of their time response.

The proportional change in EC per year has been estimated using the equation $e^{\eta} - 1$, which is then multiplied by the average EC (µS cm^{-1}) over the period of observation to give an estimate of EC change in units of µS cm^{-1} y^{-1}. This represents the annual average change in EC when the EC is at its average level. A 95% CI for this estimate has also been derived.

Each station's predicted mean percentage change in EC over the period of observation (i.e. relative to that in the first year of observation), together with 95% CLs, is also listed in Table 4. Although this is an adequate measure of the linear compound change over the period of study, it is an inadequate indication of total change over the same period. For this reason, the significance of the non-linear time component affects the interpretation of these estimates of compound change.

Although prediction of future EC levels is extremely tentative, even when the response is strictly linear, prediction of mean % EC change from the first year of observation to 2020 cannot be estimated using this method in the presence of significant non-linear trend. Therefore, the final columns of Table 4 are given only for sites whose trend is primarily linear over the period of observation.

Section 8.9 discusses EC prediction to 2020. At those few sites that have a primarily linear time trend, the linear regression portion of the time trend can be used to fit confidence belts to the response curve using Equation 5. A tentative extrapolation may then be made to 2020. The calculation of these confidence belts is found in many text books on regression analysis:

$$\hat{y} \pm t_{n-2,0.05} * \sqrt{s^2\left[\frac{1}{n} + \frac{(X-\bar{x})^2}{SSx}\right]} \qquad (5)$$

where:

- $\hat{y}$ is the estimated $\log_e$EC
- s^2 is the residual mean square derived from the data analysis
- n is the number of observations used in the analysis
- X is the time point at which the prediction is to be made
- $\bar{x}$ is the mean of the observed time points
- SSx is the sums of squares of the observed time points
- $t_{n-2,0.05}$ is Student's t statistic with $n - 2$ degrees of freedom.

Table 4. Trend statistics fitting the GAM shown as Equation 1.

The columns of Table 4 indicate the …

- station number
- station name
- probability that the linear slope (η) is equal to zero
- significance *P* of the non-linear portion C_{time} of Equation 1
- mean EC value, averaged over all data available
- estimated change in EC per annum at average EC
- estimated half 95% CI for the EC change
- estimated mean % change in EC over the period of observation
- 95% CL for this change
- the number of years between start of observations and 2020
- estimated mean % change in EC to 2020; ne = not estimable
- 95% CL for this change

							Over period of observation		Prediction to 2020		
Station No.	**Station name**	**Linearity *P***	**Non-linear *P***	**Mean EC µS cm^{-1}**	**EC trend µS cm^{-1} y^{-1}**	**Half 95% CI**	**Mean % change**	**95% CL**	**No. yrs lapsed**	**Mean % change**	**95% CL**
401009	Maragle Creek at Maragle	Nil	0.01	108	0.1	0.5	2	(–10, 16)	51	ne	ne
401013	Jingellic Creek at Jingellic	Nil	0.01	114	–0.1	0.2	–2	(–8, 4)	51	ne	ne
410091	Billabong Creek at Walbundrie	0.01	0.01	1324	26.1	7.8	94	(63, 131)	51	ne	ne
410097	Billabong Creek at Aberfeldy	0.01	0.05	507	5.6	1.9	45	(28, 65)	51	ne	ne
410024	Goodradigbee River at Wee Jasper	0.01	0.01	86	–0.4	0.3	–14	(–21, –6)	51	ne	ne
410025	Jugiong Creek at Jugiong	0.01	0.01	1184	23.3	4.7	94	(74, 116)	51	ne	ne
410026	Yass River at Yass	0.05	Nil	688	5.5	6.0	32	(3, 70)	51	50	(5, 116)
410033	Murrumbidgee R. at Mittagang Xing	0.01	0.01	76	–0.8	0.5	–30	(–41, –16)	51	ne	ne
410038	Adjungbilly Creek at Darbalara	Nil	0.05	160	–0.2	0.9	–5	(–20, 13)	51	ne	ne
410044	Muttama Creek at Coolac	0.01	0.01	1294	14.6	6.2	46	(25, 71)	51	ne	ne
410045	Billabung Creek at Sunnyside	0.10	Nil	257	7.0	5.6	50	(1, 122)	51	294	(4, 1399)
410047	Tarcutta Creek at Old Borambola	0.01	0.01	254	3.2	0.7	58	(44, 73)	53	ne	ne
410048	Kyeamba Creek at Ladysmith	0.01	0.05	836	18.0	5.4	102	(69, 141)	50	ne	ne
410050	Murrumbidgee River at Billilingra	0.01	0.01	100	–0.9	0.6	–27	(–36, –16)	52	ne	ne
410057	Goobarragandra River at Lacmalac	Nil	0.05	59	0.1	0.2	5	(–8, 20)	51	ne	ne
410061	Adelong Creek at Batlow Rd	Nil	0.01	125	–0.1	0.4	–3	(–12, 8)	51	ne	ne
410062	Numeralla R. at Numeralla School	0.01	0.01	144	–1.1	0.5	–23	(–31, –13)	51	ne	ne
410088	Goodradigbee River at Brindabella	Nil	0.01	100	0.1	0.4	2	(–9, 16)	51	ne	ne
410103	Houlaghans Creek at Downside	0.01	0.01	4707	957.7	80.9	17768	(9378, 33584)	46	ne	ne
410107	Mountain Creek at Mountain Creek	0.01	0.05	164	1.7	0.9	38	(17, 63)	48	ne	ne
412009	Belubula River at Canowindra	0.05	0.01	643	2.9	2.6	14	(3, 27)	52	ne	ne
412028	Abercrombie River at Abercrombie	Nil	Nil	280	–0.6	1.1	–8	(–18, 4)	53	–11	(-26, 6)

Station No.	Station name	Linearity *P*	Non-linear *P*	Mean EC µS cm^{-1}	EC trend µS cm^{-1} y^{-1}	Half 95% CI	Over period of observation: Mean % change	Over period of observation: 95% CL	Prediction to 2020: No. yrs lapsed	Prediction to 2020: Mean % change	Prediction to 2020: 95% CL
412030	Mandagery Creek u/s Eugowra	0.01	0.01	987	13.7	7.4	60	(29, 98)	52	ne	ne
412043	Goobang Creek at Darbys Dam	0.01	Nil	364	10.5	6.6	49	(15, 92)	52	338	(71, 1023)
412050	Crookwell River at Narrawa North	Nil	Nil	418	–0.3	2.3	–3	(–16, 12)	51	–4	(–22, 19)
412055	Belubula River at Bangaroo Bge	Nil	0.01	624	3.5	4.0	12	(–5, 33)	52	ne	ne
412065	Lachlan River at Narrawa	0.05	0.05	855	3.8	3.9	17	(0, 36)	52	ne	ne
412072	Back Creek at Koorawatha	0.05	Nil	1665	27.2	28.1	41	(1, 95)	52	132	(3, 421)
412083	Tuena Creek at Tuena	Nil	Nil	483	–4.8	3.1	–29	(–41, –15)	52	–41	(–55, –22)
412086	Goobang Creek at Parkes	0.05	0.05	573	–8.3	6.6	–26	(–44, –4)	52	ne	ne
412096	Pudmans Creek at Kennys Rd	Nil	Nil	1294	3.6	9.1	8	(–12, 33)	45	13	(–19, 59)
412099	Manna Creek near Lake Cowal	0.01	0.01	451	10.2	7.3	46	(16, 84)	45	ne	ne
412103	Bland Creek at Morangarell	0.01	Nil	326	29.6	11.1	269	(120, 521)	44	4517	(905, 21113)
416003	Tenterfield Creek at Clifton	Nil	0.05	332	–0.2	1.3	–2	(–12, 8)	51	ne	ne
416008	Beardy River at Haystack	0.01	0.01	233	–2.3	1.3	–29	(–39, –18)	51	ne	ne
416010	Macintyre River at Wallangra	Nil	0.01	515	–1.7	3.4	–11	(–24, 4)	51	ne	ne
416016	Macintyre River at Inverell	Nil	0.05	493	–1.3	3.5	–9	(–25, 11)	50	ne	ne
416020	Ottleys Creek at Coolatai	Nil	0.05	724	1.0	4.2	5	(–13, 26)	51	ne	ne
416021	Frazers Creek at Ashford	0.01	0.01	433	3.5	2.9	33	(13, 57)	51	ne	ne
416023	Deepwater Creek at Bolivia	Nil	0.01	159	–0.1	0.9	–2	(–18, 16)	51	ne	ne
416027	Gil Gil Creek at Weemelah	Nil	Nil	420	1.1	2.9	10	(–12, 38)	51	15	(-18, 60)
416032	Mole River at Donaldson	0.10	0.01	204	–0.4	0.6	–7	(–15, 1)	51	ne	ne
416039	Severn River at Strathbogie	0.05	0.01	298	1.7	2.0	18	(4, 35)	45	ne	ne
417001	Moonie River at Gundablouie	Nil	0.10	141	0.1	1.0	1	(–23, 34)	51	ne	ne
418005	Copes Creek at Kimberley	0.01	Nil	178	–1.2	0.8	–20	(–31, –8)	50	–28	(–42, –12)
418008	Gwydir at Bundarra	0.05	0.01	284	0.8	0.9	12	(2, 23)	56	ne	ne
418014	Gwydir at Yarrowyck	0.01	Nil	357	–1.6	1.4	–14	(–24, –4)	51	–20	(–33, –5)
418015	Horton River at Rider (Killara)	Nil	0.01	622	–0.6	2.3	–4	(–11, 4)	52	ne	ne
418016	Warialda Creek at Warialda	Nil	0.10	833	–0.7	5.1	–3	(–15, 11)	48	ne	ne
418017	Myall Creek at Molroy	Nil	0.01	1046	–1.9	4.8	–6	(–18, 7)	51	ne	ne
418018	Keera Creek at Keera	Nil	0.01	611	–4.2	8.2	–13	(–31, 10)	51	ne	ne
418021	Laura Creek at Laura	Nil	Nil	266	0.2	1.1	2	(–10, 17)	51	4	(–15, 27)
418023	Moredun Creek at Bundarra	Nil	0.05	238	0.8	2.7	6	(–12, 28)	50	ne	ne
418025	Halls Creek at Bingara	0.01	0.01	1039	–4.7	3.2	–15	(–22, –7)	51	ne	ne
418027	Horton River at DamSite	0.01	0.05	506	–9.2	4.4	–47	(–57, –35)	51	ne	ne
418029	Gwydir River at Stoneybatter	Nil	0.01	301	0.3	3.0	2	(–12, 17)	51	ne	ne
418032	Tycannah Ck at Horseshoe Lagoon	Nil	0.01	749	–0.7	4.3	–3	(–17, 12)	49	ne	ne
418052	Carole Creek near. Garah	Nil	0.01	400	–2.2	4.1	–12	(–30, 10)	40	ne	ne
419005	Namoi River at North Cuerindi	0.01	0.10	278	–3.2	2.7	–33	(–48, –13)	50	ne	ne
419016	Cockburn River at Mulla Xing	0.01	Nil	434	–4.3	2.4	–30	(–39, –19)	51	-40	(–51, –26)
419027	Mooki River at Breeza	0.01	0.01	975	12.5	6.8	54	(32, 80)	50	ne	ne
419029	Halls Creek at Ukalon	0.05	0.01	669	–4.3	3.7	–20	(–32, –5)	50	ne	ne

							Over period of observation		Prediction to 2020		
Station No.	**Station name**	**Linearity *P***	**Non-linear *P***	**Mean EC µS cm^{-1}**	**EC trend µS cm^{-1} y^{-1}**	**Half 95% CI**	**Mean % change**	**95% CL**	**No. yrs lapsed**	**Mean % change**	**95% CL**
419032	Coxs Creek at Boggabri	Nil	0.05	660	–4.7	10.7	–22	(–48, 17)	51	ne	ne
419033	Coxs Creek at Tambar Springs	Nil	0.10	1092	–1.9	5.7	–6	(–19, 10)	51	ne	ne
419035	Goonoo Goonoo Ck at Timbumburi	Nil	Nil	1040	–2.4	8.4	–8	(–28, 18)	50	-11	(–38, 28)
419051	Maules Creek at Avoca	Nil	0.01	363	–0.4	1.2	–3	(–13, 7)	48	ne	ne
419053	Manilla River at Black Springs	Nil	0.01	875	–1.2	3.8	–4	(–14, 6)	48	ne	ne
419054	Swamp Oak Creek at Limbri	Nil	0.01	519	–2.5	4.8	–13	(–31, 8)	46	ne	ne
419072	Baradine Creek at Kienbri	Nil	0.01	289	1.6	2.8	14	(–9, 42)	39	ne	ne
420003	Belar Creek at Warkton	0.01	Nil	176	–2.2	1.1	–25	(–36, –12)	52	–48	(–63, –26)
420004	Castlereagh River at Mendooran	Nil	0.01	676	1.2	3.4	6	(–6, 21)	52	ne	ne
420005	Castlereagh River at Coonamble	Nil	0.01	434	–0.4	3.3	–3	(–22, 21)	52	ne	ne
420010	Wallumburrawang Ck at Bearbung	Nil	0.10	491	3.7	11.0	25	(–22, 98)	51	ne	ne
420012	Butheroo Creek at Neilrex	Nil	0.01	4994	17.5	79.5	12	(–28, 74)	51	ne	ne
420015	Warrena Creek at Warrana	Nil	0.01	290	1.1	5.8	13	(–29, 79)	50	ne	ne
420017	Castlereagh River at Hidden Valley	0.10	0.01	389	3.7	4.4	26	(–3, 63)	40	ne	ne
421018	Bell River at Newrea	0.05	0.01	651	1.8	1.6	11	(1, 21)	53	ne	ne
421023	Bogan River at Gongolgon	Nil	0.01	347	1.1	2.8	13	(–6, 34)	52	ne	ne
421025	Macquarie River at Bruinbun	Nil	0.05	318	0.8	1.0	9	(–2, 21)	52	ne	ne
421026	Turon River at Sofala	Nil	0.10	378	–0.9	1.6	–9	(–21, 6)	52	ne	ne
421035	Fish River at Tarana	Nil	Nil	124	0.1	2.0	3	(–35, 64)	51	6	(–56, 155)
421039	Bogan River at Neurie Plains	Nil	Nil	131	0.2	1.3	5	(–27, 50)	52	8	(–37, 83)
421042	Talbragar River at Elong Elong	0.01	0.01	1052	8.8	9.9	33	(8, 63)	52	ne	ne
421048	Little River at Obley	0.01	0.10	609	13.7	3.9	118	(82, 161)	51	ne	ne
421055	Coolbaggie Creek at Rawsonville	Nil	0.05	153	0.4	2.1	9	(–28, 65)	51	ne	ne
421056	Coolaburragundy Creek at Coolah	Nil	0.05	834	0.4	5.0	2	(–12, 18)	52	ne	ne
421059	Buckinbar Creek at Yeoval	Nil	0.05	1392	2.5	6.7	7	(–8, 24)	51	ne	ne
421072	Winburndale Rivulet Howards Bridge	Nil	0.01	297	3.6	7.4	13	(–8, 37)	52	ne	ne
421073	Meroo Creek at Yarrabin 2	Nil	Nil	392	–0.3	5.6	–1	(–23, 26)	52	-4	(–59, 124)
421076	Bogan River at Peak Hill 2	Nil	0.10	136	0.6	2.5	16	(–27, 84)	51	ne	ne
421084	Burrill Creek at Mickibri	Nil	Nil	209	1.6	3.8	14	(–22, 67)	47	43	(–50, 310)
421101	Campbells R. u/s Ben Chifley Dam	Nil	Nil	440	1.2	2.0	7	(–5, 21)	42	12	(–9, 38)

Shaded results based on adjusted data sets (Sections 2.2 and 3.1.3).

5.3 Catchment characteristics

The integration of catchment characteristics (Section 2.7) into the investigation increases the opportunity to explain EC trend behaviour in each catchment. The values are presented in Table 5, although some are not available for the more westerly catchments. It might be expected that some of the characteristics listed in Section 2.7 are interdependent. A matrix plot was produced for the catchment characteristics (Figure 26). It became necessary to remove the area of 5 sites, but only on the basis that they were greater than 8000 km^2, preventing a clearer view of the effect of area in the plot. Similarly, very large mean ECs were removed at 420012 Butheroo Creek at Neilrex and 410103 Houlaghans Creek at Downside.

We hoped to use the characteristics to assist in arranging the sites into geographic groups on the basis that each group might exhibit common EC trend behaviour. We had to take care that the gauging station location was representative of the characteristics of its catchment; otherwise the process could have become confusing. The following sections describe how the groups were determined. The station details are described in Section 6.

5.3.1 Snowy subgroup

Figure 26 shows no pattern, except in mean annual rainfall versus elevation in Column 3. The plot emphasises a small group of stations that varied from the general pattern. Although these had high mean annual rainfall, their outlets had low elevation. These sites have been identified in Figure 27. Eight sites definitely varied from the majority pattern.

Two sites (labelled in blue in Figure 27) could have been included in the Snowy group but were not. One of these is 410024 Goodradigbee at Wee Jasper, which was attached to an adjoining subgroup with similar traits. The other was 410047 Tarcutta at Old Borambola, whose area (1640 km^2) is nearly 3 times the size of the other 7 catchments. It has 2 distinct geographic components. Its top quarter is located in a mountainous, high-rainfall area—similar to the terrain of the other 7 sites—but its remainder is located in much flatter terrain with substantially less rainfall. Because of this variation in catchment characteristics, we decided not to categorise it in the Snowy subgroup.

Mathematically, there is no justification for the separation, because potentially there are an infinite number of locations that might fall in the area of interest outlined in Figure 27. In practice, there would be very few catchment sites in NSW that would be small enough to have such a high mean average rainfall and a low elevation. Six of the 7 sites became the basis of the Snowy subgroup.

5.3.2 Warrumbungle subgroup

The Warrumbungle Range protrudes onto the north-western plains of NSW, and defines the catchment boundary between the upper Castlereagh and the mid Namoi valleys. The terrain is unusual, with volcanic outcrops rising steeply out of the flat surrounding plains. There is a steep rainfall gradient on the range itself.

In their hypsometric work on the nearby Mooki River, Dowling *et al.* (1998) wrote ‘the catchment proved to be anomalous, and this was attributed to its size and internal complexity. … The outlier (Mooki) was later shown to have different land use patterns and considerable internal heterogeneity with respect to many soil/landscape variables’.

Mindful of Dowling *et al.*’s concerns, we grouped 4 sites on the basis that the Warrumbungle Range represented a large proportion of their area and gave a distorted value for the average slope of the catchment.

Figure 26. Catchment characteristics matrix plot.

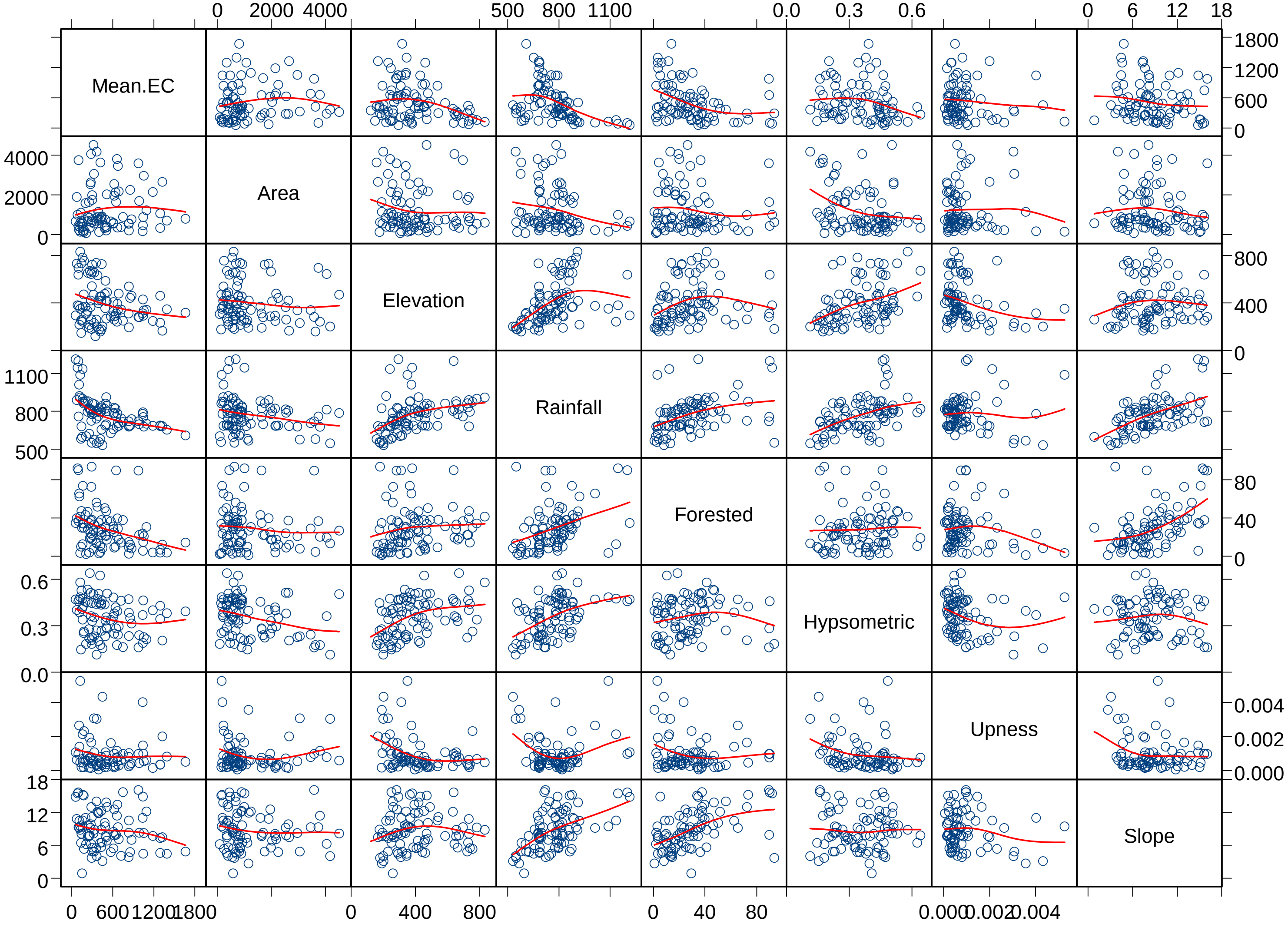
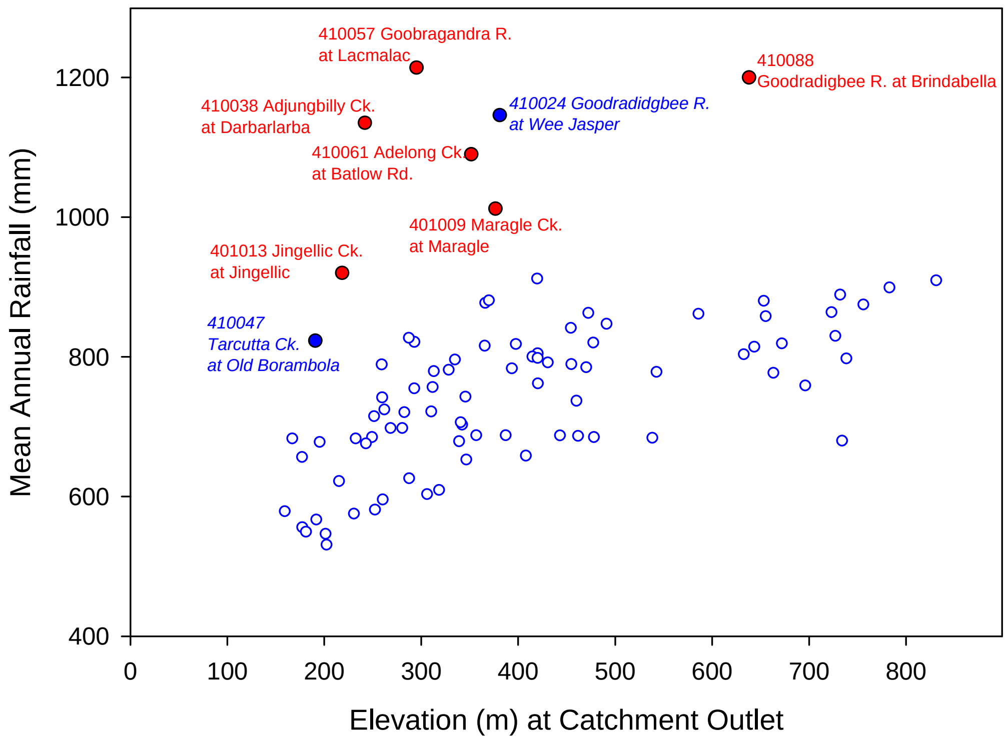


Figure 27. Highlighting the Snowy subgroup rainfall and elevation.



5.3.3 Southern Trending subgroup

This subgroup was based on the 7 sites (listed in Sect. 5.1.3) that showed a strong time trend response (Model 5). Most of these were located in the mid Murrumbidgee and mid Lachlan. With the addition of 4 nearby sites, they became the basis for the Southern Trending subgroup.

5.3.4 Other subgroups

Several other subgroups were formed around more general geographic groupings:

- 4 sites belonging to the Upper Murrumbidgee subgroup, above Burrinjuck Dam
- 3 sites in the mountainous terrain of the upper Lachlan Valley—'Lachlan Mountains'
- the mid Lachlan valley sites—'Lachlan Rising'
- the Upper Macquarie subgroup, consisting mainly of the sites in the south-east of the Macquarie and 2 Castlereagh sites
- sites in the Bogan, lower Castlereagh and lower Talbragar—'Bogan'.

The northern valleys of the Namoi, Gwydir and Border Rivers were grouped by the EC trend calculated in Model 7. The classifications were Northern Falling, Northern Insignificant and Northern Rising, as described in Section 6.1.6.

Table 5. Trend, cyclicity and catchment characteristics.

No.	Station Name	Mean annual rainfall (mm)	Elevation at gauge (m)	Average slope catchment	Linear coefficient	SE of linear coefficient	*P* (slope) = 0 (stat. signif.)	Cycle ratio	% of cycle	Recovery factor	Mean EC	Area (km^2)	UPNESS midpoint	Hypsometric integral	% Forested	Model 3 R^2	Model 5 R^2 #	Model 7 R^2 ♫	Flow %ile Highest Flow
	Snowy Sub-group																		
401009	Maragle Ck. at Maragle	1012	376.6	9.1	0.0007	0.0019	Nil	1.08	37.0	0.96	108	216	0.00264	0.470	65.5	0.45	0.21	0.56	12
401013	Jingellic Ck. at Jingellic	920	218.5	10.4	-0.0007	0.0009	Nil	1.03	12.9	0.98	114	394	0.00139	0.385	62.6	0.59	0.14	0.65	8
410038	Adjungbilly Ck. at Darbalara	1135	241.8	10.5	-0.0015	0.0026	Nil	1.04	21.3	1.11	160	386	0.00212	0.475	17.0	0.46	0.04	0.49	4
410057	Goobarragandra R. at Lacmalac	1214	295.2	14.8	0.0015	0.0020	Nil	1.04	16.7	1.00	59	665	0.00106	0.469	2.4	0.22	0.04	0.25	9
410061	Adelong Ck. at Batlow Rd.	1090	351.5	9.4	-0.0008	0.0015	Nil	1.03	16.3	1.10	125	146	0.00526	0.484	36.6	0.46	0.05	0.49	25
410088	Goodradigbee R. at Brindabella	1200	638.0	15.6	0.0007	0.0018	Nil	1.04	17.6	1.00	100	431	0.00097	0.458	3.2	0.66	0.10	0.69	2
	Upper Murrumbidgee																		
410024	GoodradidgbeeR.at Wee Jasper	1146	381.0	15.4	-0.0043	0.0013	0.01	1.06	25.8	1.12	86	990	*	*	11.9	0.63	0.20	0.71	16
410033	Murrumbidgee R.at Mittagang Xing	889	732.0	10.8	-0.0100	0.0025	0.01	1.10	37.8	1.79	76	1891	0.00063	0.401	3.8	0.08	0.14	0.22	*
410050	Murrumbidgee R. at Billilingra	759	696.0	9.3	-0.0087	0.0019	0.01	1.08	35.1	1.29	100	3745	*	*	34.6	0.09	0.18	0.27	19
410062	Numeralla R. at Numeralla Sch.	680	734.0	8.1	-0.0074	0.0017	0.01	1.07	34.2	1.24	144	675	0.00020	0.528	34.8	0.56	0.16	0.63	38
410107	Mountain Ck. at Mountain Ck.	877	366.0	15.2	0.0101	0.0026	0.01	1.09	43.6	0.70	164	167	0.00046	0.424	73.5	0.69	0.13	0.73	32
420003	Belar Ck. at Warkton	863	472.3	15.0	-0.0124	0.0034	0.01	1.04	21.2	1.16	176	131	0.00020	0.252	33.9	0.21	0.07	0.27	5
	Southern Trending Sub-group																		
410025	Jugiong Ck. at Jugiong	685	249.3	7.7	0.0195	0.0016	0.01	1.08	55.0	0.57	1184	2140	0.00015	0.399	20.9	0.52	0.42	0.74	5
410044	Muttama Ck. at Coolac	683	232.3	7.3	0.0112	0.0023	0.01	1.06	42.0	0.90	1294	1059	0.00035	0.343	39.7	0.59	0.18	0.68	14
410045	Billabung Ck. at Sunnyside	622	215.2	7.7	0.0269	0.0133	0.10	1.09	46.3	0.62	257	842	0.00193	0.219	12.5	0.13	0.12	0.29	20
410047	Tarcutta Ck. at Old Borambola	823	190.7	7.6	0.0127	0.0013	0.01	1.08	41.3	0.79	254	1641	0.00016	0.277	3.6	0.42	0.39	0.65	1
410048	Kyeamba Ck. at Ladysmith	678	195.2	8.3	0.0213	0.0027	0.01	1.12	70.5	0.55	836	550	0.00102	0.233	3.5	0.54	0.31	0.70	1
410091	Billabong Ck. at Walbundrie	683	167.1	7.4	0.0195	0.0026	0.01	1.11	65.5	0.52	1324	2657	0.00200	0.204	47.1	0.73	0.27	0.81	37
410097	Billabong Ck. at Aberfeldy	698	268.4	7.4	0.0109	0.0019	0.01	1.06	37.4	0.72	507	346	0.00037	0.290	90.1	0.55	0.18	0.63	23
410103	Houlaghans Ck. at Downside	567	191.6	2.7	0.1852	0.0115	0.01	1.90	195.0	0.01	4707	1144	0.00357	0.396	0.9	0.59	0.37	0.95	0
412099	Manna Ck. near Lake Cowal	531	202.4	3.1	0.0223	0.0069	0.01	1.12	64.5	0.67	451	10857	0.00432	0.154	8.4	0.29	0.38	0.57	15
412103	Bland Ck. at Morangarell	576	230.7	4.9	0.0871	0.0176	0.01	1.23	106.0	0.35	326	3050	0.00307	0.232	7.6	0.26	0.46	0.61	23
	Lachlan Mountains Sub-group																		
412028	Abercrombie R. at Abercrombie	805	420.0	9.8	-0.0023	0.0017	Nil	1.01	4.0	1.08	280	2625	0.00014	0.512	37.2	0.58	0.01	0.58	14
412050	Crookwell R. at Narrawa North	789	454.8	6.5	-0.0008	0.0021	Nil	1.01	5.5	1.11	418	756	0.00047	0.625	10.6	0.66	0.00	0.65	12
412083	Tuena Ck. at Tuena	820	477.4	10.0	-0.0100	0.0027	Nil	1.01	9.1	1.03	483	320	0.00019	0.437	50.3	0.68	0.01	0.69	20
	Lachlan Rising Sub-group																		
410026	Yass R. at Yass	685	478.0	7.1	0.0080	0.0036	0.05	1.04	25.6	0.83	688	2171	0.00029	0.295	92.0	0.36	0.03	0.37	2
412009	Belubula R. at Canowindra	821	292.8	8.1	0.0045	0.0018	0.05	1.02	13.5	0.86	643	2133	0.00023	0.418	9.9	0.48	0.08	0.52	15
412030	Mandagery Ck. at U/S Eugowra	698	280.4	8.3	0.0138	0.0032	0.01	1.04	30.1	0.61	987	1689	0.00043	0.239	22.1	0.42	0.23	0.57	40
412043	Goobang Ck. at Darbys Dam	547	201.3	4.0	0.0284	0.0092	0.01	1.04	21.9	0.69	364	4172	0.00304	0.113	13.2	0.43	0.14	0.51	*
412055	Belubula R. at Bangaroo Bridge	789	259.2	7.8	0.0056	0.0040	Nil	1.03	18.1	0.76	624	2550	0.00018	0.379	8.9	0.40	0.12	0.48	*
412065	Lachlan R. at Narrawa	688	443.1	4.8	0.0044	0.0022	0.05	1.03	17.3	0.87	855	2252	0.00033	0.350	11.8	0.56	0.06	0.59	8
412072	Back Ck. at Koorawatha	609	318.4	4.8	0.0162	0.0079	0.05	1.02	15.9	0.74	1665	800	0.00050	0.393	14.0	0.38	0.05	0.41	11
412086	Goobang Ck. at Parkes	626	287.4	4.7	-0.0146	0.0064	0.05	1.06	32.7	1.15	573	653	0.00162	0.338	36.4	0.60	0.08	0.63	19
412096	Pudmans Ck. at Kennys Rd	687	461.8	4.6	0.0028	0.0038	Nil	1.02	10.8	0.84	1294	331	0.00033	0.429	6.5	0.71	0.00	0.71	6

Table 5. Trend, cyclicity and catchment characteristics (continued)

No.	Station Name	Mean annual rainfall (mm)	Elevation at gauge (m)	Average slope catchment	Linear coefficient	SE of linear coefficient	*P* (slope) = 0 (stat. signif.)	Cycle ratio	% of cycle	Recovery factor	Mean EC	Area (km^2)	UPNESS midpoint	Hypsometric integral	% Forested	Model 3 R^2	Model 5 R^2 #	Model 7 R^2 ♫	Flow %ile highest flow
	Upper Macquarie Sub-group																		
420004	Castlereagh R. at Mendooran	706	340.6	9.3	0.0018	0.0019	Nil	1.03	16.7	0.83	676	3451	0.00078	0.241	28.7	0.59	0.10	0.63	17
421025	Macquarie R. at Bruinbun	785	470.2	8.1	0.0024	0.0015	Nil	1.03	15.5	0.90	318	4507	0.00059	0.504	26.5	0.53	0.03	0.55	22
421026	Turon R. at Sofala	803	632.7	12.1	-0.0025	0.0021	Nil	1.03	19.1	0.94	378	880	0.00024	0.474	51.6	0.66	0.03	0.67	6
421035	Fish R. at Tarana	909	831.0	8.8	0.0012	0.0087	Nil	1.05	21.9	0.88	124	593	0.00047	0.579	41.3	0.21	0.00	0.21	21
421056	Coolaburragundy Ck. at Coolah	684	538.4	10.5	0.0005	0.0025	Nil	1.01	8.7	0.95	834	212	0.00024	0.384	9.1	0.32	0.04	0.34	39
421072	Winburndale Rivlt at Howards Bdge	778	542.6	11.1	0.0119	0.0101	Nil	1.04	23.0	*	297	720	0.00041	0.446	38.1	0.67	0.20	0.73	2
421073	Meroo Ck. at Yarrabin 2	818	397.5	11.8	-0.0008	0.0083	Nil	1.00	1.9	1.02	392	729	0.00006	0.505	35.2	0.59	0.00	0.57	*
421101	Campbells R. U/S Ben Chifley Dam	830	727.1	6.5	0.0027	0.0025	Nil	1.01	8.3	0.94	440	918	0.00032	0.465	22.1	0.78	0.00	0.78	21
	Central Macquarie Sub-group																		
420012	Butheroo Ck. at Neilrex	688	387.1	5.6	0.0035	0.0070	Nil	1.08	62.5	0.85	4994	405	0.00191	0.325	41.3	0.79	0.15	0.82	67
421018	Bell R. at Newrea	757	311.7	7.9	0.0027	0.0012	0.05	1.01	9.2	0.92	651	1629	0.00075	0.282	89.6	0.65	0.09	0.68	15
421042	Talbragar R. at Elong Elong	679	339.1	8.2	0.0083	0.0031	0.01	1.08	51.0	0.73	1052	2963	0.00054	0.226	20.6	0.34	0.12	0.42	16
421048	Little R. at Obley	658	407.8	5.4	0.0223	0.0026	0.01	1.12	66.3	0.50	609	577	0.00026	0.358	28.2	0.65	0.30	0.76	99
421059	Buckinbar Ck. at Yeoval	653	346.5	4.5	0.0018	0.0022	Nil	1.04	27.0	0.90	1392	701	0.00082	0.380	3.7	0.53	0.07	0.56	3
	Bogan Sub-group																		
420005	Castlereagh R. at Coonamble	657	176.9	8.8	-0.0009	0.0034	Nil	1.04	26.2	0.92	434	8302	*	0.268	27.9	0.74	0.18	0.79	0
420015	Warrena Ck. at Warrana	550	181.1	3.7	0.0039	0.0076	Nil	1.19	87.3	0.57	290	621	*	0.181	93.7	0.38	0.14	0.47	30
421023	Bogan R. at Gongolgon	*	122.5	*	0.0033	0.0025	Nil	1.05	30.7	0.82	347	27970	*	*		0.32	0.11	0.39	63
421039	Bogan R. at Neurie Plains	*	*	*	0.0014	0.0052	Nil	1.04	19.8	1.01	131	14760	*	*		0.09	0.00	0.05	74
421055	Coolbaggie Ck. at Rawsonville	596	260.3	0.9	0.0025	0.0060	Nil	1.13	56.7	1.05	153	566	*	0.408	29.6	0.10	0.07	0.16	4
421076	Bogan R. at Peak Hill 2	581	252.3	6.4	0.0045	0.0071	Nil	1.06	28.2	0.84	136	1099	*	0.146	9.9	0.14	0.11	0.23	31
421084	Burrill Ck. at Mickibri	603	306.0	6.2	0.0076	0.0114	Nil	1.08	39.4	*	209	71	*	0.182	2.2	0.32	0.01	0.34	51
	Warrumbungle Sub-group																		
419027	Mooki R. at Breeza	721	282.6	16.0	0.0127	0.0023	0.01	1.08	52.7	0.70	975	3587	0.00098	0.160	89.5	0.23	0.24	0.42	14
419072	Baradine Ck. at Kienbri	725	261.9	13.0	0.0056	0.0049	Nil	1.06	33.5	0.78	289	982	0.00165	0.205	72.5	0.60	0.20	0.70	35
420010	Wallumburrawang Ck. at Bearbung	688	356.7	9.4	0.0076	0.0081	Nil	1.04	26.0	0.80	491	434	0.00057	0.231	21.7	0.36	0.07	0.41	28
420017	Castlereagh R. at Hidden Valley	762	420.3	11.9	0.0095	0.0055	0.10	1.06	37.1	*	389	1147	0.00058	0.201	26.6	0.31	0.11	0.38	43
	Norther Falling Sub-group																		
416008	Beardy R. at Haystack	796	334.7	9.6	-0.0098	0.0021	0.01	1.09	32.3	1.13	233	903	0.00057	0.534	46.4	0.37	0.22	0.51	33
418005	Copes Ck. at Kimberley	875	756.0	5.3	-0.0066	0.0021	0.01	1.03	15.2	1.17	178	235	0.00232	0.262	29.8	0.51	0.05	0.54	38
418014	Gwydir R. at Yarrowyck	798	738.4	5.5	-0.0044	0.0017	0.01	1.02	12.0	1.12	357	827	0.00035	0.441	14.0	0.63	0.03	0.65	30
418025	Halls Ck. at Bingara	779	313.0	11.0	-0.0045	0.0013	0.01	1.02	16.9	1.10	1039	171	0.00402	0.368	23.6	0.02	0.12	0.14	44
418027	Horton R. at DamSite	912	419.6	13.8	-0.0183	0.0030	0.01	1.10	53.7	1.69	506	207	0.00087	0.355	46.9	0.64	0.22	0.72	22
419005	Namoi R. at North Cuerindi	816	365.5	9.2	-0.0116	0.0038	0.01	1.07	33.1	1.44	278	2524	0.00070	0.512	23.9	0.55	0.08	0.59	22
419016	Cockburn R. at Mulla Crossing	841	454.3	12.2	-0.0100	0.0021	0.01	1.03	16.8	1.34	434	893	0.00080	0.444	37.6	0.27	0.11	0.36	28
419029	Halls Ck. at Ukalon	783	393.4	13.4	-0.0065	0.0025	0.05	1.04	25.5	1.08	669	357	0.00053	0.394	39.5	0.58	0.14	0.64	25

Table 5. Trend, cyclicity and catchment characteristics (continued)

No.	Station Name	Mean annual rainfall (mm)	Elevation at gauge (m)	Averge slope catchment	Linear coefficient	SE of linear coefficient	*P* (slope) = 0 (stat. signif.)	Cycle ratio	% of cycle	Recovery factor	Mean EC	Area (km^2)	UPNESS midpoint	Hypsometric integral	% Forested	Model 3 *R*^2	Model 5 R^2 #	Model 7 R^2 ♫	Flow % ile Highest Flow
	Northern Rising Sub-group																		
416020	Ottleys Ck. at Coolatai	743	345.6	4.1	0.0014	0.0027	Nil	1.03	21.8	0.89	724	385	0.00060	0.462	14.0	0.22	0.04	0.25	60
416021	Frazers Ck. at Ashford	798	420.1	5.7	0.0081	0.0024	0.01	1.08	45.2	0.72	433	821	0.00041	0.435	25.1	0.45	0.26	0.59	62
416039	Severn R. at Strathbogie	864	723.2	4.8	0.0058	0.0023	0.05	1.04	20.5	0.72	298	1747	0.00039	0.223	22.2	0.29	0.07	0.34	40
417001	Moonie R. at Gundablouie	*	149.4	*	0.0004	0.0040	Nil	1.06	30.2	1.05	141	15810	*	*	*	0.03	0.06	0.08	27
418008	Gwydir at Bundarra	814	643.4	6.2	0.0028	0.0012	0.05	1.02	8.8	0.93	284	4048	0.00079	0.362	19.4	0.58	0.08	0.61	40
418021	Laura Ck. at Laura	819	671.8	7.8	0.0007	0.0020	Nil	1.01	4.5	0.97	266	344	0.00076	0.640	18.8	0.79	0.00	0.78	43
418023	Moredun Ck. at Bundarra	880	653.2	7.6	0.0034	0.0053	Nil	1.04	22.3	*	238	668	0.00086	0.449	28.0	0.48	0.05	0.50	36
418029	Gwydir R. at Stoneybatter	777	663.2	5.6	0.0009	0.0038	Nil	1.07	38.6	*	301	1986	0.00053	0.330	17.2	0.60	0.19	0.68	31
	Northern Insignificant Sub-group																		
416003	Tenterfield Ck. at Clifton	858	655.3	8.8	-0.0007	0.0015	Nil	1.02	9.7	0.97	332	557	0.00107	0.353	33.1	0.63	0.02	0.64	31
416010	Macintyre R. at Wallangra	800	414.6	6.8	-0.0033	0.0023	Nil	1.03	17.5	1.04	515	2020	0.00049	0.283	17.1	0.37	0.06	0.41	48
416016	Macintyre R. at Inverell	861	585.9	7.7	-0.0027	0.0029	Nil	1.04	23.4	1.00	493	754	0.00107	0.332	31.1	0.25	0.05	0.28	48
416023	Deepwater Ck. at Bolivia	899	782.9	9.3	-0.0007	0.0025	Nil	1.03	15.5	0.96	159	536	0.00067	0.340	34.2	0.46	0.07	0.49	30
416027	Gil Gil Ck. at Weemelah	579	159.4	*	0.0027	0.0033	Nil	1.03	14.7	0.90	420	3627	*	0.175	4.4	0.54	0.01	0.54	47
416032	Mole R. at Donaldson	881	369.8	11.0	-0.0022	0.0012	0.10	1.01	6.6	1.03	204	1583	0.00056	0.455	43.0	0.69	0.05	0.70	8
418015	Horton R. at Rider (Killara)	827	287.3	12.5	-0.0010	0.0011	Nil	1.03	19.4	1.00	622	1955	0.00099	0.249	24.9	0.48	0.21	0.59	55
418016	Warialda Ck. at Warialda	722	310.3	3.8	-0.0008	0.0021	Nil	1.01	6.2	0.92	833	535	0.00080	0.472	14.8	0.54	0.03	0.56	27
418017	Myall Ck. At Molroy	755	292.7	4.5	-0.0018	0.0019	Nil	1.04	24.7	0.98	1046	871	0.00099	0.463	14.5	0.36	0.09	0.42	60
418018	Keera Ck. at Keera	781	328.4	8.4	-0.0069	0.0060	Nil	1.06	35.8	*	611	556	0.00050	0.482	31.2	0.31	0.09	0.37	41
418032	Tycannah Ck. at Horseshoe Lagoon	715	251.3	15.7	-0.0010	0.0023	Nil	1.04	22.6	0.97	749	882	0.00098	0.161	37.6	0.52	0.09	0.56	36
418052	Carole Ck. near Garah	556	177.3	*	-0.0055	0.0048	Nil	1.05	30.6	1.05	400	120	*	0.445	2.7	0.30	0.14	0.40	17
419032	Coxs Ck. at Boggabri	676	242.9	11.4	-0.0071	0.0059	Nil	1.09	52.3	1.33	660	3803	0.00116	0.174	20.3	0.14	0.08	0.21	74
419033	Coxs Ck. at Tambar Springs	703	342.2	12.1	-0.0017	0.0022	Nil	1.02	13.6	1.05	1092	1227	0.00062	0.212	30.4	0.48	0.03	0.49	74
419035	Goonoo Goonoo Ck. at Timbumburi	792	430.4	14.9	-0.0023	0.0037	Nil	1.03	17.5	0.97	1040	459	0.00147	0.189	5.3	0.38	0.01	0.38	40
419051	Maules Ck. At Avoca	742	259.7	14.0	-0.0011	0.0016	Nil	1.04	22.2	1.10	363	664	0.00032	0.269	56.2	0.29	0.07	0.35	*
419053	Manilla R. at Black Springs	737	460.0	7.0	-0.0014	0.0016	Nil	1.03	18.4	0.94	875	769	0.00043	0.313	7.9	0.58	0.10	0.63	31
419054	Swamp Oak Ck. at Limbri	847	491.1	13.0	-0.0048	0.0038	Nil	1.03	19.8	0.71	519	393	0.00021	0.508	37.7	0.42	0.09	0.48	39

Shaded results based on adjusted data sets (Sections 2.2 and 3.1).

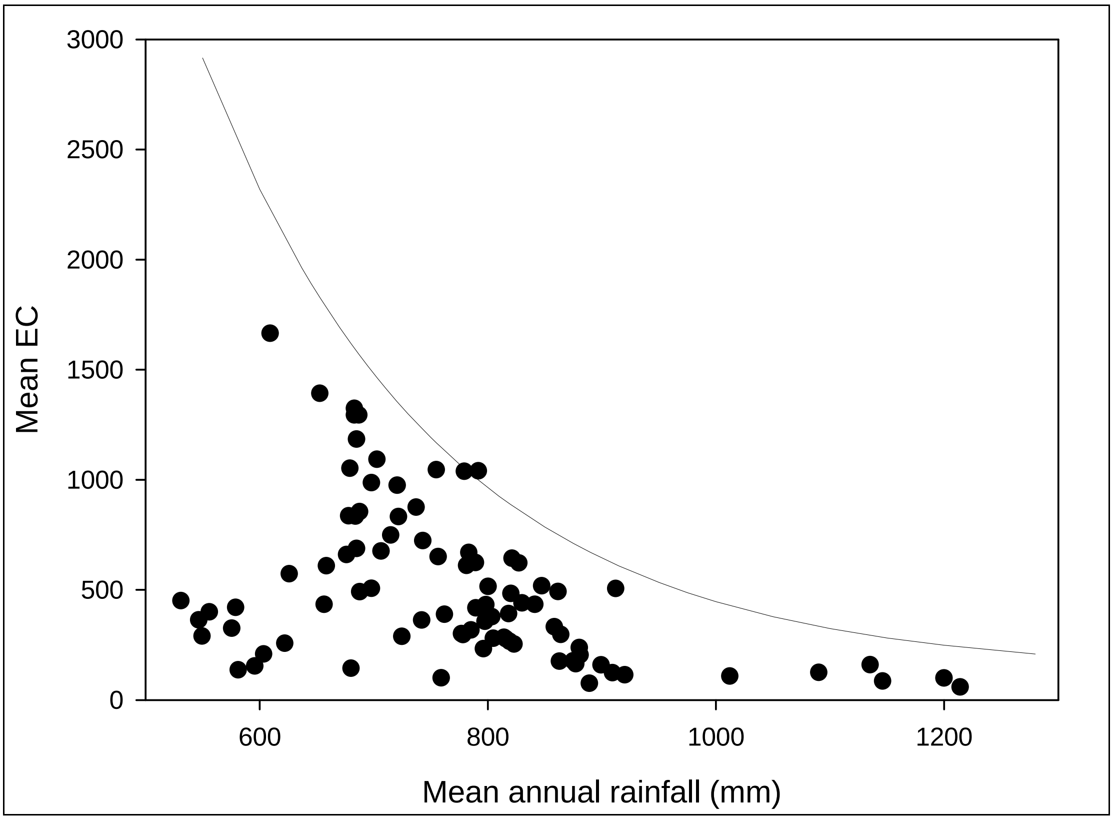
See Figures 17 and 18 (colour codes coincide).

♫ See Figures 20 and 21 (colour codes coincide).

5.3.5 Mean EC envelope

One of the minor traits in the catchment characteristics matrix plot (Figure 26) relates to the mean EC and mean annual rainfall (row 1, column 4). A mean EC envelope has been plotted as Figure 28. The plot does not represent a rigorous concept, because the sampling is infrequent. However, it is of interest because it demonstrates that highly saline catchments are unlikely to be found in high rainfall areas.

Figure 28. Mean EC envelope.

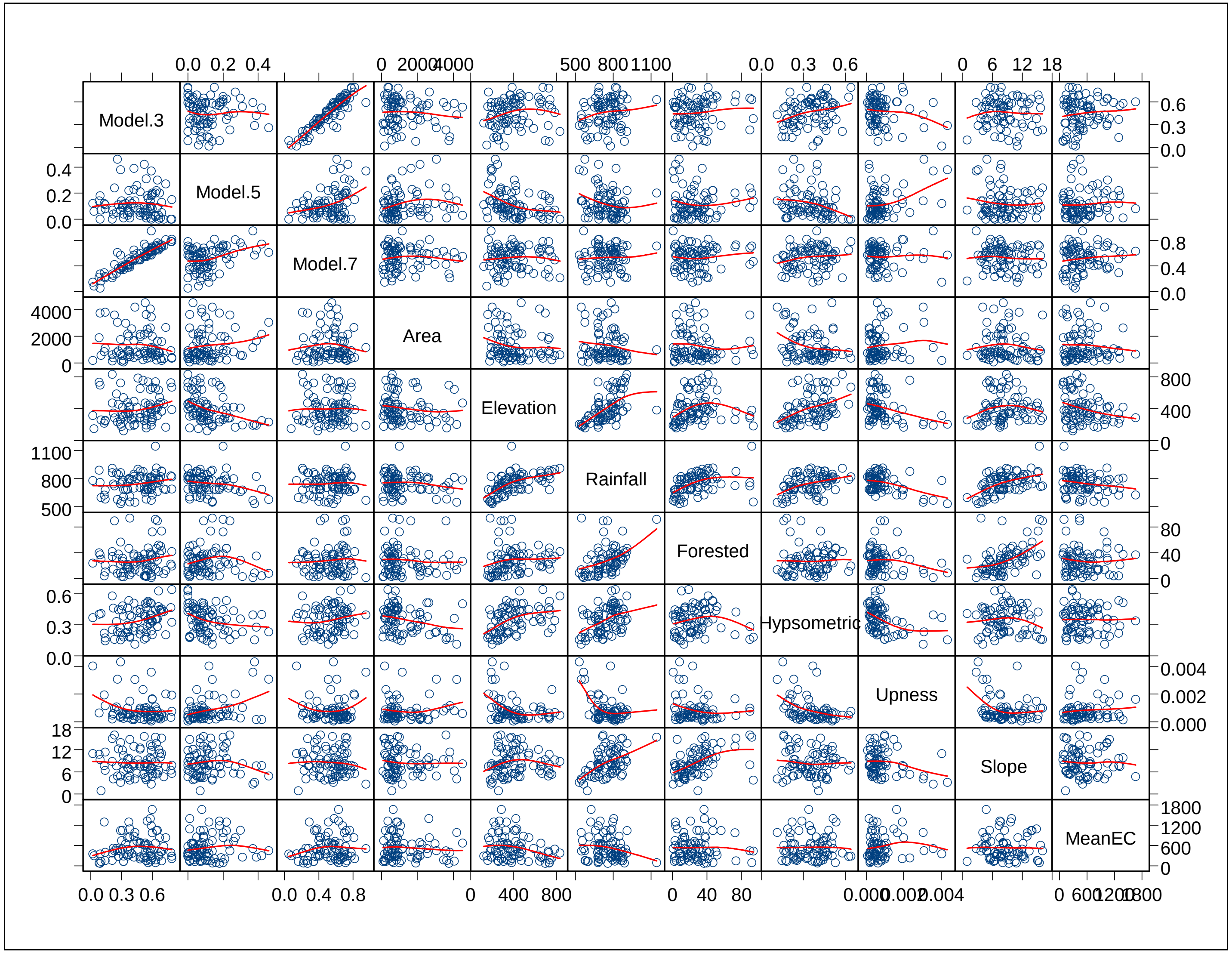


5.4 Model performance and catchment characteristics

We generated plots to examine the link between model performance and the physical characteristics in the field. In Figure 29, all the catchment characteristics are plotted for all sites, excluding the 6 sites of the Snowy subgroup. The plots are supplemented with a smoothing spline (3 df). The areas of 5 sites were removed on the basis that they were outliers preventing a clearer view of the effect of area in the matrix plot. Two sites were also removed owing to very high EC values: 420012 Butheroo Creek at Neilrex and 410103 Houlaghans Creek at Downside (EC = 4994 and 4707 µS cm^{-1} respectively).

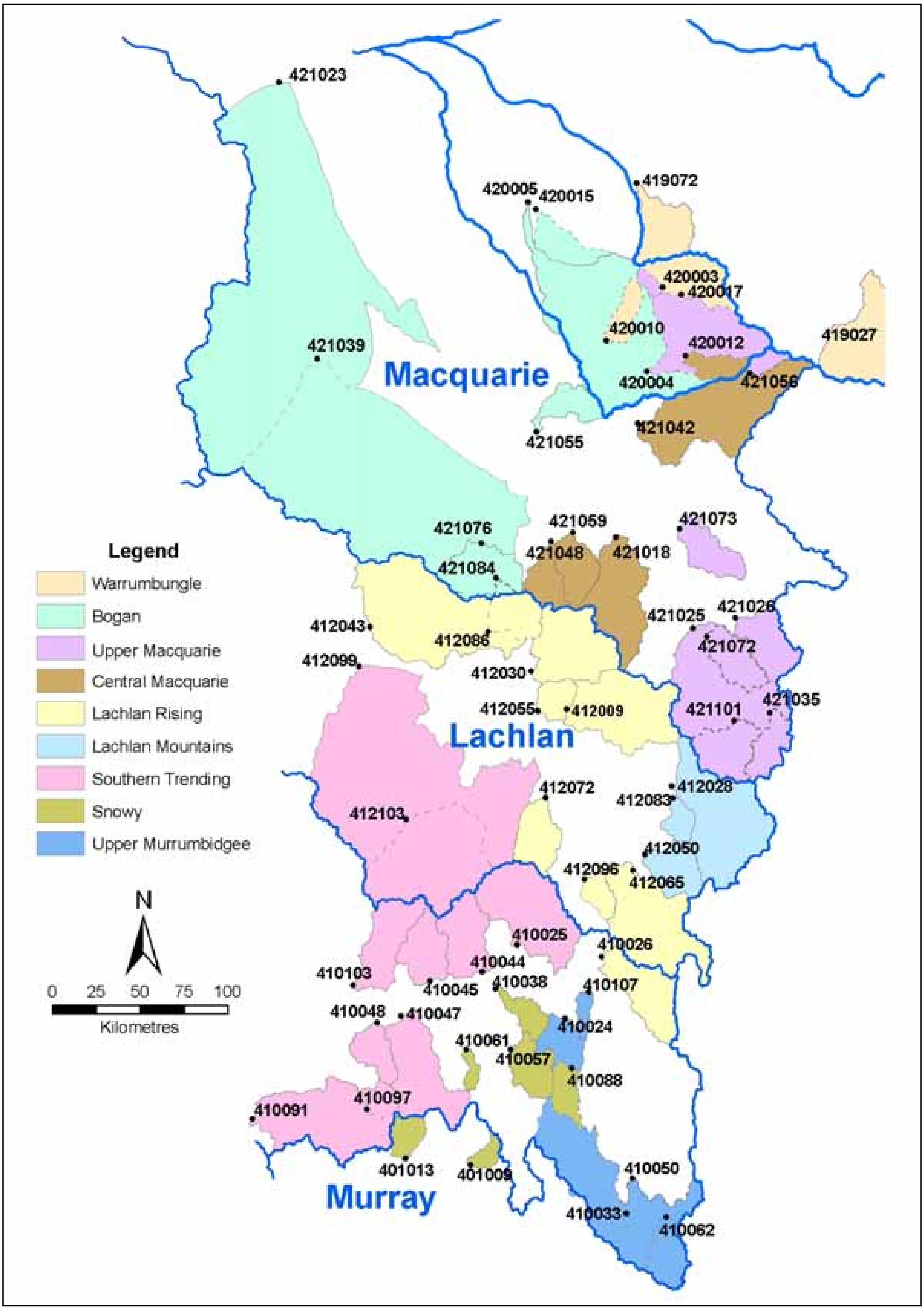
Apart from the elevation vs mean annual rainfall plot, little was obvious. Model 5 and elevation (row 2, column 5) suggested that the time trend had very little relevance to catchments with high-elevation outlets. But some catchments with low elevation (listed in Section 5.1.3) seemed to have a high degree of fit to Model 5. The catchments with the stronger trend components were nearly all in the southern valleys. Based on row 2 of Figure 29, their outlets had comparatively low elevation, their forested percentage was small, and their average slope was at the low end of the range.

Figure 29. Model performance and catchment characteristics (excluding Snowy group).



6 Preliminary Catchment Groups

Figure 30. Subgroups in southern NSW.



6.1 Categorisation (southern valleys)

6.1.1 Southern catchments in equilibrium

Three of the subgroups of Section 5.3 and Figure 30 are strong candidates for the equilibrium category.

a) Snowy subgroup (6)

- 401009 Maragle Creek at Maragle
- 401013 Jingellic Creek at Jingellic
- 410038 Adjungbilly Creek at Darbalara
- 410057 Goobarragandra River at Lacmalac
- 410061 Adelong Creek at Batlow Road
- 410088 Goodradigbee River at Brindabella

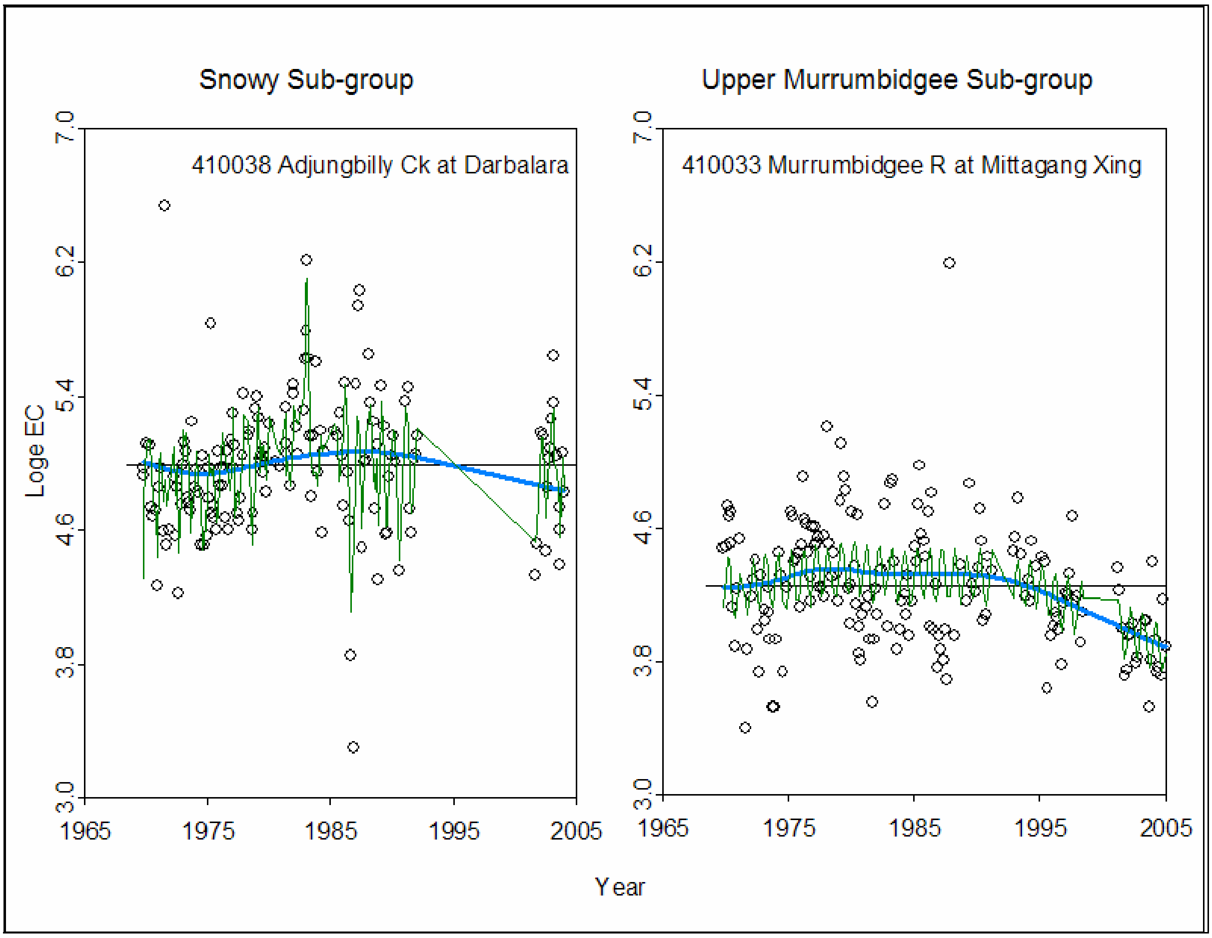
We concluded that this subgroup was more or less in equilibrium, with none of the trend slopes being statistically significant. The cyclic indicators were small, but not negligible.

General characteristics:

- All have a data gap in the early 1990s. We have assumed there are sufficient data-points after the gap.
- The mean annual rainfalls are in the high range. The lowest is at Jingellic (920 mm), and the rest are >1000 mm.
- Elevations are generally in the range of 218 to 377 m, except Goodradigbee at Brindabella at 638 m.
- Low non-significant trend slopes are close to zero; largest $\log_e$ slope is +0.0015 for 410057 for Goobarragandra River at Lacmalac. The slope is not significant.
- The recovery range is 0.96 to 1.11.
- The percentage of cycle ranges from 13% to 21%; However, 401009 Maragle at Maragle has 37%, suggesting catchment heterogeneity.
- The cycle ratios were 1.03 to 1.04, except Maragle Creek again at 1.08.
- Average catchment slopes are >9.
- The graphs of the unadjusted data in Appendix 2 indicate that these sites have not (or only just) completed the cycle. A reliable assessment of trend can't really be made until a full cycle is complete.
- The sites were in the top half of the hypsometric rankings (5 of them in the top quarter).
- Three of the catchments were heavily forested, 1 moderately so, and 2 low.
- The trend at 401013 Jingellic Creek at Jingellic may be rising once more. In the 1980s and 1990s this site peaked much earlier than the other Murrumbidgee–Murray sites. It is possibly heralding a general trend upturn. Even if it is the only site rising, in about 10 years it may have achieved another peak, which will enable a comparison of successive EC peaks and thus provide a better insight into the long-term trends of this subgroup.

See Figure 31 for a GAM curve typical of this subgroup.

Figure 31. Typical GAM curves for Snowy and Upper Murrumbidgee subgroups.



b) Upper Murrumbidgee (6)

This subgroup includes 4 sites near the rain-shadow to the east of the Snowy subgroup:

- 410024 Goodradigbee River at Wee Jasper
- 410033 Murrumbidgee River at Mittagang Crossing
- 410050 Murrumbidgee River at Billilingra
- 410062 Numeralla at Numeralla School
- 410107 Mountain Creek at Mountain Creek
- 420003 Belar Creek at Warkton

The last 2 sites require comment. 410107 Mountain Creek fits into the subgroup in terms of its proximity and characteristics. However, its GAM curve (Appendix 2.20) has a much longer cycle, and the site is a candidate for the Southern Trending subgroup. 420003 Belar Creek is far from the upper Murrumbidgee, and does not fit with its neighbouring catchments. It has been attached to this subgroup because its catchment characteristics and GAM curve behaviour are similar.

These sites are on a falling trend and have a cyclic component.

- The 6 trend slopes are negative and significant (except for 410107 Mountain Creek).
- Catchment areas are moderate: 131 to 3745 km^2.

- Mean annual rainfalls are within a narrow band of 680 to 889 mm except for 410024 at 1146 mm.
- Outlet elevations range from 366 to 734 m.
- Recovery ranges from 1.12 to 1.79.
- The percentage of cycle range is 21% to 44%.
- The cycle ratio is 1.04 to 1.10.
- Average catchment slopes are 8.1 to 15.4.
- Mean ECs are all <176 µS/cm.

See Figure 31 for a GAM curve typical of this subgroup.

c) Lachlan mountains subgroup (3)

- 412028 Abercrombie River at Abercrombie
- 412050 Crookwell River at Narrawa North
- 412083 Tuena Creek at Tuena

With only 5 data points after a gap in time, 412083 probably needs another 12 months of records before we can be definitive about its trend. The statistics are more appropriate to the period 1968–1992.

General characteristics:

- The 3 trend slopes are small, negative and insignificant.
- Mean annual rainfall varies from 789 to 820 mm.
- Elevations are in the range of 420 to 480 m.
- The low negative trend slope (not significant) is close to zero.
- Resilience ranges from 1.03 to 1.11.
- The cyclicity range is 4% to 9.1%.
- Average catchment slopes are 6.45 (Narrawa North), 9.8 and 10.

See Figure 32 for a GAM curve typical of this subgroup.

6.1.2 Lachlan Rising subgroup (9)

- 410026 Yass River at Yass
- 412009 Belubula River at Canowindra
- 412030 Mandagery Creek upstream of Eugowra
- 412043 Goobang Creek at Darbys Dam
- 412055 Belubula River at Bangaroo Bridge
- 412065 Lachlan at Narrawa
- 412072 Back Creek at Koorawatha
- 412086 Goobang at Parkes
- 412096 Pudmans Creek at Kennys Road

Two sites that would currently benefit from another year of monthly EC samples: 412096 and 412030. Unlike the Murrumbidgee–Murray sites, the Lachlan sites appear to be on a shorter cycle than the period of record. In assessing some of these sites, we have relied heavily on the plots in Appendices 2.21 to 2.33. Because of the data gaps and irregular periods of record, it is necessary to check how a short period of record at a particular site dovetails into the longer records at other sites. For example, the negative slope at 412086 coincides with a falling phase at other stations. The site has been included in this subgroup despite showing a recovery factor of >1 and a positive slope.

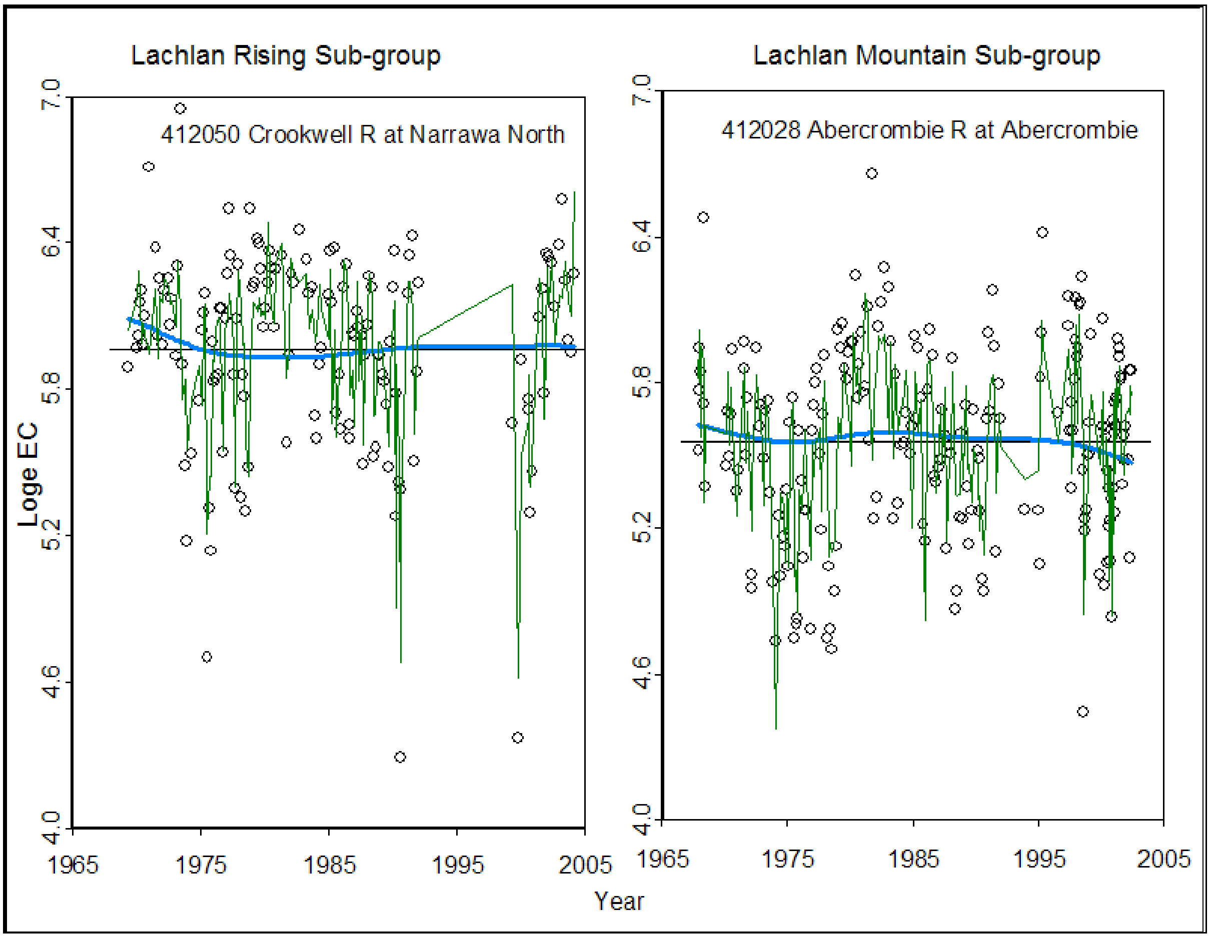
General characteristics:

- Mean annual rainfall ranges from 546 to 820 mm.
- Elevation ranges from 201 m (412043 Goobang at Darbys Dam) to 478 m.
- The trend slopes are all positive (except at 412086), which is discussed above. They range from 0.0028 to 0.0284 (again, 412043), and 5 of these are significant. Hypothetically, if the 15% correction were applied as suggested in Annexure A, then the slope at 4 of the 8 sites would be statistically insignificant. But such a correction will not change the overall positive trend of the subgroup.
- Resilience of the 7 sites with a positive log slope ranges from 0.61 to 0.87.
- Cyclicity ranges from 11% to 33%.
- Average catchment slopes range from 4.0 (412043) to 8.3.
- The cycle ratio varies from 1.02 to 1.06 (412086).
- Several of these catchments show little response to Model 5, indicating no or small trends over time.

See Figure 32 for a GAM curve typical of this subgroup.

412043 Goobang at Darbys Dam has sufficient extreme characteristics to make it a candidate for Southern Trending (Section 6.1.3). Both of the Belubula River catchments (412009 and 412055) border on characteristics that would place them in the Lachlan Mountains subgroup in Equilibrium (Section 6.1.1). Indeed, had the 412009 Belubula at Canowindra gauging site been located further up the catchment, its catchment characteristics would have assigned it to the Lachlan Mountains subgroup.

Figure 32. Typical GAM curves for Lachlan Mountains and Lachlan Rising subgroups.

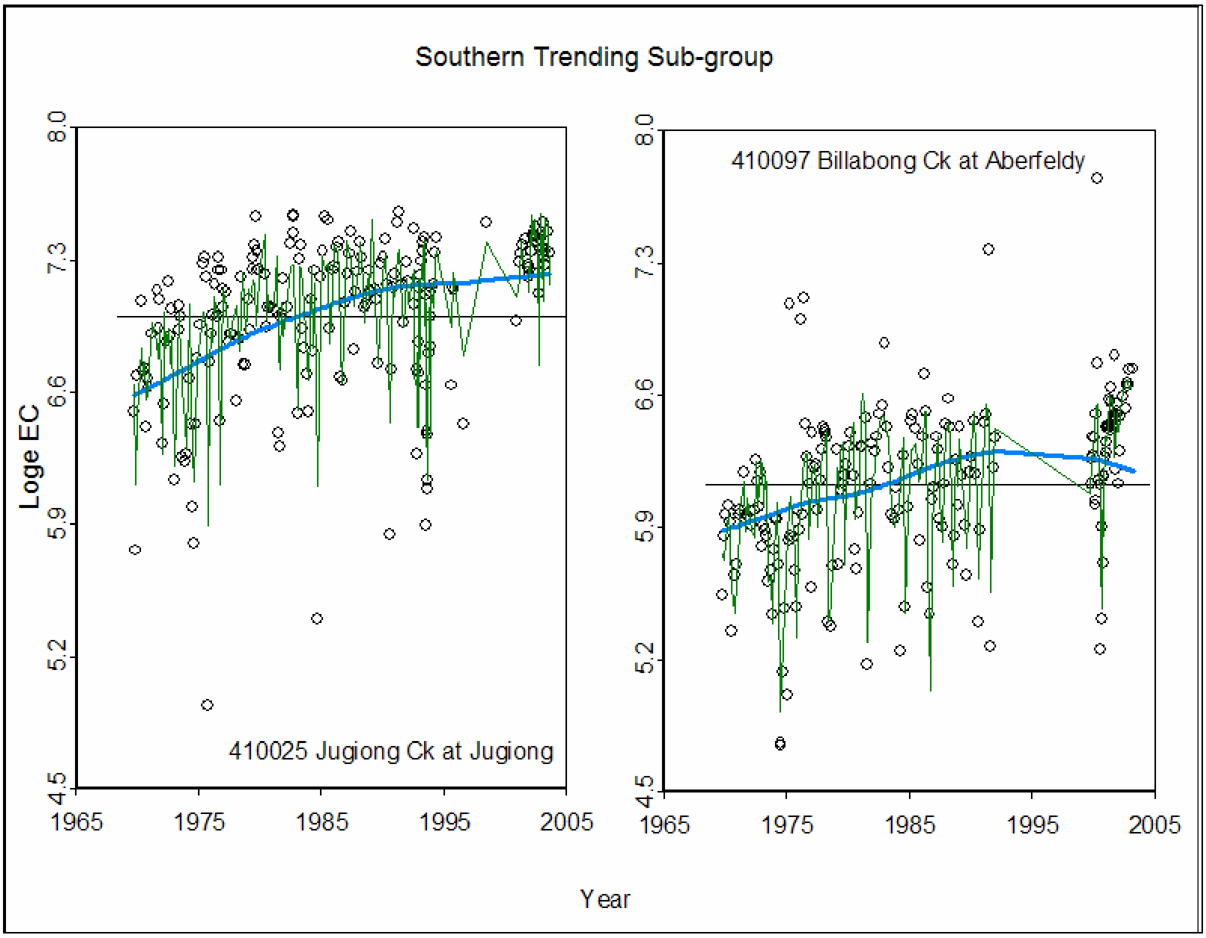


6.1.3 Southern Trending subgroup (10)

This grouping was based mainly on 6 sites around Wagga Wagga, in southern NSW. As indicated in Section 5.1.3, these sites were chosen as having R^2 > 0.3 for Model 5. Four nearby sites (labelled with *) have been added to the list on the basis that they are all close to the original 6 sites; the 2 Billabong sites show poor recovery (Table 5), and Muttama at Coolac is a special case.

- 410091 Billabong Creek at Walbundrie *
- 410097 Billabong Creek at Aberfeldy *
- 410025 Jugiong Creek at Jugiong
- 410044 Muttama Creek at Coolac *
- 410045 Billabung Creek at Sunnyside *
- 410047 Tarcutta Creek at Old Borambola
- 410048 Kyeamba Creek at Ladysmith
- 410103 Houlaghans Creek at Downside
- 412099 Manna Creek Nr Lake Cowal
- 412103 Bland Creek at Morangarell

Figure 33. Typical GAM curves for Southern Trending subgroup.



Three other sites scattered across the area could have easily been categorised in the Southern Trending subgroup because of their GAM curve behaviour. Instead, they have been placed in local subgroups. These are:

- 410107 Mountain Creek at Mountain Creek
- 419027 Mooki River at Breeza (the behaviour of both sites is discussed in Section 7)
- 421048 Little River at Obley

General characteristics:

- The range of mean annual rainfall is 531 to 698 mm, except 410047 Tarcutta Old Borambola is at 823 mm. Originally (Section 5.3.1), this was considered for inclusion in the nearby Snowy subgroup on the basis of its rainfall average. However, most of the catchment has characteristics similar to the other sites in the Major Rising Trends sub-group.
- The outlet elevation range is bracketed by the 2 Billabong Creek sites. The elevation of 410091 Walbundrie is 167 m. The range at the rest of the sites is 192 to 268 m (Aberfeldy).
- The log trend slope ranges from 0.0109 to 0.0269, with 410103 Houlaghans Creek indicating a deceptive 0.1852.
- The recovery factor for 410103 Houlaghans Creek is 0.01, whereas the general range for the subgroup is 0.35 to 0.79. 410044 Muttama Creek at Coolac has the largest, at 0.9.

- The smallest cycle ratio is 1.06, and most range between 1.08 and 1.12. Two values are much higher than the rest.
- The cyclicity ranges from 37% to 106%, except Houlaghans Creek at 195%.
- The average catchment slopes range from 2.7 to 7.7, except Kyeamba at Ladysmith at 8.25.
- Many of the sites in this subgroup are undergoing substantial trend or cyclicity. It is therefore important to evaluate some of the processes if NSW salinity issues are to be addressed (see Sections 7 and 8).
- With the exception of 410044 Muttama Creek at Coolac and possibly 410045 Billabung at Sunnyside, none of the sites has gone through a full cycle.
- It is possible that none of the sites have unrestricted access to the regional groundwater zones described in Evans and Kellett (1989). For example, the Malebo Ranges straddle the Murrumbidgee River immediately downstream of Wagga Wagga. It is feasible that similar mechanisms exist in the Billabong and Lachlan systems (see Discussion, Section 8.6).
- The extreme behaviour at 410103 Houlaghans Creek is a legitimate reflection of the limited data available. An examination of the model outputs suggests that the calculated trend is a reasonable account of base flows. Above these flows, it is likely to be a gross misrepresentation at this point in time.
- There is nothing to indicate that the trend at 410045 Billabung Creek at Sunnyside is limited to base flow. However, the dataset is not large. Its period of record coincides with rising trends in many of the other catchments in the subgroup. This site should be matched with the adjoining site 410044 Muttama at Coolac.
- The period of record at 412099 Manna at Lake Cowal is 1975 to 1992. The calculated log-space linear trend is likely to be a good representation of the record period, and in turn, the period of record may be a good representation of the period of EC data collection in general. Whether this trend continues throughout the 1990s is the big question. The assumption has been made that it does.
- Four of the trend curves require interpretation and comment. 410048 Kyeamba at Ladysmith (Appendix 2.13) and 410047 Tarcutta at Old Borambola (Appendix 2.12) have higher rainfall in the upper catchment. The lower parts of the catchments are likely to have had minimal runoff during the recent drought years, although the upper catchments (particularly in Tarcutta Creek) would have been generating streamflow (and possibly groundwater flow) down through the catchment. There is little doubt that both of these catchments will return to a rising phase after the drought fades. 410025 Jugiong Creek at Jugiong (Appendix 2.6) and 410044 Muttama Creek at Coolac (Appendix 2.10) go through a similar process, but in reverse. In this case, the higher-rainfall portions of these catchments are at the lower end. During prolonged drought, the upper catchments are likely to be ‘locked out’ of the hydrological process. Appendix 2.6 indicates a continuing rise, albeit at a reduced rate, throughout the drought. On the other hand, Appendix 2.10 suggests a complete recovery at Muttama Creek. This is probably a misconception—Harvey and Jones (2001) identified ‘extreme non-homogeneity’ based on negative spikes observed during a number of sampling sequences. Based on a combination of heterogeneity and the extreme drought conditions at present, it is likely that the current trough in Appendix 2.10 is a temporary aberration.
- The $\log_e$ trend slope at 412103 Bland at Morangarell is steep. The period of record goes from 1976 to 1991. In projecting the EC behaviour beyond 1991, we decided to adopt a flatter slope, in much the same manner as at Jugiong.

These sites were grouped because of their responses to Model 5. The subgroup generally provided good responses to Models 3 and 7. See Figure 33 for a GAM curve typical of this subgroup.

6.1.4 Macquarie and Castlereagh valleys

A preliminary indication as to how the Macquarie and Castlereagh sites should be grouped was provided by Chris Burton (pers. comm. 2005, DWE, Dubbo), who indicated that some streams in the Macquarie Valley flowed below the bed. These streams break the surface intermittently, and thus acquire a high EC from the groundwater.

Upstream of Dubbo, the tributaries generally responded to the EC–flow concept of Model 7. Because the EC–flow concept appears poor, the tributaries downstream of Dubbo have been grouped with the Bogan and 2 Castlereagh sites into a subgroup called 'Bogan'. Five sites in the Central Macquarie were grouped purely on the basis of high salinity.

Many of the sites show a steepening trend over the last decade. There is nothing to indicate that the rise is caused by the collection program. Possibly the change is being driven by the drought, but it requires close monitoring.

a) Upper Macquarie subgroup (8)

- 420004 Castlereagh River at Mendooran
- 421025 Macquarie River at Bruinbun
- 421026 Turon River at Sofala
- 421025 Fish River at Tarana
- 421056 Coolaburragundy Creek at Coolah
- 421072 Winburndale Rivulet at Howards Bridge
- 421073 Meroo Creek at Yarrabin 2
- 421101 Campbells River upstream of Ben Chifley Dam

General characteristics:

- Two stations from the Castlereagh Valley were initially considered for inclusion. The characteristics of one of these, 420003 Belar at Warkton, pointed to its belonging to a grouping outside the Macquarie–Castlereagh valleys. It was fitted into the Upper Murrumbidgee subgroup.
- The range of mean rainfall is 684 to 909 mm.
- Elevations range from 341 to 831.
- Catchment slopes range from 6.5 to 12.1.
- The linear trends were mainly positive and insignificant and generally in the range of 0.0015 to 0.0100.
- The cycle ratio ranged from 1.00 to 1.05.
- The percentage of cycle ranged from 2% to 23%.
- Recovery factors were generally <1.
- Mean ECs ranged widely from 124 to 834.
- Catchment areas ranged widely.

- The hypsometric integrals ranged from 0.24 to 0.58.
- Most of the tributaries to the Upper Macquarie showed very little response relation to Model 5.

See Figure 34 for a GAM curve typical of this subgroup.

b) Central Macquarie subgroup (5)

- 420012 Butheroo Creek at Neilrex
- 421018 Bell River at Newrea
- 421042 Talbragar River at Elong Elong
- 421048 Little River at Obley
- 421059 Buckinbar Creek at Yeoval

These sites have high mean EC or are showing a significant rising trend. Three are adjacent. 421059 Buckinbar Creek at Yeoval, with one of the highest ECs in the study, lies to the immediate west of 421018 Bell River at Newrea. Adjacent to 421059 is 421048 Little River at Obley, which has the third highest percentage increase in the study.

General characteristics:

- The range of mean rainfall is small, from 653 to 757 mm.
- The range of elevation is also narrow, from 312 to 408 m.
- Catchment slopes range from 4.5 to 8.2.
- The linear EC trends were all positive and 3 were significant.
- The cycle ratio ranged from 1.0 to 1.12.
- The percentage of cycle ranged from 9% to 66%.
- The mean ECs were high, varying from 609 to 4994 µS/cm.
- The catchment area range was modest, ranging from 405 to 2963 km^2.
- The hypsometric integrals ranged from 0.23 to 0.38.

See Figure 35 for a GAM curve typical of this subgroup.

c) Bogan subgroup (7)

- 420005 Castlereagh River at Coonamble
- 420015 Warrena Creek at Warrana
- 420023 Bogan River at Gongolgon
- 421039 Bogan River at Neurie Plain
- 421055 Coolbaggie Creek at Rawsonville
- 421076 Bogan River at Peak Hill 2
- 421084 Burrill Creek at Mickibri

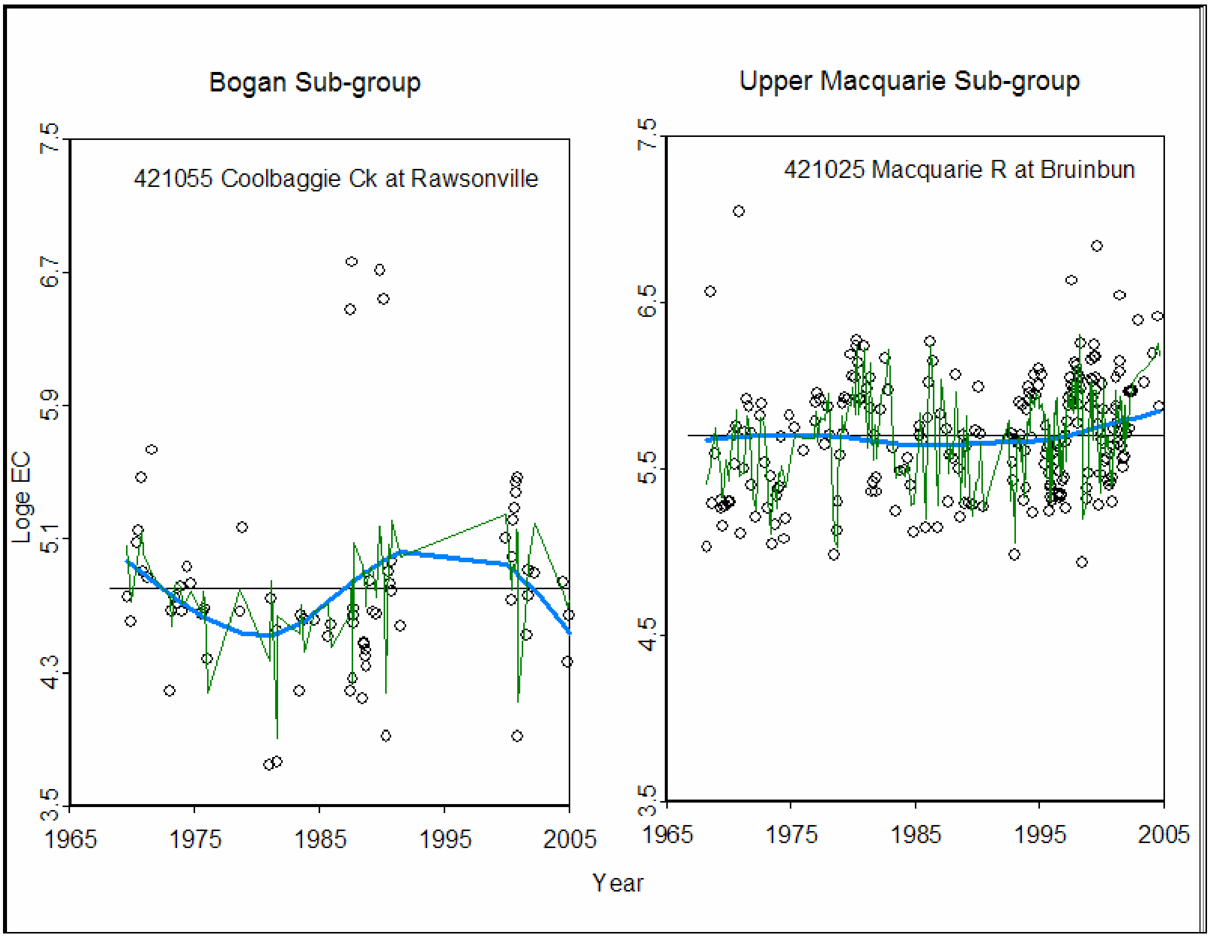
General characteristics:

- 420005 Castlereagh at Coonamble was the only one to show a good relation to Model 7, most of the sites being poor.

- All showed a positive but not significant trend. At the bottom of the Bogan system, 421023 showed the same sharply rising trend as in the upper Macquarie catchments, but this is attributed to its receiving regulated flows from the upper catchments.
- Catchment characteristic information was not always readily available.
- The mean annual rainfall varied from 550 to 657 mm.
- The elevations varied from 122 to 306 m.
- Slopes were at the lower end, starting at 0.9, and generally ranging from 3.7 to 8.8.
- 420005 Castlereagh at Coonamble was the only site to show a small, albeit negative trend. All other sites showed small rising trends—0.0014 to 0.0076—although none were statistically significant.
- The cycle ratio generally varied from 1.04 to 1.08, but 2 were much larger.
- The percentage of cycle ranged from 26% to 87%.
- Mean EC occupied the lower to mid range—131 to 434 µS/cm.
- Areas varied from a small 71 to 27 970 km^2.

See Figure 34 for a GAM curve typical of this subgroup.

Figure 34. Typical GAM curves for the Bogan and Upper Macquarie subgroups.



6.1.5 Warrumbungle subgroup

- 419027 Mooki at Breeza (adjusted dataset)
- 419072 Baradine Creek at Kienbri (adjusted dataset)
- 420010 Wallumburrawang Creek at Bearbung
- 420017 Castlereagh at Hidden Valley

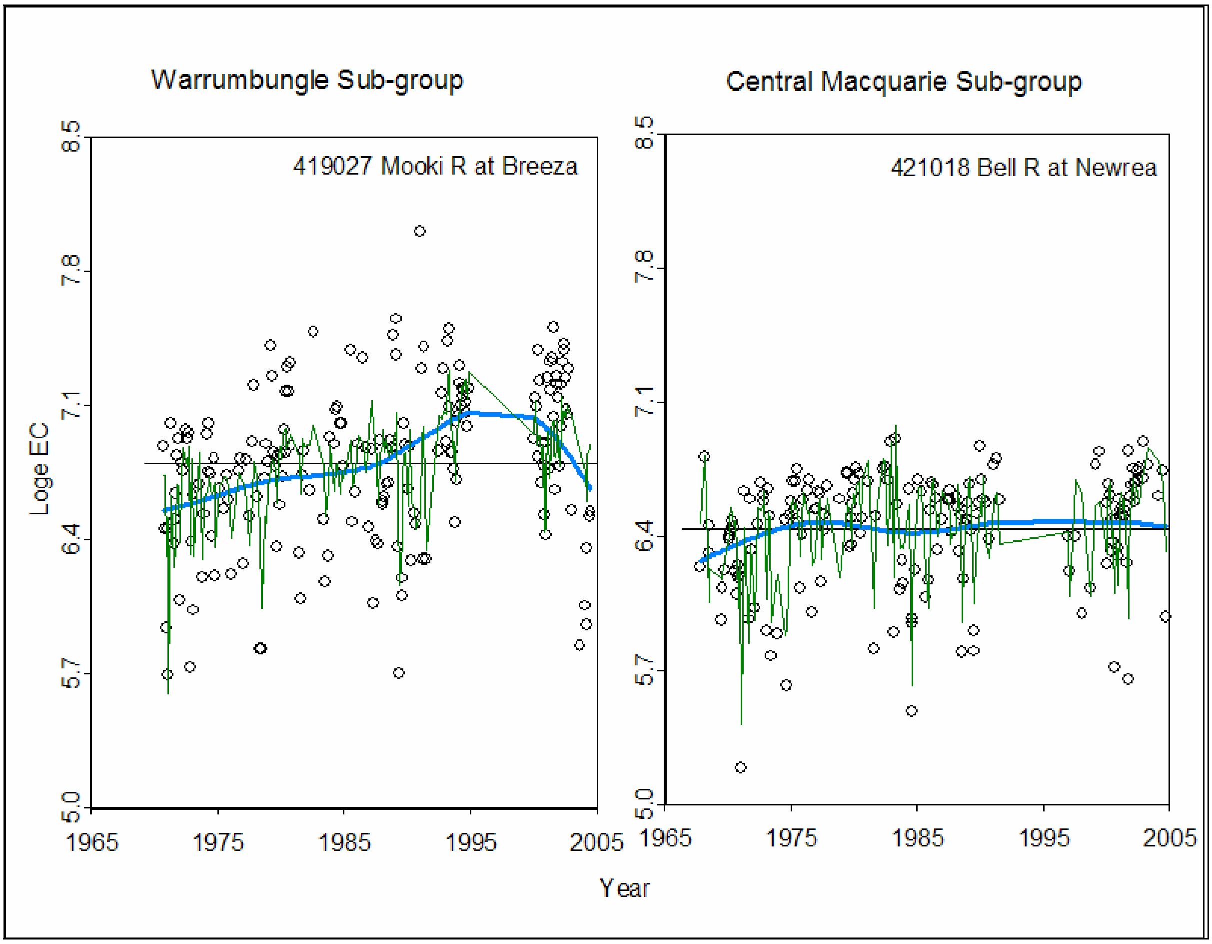
The purpose behind the grouping is described in Section 5.3.2. Essentially the 4 stations had high positive EC trends, but contrary to the norm, also had high average slopes. What linked them was the proximity of 3 of them, and the fact that all were influenced by the Warrumbungle and Liverpool ranges.

General characteristics:

- The mean annual rainfall range was narrow, varying from 688 to 762 mm.
- Elevations ranged from 282 to 420 m, the 2 Namoi sites being lower.
- All linear EC trends were positive, ranging from 0.0056 to 0.0127.
- The 4 sites had high slopes ranging from 9.43 to 16.04.
- The cycle ratio ranged from 1.04 to 1.08.
- The percentage of cycle varied from 26% to 52%.
- The recovery factor range was 0.70 to 0.80.
- The 4 sites responded to Model 5, with the Namoi valley site R^2s being large enough to match the Model 5 range of the Southern Trending subgroup.

See Figure 35 for a GAM curve typical of this subgroup.

Figure 35. Typical GAM curves for the Warrumbungle and Central Macquarie subgroups.



6.1.6 Namoi and Gwydir valleys and Border Rivers *(adjusted datasets)*

See Figure 36 for GAM curves typical of the 3 Northern valleys.

With the exception of the 2 sites in the Warrumbungle subgroup, the northern sites do not seem to reflect the dramatic rises noted in the Central Macquarie and Southern Trending subgroups. To a small extent, the situation may be driven by the adjustment of 10% made on the earlier data (Annexure A), which diminished the slope coefficients.

The 10% adjustment did not seem to make much statistical difference in the identification of any catchment with a salinity problem. For 12 of the northern catchments, the sign of the slope changed from positive to negative. Before and after the adjustment, the slope was statistically insignificant. These 12 became the basis for the Northern Insignificant subgroup (Section 6.1.6.2).

6.1.6.1 Northern Falling subgroup (8)

These 8 have significantly falling trend slopes after the 10 percent adjustment. Trends at 4 sites (marked '*') were falling and statistically significant before the data adjustment.

- 416008 Beardy River at Haystack *
- 418005 Copes Creek at Kimberley
- 418014 Gwydir River at Yarrowyck

- 418025 Halls Creek at Bingara *
- 418027 Horton River at Dam Site *
- 419005 Namoi River at North Cuerindi
- 419016 Cockburn River at Mulla Crossing *
- 419029 Halls Creek at Ukolan

General characteristics:

- Mean annual rainfall varies from 779 to 912 mm.
- The elevations generally range from 313 to 454 m, but 2 sites are much higher: Gwydir at Yarrowyck (738 m) and Copes at Kimberley (756 m).
- The log space trend slopes range from –0.0044 to –0.0183 and are significant.
- Recovery factors range from 1.08 to 1.69 (Horton River at the Dam Site).
- Cycle ratios generally range from 1.02 to 1.04, with the highest being 1.10.
- Cyclicity varies 12% to 33%, Horton at the Dam Site being 54%.
- Average catchment slopes vary from 5.32 to 13.8. Two sites have catchment slopes that are smaller than normally associated with a falling trend: Copes Creek at Kimberley (5.3) and Gwydir at Yarrowyck (5.5).
- The mean EC generally ranged from 178 to 669 µS/cm, with 418025 Halls Creek at Bingara a comparatively high 1039 µS/cm.
- Catchment areas ranged from 171 to 2524 km^2.

In viewing the various outputs, 2 points are worth noting. Halls Creek at Bingara had a very poor relationship between EC and flow, and a very poor fit of the flow component of the Model 7 curve (Appendix 2.54). In the Namoi River at North Cuerindi (Appendix 2.59), the later record has a long gap of a decade, followed by a group of 7 points. An additional year of samples would increase our confidence in this result. Beardy River at Haystack (Appendix 2.35) has 2 characteristics worthy of note. The EC was rising steeply at the start of its record, and it shares with Horton River at Dam Site (Appendix 2.55) a very pronounced cycle in comparison with the rest of the subgroup.

6.1.6.2 Northern Insignificant subgroup (16)

When the data correction was applied to the Northern record, 12 sites changed sign from positive to negative, but the trend slopes remained statistically insignificant. Of the 12, 3 had a slope very close to zero before the adjustment. A further 6 sites marked '*' had a negative, insignificant $\log_e$ trend both before and after the adjustment:

- 416003 Tenterfield Creek at Clifton
- 416010 Macintyre River at Wallangra*
- 416016 Macintyre River at Inverell
- 416023 Deepwater Creek at Bolivia
- 416027 Gil Gil Creek at Weemalah *
- 416032 Mole River at Donaldson*
- 418015 Horton River at Rider (Killara)
- 418016 Warialda Creek at Warialda

- 418017 Myall River at Molroy
- 418018 Keera Creek at Keera
- 418032 Tycannah Creek at Horseshoe Lagoon.
- 418052 Carole Creek near Garah *
- 419032 Coxs Creek at Boggabri *
- 419033 Coxs Creek at Tambar Springs
- 419035 Goonoo Goonoo Creek at Timbumburi
- 419051 Maules Creek at Avoca East.
- 419053 Manilla River at Black Springs
- 419054 Swamp Oak Creek at Limbri *

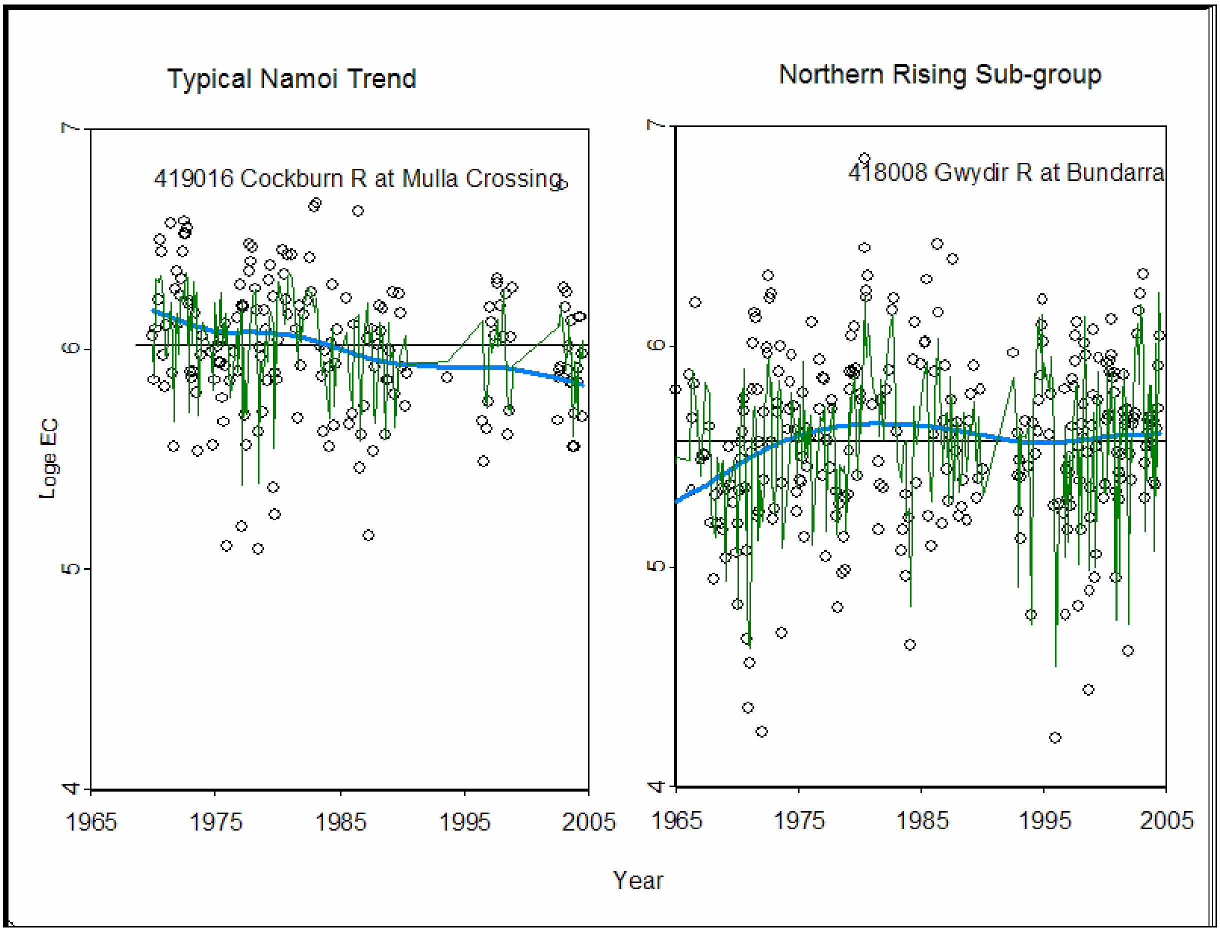
General characteristics:

- Mean annual rainfall ranges from 556 to 899 mm.
- Elevation generally ranges from 159 to 655 m, with 416023 Deepwater at Bolivia a relatively high 783 m.
- The $\log_e$ trend slopes are insignificant and range from –0.0007 to –0.0071 (419032 Coxs Creek at Boggabri).
- The recovery factors generally range from 0.92 to 1.10; 419032 Coxs Creek at Boggabri has a value of 1.33.
- The cycle ratio at 15 of the sites ranges between 1.01 and 1.04. 419032 Coxs Creek at Boggabri shows 1.09.
- The cyclicity generally varies from 6% to 35%. Once more 419032 Coxs Creek at Boggabri is at the extreme, at 52%.
- Two catchments slopes are very flat: 418016 Warialda Creek at Warialda, with an average slope of 3.8, and 418016 Myall River at Molroy, with a slope of 4.4. The remainder vary between 6.8 and 15.7.
- The mean EC ranges between 152 and 1092 µS/cm.
- The areas range between 152 and 3803 km^2.
- The hypsometric integrals range between 0.174 and 0.508.

Most sites have no serious issue in relation to sparse data after long gaps. At 2 sites, greater confidence could be drawn when more data points are added to the later record: 419035 Goonoo Goonoo Creek at Timbumburi and 419054 Swamp Oak Creek at Limbri. Perhaps there is enough evidence for 419032 Coxs Creek at Boggabri to be placed in another subgroup.

6.1.6.3 Northern Rising subgroup (8)

Figure 36. Typical GAM curves for the 3 northern valleys.



Eight sites showed a rising trend both before and after the 10% adjustment. At 3, the trend was still significant after the adjustment; at 3 others (in the upper Gwydir) it became insignificant ('*') after the adjustment:

- 416020 Ottleys Creek at Coolatai
- 416021 Frazers Creek at Ashford
- 416039 Severn River at Strathbogie
- 417001 Moonie River at Gundablouie
- 418008 Gwydir River at Bundarra
- 418021 Laura Creek at Laura *
- 418023 Moredun Creek at Bundarra *
- 418029 Gwydir River at Stoneybatter *

General characteristics:

- The mean annual rainfall ranges between 743 and 880 mm.
- Most of the site elevations range between 346 and 723 m. 417001 Moonie River at Gundablouie is much lower, at 149 m.
- The catchment slopes are all <7.8.

- The $\log_e$ space EC trends are all positive, and range between 0.0004 and 0.0081. Three of these are statistically significant, even after the adjustment: 416021 Frazers Creek at Ashford, 416039 Severn River at Strathbogie and 418008 Gwydir River at Bundarra.
- The percentage of cycle varies from 4.5% to 45% (Frazers Creek at Ashford).
- The cycle ratio ranges from 1.01 to 1.08.
- The mean EC range is tight: 141 to 433 µS/cm, except 416020 Ottleys Creek at Coolatai at 724 µS/cm.
- Most areas range from 344 to 4048 km^2, except Moonie at Gundablouie at 15,810 km^2.

6.2 Catchment characteristics as an explanation of trend

The subgroups of Section 6.1 and Table 5 were a convenient starting point in trying to relate salinity trends to catchment characteristics. If relationships can be found, then it may be possible to use the characteristics to infer rising salinity trends at catchments where there is no EC monitoring. Figures 37 to 42 were used to seek out any such patterns. The following work is a diagrammatic presentation of Table 5, but is based on the assumption that the processes at the collection sites are representative of the catchment above. This is not always the case. The groups were colour-coded based on whether their constituents were seen as not having a short-term problem (green) or having a major problem (red). The colour coding was subjective, but is convenient for viewing. For example, the Lachlan Rising and Northern Rising were both colour coded yellow, although they were known to have a rising trend (Figure 37).

The first step involved revisiting the mean annual rainfall vs site elevation graph of Figure 27. 417001 Moonie River at Gundablouie has not been included in Figure 37 because the rainfall data were not readily available. Five sites in the remaining Northern Rising subgroup are higher than 640 m, and receive modest rainfall in excess of 770 mm per year. The northern group is at odds with rising trend catchments in the rest of the State. As can be seen from the marked lines, most of the problem sites have outlets bounded below 825 mm rainfall and below 430 m altitude. In summarising Figure 37, the 800 mm rainfall could be used as a defining boundary that separates the problem sites from the falling trend site at outlet elevations below 600 m. For the catchments above 430m, there is no defining rainfall boundary.

Figure 37. Catchment groups relative to mean annual rainfall and elevation.

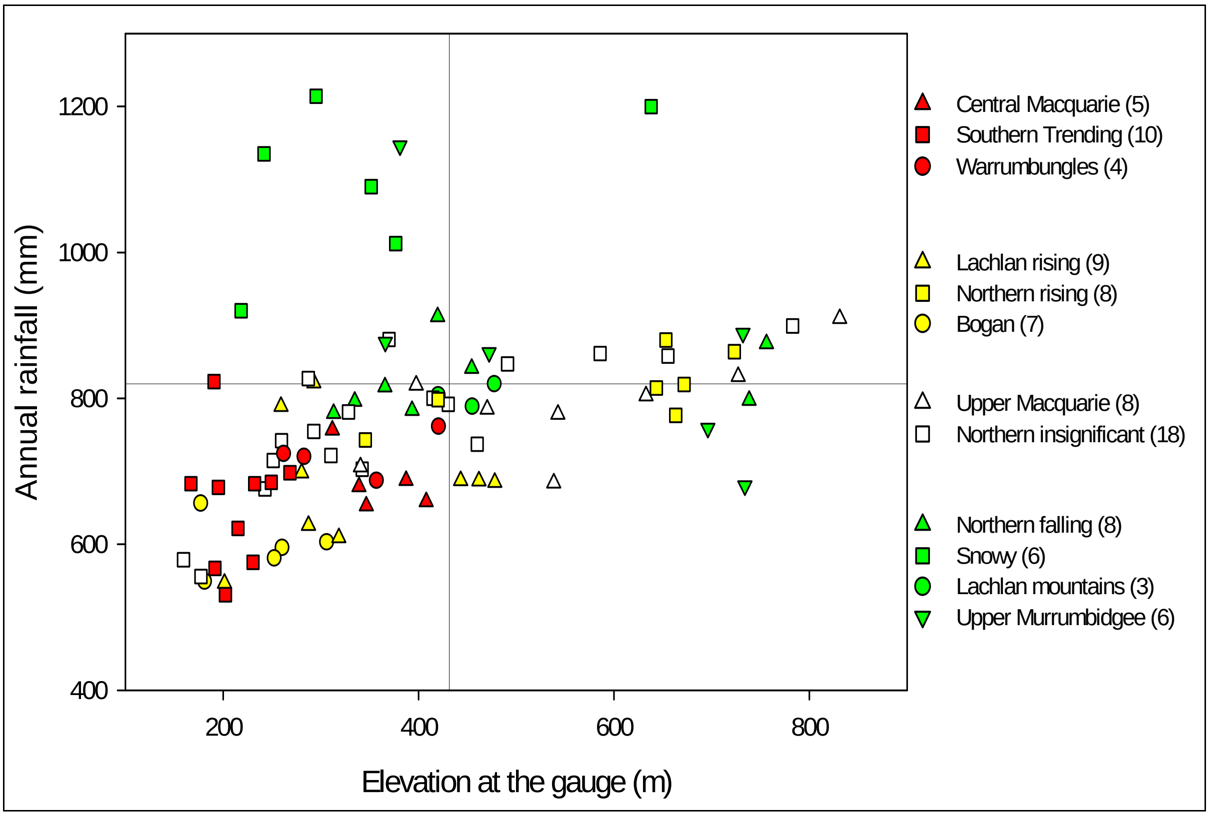
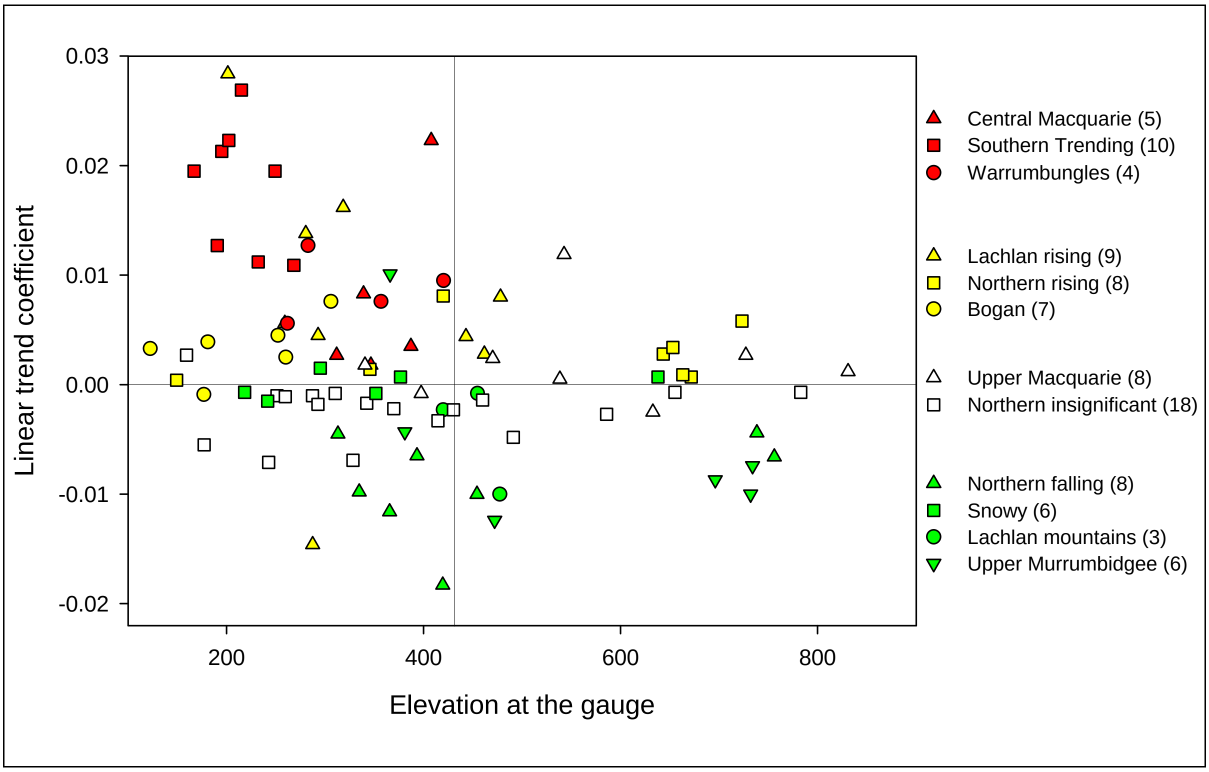


Figure 38. Catchment groups relative to linear trend and gauge elevation.



The following graphs relate the EC linear trend coefficient to various catchment characteristics. The trend coefficients are on the $\log_e$ scale. The following site information pertains to all graphs, and has already been alluded to in the subgroup descriptions (Section 6.1).

Linear trend coefficient vs elevation (Figure 38). This graph partly describes EC trend, by grouping the catchments with steeply rising trends below an elevation 430 m. It does not account for the Northern Rising sites with high elevations.

In Figure 38, the highest trend belongs to a member of the Lachlan Rising subgroup: 412034 Goobang at Darbys Dam, which could have been categorised in the Southern Trending subgroup. There is also a Lachlan Rising site in the bottom left quadrant: 412086 Goobang at Parkes, which has a negative trend because there is not a full length of record.

In the Upper Murrumbidgee subgroup, 410107 Mountain Creek at Mountain Creek has a linear trend of 0.01. This behaviour is discussed in Section 8.6.2. In the top-right quadrant, there is an upper Macquarie site with a trend > 0.01: 421072 Winburndale Rivulet at Howards Bridge, for which there is not a full length of record.

Linear trend coefficient vs hypsometric integral (Figure 39). This graph brackets the steeply rising trends within an integral of 0.41. Use of this characteristic has diminished the isolation of the Northern Rising subgroup.

Linear trend coefficient vs rainfall (Figure 40). The use of rainfall draws in the Northern Rising subgroup, but it also draws in most of the other sites. As alluded to in the description of Figure 37, a rainfall of 825 mm would encompass all the problem catchments, but a value of 800 mm as the boundary would be more realistic.

Figure 39. Catchment groups relative to linear trend and hypsometric integral.

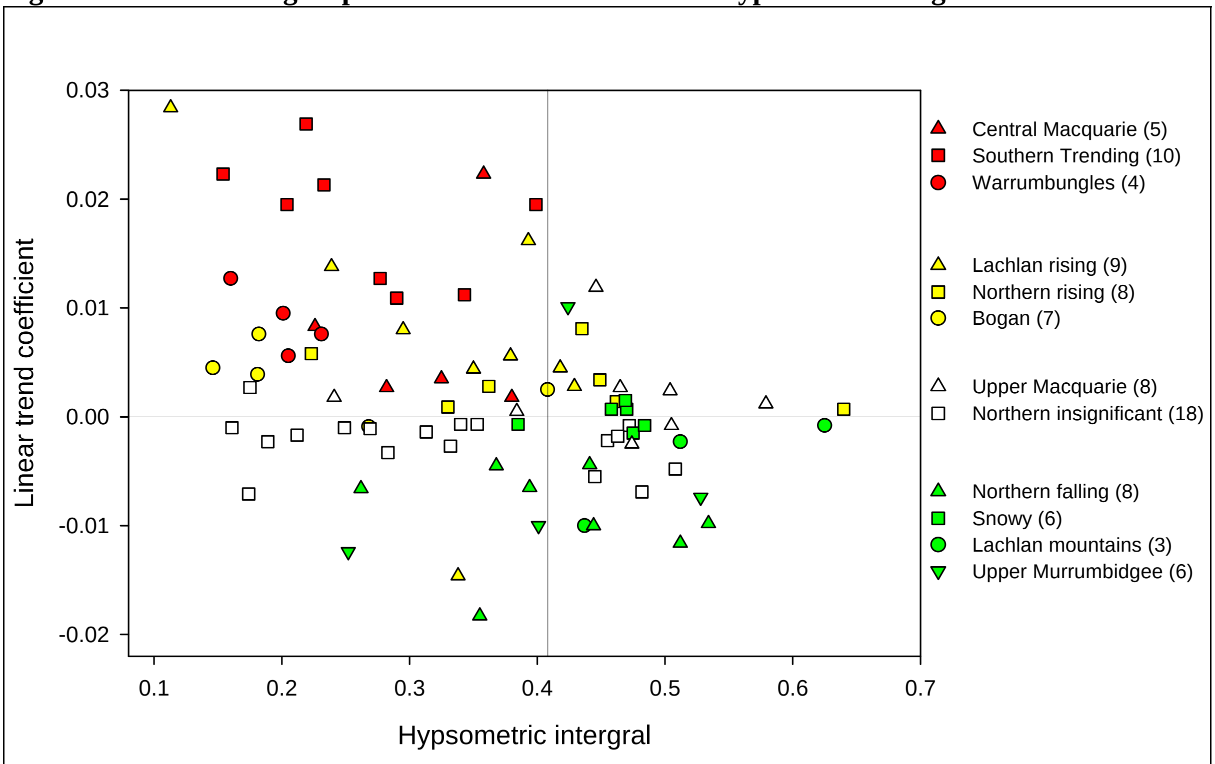


Figure 40. Catchment groups relative to linear trend and mean annual rainfall.

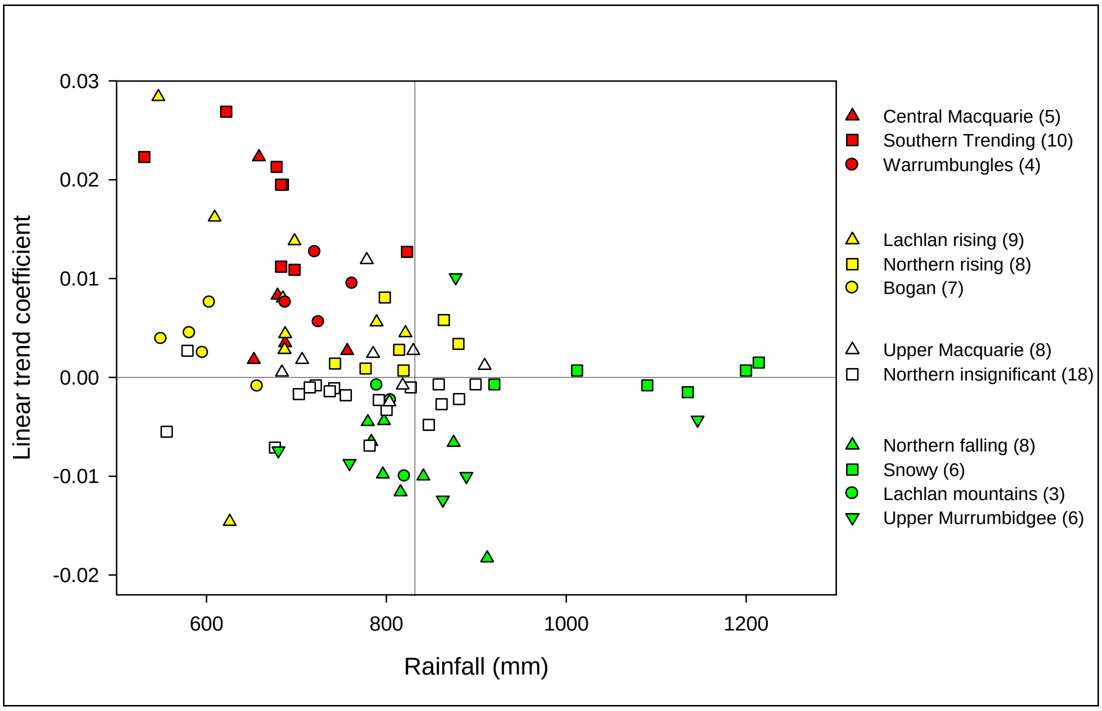
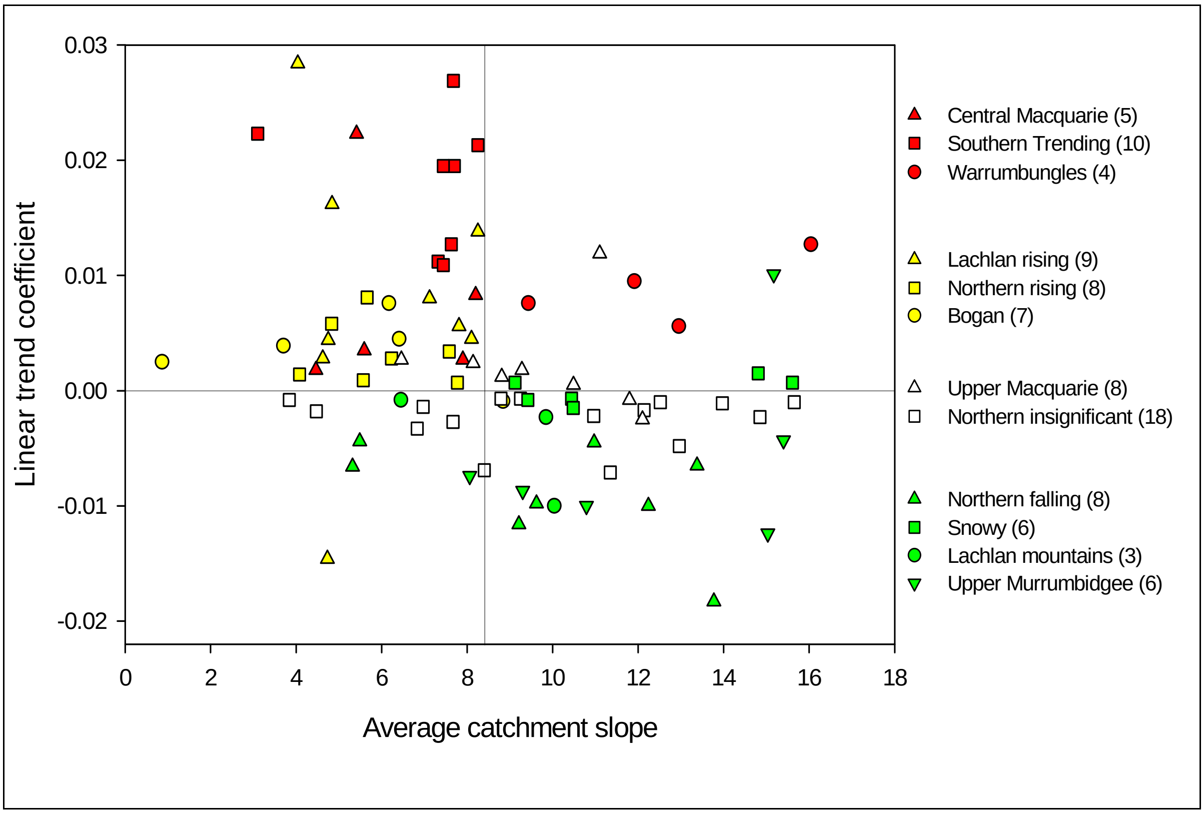


Figure 41. Catchment groups relative to linear trend and catchment slope.

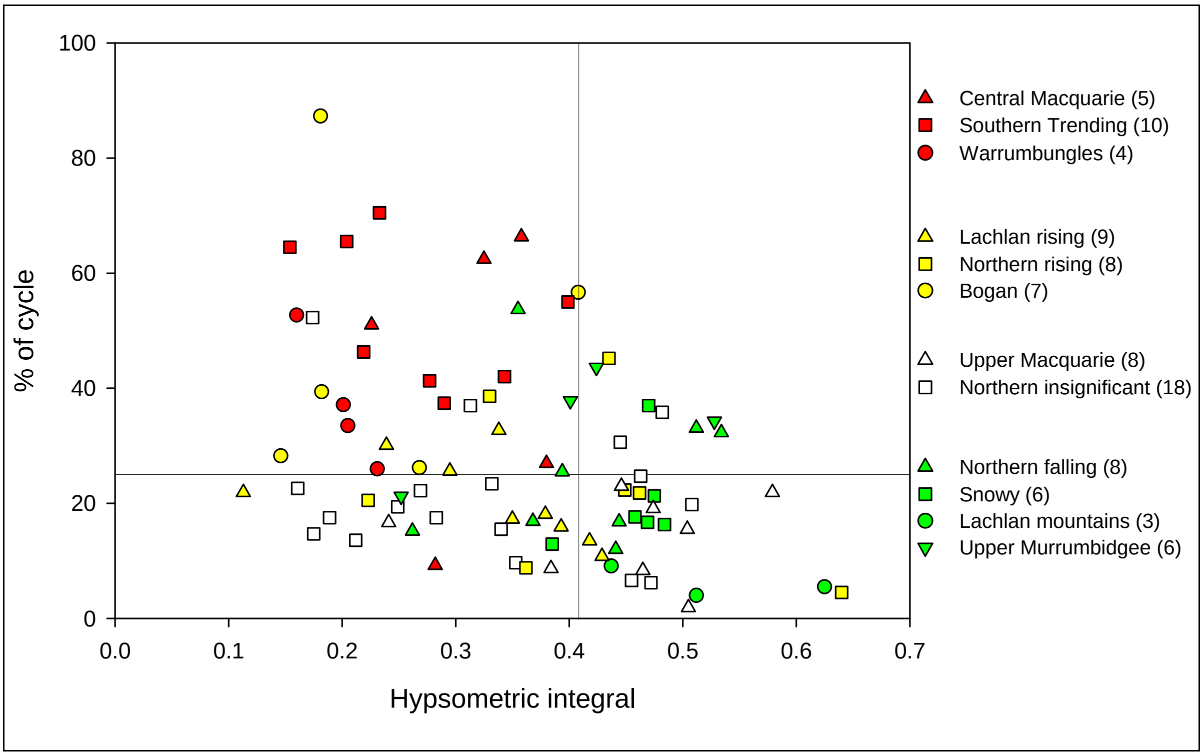


Linear trend coefficient vs average catchment slope (Figure 41). This figure suggests that catchment slope (expressed as an angular measure), may explain EC trend. The vertical line represents a slope of 8.4°. The upper left quadrant contains all the rising trend sites except the Warrumbungle subgroup and the 2 sites 410107 and 421072 already alluded to in this section. The graph implies that rising trend is usually associated with flat catchments. With the exception of the Warrumbungle subgroup, the converse is also true—that steep slopes are not associated with severe rising EC trend.

In one way the Warrumbungle subgroup is the exception: its average slopes are steep. In another way it is not the exception: the average slope incorporates an upper catchment that is very steep and a lower catchment that is very flat. It is probably the lower half of the catchment that is controlling the salinity behaviour.

Percentage of cycle versus hypsometric integral (Figure 42). The cyclic nature of the GAM curves is important in understanding the catchment EC process. The time span (and the amplitude) associated with the full cycle at a site has a big influence on the linear EC trend calculations. In this context, we tried to relate catchment characteristics to the cyclic parameters. Figure 42 does not suggest any concise relationships. Most of the problem sites seem to be contained within the bounds of 25% of the cycle and a hypsometric integral < 0.41. But Figure 42 doesn't provide an explanation for catchments with a falling trend.

Figure 42. Catchment groups relative to percentage of cycle and hypsometric integral.



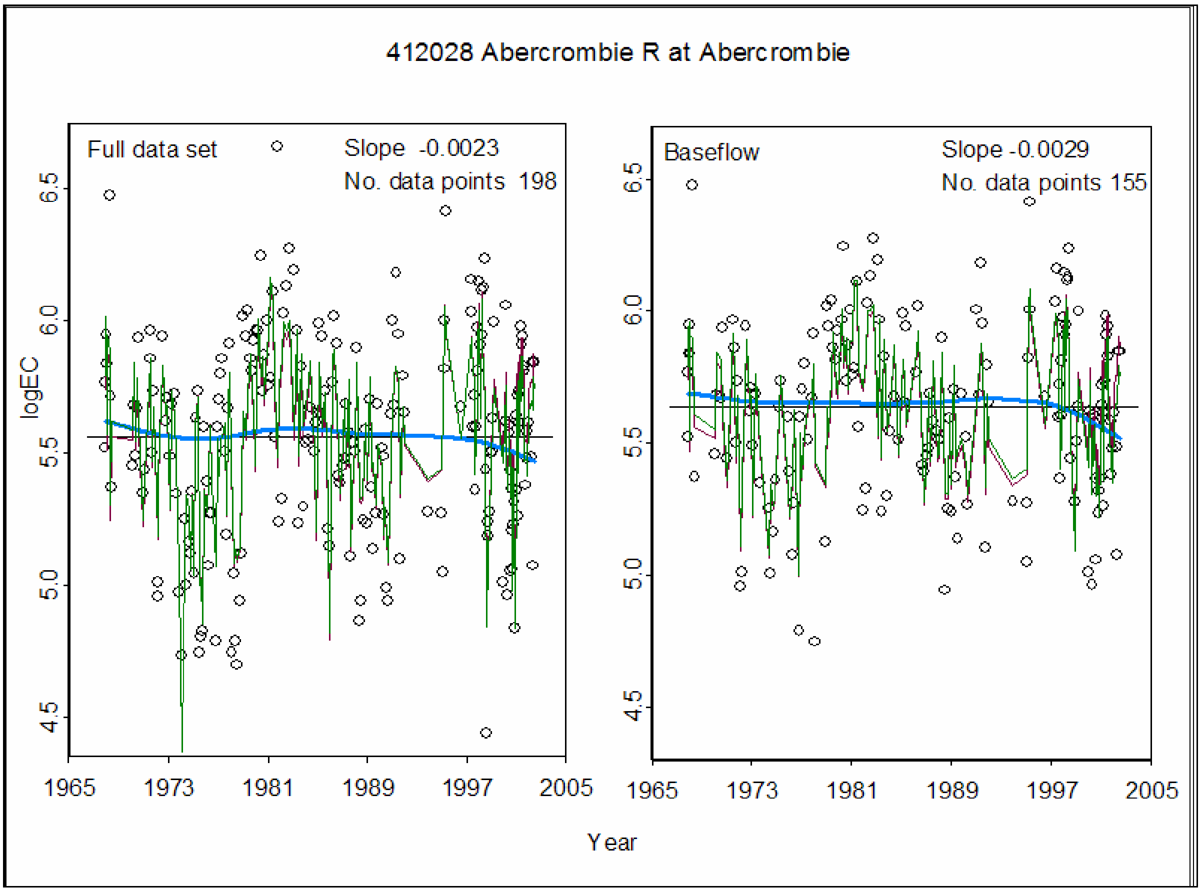
7 Ancillary Investigations

7.1 Modelling base flow separately

Most samples had been taken during base flow sequences (Section 3.2). However, we were concerned that the inclusion of a (comparatively small) number of event samples might be affecting the trend results. As part of a sensitivity test, we isolated base flow data sets for 10 of the southern sites by using the separation method described in Harvey and Jones (2001).

Model 7 was run using the base flow datasets, and we compared the outputs with the study results that used all the data. Figures were prepared showing plots of the full data set versus the base flow. The linear coefficient was included as slope, as were the number of data points in each sample. Figure 43 compares 412028 Abercrombie River at Abercrombie. All 10 sites are presented in Appendix 3.

Figure 43. Comparison of all data with base flow data only.



The results were tabulated (Table 6), mainly to see whether the slope changed by much in magnitude, sign or statistical significance. The statistical significance was also tabulated to show any change. The plots in Appendix 3 were used to confirm that the GAM curves were similar in both data sets. We deemed the difference between the summary statistics and the fitted spline curve for the pairs of data sets to be minimal.

Table 6. Comparison of linear coefficients of all data and base flow data.

Station Number	Station Name	All data Slope	Significant If <0.01	Baseflow Slope	Significant If <0.01
412028	Abercrombie R at Abercrombie	-0.0023	0.1763	-0.0029	0.1001
410097	Billabong Ck at Aberfeldy	0.0109	0.0000	0.0113	0.0000
410061	Adelong Ck at Batlow Rd	-0.0008	0.6015	-0.0018	0.2606
410038	Adjungbilly Ck at Darbalara	-0.0015	0.5657	0.0008	0.8025
401013	Jingellic Ck at Jingellic	-0.0007	0.4123	-0.0004	0.6642
410025	Jugiong Ck at Jugiong	0.0195	0.0000	0.0172	0.0000
401009	Maragle Ck at Maragle	0.0007	0.6933	0.0004	0.8704
410044	Muttama Ck at Coolac	0.0112	0.0000	0.0100	0.0001
410047	Tarcutta Ck at Old Borambola	0.0127	0.0000	0.0117	0.0000
410091	Billabong Ck at Wallbundrie	0.0195	0.0000	0.0216	0.0000

Note: The yellow shading signifies statistical non-significance. The brown shading indicates a change in sign of the EC trend at 410038.

7.2 Groundwater pilot study

7.2.1 Scope

If the bore data archive had been packaged in a more accessible way, the groundwater data would have been routinely included in the project.

We chose 8 sites to test the hypothesis that the deep aquifers may have been contributing to the long-term trend. We intended to link water level data from deep bores with the gauging station data. We encountered 2 obstacles in making that link:

- It was preferable that the gauging station and the bore both be surveyed to the same datum. (If the bore was not connected to a datum, we estimated the bore surface level from topographic maps. This was not a satisfactory solution.)
- The bore data were collected infrequently and were not synchronised with the stream data. Therefore, it was necessary to interpolate the bore data to match the time of the EC sampling. This process would not effectively track minor fluctuations in the water table, but should be adequate to track long-term groundwater trends.

7.2.2 Bore data preparation

At each of the 8 sites, the steps were as follows:

- The bore datum was expressed as height in metres (AHD).
- A group of 'nearby' deep bores was selected, and the observed water table height data were plotted against time. A representative bore was picked from each group (Kyeamba at Ladysmith was an exception to this process).
- The data at each representative bore were then interpolated to produce hourly data.
- The bore data were then matched against the equivalent stream EC and flow.

7.2.3 Presentation of groundwater results

As can be seen from Section 5.1, in the main study the 2 equations that generated the most interest were Models 3 and 7. We were interested in the effect of adding a groundwater component to these models. This was done in the form of a spline of water table heights with 2 df. Models 3a and 7a have the groundwater component added (Figure 13).

$$\text{Model 3a: } \log_e\text{EC} \sim s(\log_e\text{flow}, 2) + \cos t + \sin t + s(\text{groundwater}, 2)$$

$$\text{Model 7a: } \log_e\text{EC} \sim s(\log_e\text{flow}, 2) + \cos t + \sin t + s(\text{yrfrac}, 4) + s(\text{groundwater}, 2)$$

The addition of the groundwater component was tracked using 2 approaches. First, we plotted the flow-adjusted EC against the groundwater level data to examine the strength of the relationship. A LOWESS smoothing curve was used to reveal the shape of this relationship. This graph also plotted the flow-adjusted EC against time. These plots are presented in Appendix 4.

Secondly, Table 7 presents summary statistics from fitting these new models. We subjectively compared the differences in R^2 from the previous models to ascertain whether the inclusion of groundwater gives any improvements in goodness of fit. Future comparisons of these models should allow enough time for a more comprehensive statistical analysis, including testing for statistical significance of the reduction in residual sums of squares due to additional components, in the usual manner for model-building exercises.

Two decisions are worthy of note:

- Near 410048 Kyeamba at Ladysmith, the bores of interest are not surveyed to a datum. The nearest suitable bores were several kilometres away. We chose one west of O'Briens Creek because its behaviour better matched the stream EC plot of 410048 in Appendix 2.
- The first attempt at Tarcutta produced a confusing plot (Appendix 4-3a). We decided to remove the 8 bore readings at the lower end of the dataset on the assumption that the water table would have been too low to influence the stream—they were well below the gauging station gauge zero level of 190.7 m AHD. The new graph appeared more realistic (Appendix 4-3b).

Table 7. Impact on R^2 of adding a groundwater component (shaded columns).

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
StationNo.	Station Name	Start Stream EC	End Stream EC	Model 1	Model 2	Model 3	Model 3a	Model 4	Model 5	Model 6		Model 7	Model 7a	Start Groundwater Data	End Groundwater Data	Representative Bore	Datum
410091	Billabong Ck at Walbundrie	1969	2003	0.85	0.85	0.85	0.87	0.06	0.07	0.86		0.86	0.87	1979	2003	025133	Ass.
410097	Billabong Ck at Aberfeldy	1969	2003	0.47	0.49	0.5	0.52	0.08	0.12	0.53		0.57	0.58	1969	2003	025352	AHD
410047	TarcuttaCk. at Old Borambola	1967	2003	0.34	0.34	0.35	0.39	0.19	0.33	0.46		0.61	0.62	1974	2003	030385	AHD
	TarcuttaCk at Old Borambola #	1967	2003	0.28	0.28	0.29	0.38	0.21	0.33	0.41		0.58	0.59	1974	2002		
410048	Kyeamba Ck at Ladysmith	1970	2003	0.56	0.57	0.59	0.75	0.29	0.32	0.68		0.75	0.77	1973	2002	030355	Ass.
419027	Mooki R at Breeza	1970	2004	0.19	0.20	0.22	0.39	0.12	0.18	0.30		0.45	0.58	1970	2004	030002	AHD
419032	Coxs Ck at Boggabri	1969	2004	0.06	0.08	0.09	0.27	0.02	0.10	0.10		0.38	0.41	1983	2004	036433	AHD
419033	Coxs Ck at Tambar Springs	1969	2004	0.51	0.52	0.53	0.57	0.01	0.09	0.53		0.61	0.66	1986	2004	036599	AHD
419051	Maules Ck at Avoca	1972	2004	0.15	0.15	0.21	0.35	0.00	0.08	0.17		0.39	0.41	1972	2004	030130	AHD

# Eight data points removed.
Ass. = Assumed

At 5 of the 8 sites, the record length had to be shortened to match the bore data record. Columns 1 and 2 show the stream EC record details. These should be compared with columns 13–16, which list the bore record period, the bore number, and whether the bore has been surveyed into AHD or an assumed datum. (The length of the bore data record determined the values in Table 7.)

Comparison of Models 3 and 3a (Columns 5 and 6)

The addition of a groundwater component produced a big improvement at 3 of the 4 Namoi sites (4190--), and only marginal improvement at Tambar Springs. It also gave an improvement at Kyeamba at Ladysmith, but this could be due to the subjective choice of the representative bore.

Comparison of Model 3a Columns 6 and 11

This comparison looked at the impact of substituting the time trend component of EC with a ground water component. If the values in Columns 6 and 11 were in close agreement and were noticeably larger than that in Column 5, then the groundwater might equally explain the observed variation in EC. Using this approach, we might infer from Table 7 that the representative bores could equally explain much of the stream EC trend at Kyeamba Creek at Ladysmith, Mooki River at Breeza, Coxs Creek at Boggabri and Maules Creek at Avoca.

Comparison of Models 7 and 7a (Columns 11 and 12)

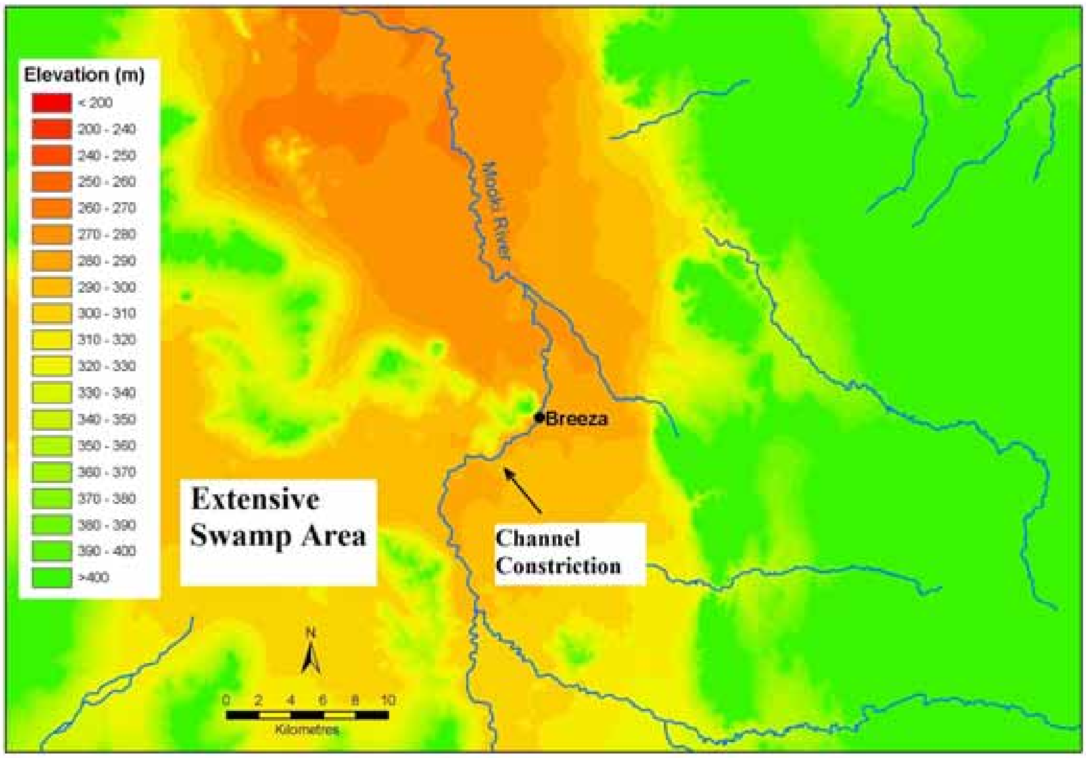
A difference in these statistics suggests that any EC trend is not entirely explained by the groundwater behaviour. At Mooki River at Breeza, groundwater appears to explain additional variation over and above that explained by flow, seasonality and time.

We checked whether the water table was higher than stream gauge zero level. Unfortunately, it was not. At least 2 sites showed promise of a ground water table connection—419027 Mooki River at Breeza (282.6 m) and 419032 Coxs Creek at Boggabri (242.9 m). At 419027, the table was 2 to 3 m below the gauge zero, and at 419032 the water table was not remotely close.

The 419027 site warranted closer scrutiny. Model 7a registers a groundwater component response, so we conclude that a stream–groundwater interaction is occurring upstream of the gauging station. The likely source is located several kilometres upstream. An extensive perched aquifer to the west of the Mooki (Figure 44) (pers. comm. D. Berhane 2006, DWE, Barwon Region) is a source of some very high EC readings. This perched table appears to be influencing the EC behaviour of Mooki River at Breeza. The outcome suggests that the inclusion of Models 3a and 7a could be used as indicators of upstream ‘point-source’ groundwater intrusion.

Had the groundwater table been above the gauge zero level, there would have been firm support for the use of Models 3a and 7a. The fact that the water table wasn’t as high diminishes the strength of the argument. The possibility that the water table gradient is steeper than the stream bed leads to the possibility of upstream encroachments, as confirmed at the Mooki. Generally speaking, there is also a chance of interactions in some of the deeper stream pools. If bore data nearer the aquifer than the gauging station had been used, a better fit for Models 3a and 7a might have been obtained.

Figure 44. Geomorphology near Breeza.



7.3 Salt load calculations

Electrical Conductivity is a surrogate for the measurement of salt load. One of the difficulties in calculating salt load is the determination of the conversion equation that should be applied. Traditionally within the DWE, and in some studies in the Murray–Darling Drainage Division (Williamson *et al.* 1997), a linear conversion equation is used:

$$\text{TDS (total dissolved solids) (mg/L)} = A \times \text{EC } (\mu\text{S/cm}), \qquad (6)$$

where *A* is ascribed a value of 0.6. However, the relationship will vary depending on the types of ions dissolved in the measured sample. Greenberg et al. (1992) give a possible range of 0.5 to 0.9 if a linear equation is used.

The 1999 Salinity Audit (Beale *et al*. 2000) used values for *A* of 0.625 and 0.64. At the time, no work had been done by the Department in this critical area. Since then, work has been done in the Macquarie Valley at 21 sites (Burton *et al.* 2001). At those sites, the range was 0.5 to 0.7. Only 2 were higher than the 1999 Audit's adopted value of A = 0.625. Most sites gave conversions factors that were about 15% lower.

There is a view that the TDS–EC relationship is not linear. White (2002) questions the validity of applying a linear conversion factor over the whole range of EC, indicating that a much better understanding is required of the local processes. White cites as an example the polynomial salt load conversion equation used by the SA Department of Water Resources:

$$\text{TDS} = 0.548 \times EC_{25} + 2.2 \times 10^{-6} (EC_{25})^2 - 2.02 \times 10^{-12}(EC_{25})^3. \qquad (7)$$

It is possible that by the time the salt load modelling is undertaken for this study, there will be a much better knowledge of salt load conversion in at least 2 of the NSW valleys. If the information is readily available, attempts should be made to use it.

7.4 Year of peak

Model 7 GAM curves (Appendix 2) were inspected to determine the year of highest GAM EC at each station. The results suggest that the timing of the phases varied across the State. We were interested to know whether the EC peak was operating like a pulse in each valley, occurring later as it moved down the valley. Figure 45—Elevation versus year of GAM peak—was plotted to test this. The Macquarie and Castlereagh sites were not included because of the current sharp upward trend at many sites in these valleys.

Murrumbidgee Valley sites plus Maragle

No estimate of year of peak could be made for 410045 Billabung at Sunnyside. At the 12 remaining sites, the peaks ranged from 1978 to an estimated peak at 2002, a span of at least 18 years. Figure 45 suggests that the mid Murrumbidgee is still draining out—at least at the sites that were used in this report. The plots of the various catchment characteristics suggest that the EC trend takes longer to stabilise and fall if the catchment has a low outlet elevation.

401013 Jingellic Creek at Jingellic peaked much earlier than the Murrumbidgee sites (including Maragle Creek at Maragle). At all the Murrumbidgee–Murray sites with comparable record lengths, Jingellic is the only site where the GAM plot (Appendix 2.2) has gone through a trough and is starting to rise again. Is this behaviour a precursor for other sites?

Lachlan Valley

It was difficult to discern a peak, let alone any pattern, at many of the sites in this valley. The peaks occurred over 1991 to 1996, with little evidence of outlet elevation having an influence.

Macintyre Valley

No convincing pattern was discernible. Seven catchments peaked between 1977 and 1981, with the more westerly catchment (Gil Gil at Weemalah) lagging behind as late as 1984. Two catchments seemed grossly at odds with the others: 416020 Ottleys Creek at Coolatai and 416039 Severn at Strathbogie. It may be that their behaviour is heralding a new pulse or a new local issue.

Gwydir Valley

No convincing pattern was discernible. The range of years was 1977 to 1985.

Namoi Valley

The Namoi appears to have some similarity with the Murrumbidgee–Murray. The upper catchments appeared to have peaked much earlier (1972 to 1981) than 3 of the lower-elevation catchments (1995–2000).

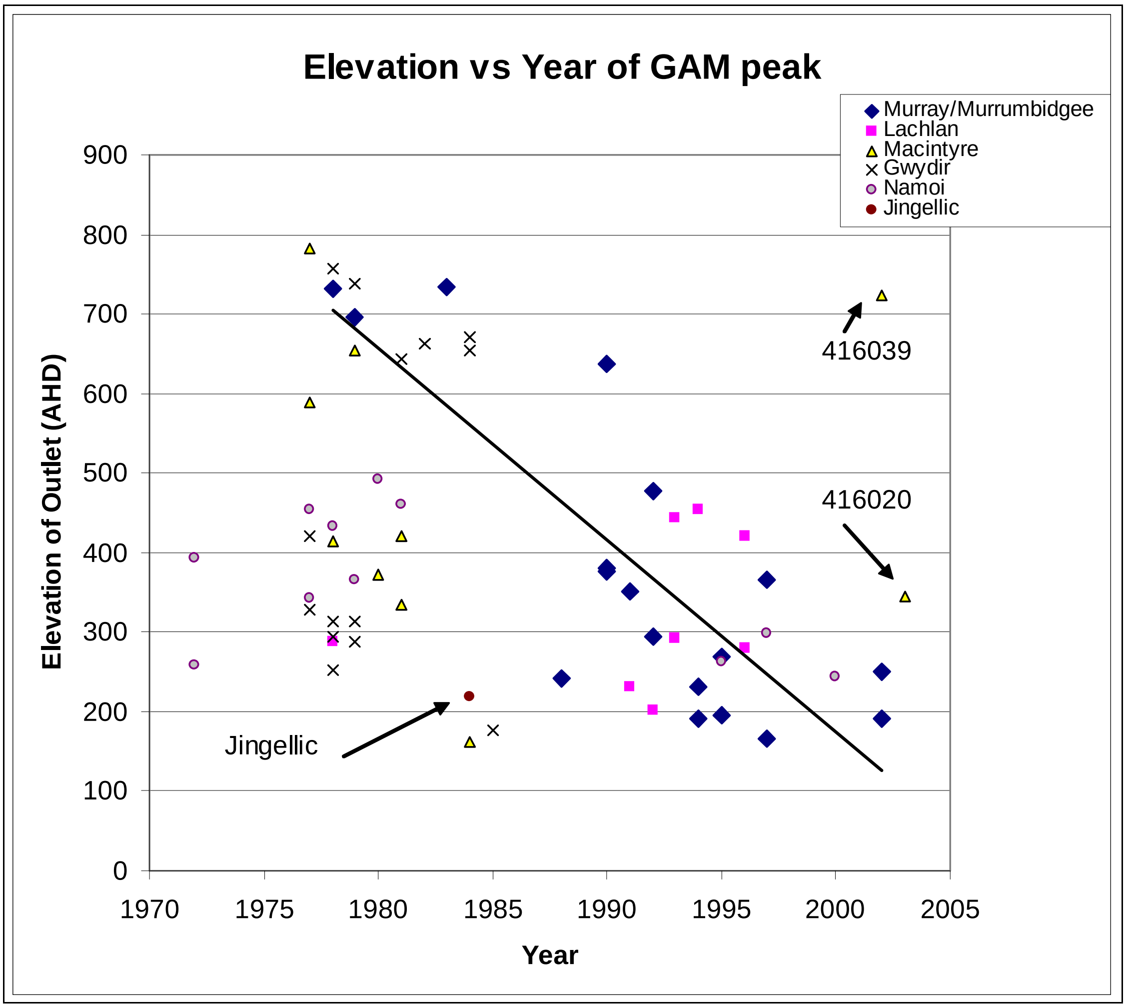
7.4.1 Tardiness of GAM peak

The Murrumbidgee peaks, and to a lesser extent the Namoi Valley peaks, appear to be moving westward. The Gwydir and Macintyre generally seem to have peaked over 1977 to 1984. The Lachlan peaked from 1991 to 1996.

The lag in the south is interesting, particularly where the peak is moving so slowly near Wagga Wagga. It is not clear whether a series of geological constrictions is preventing its escape to the rim of the Riverine Province described in Evans and Kellett (1989).

It is also worth noting that the outlet elevations in the mid Murrumbidgee are lower than at most other sites (Figure 45). Even many of the steep Murrumbidgee sites have their outlets close to the riverine plain, in comparison with their counterparts in other valleys. The slow movement down this particular valley may be due to hydraulic gradient (see Discussion, Section 8.6.2).

Figure 45. Elevation v year of GAM peak.

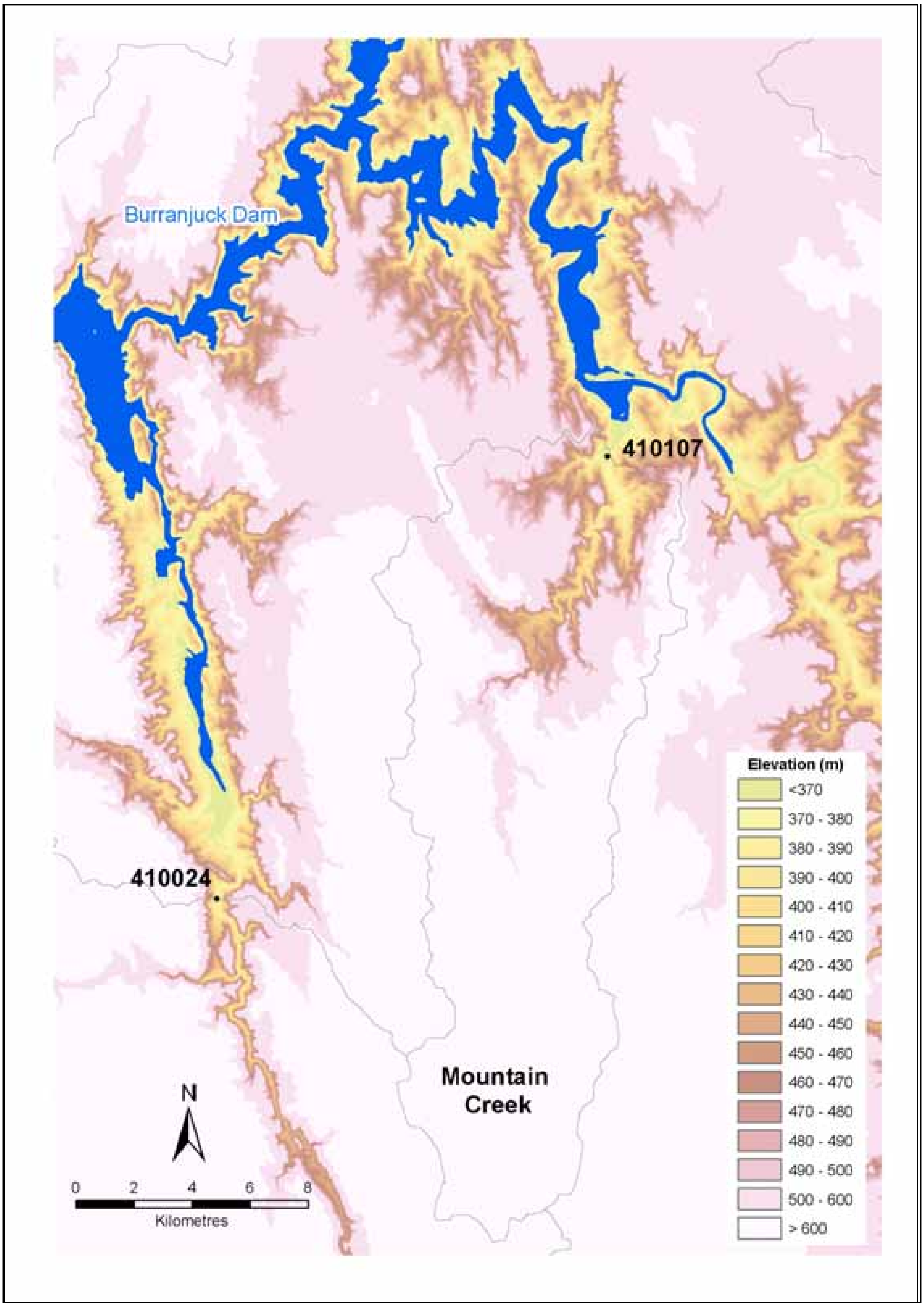


7.5 410107 Mountain Creek at Mountain Creek

This catchment (Figure 46) has been placed in the Upper Murrumbidgee subgroup because its geomorphology assigns it there. However, its GAM curve cycle is more typical of the Southern Trending subgroup. Further enquiries confirmed that the site was prone to problems. It represented a high-rainfall, steep catchment but it was located adjacent to a flood plain. Upstream of the site, the creek re-emerged after flowing subsurface.

What was occurring downstream was also very interesting. As well as being on the edge of the floodplain, the site was near a large artificial lake (Burrinjuck), which arguably was controlling the downstream groundwater hydraulic gradient. We later estimated that the site was approximately 5 m above the spillway. The GAM curve behaviour at this site gave credence to the concepts that the site was not representative of the catchment, a downstream impediment was in place, and the dam catchment close to the top water levels may be a salt accumulation zone.

Figure 46. 410107 Mountain Creek at Mountain Creek and environs.



8 Discussion

In undertaking such an investigation, not only are the final calculations important, but so too is the level of confidence that can be attributed to them. Much of this section is dedicated to discussing the limitations of each step in the achievement of a final result.

8.1 Limitations in the EC–flow relationship

The relationship between $\log_e$EC and $\log_e$(instantaneous flow) is the cornerstone of a successful Model 7 fit (Section 5.1). At some sites the relationship was good, whereas at others it was not. There are a number of reasons why the catchment upstream of the gauging station might not exhibit a good correlation.

8.1.1 Catchment processes

8.1.1.1 Catchment heterogeneity

There may be spatial variability in salt supply due to different geologies and different aquifer exposures. Some parts of the catchment may receive higher rainfall. These subcatchments have had greater opportunity for mobilisation over the centuries, and might already be well leached. In contrast, the drier subcatchments will have had comparatively less opportunity for mobilisation, and consequently have more salt available for mobilisation in wetter decades. A high variability in a catchment's rainfall could point to a high cyclicity, which in turn points to mercurial EC trend behaviour over the long term.

8.1.1.2 Systematic errors in the data

The study has flagged a possible systematic error in the discrete EC data set due to instrument limitations. This is discussed extensively in Annexure A.

Rating tables that are not representative of the stream behaviour can cause systematic errors in the high flow regimes. Sites with poor controls can greatly affect the definition of low flows, and these errors will be magnified by the fact that the calculations are performed in the scale of natural logarithms.

8.1.1.3 Hysteresis

There could be an offset in the relationship between EC and flow between the rising and falling limbs of an event hydrograph (Harvey and Jones 2001). It has implications in the development of EC–flow relationships at high flows. In this study, it may have some negative effects—particularly if there are few data points.

8.1.1.4 Precision of instrumentation

At some of the study sites, the EC range and individual EC values were low. It is conceivable that instrument errors were as large as (if not larger than) the trend being measured.

8.1.1.5 The relationship does not exist

At many sites, particularly in the 3 northern valleys, the EC–flow relationship was poor (Tables 2 and 3, Model 3 column). At 1 other site (410103 Houlaghans at Downside), the statistics of Table 2 point to a good relationship. However, closer scrutiny shows that with just 28 data values spanning 28 years, the EC–flow relationship is weak.

8.1.2 Choice of equation to explain the EC–flow relationship

Jolly *et al*. (1997, 2001) relied on the monthly means of EC and flow. Because many of their catchments were large and regulated, this appears the best way to go. Our study deals mainly with tributaries, which would tend to have larger variations in flow and EC. We decided to relate EC to instantaneous flow (Harvey and Jones 2001). This is likely to provide a closer EC–flow relationship, but the 'flashier' nature of smaller tributaries could generate other difficulties in the relationship.

8.2 Limitations in the data

Is it possible that the GAM output is describing a process which is different to an EC trend?

Data preparation is described at length in Sections 2 and 3 and in Annexure A. The quality of the EC data is likely to have varied over time. The original collection program may have gone through quality assurance difficulties in the early 1970s, but is likely to have recovered by the late 1970s, and was producing good results through to the early 1990s. A new collection program began by the mid 1990s, but has associated data gaps and 'teething' problems. We can expect that the discrete EC data being collected today are gradually improving in quality.

The cyclic nature of the GAM curves (Appendix 2) may be due to:

- the collection program itself
- the cyclic nature of the tributary flow patterns
- decisions made in the data editing of this project.

8.2.1 Data collection program itself

Early record. Annexure A reports possible instrument limitations in the early 1970s. We tried to neutralise the problem in the Macintyre, Gwydir and Namoi, but found insufficient evidence to address the problem in the Lachlan, Murrumbidgee and Murray. The GAM behaviour in the earlier years of record might be explained by data collection problems.

Data gaps. It is not clear how the gap years in the early 1990s might have influenced the model results, particularly at the end of the record. What are an acceptable number and density of sample points to 'tie down' the post-gap statistics? One view suggests that trend analyses should not be undertaken if there are gaps, particularly if there are few data points after the gap, because only 1 or 2 data points would have an unacceptable influence on a trend calculation. An opposing view says that the dataset should be analysed, because it can flag possible problems. These unacceptable data points can easily be discarded at a later date if the addition of a dozen or so data points provides contradictory evidence.

Ephemeral streams. At some sites in lower-rainfall zones, streams ceased to flow during a sequence of drier years. It is not clear whether this influences trends in the neighbouring years when there was a record. At other sites, the number of samples fell during drier years because the stream flowed only intermittently. The samples were probably associated with surface runoff, rather than the usual base flow. It is not clear whether this behaviour would cause any bias in the GAM curve, particularly if the dry sequence lasted several years.

Future filling of long data gaps. Our policy was to involve field personnel wherever possible. At the study commencement, we tried to obtain input from various water quality officers concerning the 'Recent' dataset. Unfortunately, the work was done at a time of organisational upheaval, and some of the key players were in the process of leaving the organisation. This has meant that expert input was not always available during the data editing phase.

As the study progressed and some of the preliminary findings were made known, it became apparent that additional datasets might be available to cover some of the ‘gaps’. This situation appears to be the exception rather than the rule, but it is worth noting for future studies.

8.2.2 Sampling frequency

As alluded to in Section 2.5, we tried to keep the sampling frequency for the ‘recent’ and historical records roughly the same. This was not always easy, but there was a rationale behind it. In generating the data to be used in this technique, we chose a representative flow value: the mean of the $\log_e$flow values paired with the EC samples (Appendix 1). Because wetter decades would contain much higher flows than drier decades, it was important to keep the mean $\log_e$flow as representative as possible of the field conditions experienced throughout the collection program.

8.2.3 Representative tributary flows

The representative $\log_e$flow (referred to in Section 4.6 and listed in Appendix 1) was held constant when the curves in Appendix 2 were generated. We were concerned that this mechanism might distort the trend results. In wetter decades, the representative flow would probably be classified as base flow. In drier cycles, particularly in cases of ephemeral streams, the same flow might be surface runoff—representing a completely different regime of EC. The scenario (of a switch between surface and base flow) is not a probable one, but it should be kept in mind. It provides a good argument for separating the event and base flows with a view to analysing the data sets separately (Section 7.1). Unfortunately there are not enough event data points to perform this operation successfully.

This type of problem is not limited to tributary catchments. It is possibly just as great a problem for sites on regulated streams. During drier years, greater reliance is placed on dam releases. In wetter cycles, the source of flow in the river might be completely different.

8.3 Limitations in the models

The flow spline and the number of degrees of freedom chosen in the time spline might cause limitations. In future studies, there probably needs to be a more flexible approach to handling the number of df chosen in the $\log_e$EC–$\log_e$flow relationship. At sites with few data points, there needs to be a more flexible df approach in the generation of the GAM trend curve.

a) The flow spline

In some cases, the relationship between $\log_e$EC and $\log_e$flow was good, but in others it was poor. The spline fits site No. 410091 adequately (Figure 47), but has trouble bending sufficiently to fit either end of the observed flow range at 416010 (Figure 48). When a value of 2 df is not adequately flexible, the time component (in the form of the GAM curve) might try to compensate for any systematic error. If the EC–flow relationship has a high degree of curvature, then the spline will anchor to the mass of points usually at the low end of the flow range. Inflexibility may cause the spline to have difficulty fitting to data points at the high flow end. The question arises as to whether the full model will try to compensate for this high flow/low EC inadequacy by the time spline modelling the inflexibility as a natural fall in EC.

It is interesting to note that there is generally a poor fit between $\log_e$EC and $\log_e$flow at the site shown in Figure 48. Not only does the spline function fail to follow the few high flow / low EC events as adequately as one may desire, but a cluster of data at medium flow exhibit quite a broad range of EC values. As can be seen from the fitted curve in Appendix 2.36, both high and low recorded EC values are not modelled well at this site.

The predominance of points in base flow could be biasing high flow results, generally predicting too high. On its own, this is not a problem in the trend analysis, for 2 reasons:

- We are interested not so much in the magnitude of an individual value as in how it compares with EC during similar flows in other years.
- If the high flow samples occur randomly across time, then it shouldn't unduly influence the shape of the trend curve.

But a sequence of 3 or 4 wetter years may cause the trend component to compensate for the inflexibility of the flow spline, generating a chronic overestimate in those years and causing a bulge on the GAM curve. If the undulations were solely caused by this statistical weakness, then sites with a predominantly linear EC–flow relationship (i.e. the non-linear component is not significant) should not show undulations. An inspection of a number of relevant sites refuted our concern by revealing undulations.

To address the above concerns, knowledge of EC behaviour at high flows needs to be improved. This in turn emphasises the importance of having confidence in the accuracy of the data, particularly time-series. With future data improvements, consideration could be given to increasing the df of the spline or to separating the dataset into event and base flows.

Figure 47. Adequate spline fit.

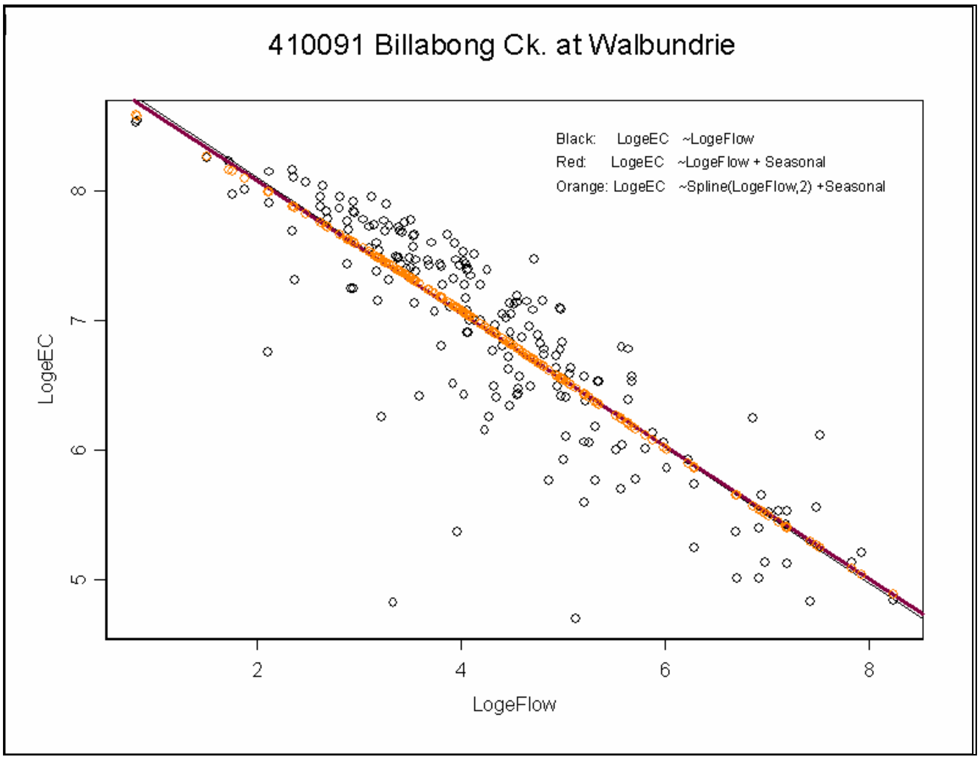
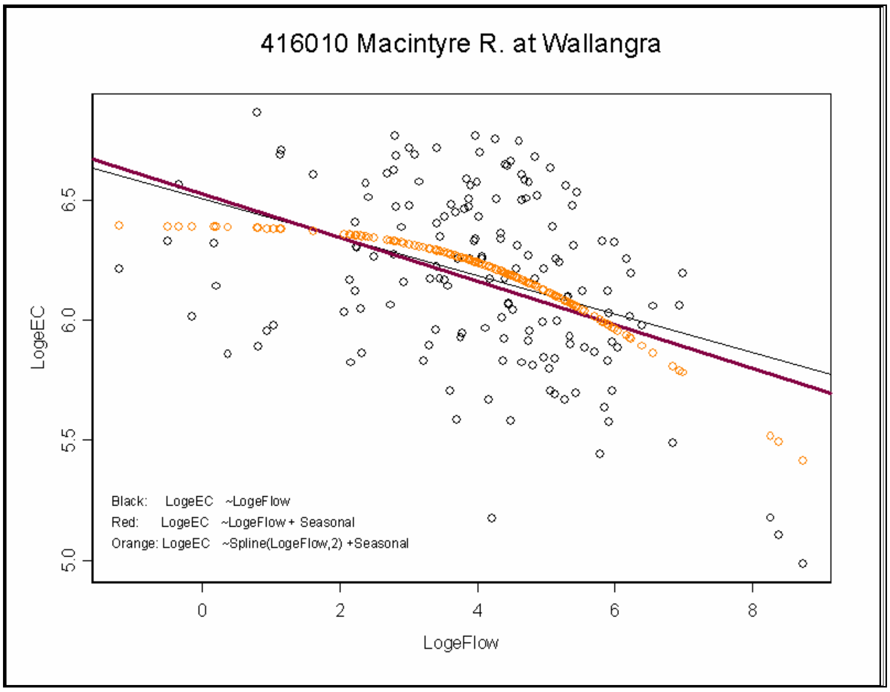


Figure 48. Spline not fitting flow extremes.



b) Degrees of freedom in the time spline

The issue of spline-smoothing is discussed in Section 4.3. At most sites, the choice of 4 df has been appropriate. At sites with comparatively fewer data points, a lower df might be preferable in future.

8.4 Synthesis and cyclicity implications

In viewing the various constraints discussed in Sections 8.1 to 8.3, we need to take into account several major issues. One of the big unknowns in this work pertains to the uncertainty of the systematic errors of the early data sets. Although the impact of the uncertainty may be marginal in a technical sense, it blurs the issue of whether an individual site is experiencing a rising trend or not.

The Model 3 relationship between EC and flow is not always strong. In fact, it is poor at a number of the sites in the northern half of NSW. How this weakness affects accuracy in the trend analysis is uncertain. There appeared to be enough good performances for us to persist with the results. The non-linear component of the GAM curves (Appendix 2) makes trend analysis and forecasting difficult. Therefore, it is important to understand the nature of the cyclic behaviour of the GAM as a prelude to understanding linear trend. By placing emphasis on the cyclic nature of the trends, this study differs from Beale *et al*. (2000) and Jolly *et al*. (1997, 2001).

8.4.1 Implications of cyclicity

The subgroups were developed based on similar catchment characteristics and similar GAM curve shapes (Section 6, Figure 30, Table 5) in adjacent catchments. The similarity in subgroup GAM shapes points to climate being the prime driver of cyclic behaviour.

At some sites, the cycle length is shorter than the 30-plus years of data available. In such cases a linear trend has been estimated with a degree of confidence. At other locations, the cycle length appears longer than a lifetime (Appendices 2.3, 2.6 and 2.84), and it is much more difficult to understand the processes, because they may never return to the low EC levels of the early 1970s. At other sites, an addition of 10 or so years of data will complete the cycle and enable a much better assessment of long-term trend.

8.4.2 Cycle amplitude and modelling

In some catchments, the cycles are of large amplitude, suggesting the involvement of factors that magnify the climatic fluctuations. Large cycle amplitudes appear to indicate wide characteristic variations within individual catchments—for example, mountains versus plains; wide variations in annual rainfall or water chemistry. It is likely that such characteristics work in combination to magnify the climate fluctuations.

At present, wide variations in catchment characteristics are blurring any evaluation of EC trend. From a modelling perspective, there is need to identify the extent of the catchment variations with a view to disaggregating existing modelled subareas. Modelling that is solely based on existing gauging networks may be inadequate for tracking EC trends. This concept is further supported in Section 8.5.2.

8.5 Geographic subgroups

In Section 6.1, the various catchments have been grouped and linked to geomorphological characteristics (Section 6, Table 5, Figure 30). The subgroups were initially based on proximity and on the similar characteristics that proximity often entails: mean annual rainfall, elevation and slope. We also considered the $\log_e$EC trend and cyclic indicators in determining the groupings.

8.5.1 Record length

One complication was record length, which at some sites did not encompass the whole period of record. This resulted in 1 or 2 sites (such as 412086 Goobang at Parkes) seemingly to be grouped incorrectly.

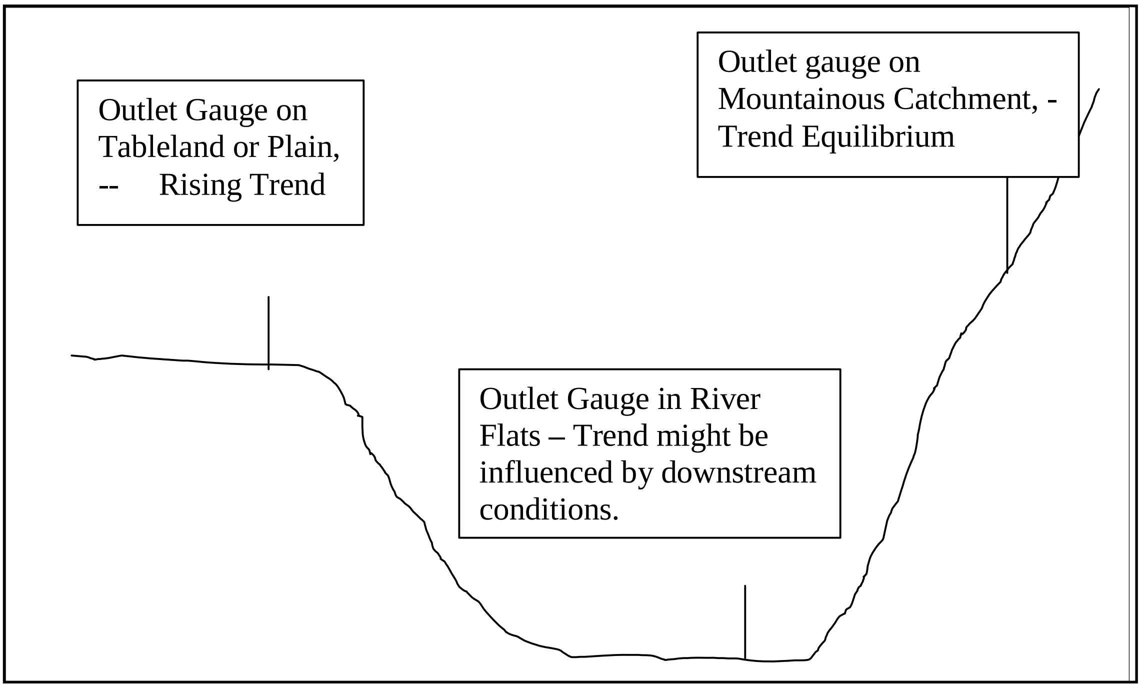
8.5.2 Site location

A second complication pertained to site location. The study was undertaken using data from gauging stations. These sites were originally located to optimise the collection of flow data. Sometimes they were placed in locations that might not be typical of the catchments they represented. For example, in Figures 27 and 38, there is an inference that most members of the Snowy subgroup are located on the river flats at the base of the mountain range. In such cases, there is always the danger that the saline processes being tracked are different from the processes in the mountainous catchments they represent.

This ‘non-representative’ aspect has wider implications. If a stream were traversed from its outlet to the top of its watershed, in most cases the EC magnitude would diminish. The decrease might be gradual, but it could be a step where point-source saline intrusions are crossed. In grouping the catchments, the location of the sampling point should always be kept in mind. The relocation of the site by several kilometres (particularly from river flats to hilly terrain) could effectively change a catchment’s EC reputation.

Examples of non-representative catchments outlets have already been discussed: Tarcutta at Old Borambola (Section 5.3.1), the Warrumbungle subgroup (Section 6.1.5), and specifically Mooki River at Breeza (Section 7.2.3). The implication of location of the outlet gauge is conceptualised in Figure 49.

Figure 49. Conceptual diagram in Section 8.5.2.



8.5.3 Flat slopes and low outlet elevation

The work in Section 6.2 and Figure 41, which links catchment slope to linear trend, suggests that the EC behaviour may be linked to how effectively the catchment substrata can drain. Catchments with low outlet elevations are likely to have difficulty draining; generally there is no opportunity for saline ground water to escape into lower country downstream. Tableland catchments with low slope could also be subject to drainage difficulties. In Figures 38 and 41, the troublesome subgroups (particularly Southern Trending) fall into the categories of low elevation and flatter slopes. It is possible that other mechanisms are at work, impeding subsurface movement and catchment flushing.

8.6 A conceptual model

The current drought has altered salinity trends. But it has affected the valleys in different ways. For example, the GAM curves for sites in the Murrumbidgee system have generally stopped rising or begun to plummet. In the Macquarie system, the drought has signalled a sharp rise in the GAM curves for the last 10 years. In developing a conceptual model of future behaviour, we must address the impact of the drought consistently. In drawing conclusions and recommendations, we have taken the GAM curve trends for the last 10 years on face value, despite possible extenuating circumstances.

The GAM curves provide little opportunity to forecast to 2020. Modelling is also difficult, because at some sites there is not a sufficiently long data set to evaluate EC behaviour under all hydrological conditions that NSW typically experiences. Careful examination of the GAM curves has led to an assessment of EC processes over the 30+ years of record. Following are some comments about what processes might come into play over the next decade or so.

We have made some fundamental assumptions that any EC peak highlighted in the GAM curves of Appendix 2 will recur or be surpassed sometime in the future. The following comments relate to what is likely to happen in the next 20 years, and acknowledge that NSW is still gripped by drought. It is assumed that observed GAM curve peaks can be expected to recur routinely at a particular site.

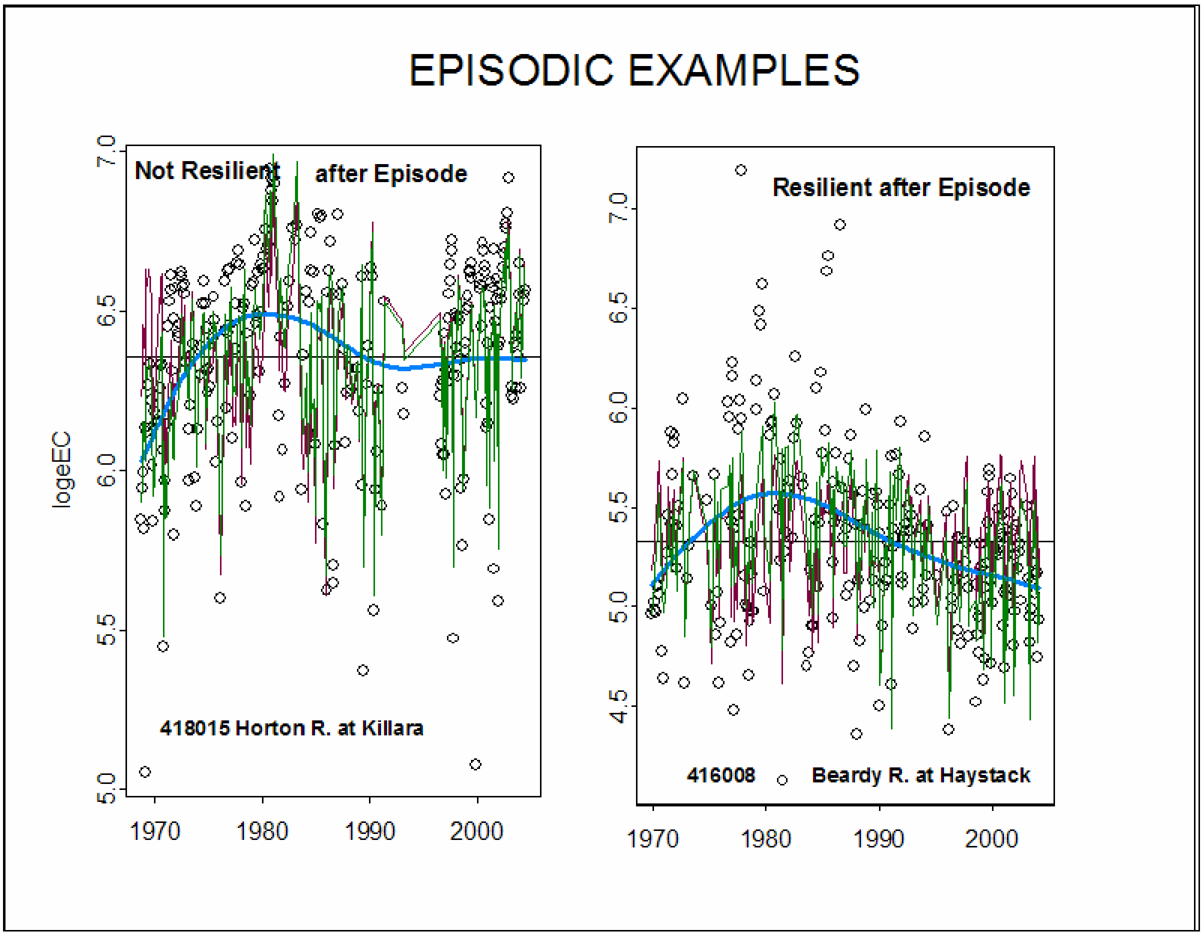
8.6.1 The ‘episodic’ change and aftermath

In an overview of the GAM curves in NSW, several patterns emerged, suggesting a conceptual model of stream EC behaviour. The various subgroups of Section 6 have highlighted that the following 12 sites showed a sharp increase in EC during the early 1970s. Most of the 12 are located in Jolly *et al.*’s (2001) ‘Zone 1, Northern–Western Dryland’. It is not clear whether the historical data collection program started after the rising trend began, but the implication seems to be that all 12 sites experienced a sharp EC rise.

The ECs at half the sites were resilient, dropping back to the levels at the start of the collection program, but the remainder dropped only part way back, registering an overall increase (Figure 50). Most sites are in the mid Gwydir Valley, but some are in the Namoi and Border River valleys, and 1 is in the Castlereagh. The catchments are marked ‘E’ in Figure 51. A catchment’s response to the episode often determined its subgroup classification as a rising or falling trend catchment. Generally the steeper catchments returned to the earlier EC levels, whereas the flatter catchments did not. (This behaviour endorses Figure 41 and 49.) Some of the sites listed below have long gaps in their record, but those that haven’t, clearly illustrate the episode’s impact.

- 416008 Beardy River at Haystack, Appendix 2.35
- 416021 Frazers Creek at Ashford, Appendix 2.39
- 418008 Gwydir River at Bundarra, Appendix 2.46
- 418015 Horton River at Killara, Appendix 2.48
- 418016 Warialda Creek At Warialda, Appendix 2.49
- 418017 Myall Creek at Molroy, Appendix 2.50
- 418018 Keera Creek at Keera, Appendix 2.51
- 418029 Gwydir River at Stoneybatter, Appendix 2.56
- 418052 Carole Creek at Near Garah, Appendix 2.58
- 419053 Manilla River at Black Springs, Appendix 2.67
- 419054 Swamp Oak Creek at Limbri, Appendix 2.68
- 420005 Castlereagh River at Coonamble, Appendix 2.72

Figure 50. Examples of episodic behaviour in Jolly *et al.*'s Zone 1.



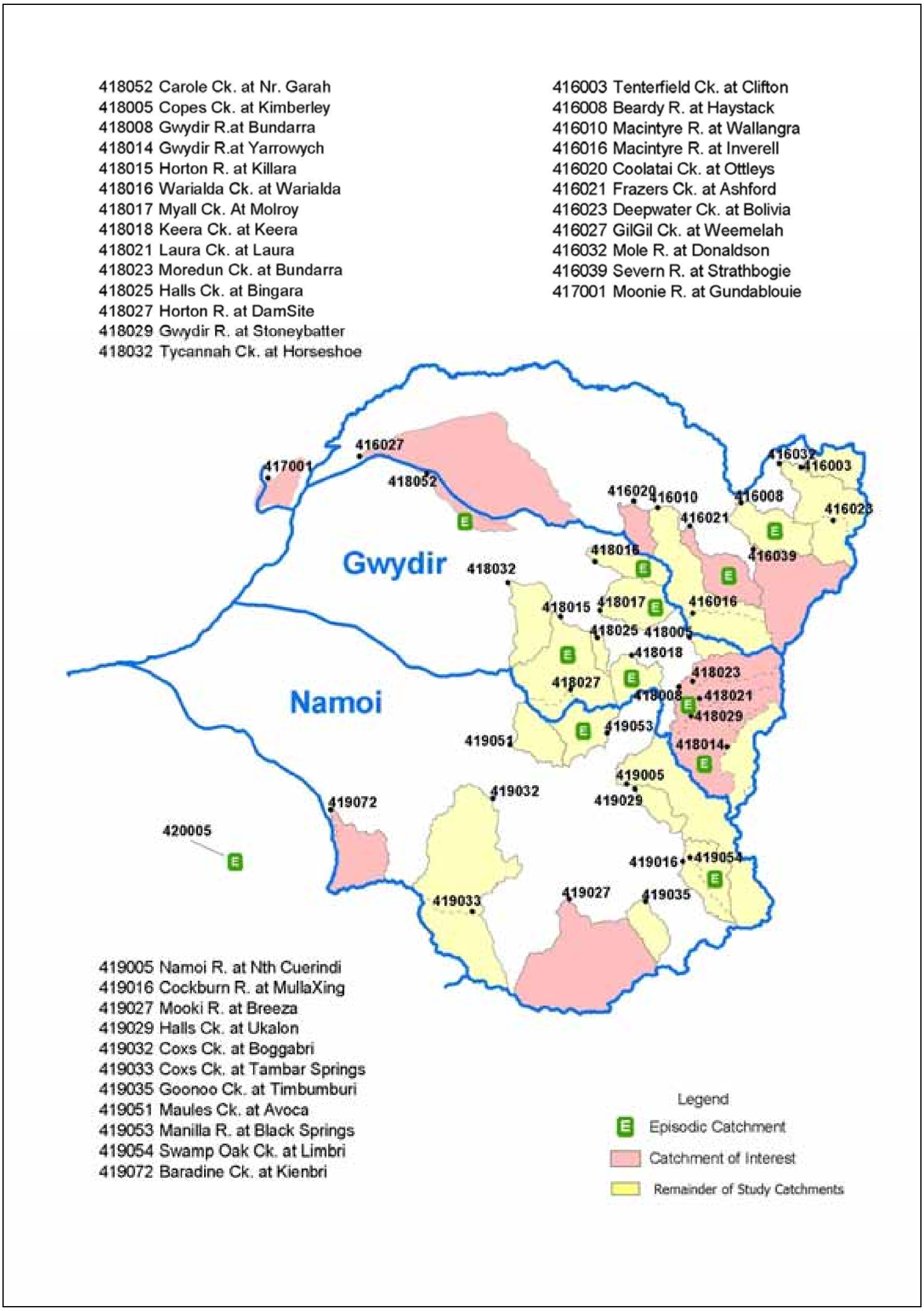
8.6.2 The 'impeded' sites

The GAM curves of some sites indicate a long cycle, and it is difficult to assess what the outcome might be at the end of it. These impeded sites encompass the Southern Trending and Warrumbungle subgroups, as well as 410107 Mountain Creek at Mountain Creek. A number of these may ultimately be termed Episodic, as described in Section 8.6.1. It is difficult to see many of the Southern Trending catchments returning to the EC levels of the early 1970s within the next 20 years. Two are trending upward with little respite—410091 Billabong at Walbundrie (Appendix 2.3) and 410025 Jugiong Creek at Jugiong (Appendix 2.6).

Probably as a result of the drought, several Southern Trending sites have started to trend downwards in recent years after prolonged climbs. There are at least two possible reasons for the various behaviours. At Kyeamba Creek at Ladysmith (Appendix 2.13), Tarcutta Creek at Old Borambola (Appendix 2.12), and Muttama Creek at Coolac (Appendix 2.10), the trends might be explained by large variations in annual rainfall across the catchments (see Section 6.1.3).

A second explanation is associated with limited hydraulic gradients or obstruction to groundwater movement, preventing access to the regional groundwater systems. The possibility of constrictions at Mooki at Breeza (Appendix 2.61) is discussed in Section 7.2.3. The Mountain Creek (Appendix 2.20) retardation scenario is discussed in Section 7.5.

Figure 51. The episodic catchments ('E') and catchments of interest (pink).



Flat hydraulic gradients in the groundwater table have implications at a valley scale. The catchments with rising trend are generally associated with low average slopes, whether plains or tablelands (Figure 41).

The Southern Trending subgroup is perplexing if its behaviour is to be explained by the regional groundwater table. There are a number of study sites in the Bogan, Castlereagh and Border Rivers that are lower than (or at approximately the same AHD as) the Southern Trending sites. However, none are showing significant rising trends or the variation in cyclicity that one would expect of a rising regional water table. It is possible that the causes of the Southern Trending behaviour might be driven by local geographic features, and relate to groundwater hydraulic gradients. There are locations where the various streams and rivers pass through ranges of hills whose geology may constrict groundwater movement. There is the possibility that (at this point in time) the problem might not be caused by the regional water table rising, but rather that the Murrumbidgee, Lachlan and Billabong systems are suffering impeded groundwater movement. Small north–south ranges of hills are the likely impediment. The Malebo Range immediately downstream of Wagga Wagga may be playing some part in impeding the mid Murrumbidgee tributaries. Braaten and Gates (2003) noted that after a large recharge event (1989), it took several years for the groundwater system to drain back into the Wagga–Narrandera section of the Murrumbidgee River.

The evidence for establishing the Warrumbungle subgroup is a little circumstantial. It is based on the extreme variations in the individual catchment characteristics. There is much higher annual rainfall along the narrow mountain strip. This flows down precipitous parts of the catchment and accumulates in the plains below. The water gradually filters into the stream systems, as described for Mooki River at Breeza in Section 7.2.3.

Sites in the Southern Trending subgroup have substantially rising ECs, and the trends are statistically significant. There is no guarantee that some will return to the EC levels of the early 1970s. Members of the Warrumbungle group are experiencing the same rising trends, but not to the same extent.

8.6.3 Subgroups in equilibrium (Table 5 and Figure 52)

These are major contributors to the valley runoff but, in terms of rangeland coverage, occupy only a small portion of the valley catchments.

Snowy subgroup (Section 6.1.1 a)

This group features a mixture of non-significant trends, both positive and negative in sign. No substantial change in behaviour is expected.

Upper Murrumbidgee subgroup (Section 6.1.1 b)

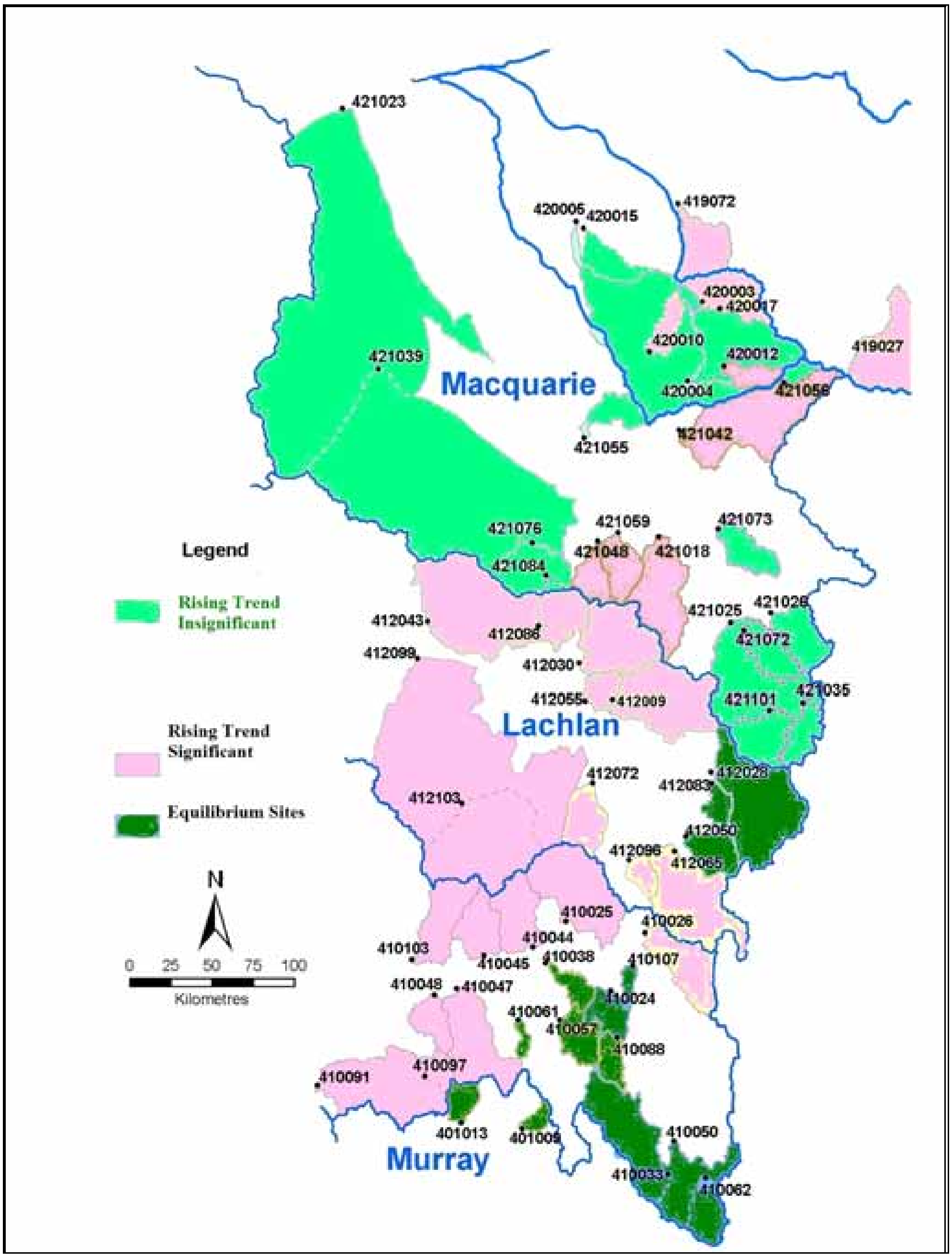
ECs at most of these sites peaked in the late 1970s and maintained that level for a decade before falling in the mid 1990s. They are falling significantly, but would be expected to return to and maintain the higher levels of the late 1970s when the drought finishes.

Lachlan Mountains subgroup (Section 6.1.1 c)

All show a falling trend at present, which is statistically insignificant. The sign of the trend might vary over the years, but no major changes are expected.

Other areas that are likely contenders for the Equilibrium group are most catchments on the northern side of the Namoi Valley. These sites fall within the Northern Falling or Northern Insignificant subgroups.

Figure 52. Zones in the southern part of NSW.



8.6.4 Rising trend, but insignificant

Upper Macquarie subgroup (Section 6.1.4 a)

All the trends are statistically non-significant. Most are rising, mainly during the last 10 years. Under normal conditions these sites would have been nominated as an Equilibrium subgroup. However, the sharply rising trend over the last decade precludes such a commitment. We advise a wait-and-see policy until the drought is broken.

Bogan subgroup (Section 6.1.4 c)

ECs at most of these sites have a rising trend which is statistically insignificant. It is of interest that several of these sites have the lowest elevation in the study. But they do not seem to be suffering the extreme impact of the Southern Trending sites.

8.6.5 Rising trend, significant

These subgroups are of grave concern. This category includes the 2 subgroups already identified and discussed in Section 8.6.2:

- Southern Trending
- Warrumbungles.

The remaining subgroups incorporate 2 tableland areas in the upper Lachlan and upper Gwydir:

- Lachlan Rising (Section 6.1.2)
- Central Macquarie (Section 6.1.4 b)
- Northern Rising (Section 6.1.6.3) plus 2 catchments from the plains: 416027 Gil Gil at Weemalah and 418052 Carole Creek at Near Garah. These 10 catchments (along with 2 of the Warrumbungle sites) are shaded pink in Figure 51.

One aspect that most of these have in common is a low average slope.

8.7 General

8.7.1 Statistically insignificant trends

The fitted GAM plots (Appendix 2) are cyclic and mainly short-term. If the cycle is much longer, the sign of the trend may fluctuate as the record extends. Not much credence can be placed on the fact that the sign is negative. The situation suggests that the sign must have been positive in the past. Statistically insignificant negative trends are treated as being in equilibrium.

8.7.2 Decisions on data adjustment

Annexure A weighs up the need to adjust the early years of data. There was sufficient evidence to make an adjustment of +10% to the data in the northern 3 valleys. The adjustment flattened the trend, and the adjusted slopes have been used in the calculations for this report. At half the 36 sites, the adjustment did not change the sign of the trend. At 12 of the sites, the trend changed from positive to negative. Linear slopes were statistically insignificant in both scenarios.

In the south, no adjustment was adopted, although we suspected that a similar problem existed. Some sensitivity tests were undertaken to see what effect a correction of 15% would have on the results. The problem catchments remained problems, although 5 of the less troublesome catchments slopes changed sign from positive to negative, but remained statistically insignificant.

In the deliberations below, the implications of the adjustments are considered, regardless of whether the changes were made (north) or not (south).

8.8 Comparison with Jolly *et al.*'s work

Model 7 and the work done in Jolly *et al.* (1997, 2001) are generic. Their methods use the same trend spline and seasonality component, although they vary substantially in the way they include flow.

The analysis by Jolly *et al*. (1997) was based on the monthly means of EC and flow. They applied a flow-weighting based on a monthly flow interval. Because many of their catchments are large and regulated, the monthly interval is a good approach.

We used Model 7 to establish a foundation relationship between EC and instantaneous flow. Tributary catchments were seen as preferable in achieving the foundation, because the EC sampling was likely to be spread more equitably over the flow range, than would be the case with sites on larger (regulated) rivers. Our work provides detail as to how well the model fitted each site.

Jolly *et al.* (2001) extended the EC trend work to incorporate salt load output–input in various river reaches. (We have not tried to cover this.) They focused on the linear EC trend to describe catchment EC behaviour. They grouped the MDB into 4 zones and based their conceptual model loosely on mean annual rainfall and elapsed time since clearing. We based our trend assessment on the linearity component, but identified the cyclic nature of the trend curve as an important guide to catchment EC behaviour. In concept, our study has sought to provide a link between EC behaviour and catchment geomorphology—mainly catchment slope, but also elevation and shape (hypsometric integral).

Both studies analysed the 7 sites compared in Table 8. We attribute any differences in mean EC to the extra 10 years of data available to us. In 6 of the 7 cases, the new trend values fall within Jolly *et al*.'s trend bands, although not vice-versa. The GAM plots of Appendix 2 give credence to the differences between the 2 trend values at each site. There is nothing untoward between the 2 sets of values.

Table 8. Comparison with Jolly *et al.*'s (1997) results at 7 common sites.

Station No.	Station name	Jolly *et al.* (2001) Mean EC (µS/cm)	Jolly *et al.* (2001) Trend (µS/cm/y)	This study Mean EC (µS/cm)	This study Trend (µS/cm/y)
416027	Gil Gil Creek at Weemalah	425	5.2 ± 6.7	420	1.1 ± 2.9
417001	Moonie River at Gundablouie	130	4.5 ± 4.6	141	0.1 ± 1.0
420005	Castlereagh River at Coonamble	485	–2.4 ± 4.6	434	–0.4 ± 3.3
421042	Talbragar River at Elong Elong	1050	8.4 ± 11.2	1052	8.8 ± 9.9
421023	Bogan River at Gongolgon	330	–3.0 ± 3.8	347	1.1 ± 2.8
410050	Murrumbidgee River at Billilingra	110	0.1 ± 1.8	100	–0.9 ± 0.6
410091	Billabong Creek at Walbundrie	1300	59.8 ± 34.6	1324	26.1 ± 7.8

8.9 EC forecasting and comparison with 1999 audit

8.9.1 Forecasting to 2020

Originally we proposed to extrapolate the GAM curves to 2020, with a view to providing a forecast for each site. Apart from making the prediction, one of the reasons for doing this was to enable a comparison to be made between this investigation and Beale *et al.* (2000). There were 3 stages involved in this task, as described in Appendix 5.

When examining the predecessor of this report, the reviewers indicated that it was statistically unsound to forecast by extending the GAM curve, because the curvature was unique to the observed record.

Forecasting was always going to be difficult. The GAM curves suggested a combination of meteorological, geomorphological and episodic influences; unless the processes driving the EC trends could be identified, then it would be very difficult to achieve predictions for 2020.

We decided to proceed with the forecasting exercise, but only to use sites whose non-linearity was statistically non-significant. Of the 92 sites, only 20 were in this category, the Lachlan and Macquarie systems each accounting for a third of the number. Results are presented in Table 9.

8.9.2 Comparison with 1999 Salinity Audit

The approaches used by the 1999 Audit and this investigation were completely different approaches. Without fully dissecting the 2 approaches, we can show a primary difference which could lead to results that are not comparable. The 1999 Audit calculated an average annual salt load for the MDB Commission Benchmark's 21 years of data (1975–1995). This average was nominated as representing the 1998 salt load. In reality, it represented the mean for the 21 years: that is, the nominated 1998 value was probably closer to the 1985 value. At many stations, the trends were not large, and there was not going to be much of a difference between the '1985' and 1998 figures. At sites where the trend was large, the average result for the Benchmark years could be vastly different from the real 1998 value.

Because we have emphasised the cyclic character of the trends, our investigation differs from both the 1999 Audit and the work by Jolly *et al*. At many sites, this approach leads to the conclusion that the linear trends may not be as large as first thought. But at sites that have not gone through a full cycle, interpretation is difficult, and assessment defaults to the linear trend calculation.

The 1999 Audit calculated ratios of the 2020 salt load to the 1998 salt load. We undertook similar calculations for the same period using the EC linear trend results (Table 9). Only 20 sites were useable in this exercise, as explained in Section 8.9.1.

Table 9. Comparison between this study and 1999 Audit for 2020/1998 EC ratios.

Column 1 No.	Column 2 Station Name	Column 3 Sub-Group Code	Column 4 2020/1998 Ratio This Study	Column 5 2020/1998 Ratio 1999 Audit	Column 6 Source - 1999 Audit Tables
412050	Crookwell R. at Narrawa North	Lachlan Mountains	0.98	1.28	Table 6.9
412083	Tuena Ck. At Tuena	Lachlan Mountains	0.80	1.30	Table 6.9
410026	Yass River at Yass	Lachlan Rising	1.19	1.35	Table 6.1
412043	Goobang Ck. at Darbys Dam	Lachlan Rising	1.87	1.16	Table 6.9
412072	Back Ck. at Koorawatha	Lachlan Rising	1.43	1.27	Table 6.9
412096	Pudman's Ck. at Kenny Rd.	Lachlan Rising	1.06	1.20	Table 6.1
412103	Bland Ck. at Morangarell	Lachlan Rising	6.80	1.20	Table 6.1
418005	Copes Ck. at Kimberley	Northern Falling	0.86	1.07	Table 6.6
418014	Gwydir R. at Yarrowych	Northern Falling	0.91	2.36	Table 6.1
419016	Cockburn R. at Mulla Crossing	Northern Falling	0.80	1.33	Table 6.7
416027	Gil Gil Ck. at Weemelah	Northern Insignif.	1.06	1.08	Table 6.3
419035	Goonoo Goonoo Ck. at Timbumburi	Northern Insignif.	0.95	1.38	Table 6.7
418021	Laura Ck. at Laura	Northern Rising	1.02	1.07	Table 6.6
410045	Billabung Ck. at Sunnyside	Southern Trending	1.80	1.22	Table 6.1
420003	Belar Ck. at Warkton	Upper Murrumbidge	0.76	1.13	Table 6.1
421035	Fish R. at Tarana	Upper Macquarie	1.03	2.15	Table 6.8
421073	Merro Ck. at Yarrabin 2	Upper Macquarie	Negligible	2.09	Table 6.8
421101	Campbell's R.- Ben Chifley Dam	Upper Macquarie	1.06	2.15	Table 6.8
421039	Bogan R. at Neurie Plains	Bogan	1.03	2.07	Table 6.1
421084	Burrill Ck. at Mickibri	Bogan	1.18	2.07	Table 6.1

These 20 sites are linear in their time response that is, the non-linear component of the time response is negligible (statistically non-significant). The 4th column is the ratio of the ECs in 2020 to those in 1998, based on this study. The 5th column is the ratio of salt loads 2020/1998 from the 1999 Audit.

The last column is the table number from which the information was drawn within the 1999 Audit. Table 6.1 is the default and represents the valley ratio rather than the individual site ratio. If the value in column 4 is <1, the EC trend is falling. The falling sites are generally linked to the Equilibrium subgroups described in Section 8.6; that they are falling should be considered as temporary.

This is probably the philosophical difference between the 2 studies. Our investigation suggests that either the steeper catchments are in equilibrium or their EC is not going to rise at anywhere near the rate that was first considered.

What is interesting is the comparison of the flatter-slope catchments. The Lachlan Rising subgroup is a case in point. Several of these sites in Table 9 have short or broken records, but are showing comparable trends with the 1999 Audit. There are also comparable values between the 2 studies for 416027 Gil Gil Creek at Weemalah and 418021 Laura Creek at Laura. Sites with much lower outlet elevations are showing very steep rises when compared with the 1999 Audit predictions: 410045 Billabung at Sunnyside, and 412103 Bland Creek at Morangarell. The inference is that it would be perilous to ignore the 1999 Audit salt load predictions for many of the flatter sites.

9 Conclusions

There were a number of intermediate steps on the path to a final conclusion. Each of those steps involved a major decision in its own right. Each step had a major influence on the final conclusion.

9.1 Data

One of the perennial laments of hydrologists is data quality. The complaints usually highlight missing data or data sets which have random inadequacies. The data problems identified in this study were not so much random as systematic.

There may be a systematic error in discrete EC data in the early TRITON data set. In the 3 most northerly valleys, a correction of +10% was made to the early years of record. We suspected that a similar situation existed in the rest of the NSW, but sufficient evidence was not readily available to justify making a correction (Section 2.2 and Annexure A). Whether or not a correction was applied affected the magnitude (and sometimes the sign) of the trend slope. Its effect on the statistical significance of the slope coefficient was not great.

The discrete data were collected at regular time intervals, and the percentage of event samples is low. This small proportion has little impact on the analyses (Section 7.1 and Appendix 3).

The time-series EC data appear to be acceptable, but they are generally unedited and are laborious to prepare. There is a lack of an official editing procedure which takes into account probe range and temperature (Section 2.4 and Harvey 2006, in preparation).

The inclusion of groundwater data in the EC–flow relationship was beneficial at several sites (Section 7.2), but this could be coincidental. Two issues made the inclusion of groundwater data difficult:

- The incapacity of the current archive to interpolate and download hourly bore data. (The latest advice suggests that this difficulty might be rectified in the near future.)
- The absence of a common datum to link the stream and bore data.

9.2 Model performance

The equations used to generate the results had mixed success. At most sites, the overall fit of Model 7 depended on the success of the EC–flow relationship of Model 3 (Section 5).

At most sites, Model 5 (the trend component based on the behaviour of flow-adjusted EC) did not respond to the data as well as Models 3 and 7. At 6 sites (Section 5.1.3), Model 5 did show promise, suggesting that time effects could be an important co-contributor to EC behaviour. These sites are the basis of the category 'Southern Trending subgroup' (Section 6.1.3).

When the final R^2 of Tables 2 and 3 was used as an approximate guide of performance, then the chosen equations seemed to perform better overall in the south of the State. At a final R^2 value of ≥0.65 as an indicator of good performance, Model 7 gave a reasonable description of the behaviour of about 40% of the southern catchments, but only about a quarter of the northern sites (Section 5.1.4). Nothing was apparent to explain this difference between north and south. But based on Table 7, the inclusion of groundwater data gave an improvement to the Model 7 fit for at least 1 site.

The S-PLUS package was recommended to us for its precision. We used the R^2 calculations only as a guide to the models' performance. We noted possible inaccuracies in the adjusted R^2 statistics given by S-PLUS, especially in models that include spline terms. If similar equations are used in future studies, we recommend a flexible approach to choosing the number of degrees of freedom in both the flow and time splines.

If these models are used again, then there should be scope for experimenting with changing the degrees of freedom for both the time and flow components. Another factor (which far outweighs the niceties of model performance) is the difficulty in assessing trend that is non-linear. This work requires expert interpretation. The value of the output is not in the precision of the linear trend, but in the assessment of the non-linear component and the subsequent general grouping of the sites, as presented in Table 5.

9.3 Catchment indicators and characteristics

In addition to calculating the linear trend in $\log_e$ space, we used 2 other parameters successfully as a guide to catchment behaviour. Cycle ratio and percentage of cycle (Section 4.8.2) both indicated the amount of fluctuation in the GAM curve. These 2 indicators proved useful adjuncts to the linear trend calculation. In conjunction with cycle length, they greatly assisted in the subgrouping of sites. We have emphasised the cyclic behaviour, leading to the conclusion that the anticipated threat to the steeper catchments has diminished.

This study focused on identifying rising trends or tardiness in catchment recovery. We conclude that a link may exist between rising trend and catchment characteristics such as outlet elevation and average catchment slope (Section 6.2). Catchments with low average slopes are likely to be tardy as self-cleansers, whether they are on the plains or on the tablelands. The method used to calculate average slope could be improved by excluding near-vertical terrain.

A plot of elevation vs mean annual rainfall (Figure 37) showed most sites falling into a grouped pattern. However, it also revealed that a number of gauging sites near the Snowy Mountains did not follow the pattern, having low elevation and high rainfall. Although the site selection was purely a management decision, this observation had some implications for understanding the salinity processes. A conceptual diagram of the implications of site location is presented in Figure 49.

We used the time of peak of the GAM curve (Figure 45) to track the movement of the EC peak down the valley systems. Although this was an imprecise method, in the Murrumbidgee–Murray, there was a 25-year delay between EC peaks in the upper catchments and EC peaks at in the lower catchment.

9.4 Forging a link between stream and groundwater levels

We tested whether the stream EC trend was influenced by the groundwater table by including a groundwater component in the models. The approach seemed to show that at least part of the EC trend could be explained by the groundwater behaviour. At several of the sites tested, the inclusion of groundwater data seemed to improve the correlations. Closer scrutiny suggested that the improvement might be more to do with chance than the result of a rigorous technique. Despite this, the preliminary results (Section 7.2) warrant further investigation. We also suspected that the drivers behind the longer GAM cycles were flat hydraulic gradients and constrictive local geological features.

9.5 EC trends in inland NSW

An evaluation of the outputs from the various models has resulted in the development of 12 subgroups (Table 5) across the State. The differences between these categories are generally stark in the Murray, Murrumbidgee, Lachlan, Macquarie and Castlereagh. In the 3 northern valleys, the differences are not as pronounced (except perhaps for the Warrumbungle area), and it took some thought to develop suitable classifications.

It needs to be acknowledged that the EC trend at many of the sites is cyclic (non-linear). To understand the salinity processes (and estimate the trends), the magnitude and length of the cycle needs to be assessed. Most of the Southern Trending sites (Section 6.1.3) have not gone through a full cycle within their 35 years of record. Consequently, it is not a simple matter to finalise the trend calculations.

Three previous studies have given cause for optimism. Beale *et al*. (2001), Harvey and Jones (2001) and Cresswell *et al*. (2003) have all pointed towards EC trend achieving equilibrium. (It appears that the drought is providing a reprieve, with many catchments going into a falling mode, and others rising less quickly.) But the EC cyclic amplitude in some catchments is probably linked to pronounced variations in characteristics across the individual catchments, such as mean annual rainfall, catchment slope, water chemistry or hydraulic gradients. These pronounced variations have implications for the way that model subareas are defined. It is not unreasonable to assume that catchments with long EC cycles may return to previous high EC levels once they wet up again. On a positive note, the current reprieve points to EC in many problem catchments not rising at anywhere near the rate suggested by studies undertaken before the mid 1990s.

In the context of Jolly *et al*. (2001), there were useful comparisons. In the Lachlan, Murrumbidgee and Murray, 3 of the subgroups, representing 14 sites (Figure 52 and Section 8.6.3), were identified as being in equilibrium. As with Jolly *et al.*, the 800 mm isohyet could be used as an indicator of the equilibrium, although catchment slope and outlet elevation were seen here as major drivers. Portions of adjacent catchments (such as 412009 Belubula River at Canowindra and 410047 Tarcutta Creek at Old Borambola) that were above the 800 mm isohyet were also likely contenders for equilibrium categorisation. Jolly *et al.*'s (2001) zone approach was useful, and our results generally agreed with theirs. However, there were indications that several sites in the Border Rivers system and the upper Gwydir tableland were considered vulnerable to rising EC trends (Catchments of Interest in Figure 51). Seven sites were common to both studies (Table 8 and Section 8.8). Comparison of the results at these sites was favourable.

Apparent episodic behaviour was observed at 12 sites in the north (Figure 51 and Section 8.6.1). We speculate that similar episodic behaviour might be under way in the Southern Trending subgroup (Section 6.1.3).

The steeper sites across the State were considered as being a minimal threat over the next 15 years. These are the Snowy, Upper Murrumbidgee and Lachlan Mountain subgroups, and the northern and eastern parts of the Namoi. Because of recent rising trends at the upper Macquarie sites, we decided not to classify that subgroup as being in equilibrium.

From the sites analysed, the problem areas were identified as being the Southern Trending subgroup, nearly all the study sites in the Lachlan, the Central Macquarie subgroup, parts of the Border Rivers, the Upper Gwydir and the Warrumbungle subgroup. ECs in the Bogan and lower Castlereagh were also rising, but the trends were statistically insignificant.

9.6 Estimating EC projections to 2020

It was concluded that it was not sound statistics to extrapolate the GAM curve trends to 2020.

The extrapolation was limited to sites that were primarily linear (insignificant non-linearity). Twenty sites fell into this category, and we compared the 2020/1998 ratios calculated in the 1999 Audit and in this study (Table 9 and Section 8.9). The results suggest that the 1999 Audit had overestimated the salt load trends in the steep catchments. Such catchments represented only a small proportion of the basin area, but were major contributors to downstream river flow. At the rest of the sites, the comparisons suggest that the rising trends might be at least as bad as the 1999 Audit indicated.

10 Recommendations

10.1 Historical TRITON archive

If a trend analysis is undertaken as part of any future study, then the datasets should be prepared well in advance. The historical TRITON dataset (late 1960s to early 1990s) will have to be statistically analysed with a view to identifying:

- trends that are due to systematic errors in the historical record
- batches of samples measured during an ‘off’ day
- the sources of the different sampling sequences.

The steering committee in this work should consist of biometricians, archivists, individuals with a laboratory background and individuals familiar with the historical workshop instrument protocols. A precise statistical evaluation of the problem would require all paired data values from all dual-program sites before 1992. (The work undertaken in this study has gone part of the way to collating such a data set.) The statistics would require some form of least-squares adjustment with a time component and possibly other variables.

10.2 Other discrete data

Unfortunately, this investigation was undertaken during a time of upheaval within the organisation preceding DWE, and key people were not in a position to assist, or were in the process of leaving the organisation. It is important that the data collectors continue to be included in the process, as there may be some means of countering data gaps. It may be possible to use EC data from other sites. This type of decision should not be taken lightly, and requires the input of someone with sound field knowledge.

10.3 Time-series EC

Time-series data offer access to event salinity readings that discrete sampling doesn’t normally provide. A comprehensive editing procedure is essential in time-series EC. It should incorporate corrections that are a function of probe range and temperature. It may be useful to incorporate individual time-series data in future trend analyses. How this might be achieved in a statistical sense needs to be carefully considered.

10.4 Ongoing data collection

When the climate becomes wet again, it will be an ideal time to track the salinity process. With this in mind, EC sampling should be re-established at a number of field sites in conjunction with flow measurements, particularly at the sites identified as having a rising trend. The sampling does not have to be intense, but can occur monthly over a year.

Because there may be links between cyclicity and water chemistry, there is a need to ensure that sample analysis is included in any EC data collection program.

10.5 Future statistical approaches to EC forecasting

Most sites are exhibiting cyclic behaviour. Perhaps there is scope to develop a monthly time-series data set of the GAM curve data. This would allow forecasting using an EC frequency analysis, perhaps using techniques similar to those used in flood frequency analysis.

10.6 The episodic sites

Some catchments respond differently to an episodic event (Section 8.6.1 and Figure 51). We conclude that the different responses are driven by catchment slope. A closer investigation of the listed episodic sites (Section 8.6.1) may reveal new information about catchment behaviour. Identifying the processes in the current episodics—all the Southern Trending subgroup, as well as 410107 Mountain Creek at Mountain Creek and 421048 Little River at Obley—will enhance understanding of how catchment salinity is behaving.

On the basis of the Mountain Creek GAM curve, sampling sites upstream of artificial lakes should be considered. This might determine whether a salt accumulation process is occurring, and whether the sites are representative of their upstream catchments.

10.7 Salt load conversion factors

Recent studies have started to build a picture of the relationship between TDS and EC. Basin management would benefit from being able to identify regional-scale sources of ‘heavy‘ EC.

10.8 Geological constrictions

In Section 8.6.2, we suggest that groundwater movement is being impeded by geological constrictions at some sites. These locations would benefit from basic water table mapping. The work would confirm whether the hydraulic gradient is an influence.

10.9 Modelling

If the investigations of Section 10.8 confirm the constriction theory, then the impedance process referred to in Section 8.6.2 needs to be built into the various salinity models. Such a step may also improve our knowledge of the processes.

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12 Salinity Study Update 2005

12.1 Decision tree used to clean EC data for use in Upper Murrumbidgee study

By David Hohnberg

There was much electrical conductivity (EC) data available that could potentially be used in the analyses of the EC–flow relationships. To fulfil the study design criteria of approximately 12 data points per year it was necessary to cull the available data. The following decision tree was used to select the data to include in the Upper Murrumbidgee component of the study:

1. Laboratory-analysed EC data were always included in preference to field-measured EC data.
2. EC data collected when flow was higher were used in preference to data collected when flow was lower.
3. EC data collected by the Hydrometric Unit (Tumut office in the upper Murrumbidgee) were used in preference to EC data collected by others, such as water quality officers. This was done purely for consistency with long-term EC data that were collected by hydrometric units from the 1970s or earlier in some cases.
4. EC data collected in the middle of the month were used in preference to EC data collected at the beginning or at the end of the month.
5. Where there were multiple EC data records on the same day (as was often the case in data collected by water quality staff at sites where there was no EC data collected by hydrometric units), EC data collected from either the mid depth or mid cross-section of the river or creek were used in preference to EC data collected from surface water, bottom water or the edge.

12.2 Data screening—Macquarie Valley

By Chris Burton

Time data and extreme outliers in flow and EC were edited by staff at the Wagga Wagga office. Data from the sites in the Macquarie Valley were further screened and in some cases edited using the systematic approach outlined below.

12.2.1 Handling of duplicate and repeated samples

The first step involved identifying duplicate and repeated samples. Repeated data were identified as identical records of EC and flow recorded on the same day and time. Repeated data were removed from the records.

In the case of duplicate records often associated with separate readings taken in the field and laboratory, a preference (quality weighting) was given to the laboratory record. In all cases where the field value was within 10% of the laboratory record, it was simply averaged to create a new record. If the 2 records differed by more than 10% of one another, the laboratory record alone was selected and the field record was removed.

If the EC record was averaged, then the corresponding flow record was also averaged. If the laboratory data were used preferentially, then the associated flow was also used preferentially.

12.2.2 Outliers

An additional screening process was used when the field data record was excessively greater or less than the laboratory data. If the field data set had records that were 50% greater or 50% less than the laboratory records and that could not be accounted for by an extreme event such as drought, then the value was removed. This was a rare event and generally occurred at the lower end of the spectrum. For example, data of <50 µS/cm were removed when there were no laboratory data of <100 µS/cm to support such as low value. There were only 2 field records that were more than 50% greater than the maximum laboratory record. Both occurred during an extreme drought period and were not discounted.

Appendix 1—Representative Flows

To produce the curves of Appendix 2, Model 7 selects a representative value which is the mean of the $\log_e$flow values observed during EC sampling. Details of the representative flows are tabulated below for each site.

Number	Station Name	Representative LogeFlow	Representative Flow (Ml/d)	Timeweighted Percentile	Flowweighted Percentile
401009	Maragle Ck. at Maragle	3.673834	39.4	55	92
401013	Jingellic Ck. at Jingellic	4.039536	56.8	46	91
410091	Billabong at Walbundrie	4.321637	75.3	52	96
410097	Billabong Ck. at Aberfeldy	2.332665	10.3	42	96
410024	Goodradigbee R. at Wee Jasper	5.982972	396.6	51	87
410025	Jugiong Ck. at Jugiong	4.167228	64.5	43	94
410026	Yass R. at Yass	3.546075	34.7	40	98
410033	Murrumbidgee R. at Mittangang Xing	5.052424	156.4	*	*
410038	Adjungbilly Ck.at Darbalara	4.662619	105.9	48	88
410044	Muttama Ck.at Coolac	3.164227	23.7	38	96
410045	Billabung Ck.at Sunnyside	2.090081	8.1	19	99
410047	Tarcutta at Old Borambola	5.440361	230.5	37	86
410048	Kyeamba Ck. at Ladysmith	2.849047	17.3	*	*
410050	Murrumbidgee R. at Billilingra	5.452709	233.4	60	96
410057	Goobarragandra R. at Lacmalac	6.042306	420.9	54	86
410061	Adelong Ck. at Batlow Rd.	4.059140	57.9	51	86
410062	Numeralla R. at Numeralla School	3.092790	22.0	60	99
410088	Goodradigbee R. at Brindabella	5.524378	250.7	49	85
410103	Houlaghans Ck. at Downside	0.972771	2.6	6	100
410107	Mountain Ck. at Mountain Ck.	2.622596	13.8	43	98
412009	Belubula R. at Canowindra	5.234972	187.7	47	92
412028	Abercrombie at Abercrombie	5.121450	167.6	51	96
412030	Mandagery at U/S Eugowra	3.701477	40.5	43	96
412043	Goobang Ck. at Darbys Dam	2.530278	12.6	36	98
412050	Crookwell R. at Narrawa North	4.230938	68.8	44	94
412055	Belubula R. at Bangaroo Bridge	4.801521	121.7	*	*
412065	Lachlan R. at Narrawa	4.490049	89.1	51	96
412072	Back Ck at Koorawatha	1.770090	5.9	40	98
412083	Tuena Ck. at Tuena	3.075803	21.7	38	96
412086	Goobang Ck. at Parkes	2.110231	8.3	21	94
412096	Pudmans Ck. at Kennys Rd	2.372895	10.7	43	97
412099	Manna Ck. near Lake Cowal	2.933310	18.8	12	100
412103	Bland Ck. at Morangarell	3.818347	45.5	15	98
416003	Tenterfield Ck. at Clifton	2.966185	19.4	42	98
416008	Beardy R. at Haystack	2.704585	14.9	47	99
416010	Macintyre R. at Wallangra	4.061977	58.1	48	97
416016	Macintyre R. at Inverell	3.592866	36.3	45	96
416020	Ottleys Ck. at Coolatai	1.640937	5.2	48	97
416021	Frazers Ck. at Ashford	2.045640	7.7	47	99
416023	Deepwater Ck. at Bolivia	3.420409	30.6	46	94
416027	Gil Gil Ck. at Weemelah	3.788538	44.2	53	98
417001	Moonie R. at Gundablouie	3.241480	25.6	22	100
416032	Mole R. at Donaldson	4.147423	63.3	50	97
416039	Severn R. at Strathbogie	4.235307	69.1	49	97
418005	CopesCk. At Kimberley	2.481278	12.0	42	97
418008	Gwydir R. at Bundarra	4.158417	64.0	58	99
418014	Gwydir R. at Yarrowych	3.101554	22.2	46	98
418015	Horton R. at Rider	4.381995	80.0	45	97
418016	Warialda Ck. at Warialda	1.456688	4.3	44	99
418017	Myall Ck at Molroy	2.742207	15.5	40	96

Number	Station Name	Representative LogeFlow	Representative Flow (Ml/d)	Timeweighted Percentile	Flowweighted Percentile
418018	Keera Ck. at Keera	2.761794	15.8	43	97
418021	Laura Ck. at Laura	2.704628	14.9	38	98
418023	Moredun Ck. at Bundarra	3.286010	26.7	41	98
418025	Halls Ck. at Bingara	2.310812	10.1	30	78
418027	Horton R. at DamSite	1.977068	7.2	45	99
418029	Gwydir R. at Stoneybatter	4.111625	61.0	52	98
418032	Tycannah Ck. at Horseshoe	2.306464	10.0	27	98
418052	Carole Ck. Nr. Garah	4.363104	78.5	45	93
419005	Namoi R. at Nth Cuerindi	5.100244	164.1	49	95
419016	Cockburn R. at Mulla Xing	3.383754	29.5	46	98
419027	Mooki R. at Breeza	2.677924	14.6	42	99
419029	Halls Ck. At Ukalon	2.746187	15.6	30	92
419032	Coxs Ck.at Boggabri	2.887043	17.9	17	100
419033	Coxs Ck.at Tambar Springs	1.704663	5.5	52	98
419035	Goonoo Ck. at Timbumburi	2.401605	11.0	41	97
419051	Maules Ck.at Avoca	2.514995	12.4	*	*
419053	Manilla R. at Black Springs	3.087662	21.9	44	95
419054	Swamp Oak Ck. At Limbri	2.469337	11.8	41	98
419072	Baradine Ck.at Kienbri	2.495872	12.1	20	98
420003	Belar Ck. at Warkton	1.913105	6.8	37	93
420004	Castlereagh R. at Mendooran	3.748378	42.5	38	96
420005	Castlereagh R. at Coonamble	5.682852	293.8	18	92
420010	Wallumburrawang Ck. at Bearbung	2.271084	9.7	16	98
420012	Butheroo Ck. at Neilrex	-1.000777	0.4	41	100
420015	Warrena Ck. At Warrana	1.083901	3.0	18	100
420017	Castlereagh R. at Hidden Valley	2.707426	15.0	44	97
421018	Bell R. at Newrea	4.346818	77.2	44	94
421023	Bogan R. at Gongolon	4.521186	91.9	41	98
421025	Macquarie R. at Bruinbun	5.443971	231.4	52	96
421026	Turon R. at Sofala	3.964065	52.7	41	96
421035	Fish R. at Tarana	4.749757	115.6	48	90
421039	Bogan R. at Neurie Plains	3.723974	41.4	18	99
421042	Talbragar R. at Elong Elong	3.386099	29.6	43	98
421048	Little R. at Obley	2.802105	16.5	30	97
421055	Coolbaggie Ck. at Rawsonville	2.316237	10.1	13	99
421056	Coolaburragundy Ck. at Coolah	2.077902	8.0	51	95
421059	Buckinbar Ck. at Yeoval	2.624640	13.8	22	56
421072	Winburndale Rivulet. at Howards Bridge	4.081947	59.3	44	95
421073	Meroo Ck. At Yarrabin 2	3.562517	35.3	10	98
421076	Bogan R. at Peak Hill 2	4.023535	55.9	8	97
421084	Burrill Ck. At Mickibri	2.214165	9.2	12	97
421101	Campbells R. U/S Ben Chifley Dam	3.526172	34.0	58	98

Appendix 2—Fitted Response Curves

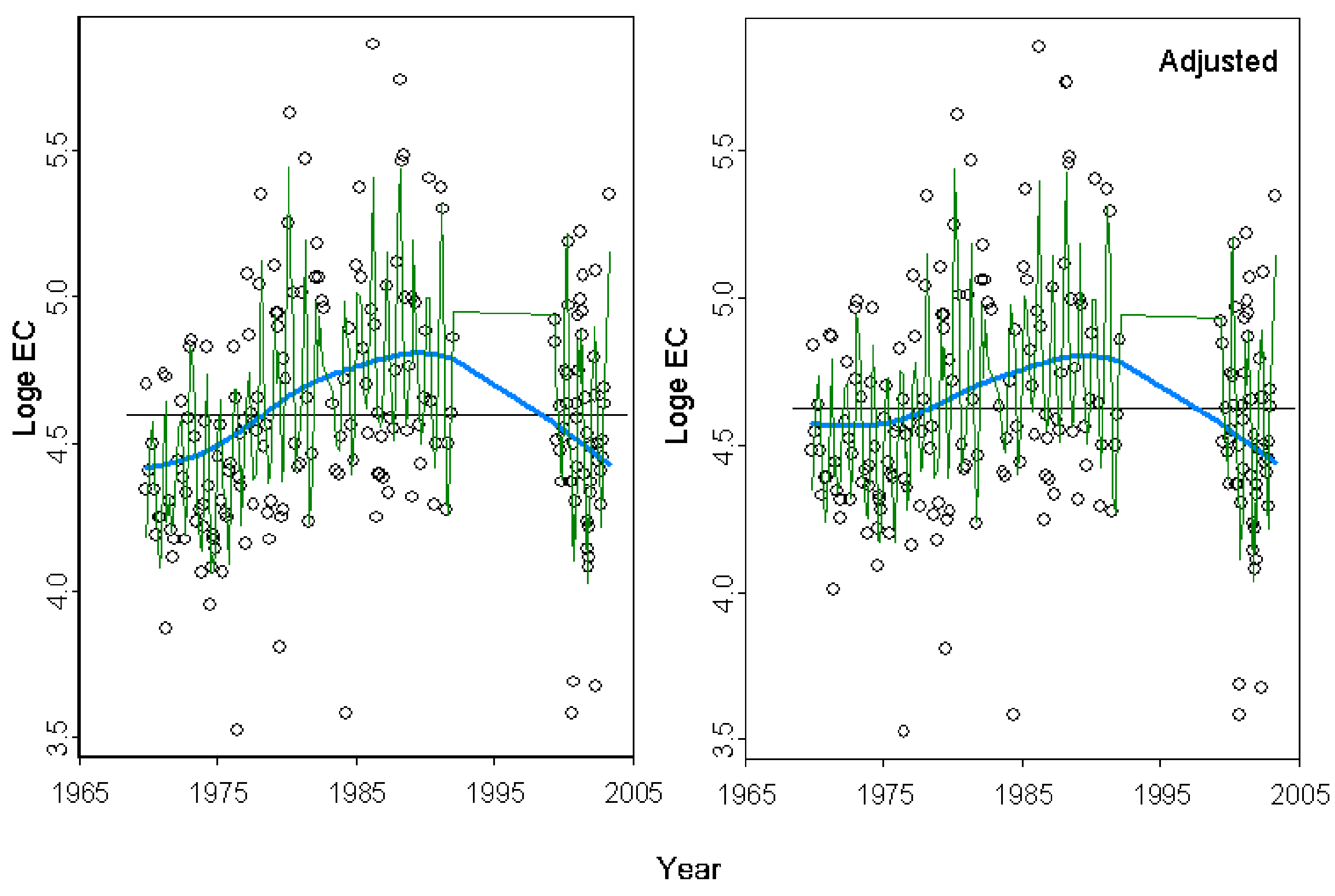
The following 92 graphs illustrate the performance of Models 3 and 7 in fitting the observed data points. The chart on the left uses the data directly from the TRITON archive. The chart on the right uses data adjusted as described in Annexure A.

Generally, the charts on the left are more relevant. As an exception, the datasets of the 3 northern valleys—Border Rivers, Gwydir and Namoi (Appendices 2.34 to 2.69)—have undergone an adjustment in the early years; the charts on the right are thus more relevant.

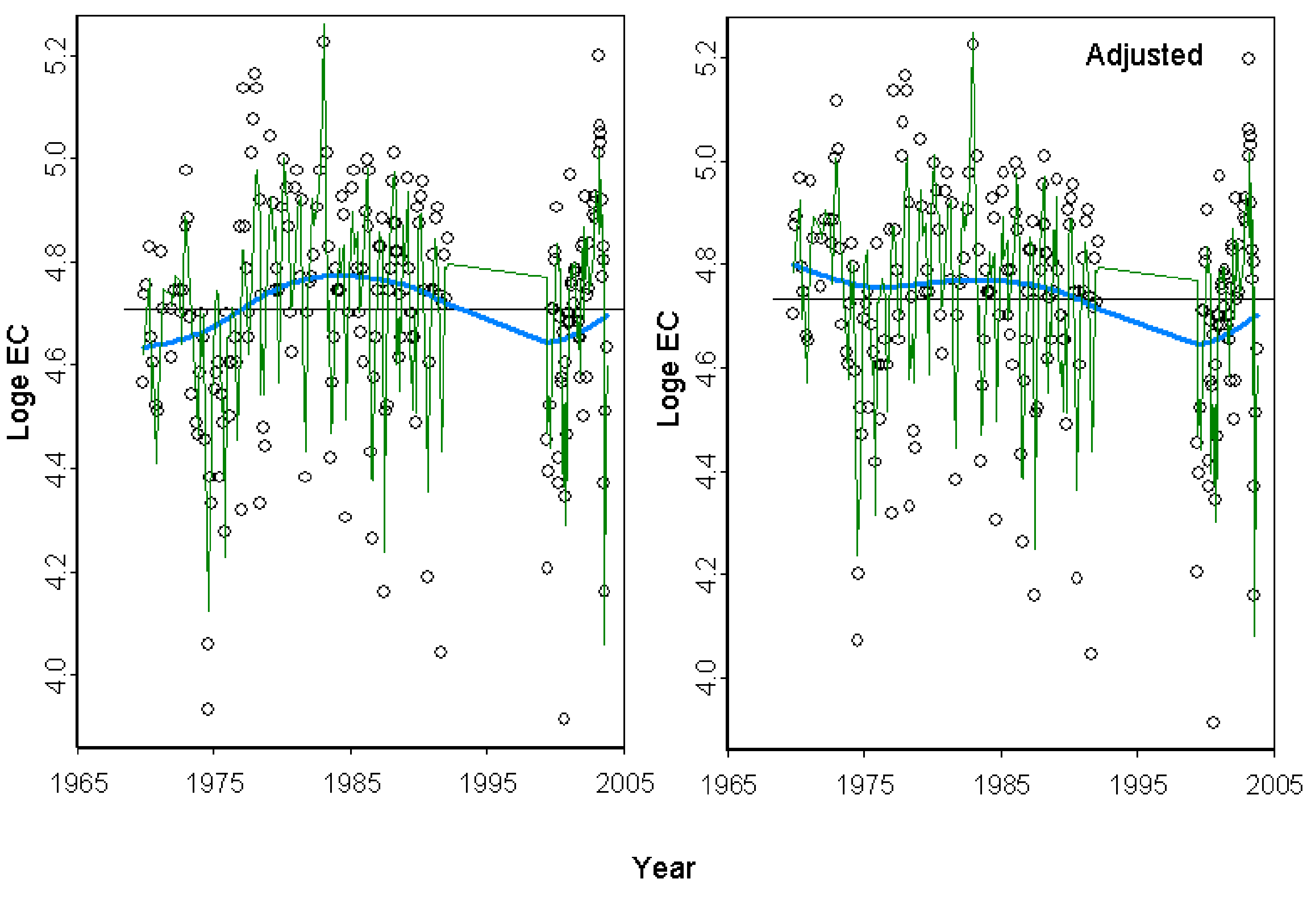
The green spiked response line represents the fitted values from Model 7, solved at the actual observed values of flow, seasonality and time. How well the model fits these data is illustrated by the extent to which the green line extends towards the observed points.

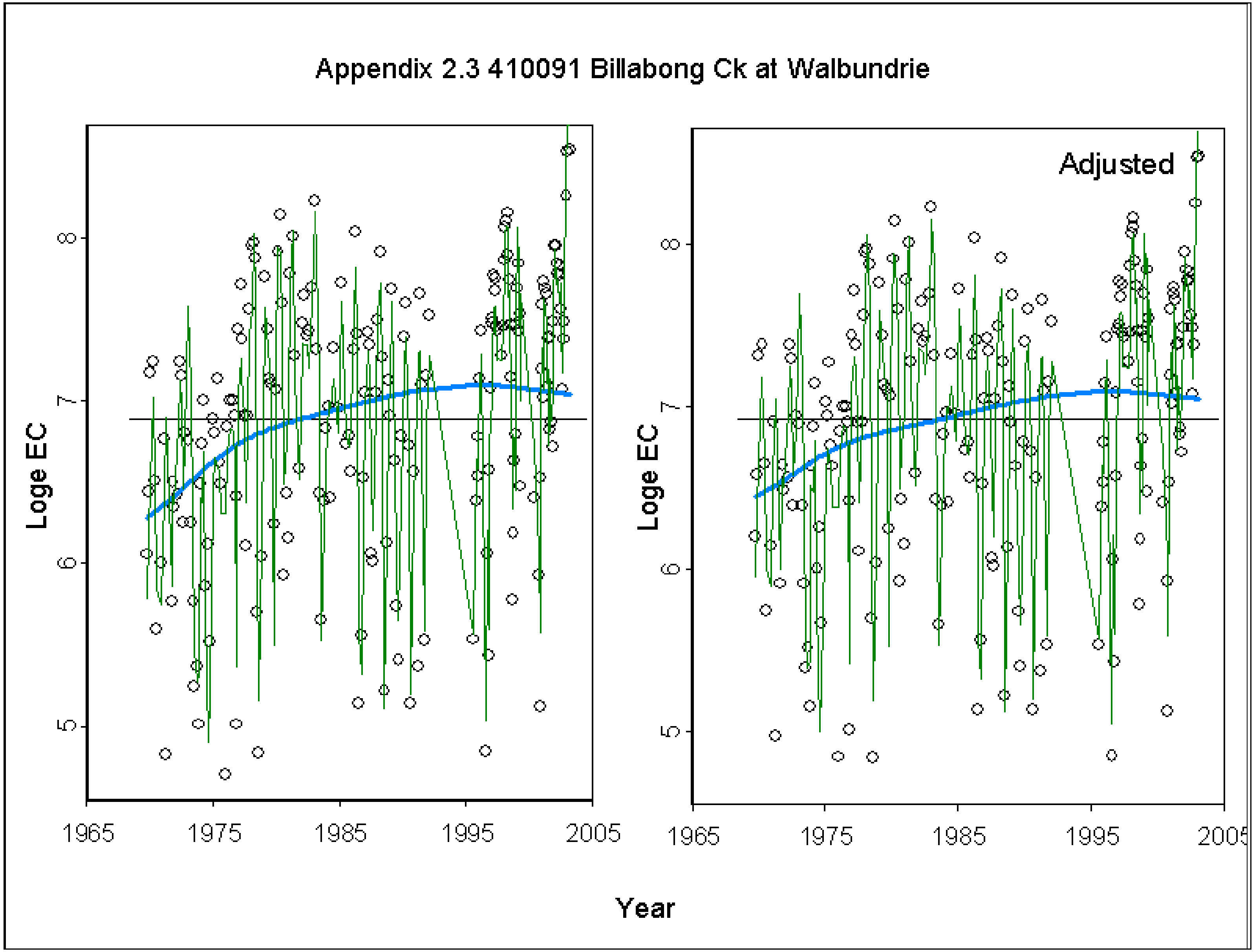
The blue smoothed curve is obtained from Model 5, and is solved at the mean values of flow and seasonality. It is smooth because it indicates the spline (linear and non-linear) effects of time for an average effect of flow and seasonality.

Appendix 2.1 401009 Maragle Ck at Maragle

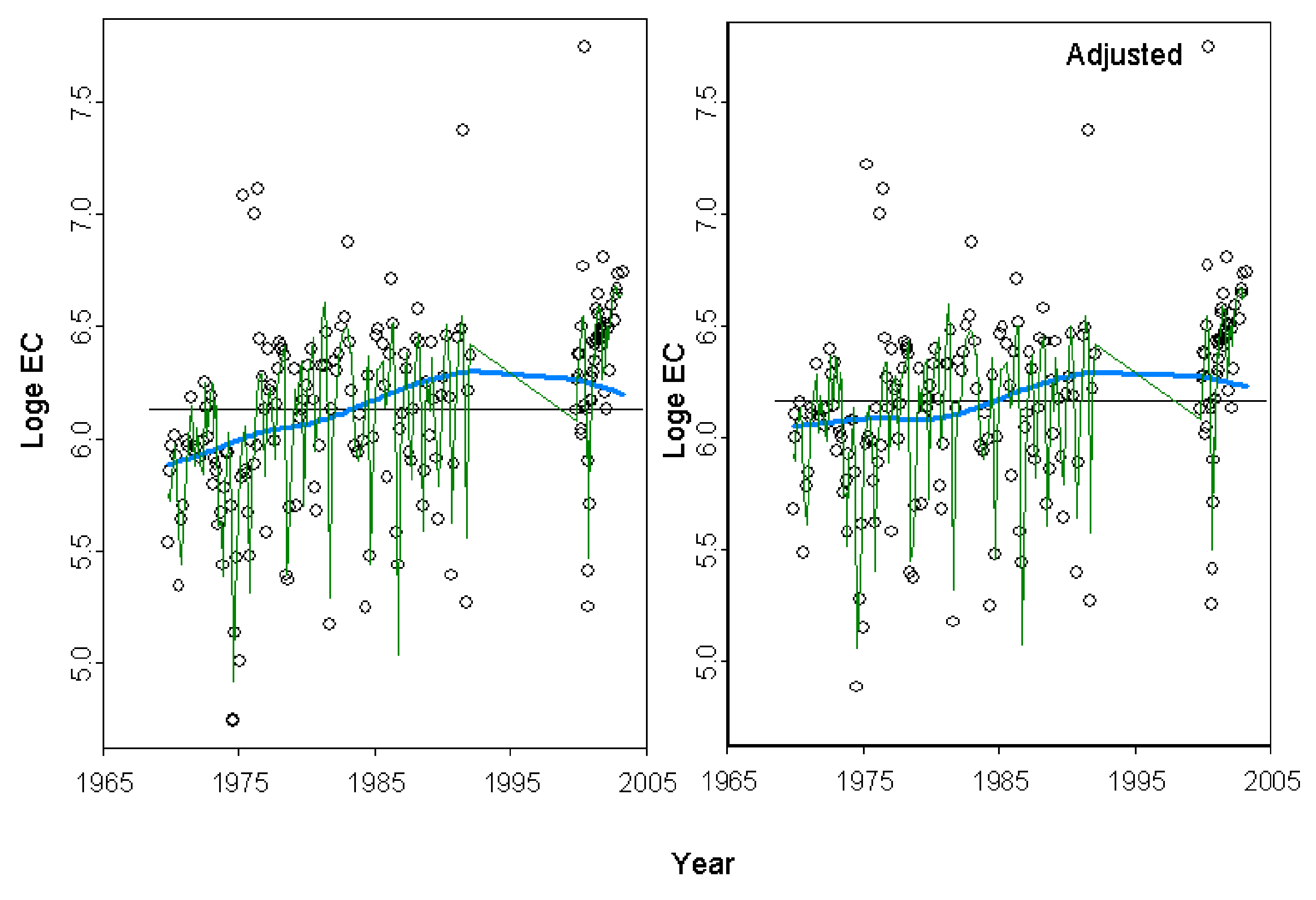


Appendix 2.2 401013 Jingellic Ck at Jingellic

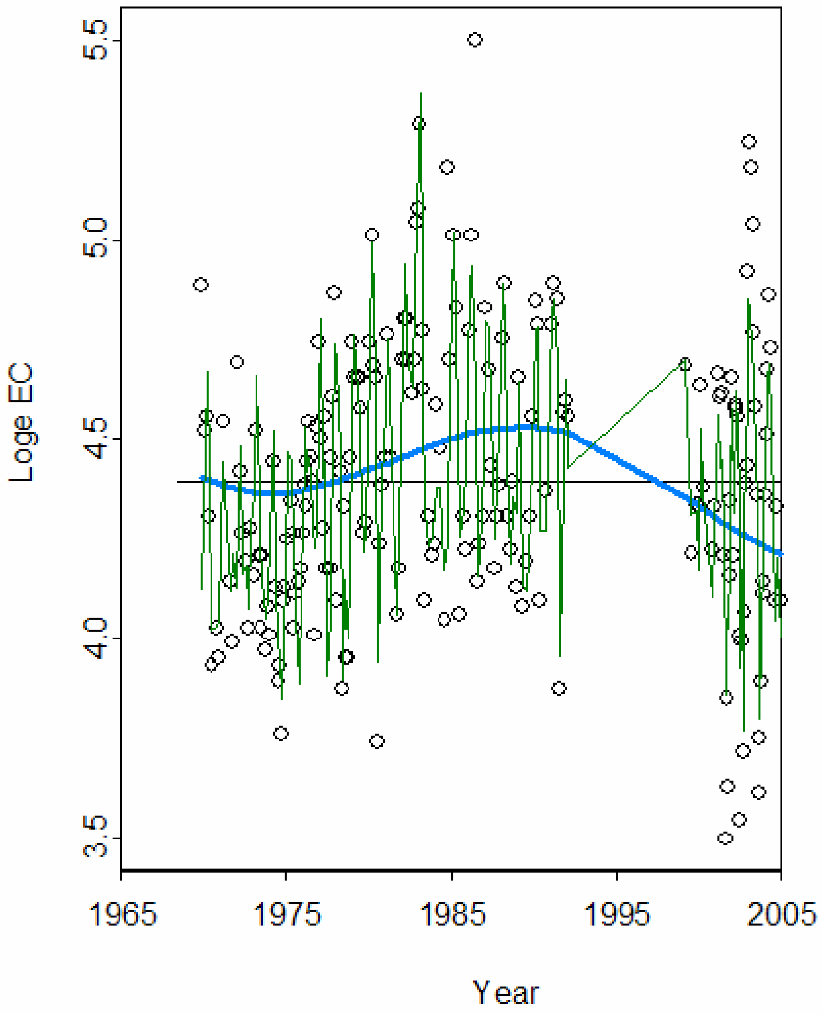



Appendix 2.3 410091 Billabong Ck at Walbundrie
Adjusted
Loge EC
Loge EC
5
6
7
8
1965
1975
1985
1995
2005
Year

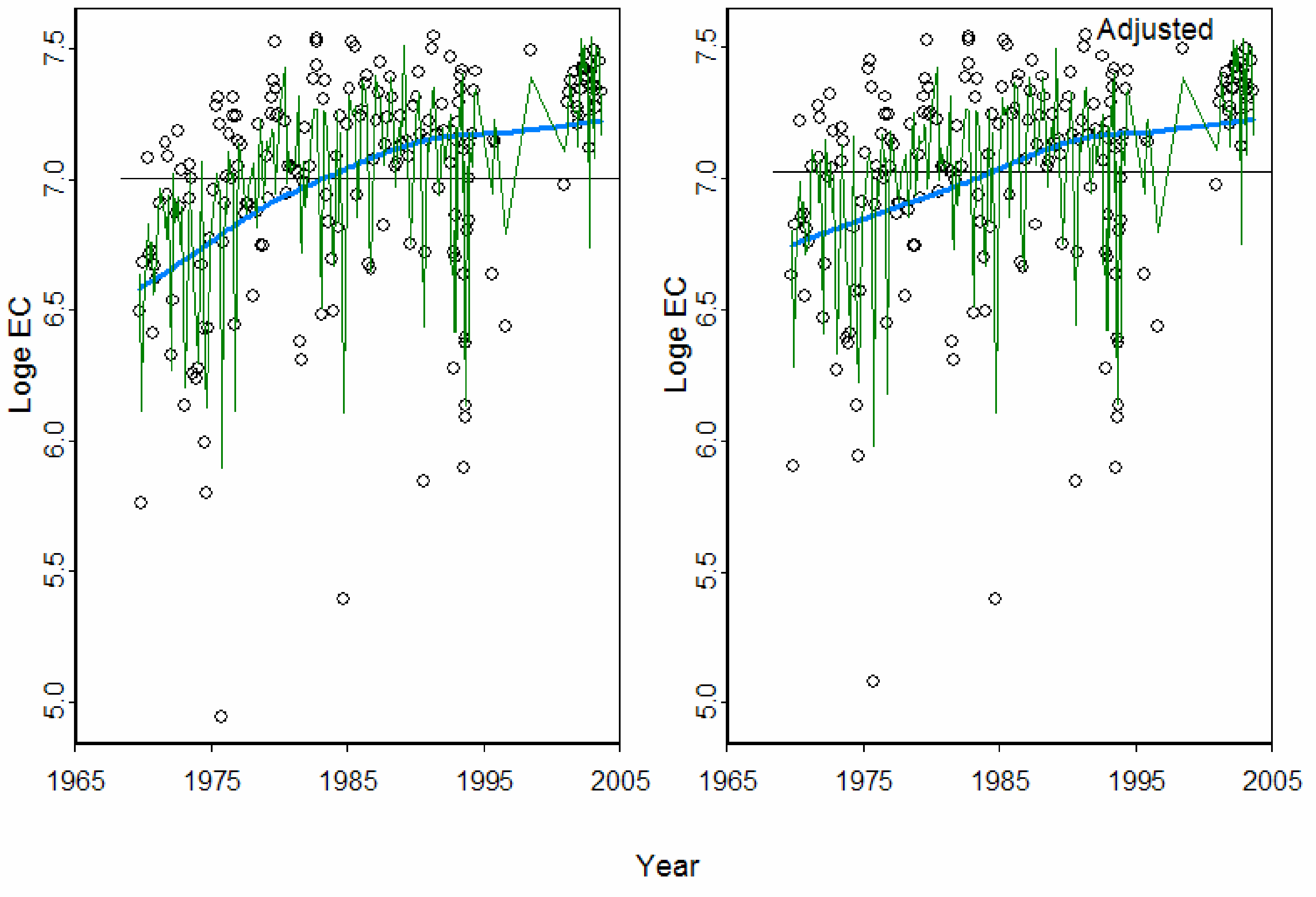
Appendix 2.4 410097 Billabong Ck at Aberfeldy



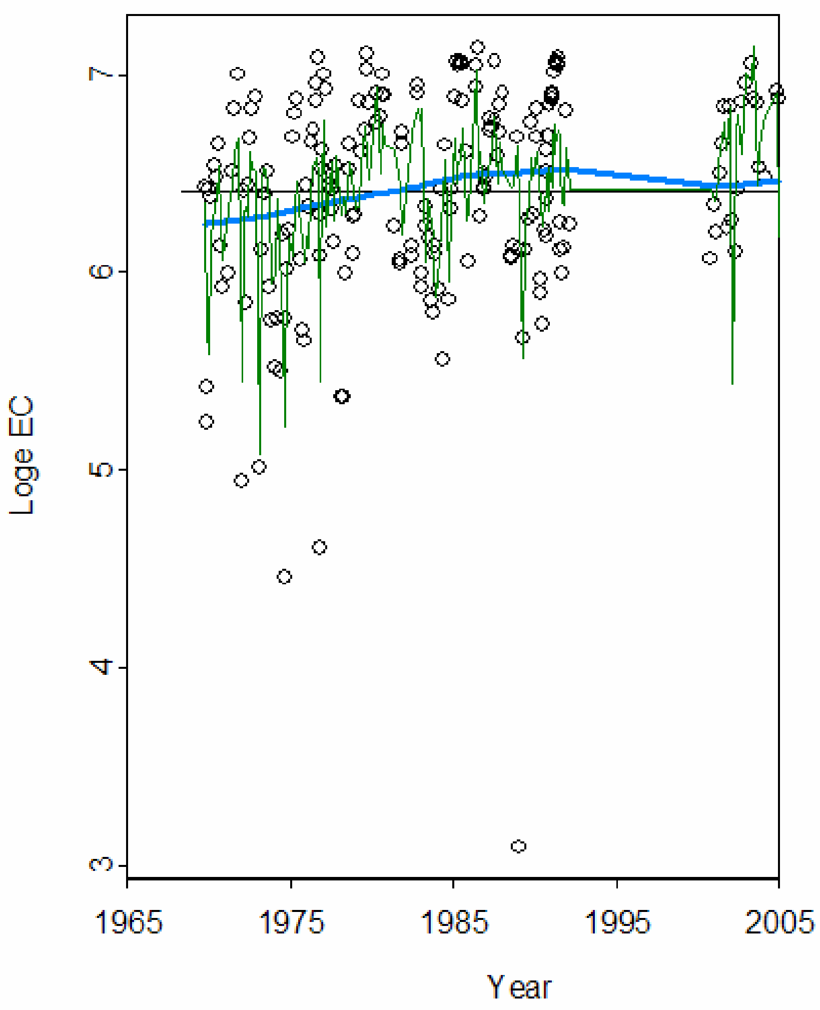
Appendix 2.5 410024 Goodradigbee R at Wee Jasper



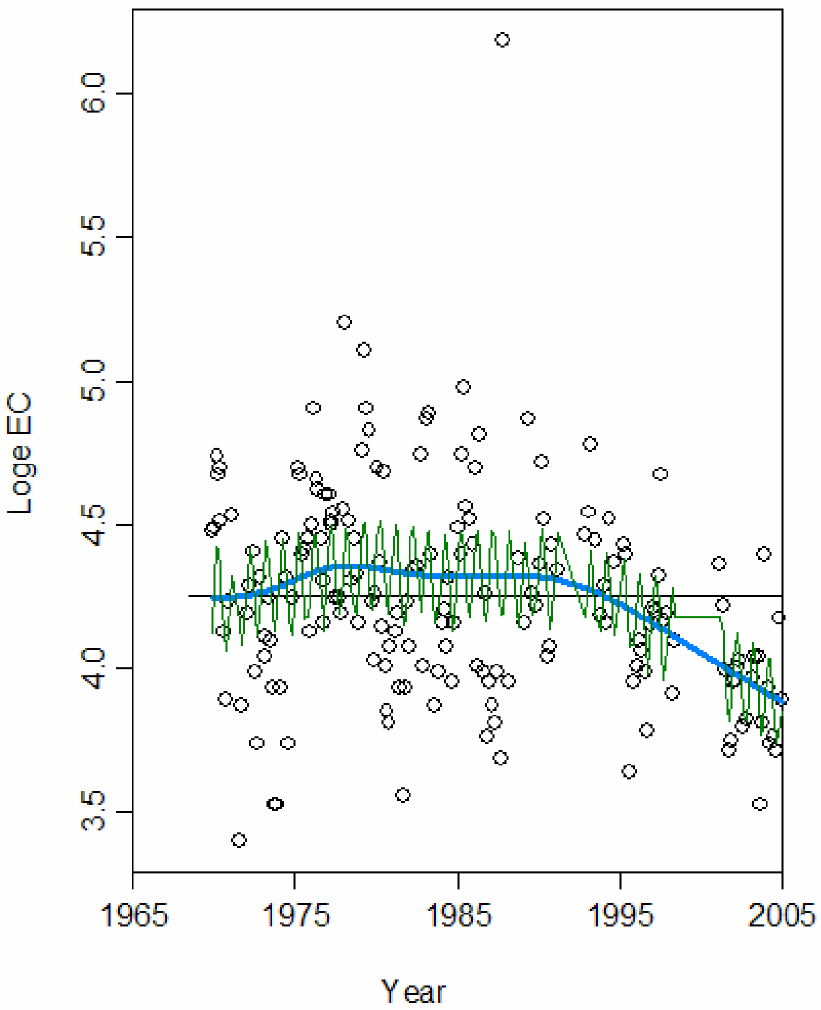
Appendix 2.6 410025 Jugiong Ck at Jugiong



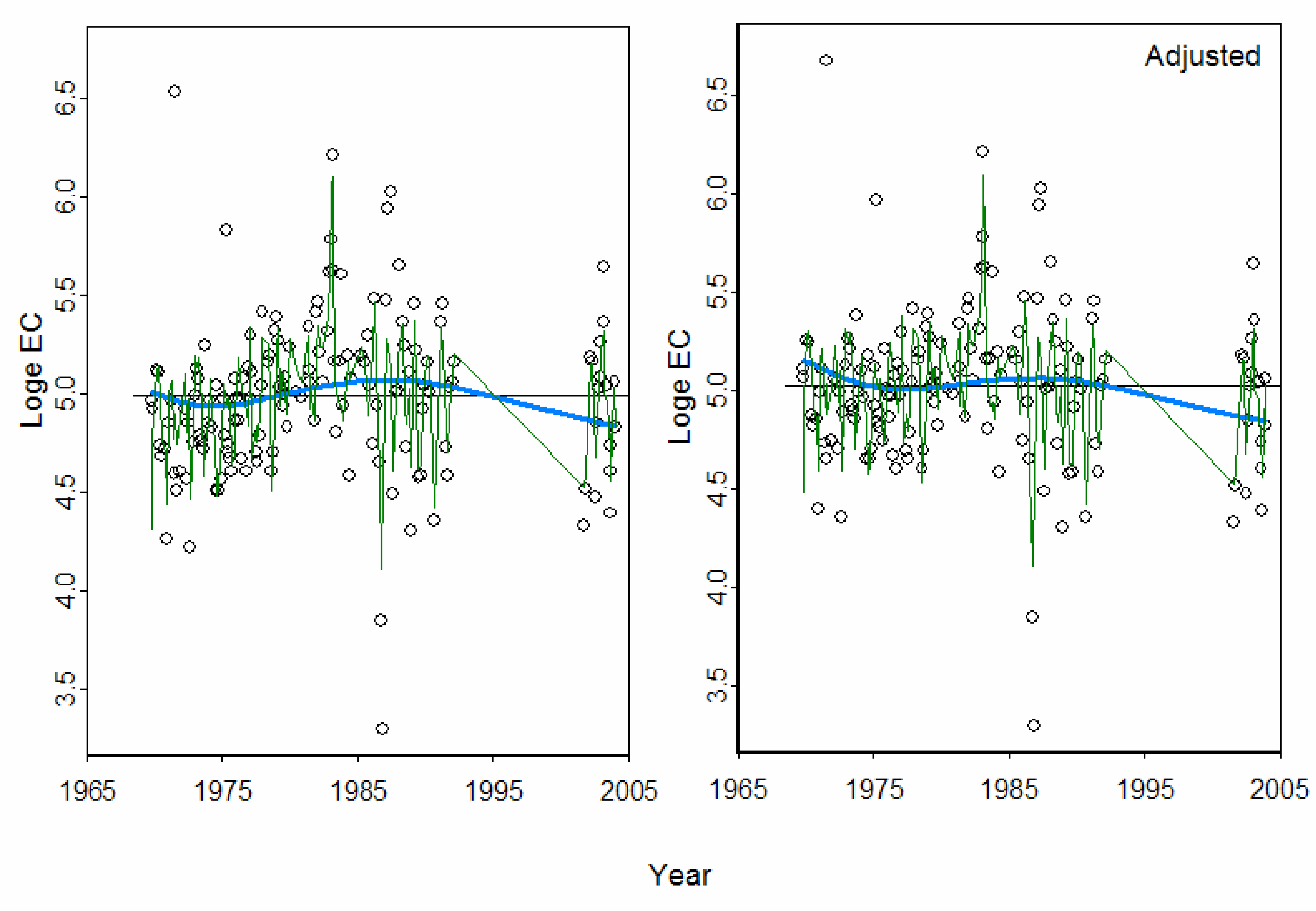
Appendix 2.7 410026 Yass R at Yass



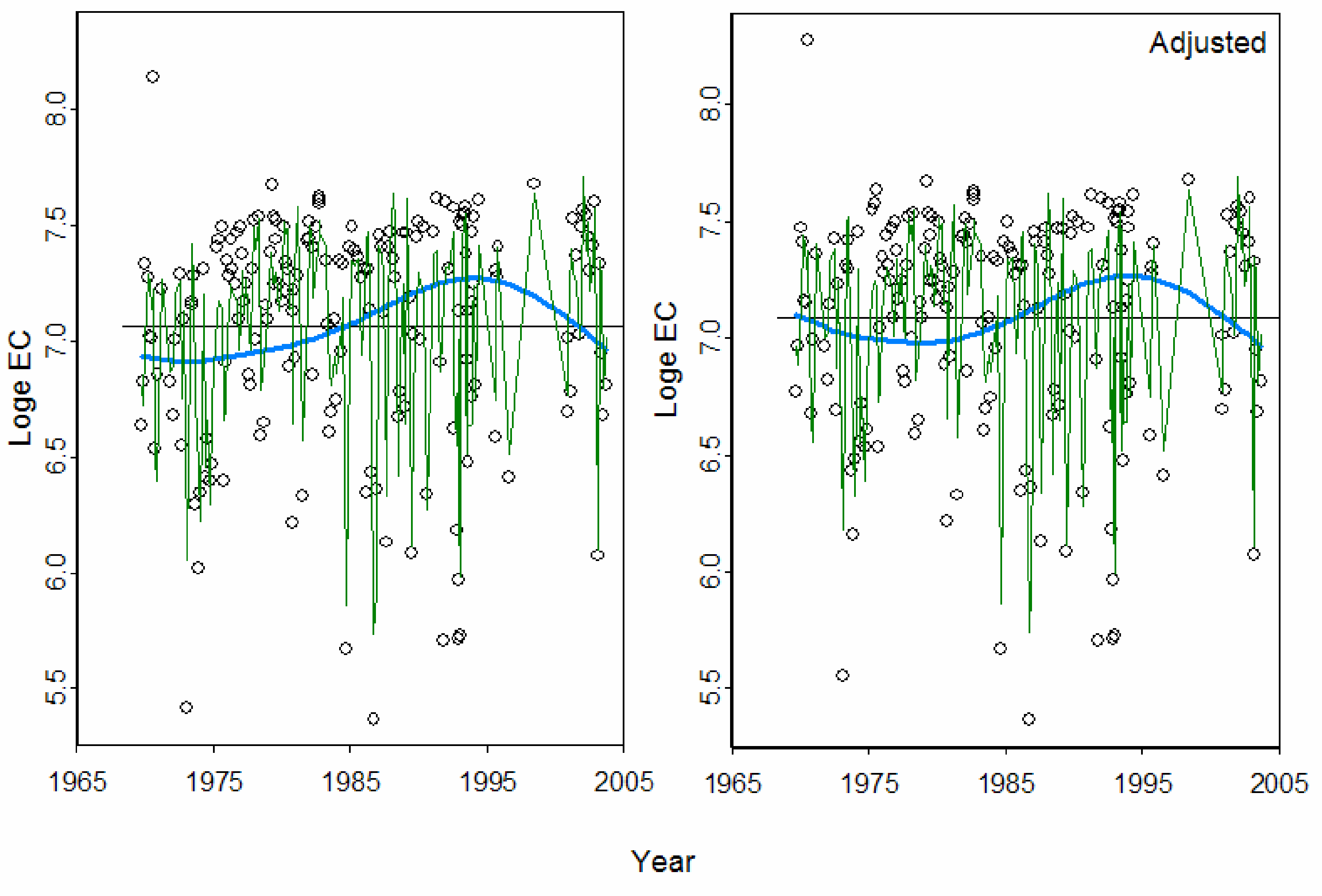
Appendix 2.8 410033 Murrumbidgee R at Mittagang Crossing



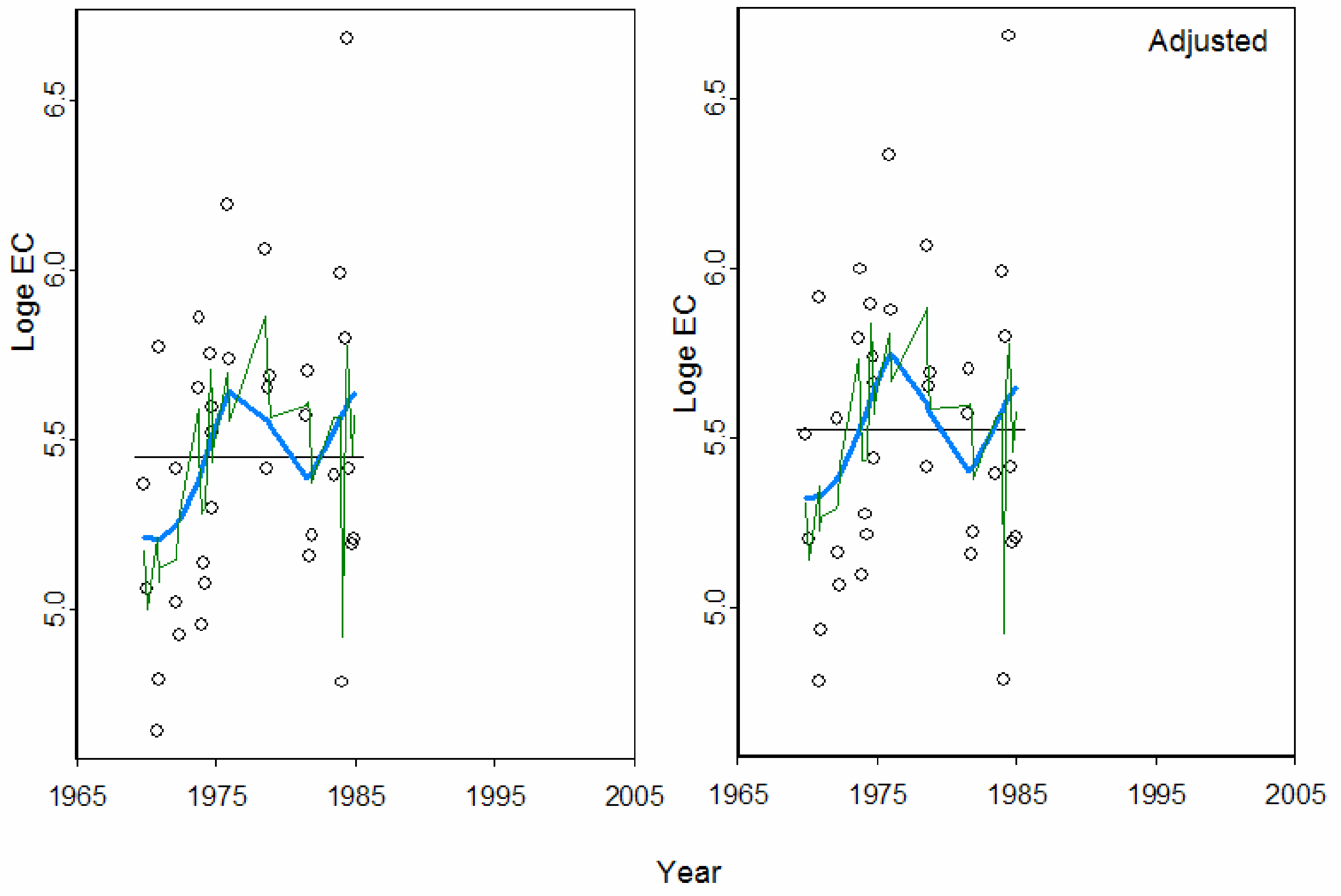
Appendix 2.9 410038 Adjungbilly Ck at Darbalara



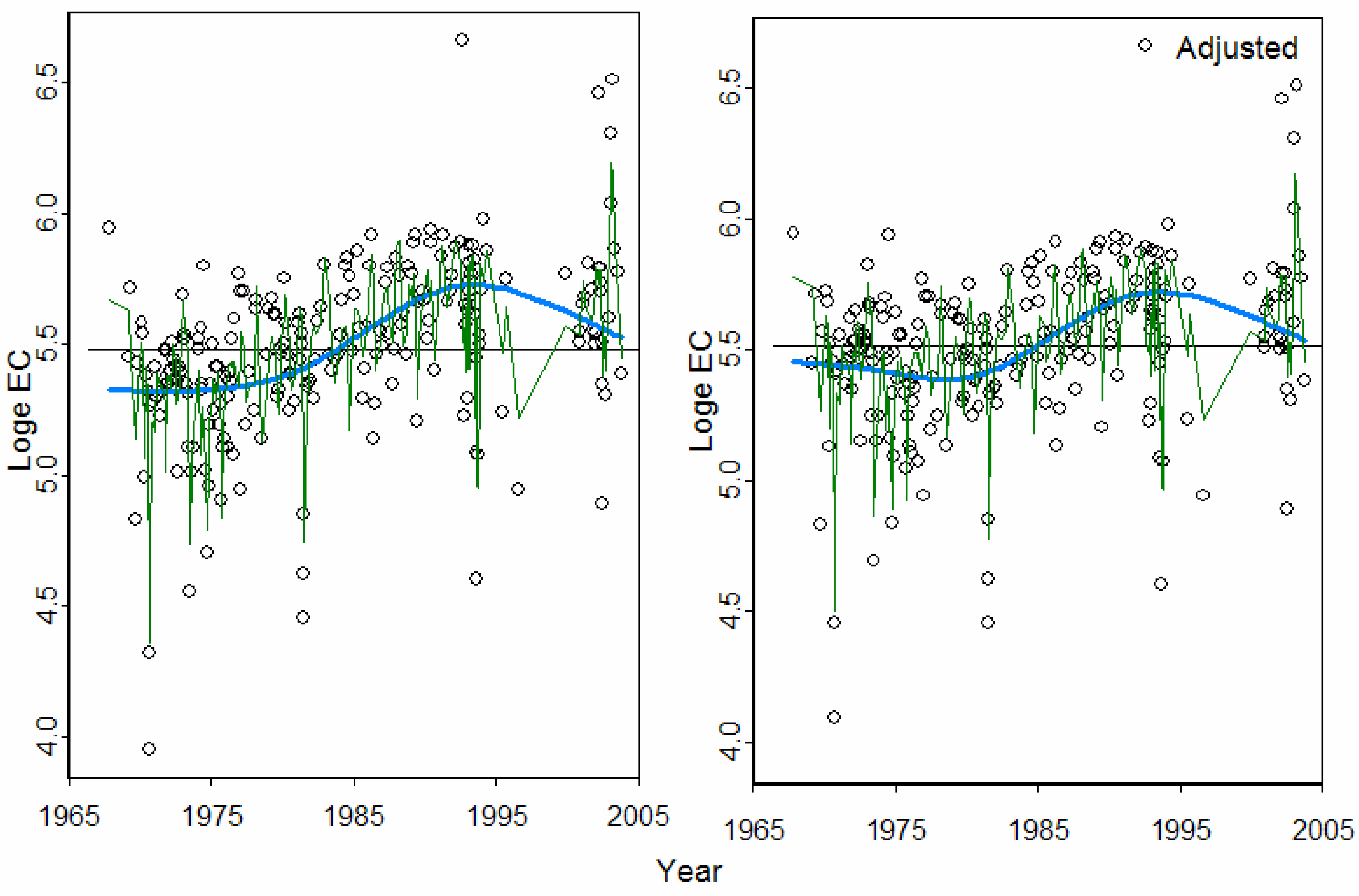
Appendix 2.10 410044 Muttama Ck at Coolac



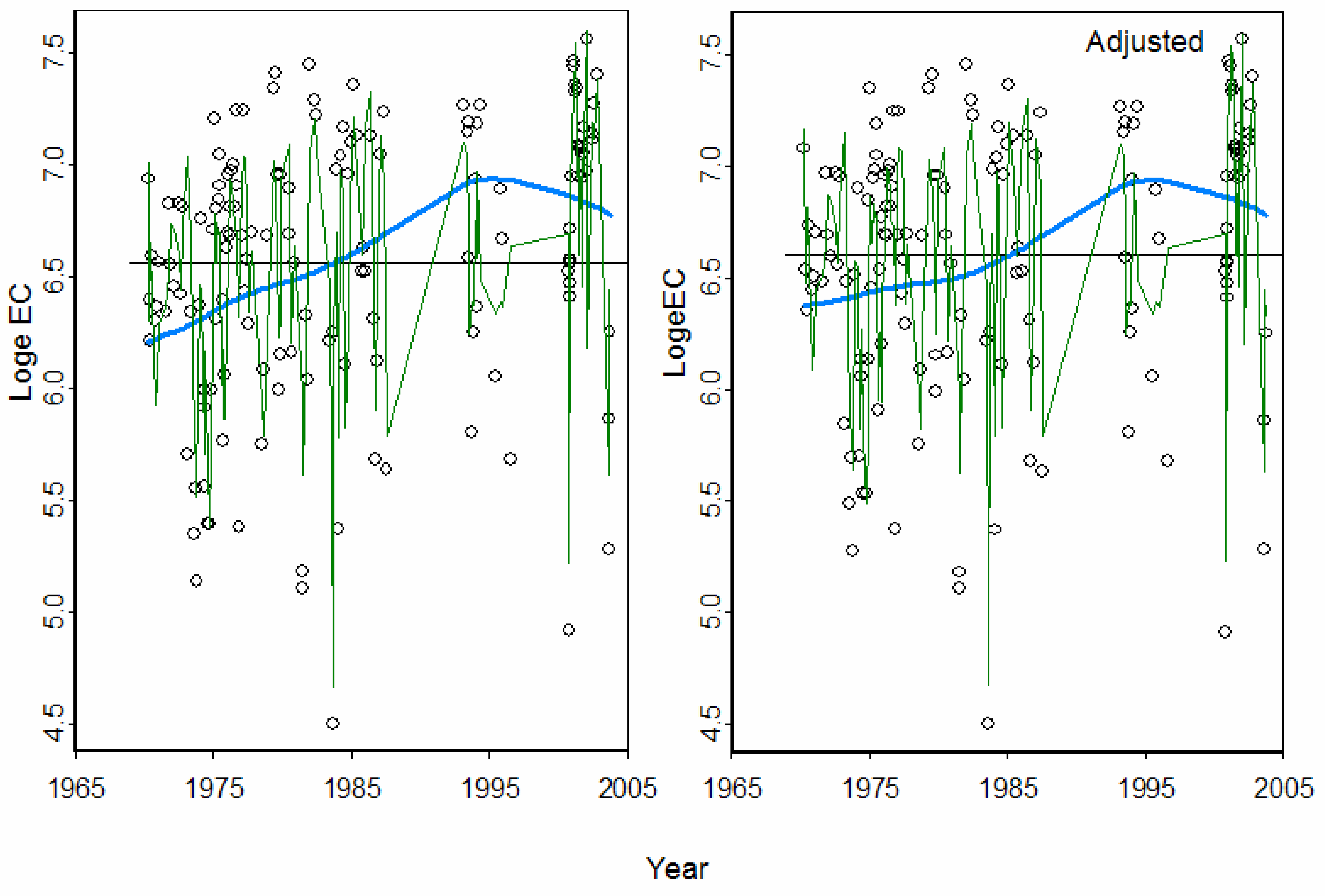
Appendix 2.11 410045 Billabung Ck at Sunnyside



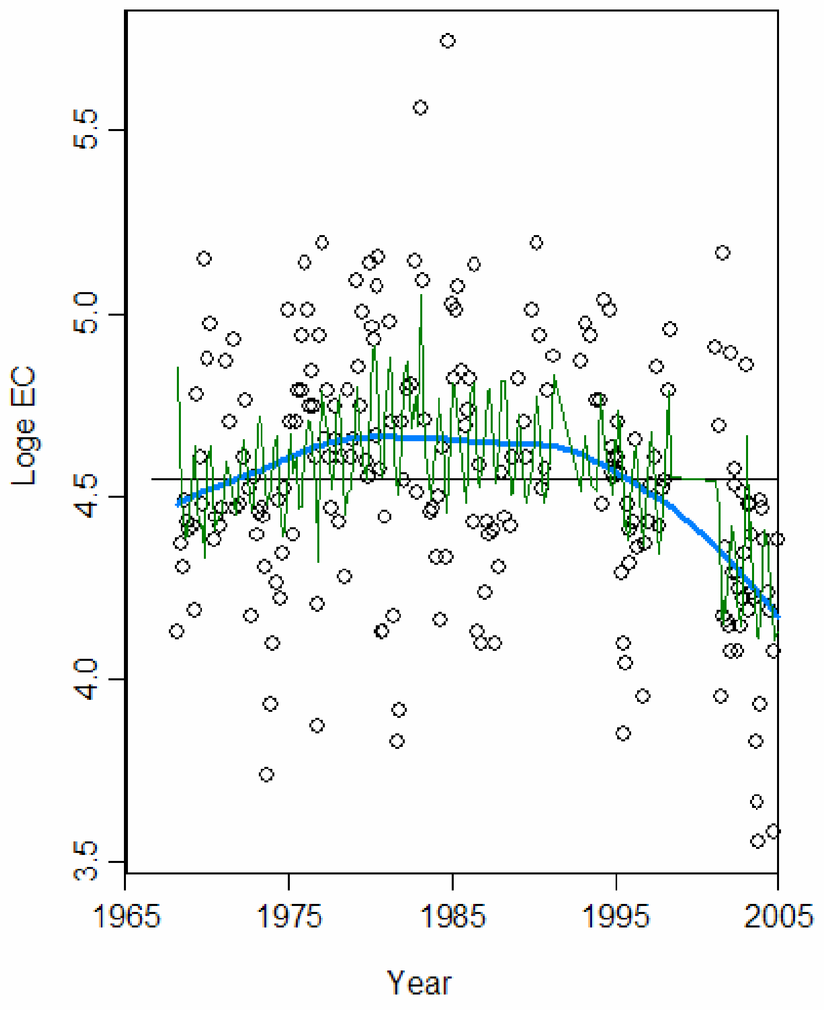
Appendix 2.12 410047 Tarcutta Ck at Old Borambola



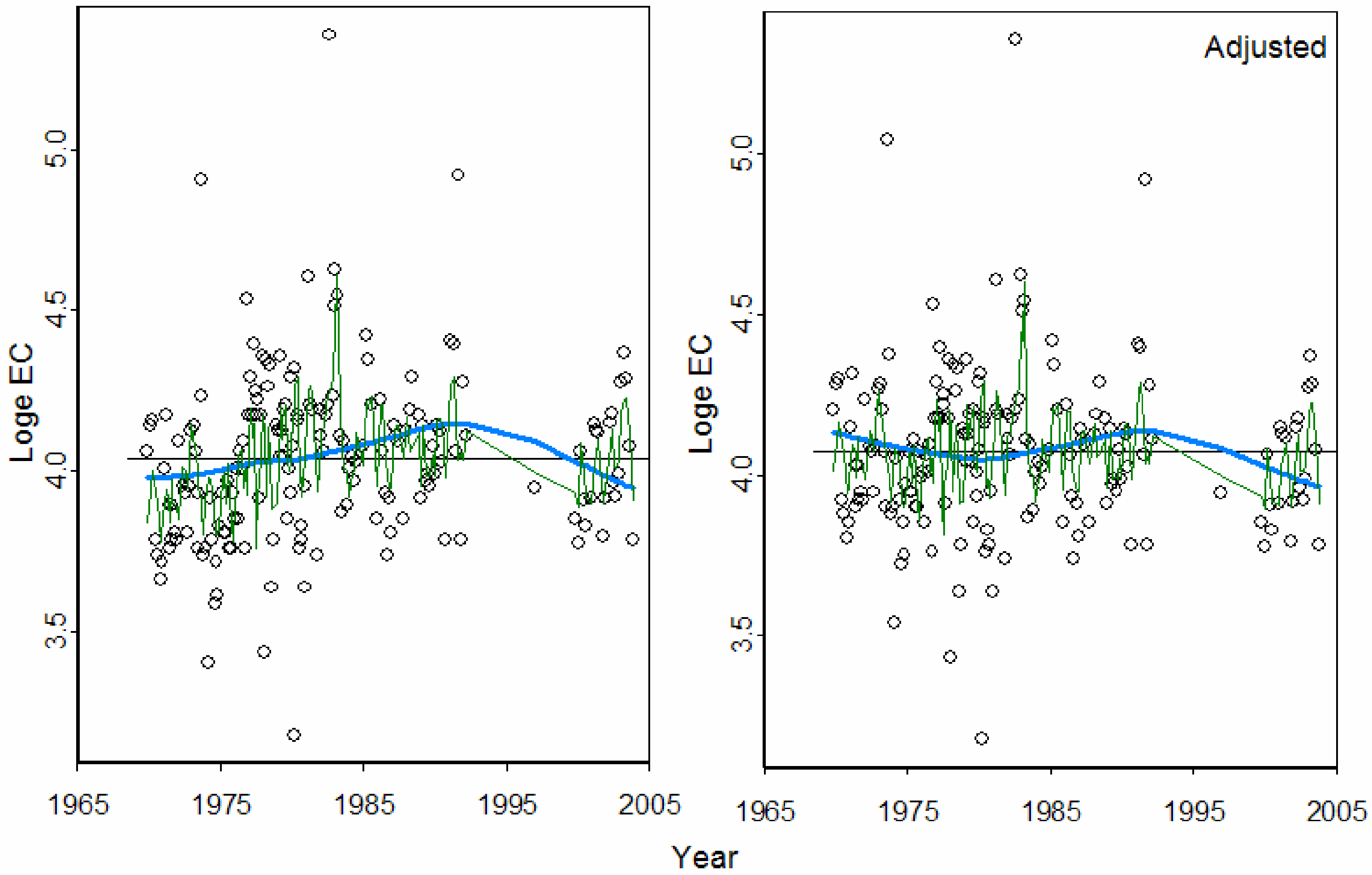
Appendix 2.13 410048 Kyeamba Ck at Ladysmith



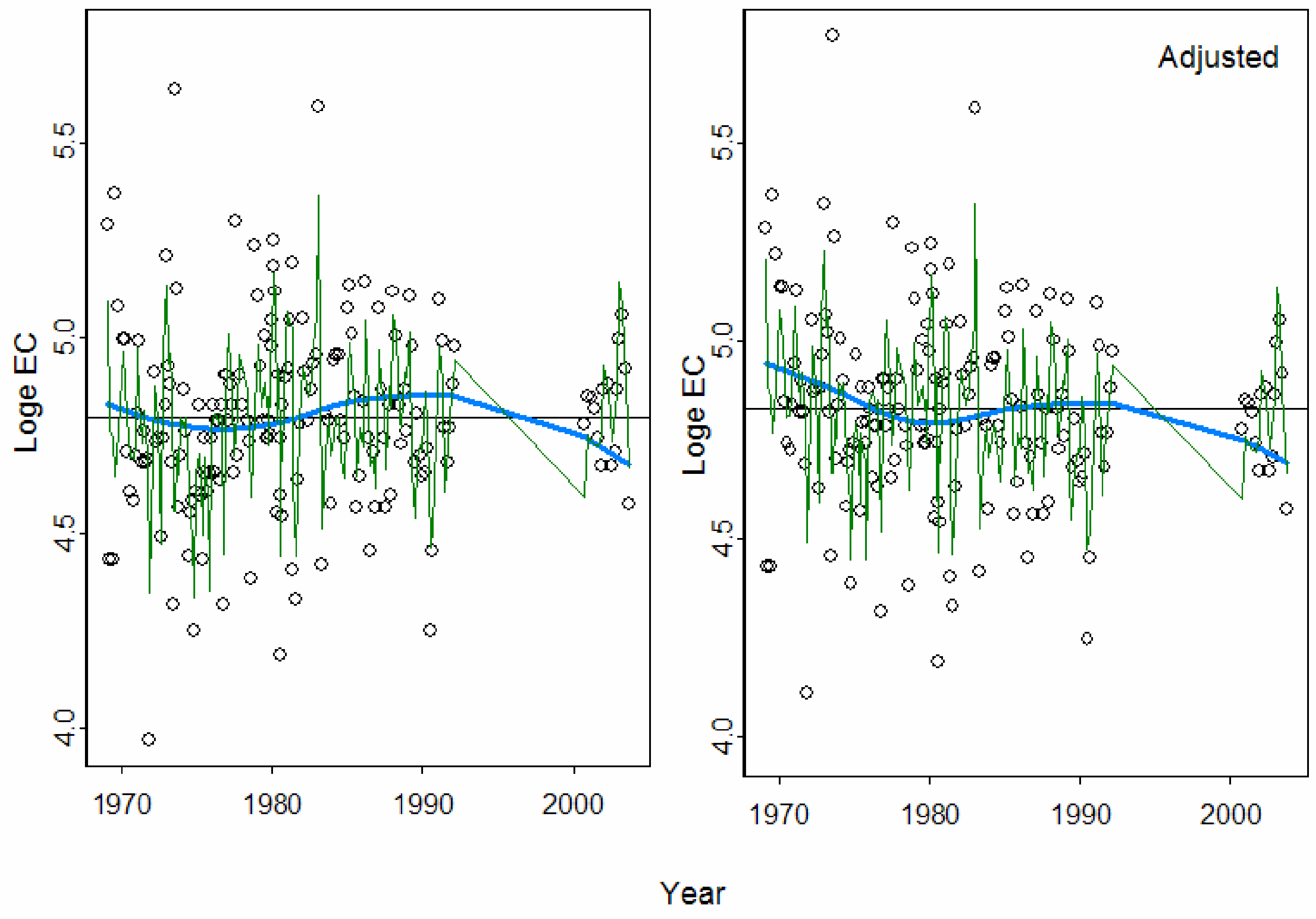
Appendix 2.14 410050 Murrumbidgee R at Billilingra



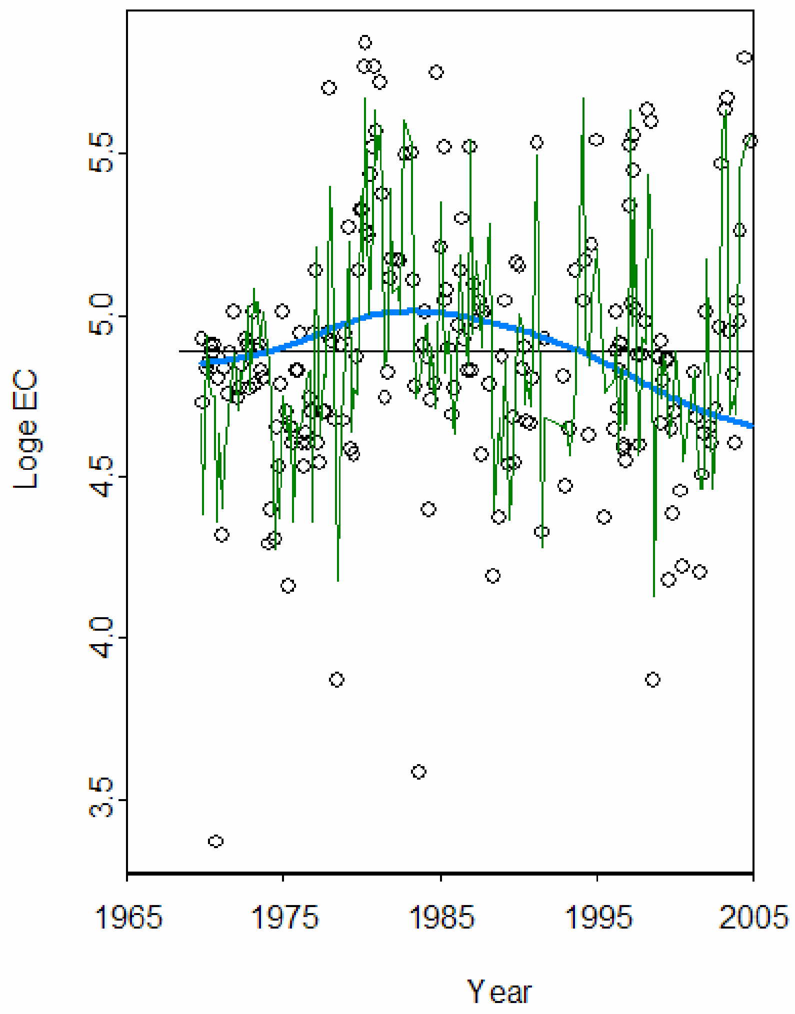
Appendix 2.15 410057 Goobarragandra R. at Lacmalac



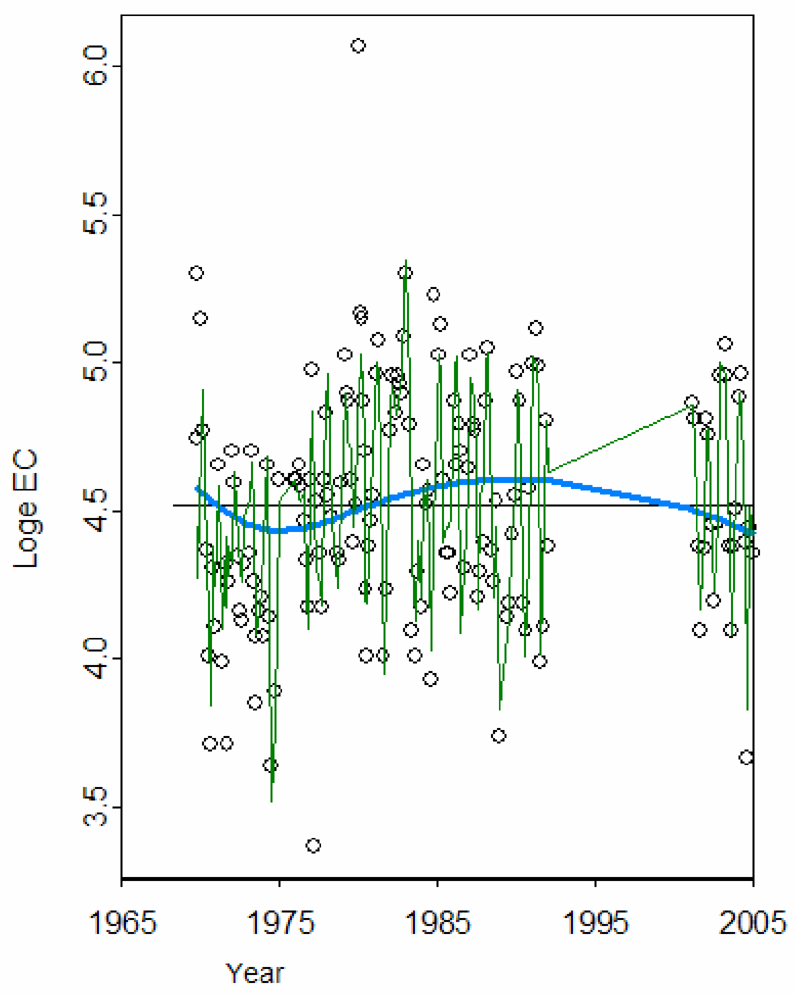
Appendix 2.16 410061 Adelong Ck at Batlow Rd.



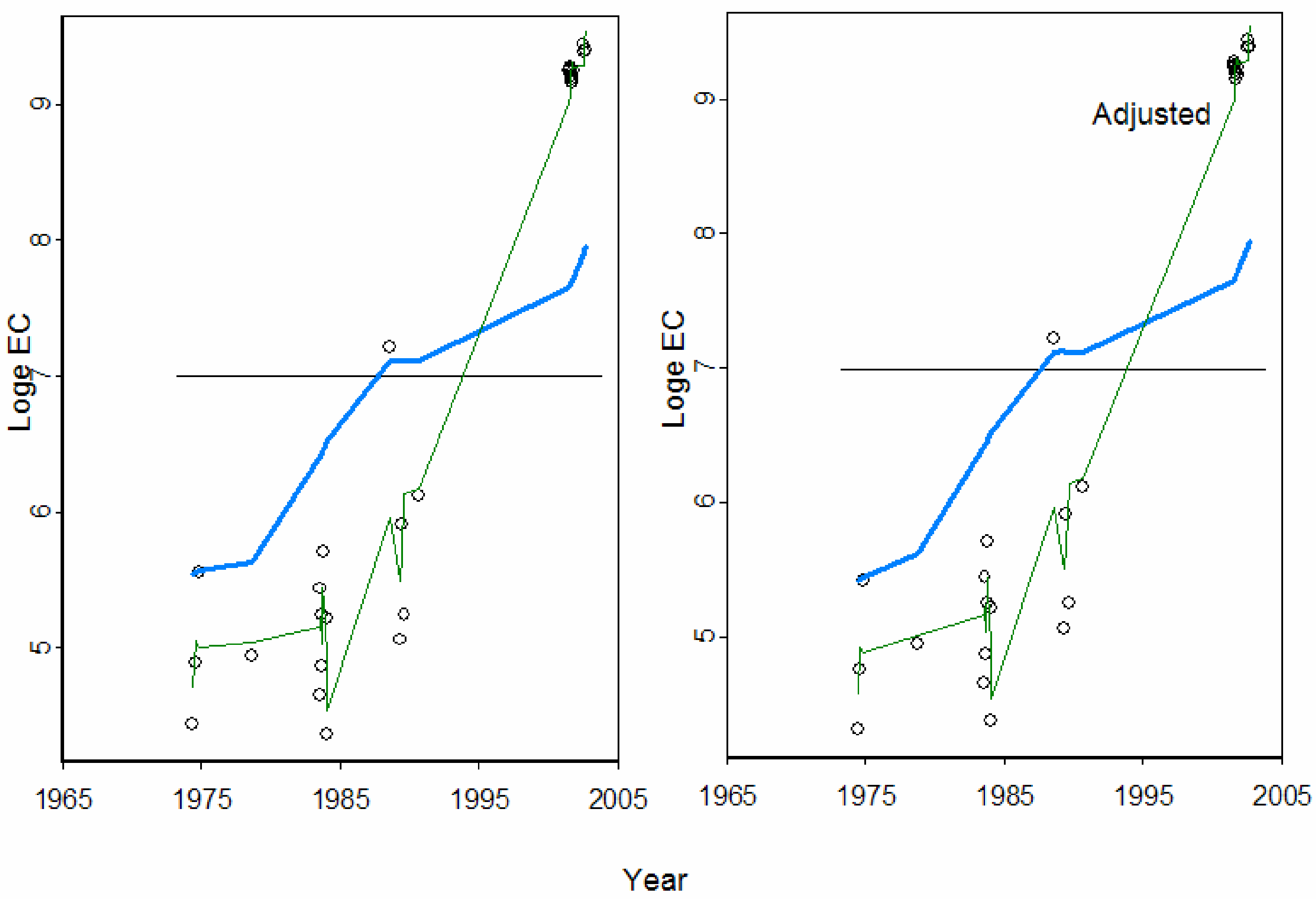
Appendix 2.17 410062 Numeralla R at Numeralla School



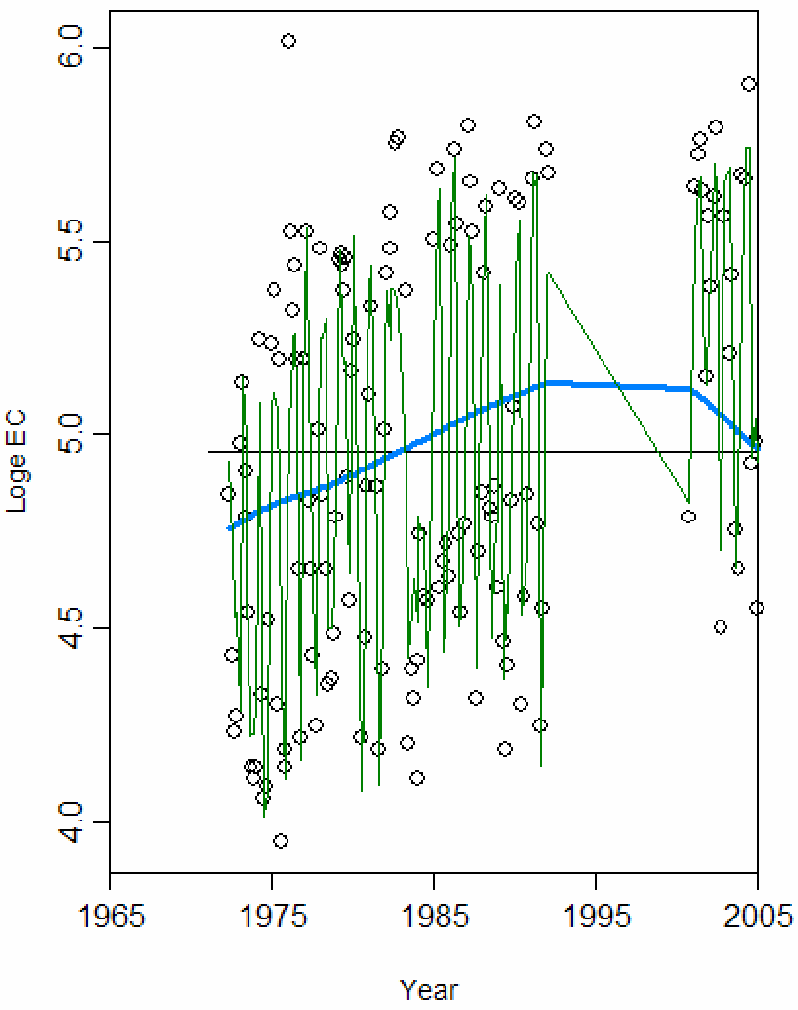
Appendix 2.18 410088 Goodradigbee R at Brindabella



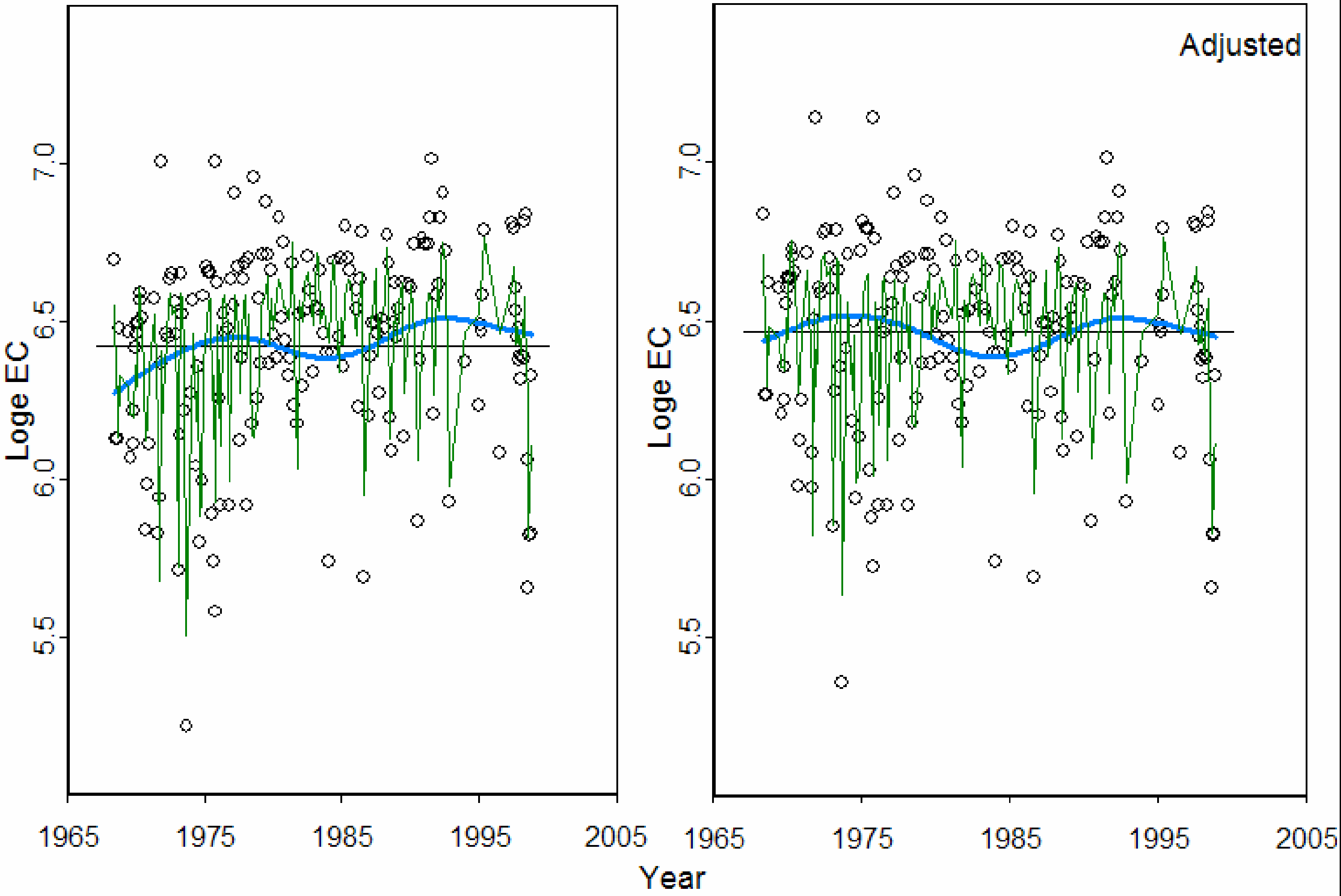
Appendix 2.19 410103 Houlaghans Ck. at Downside



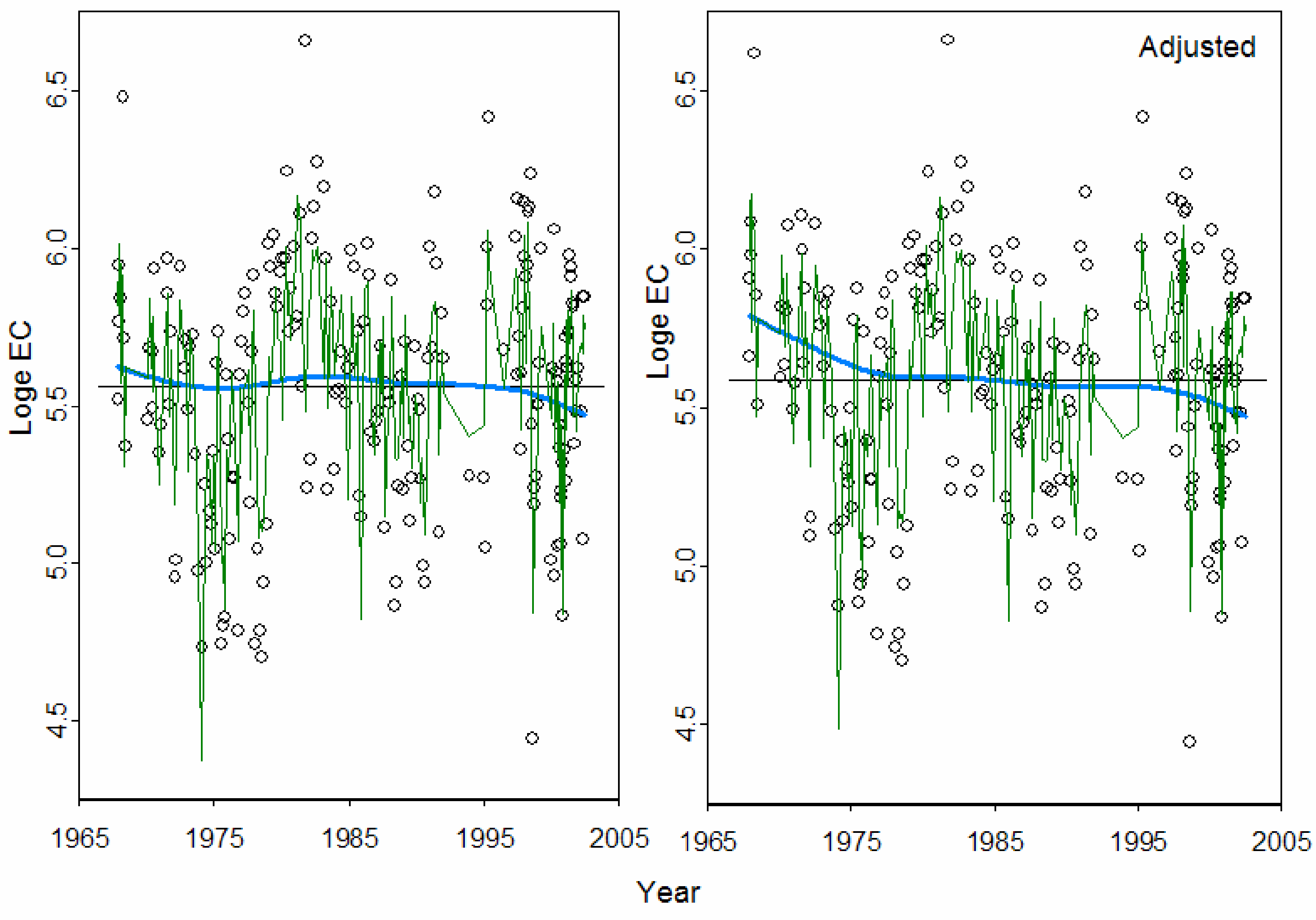
Appendix 2.20 410107 Mountain Ck at Mountain Creek



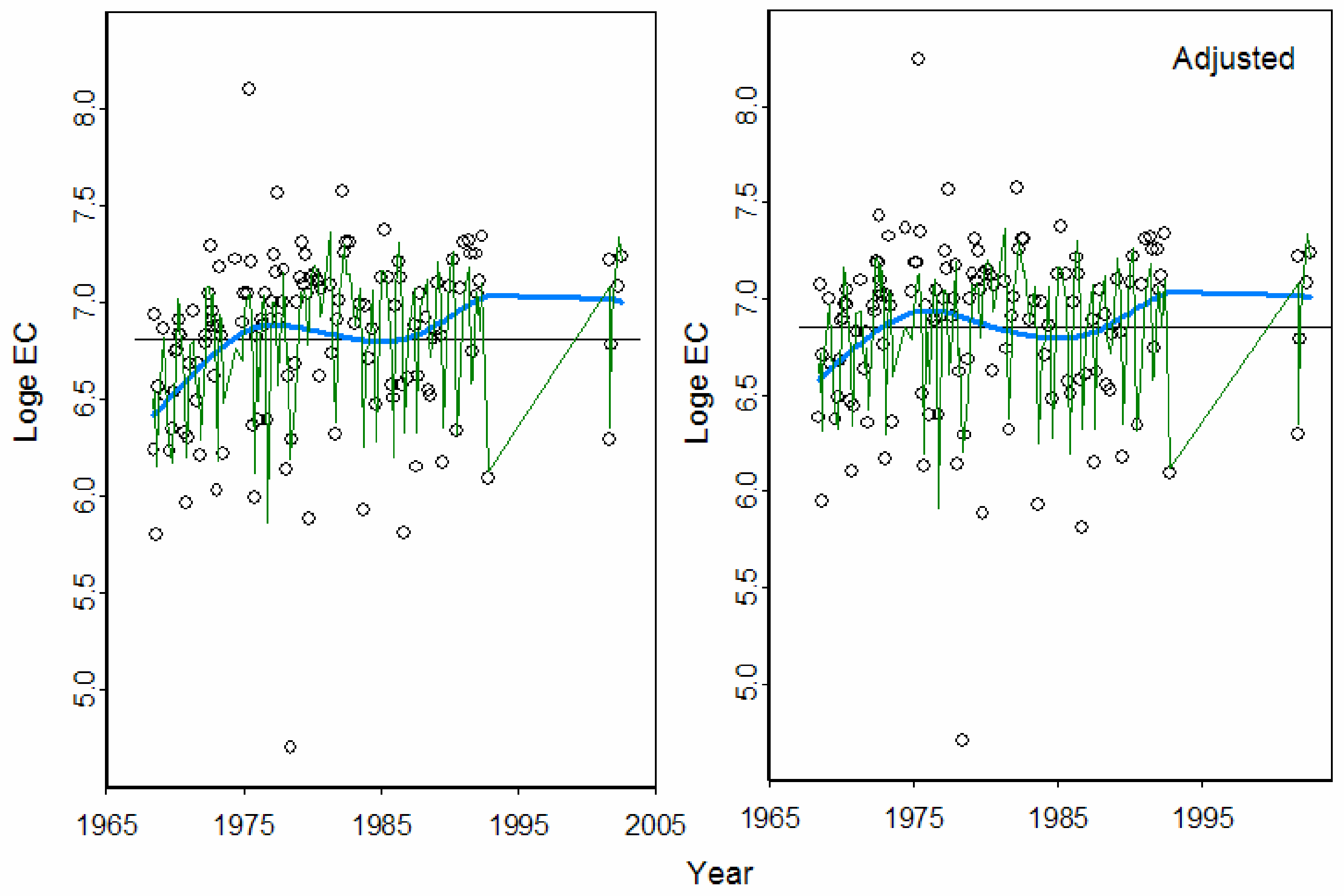
Appendix 2.21 412009 Belubula R at Canowindra



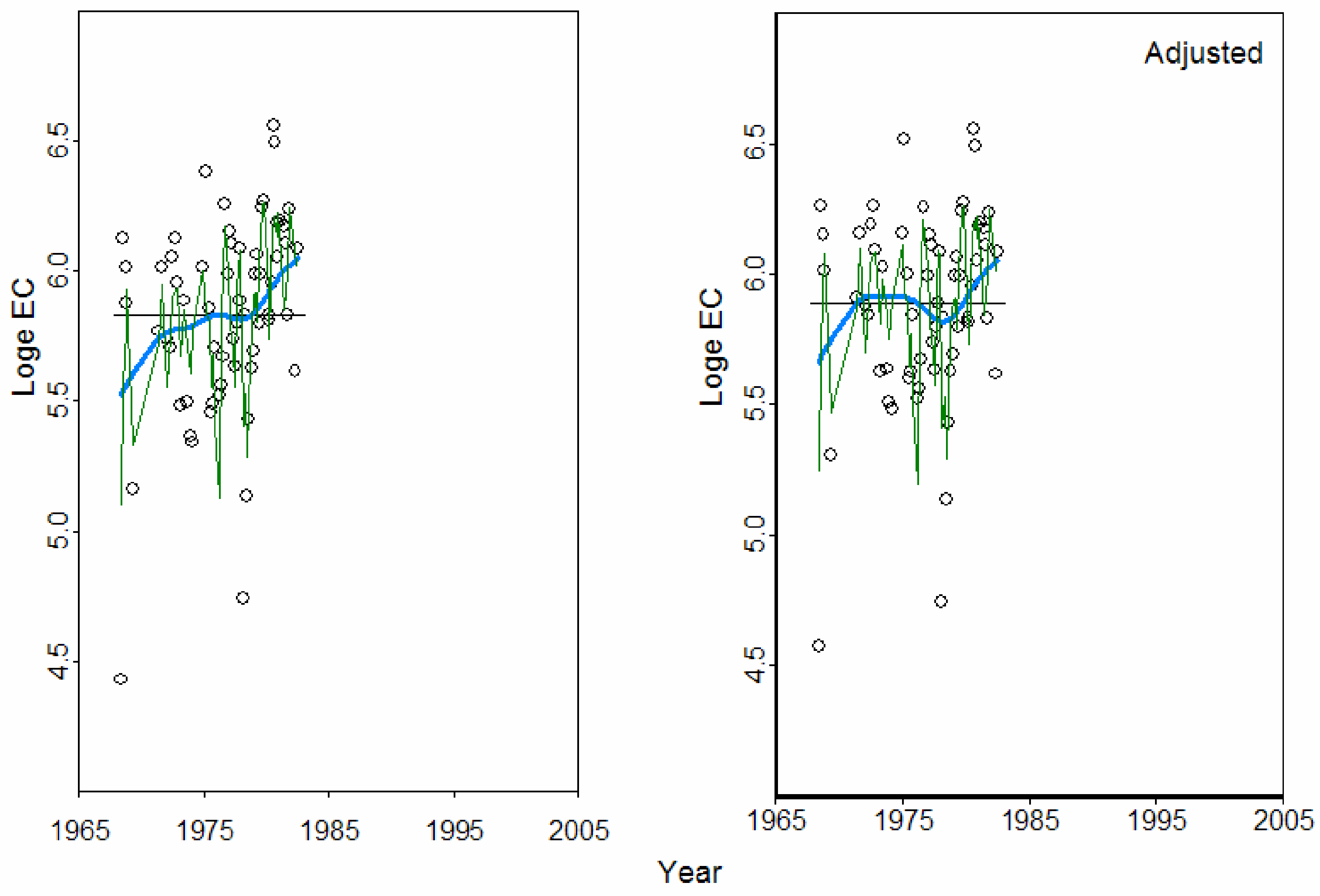
Appendix 2.22 412028 Abercrombie R at Abercrombie



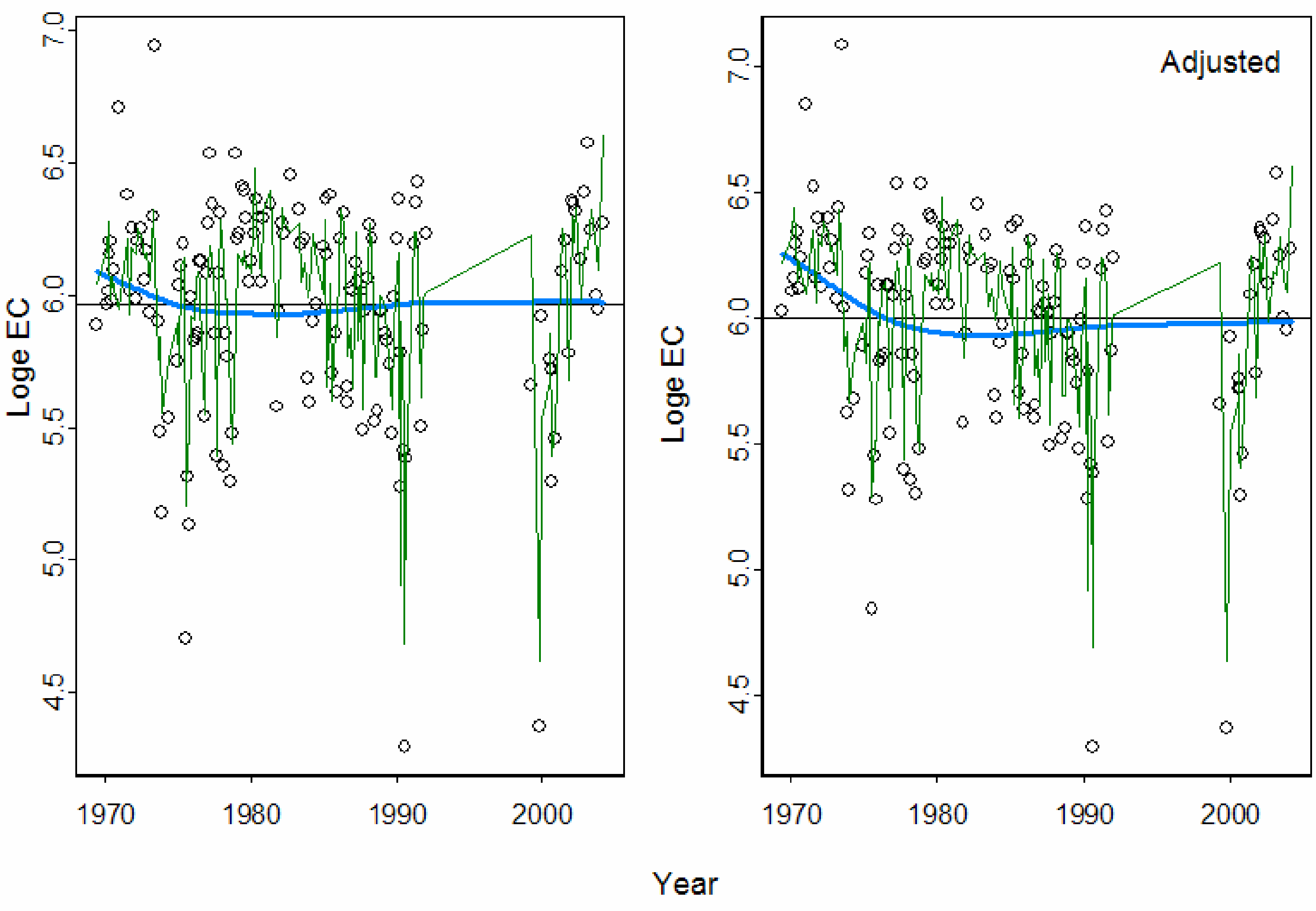
Appendix 2.23 412030 Mandagery Ck U/S Eugowra



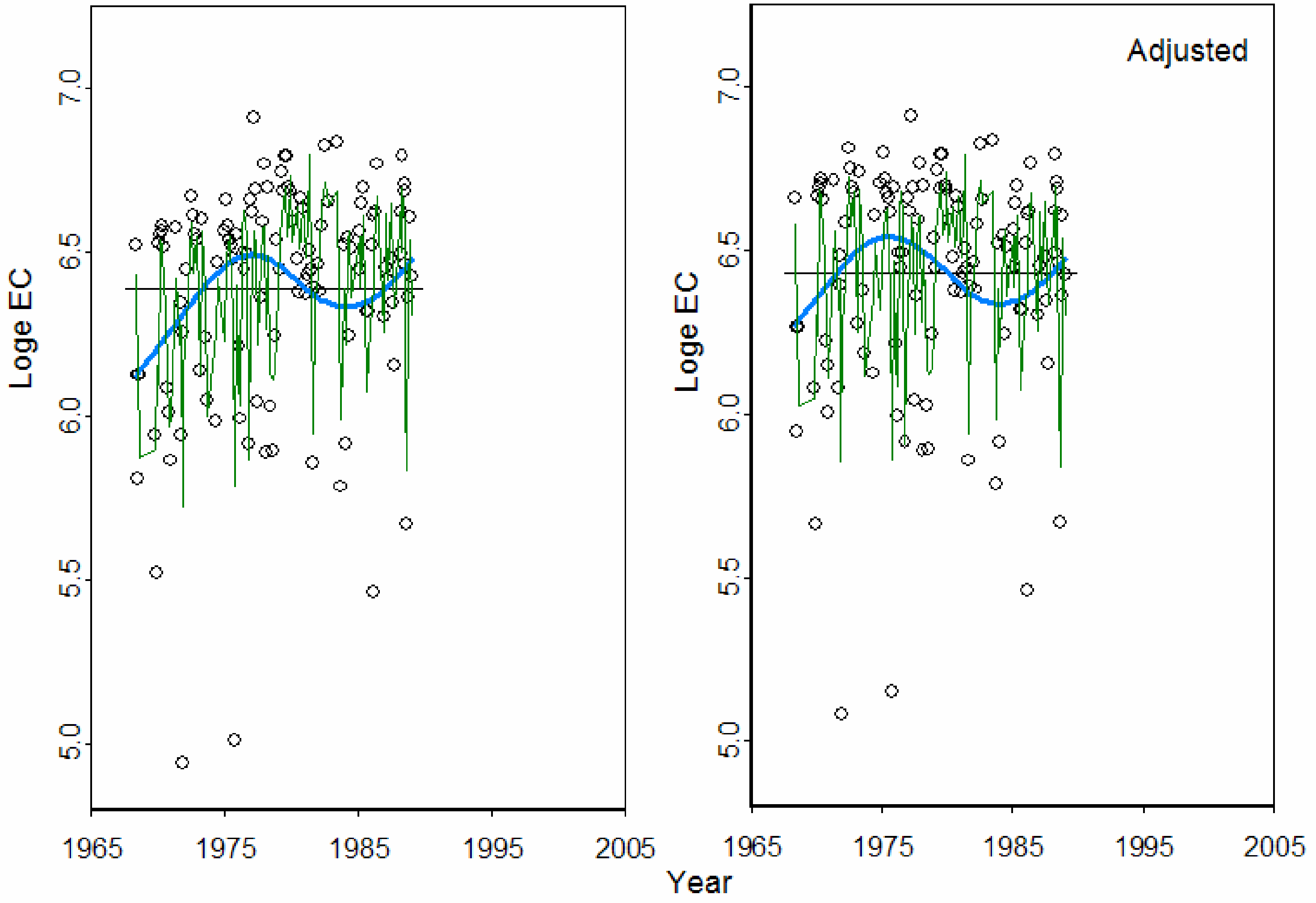
Appendix 2.24 412043 Goobang Ck at Darbys Dam



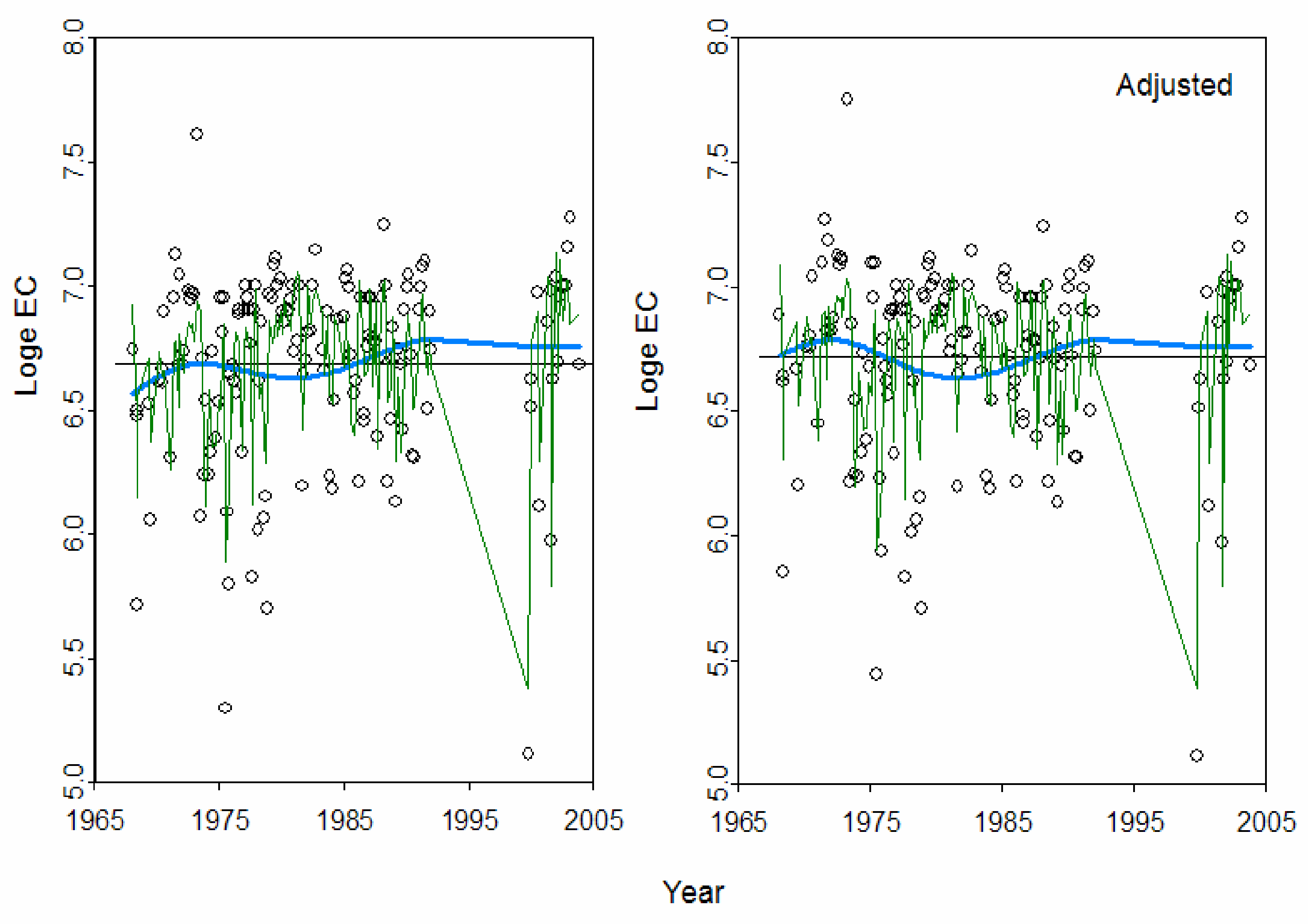
Appendix 2.25 412050 Crookwell R at Narrawa North



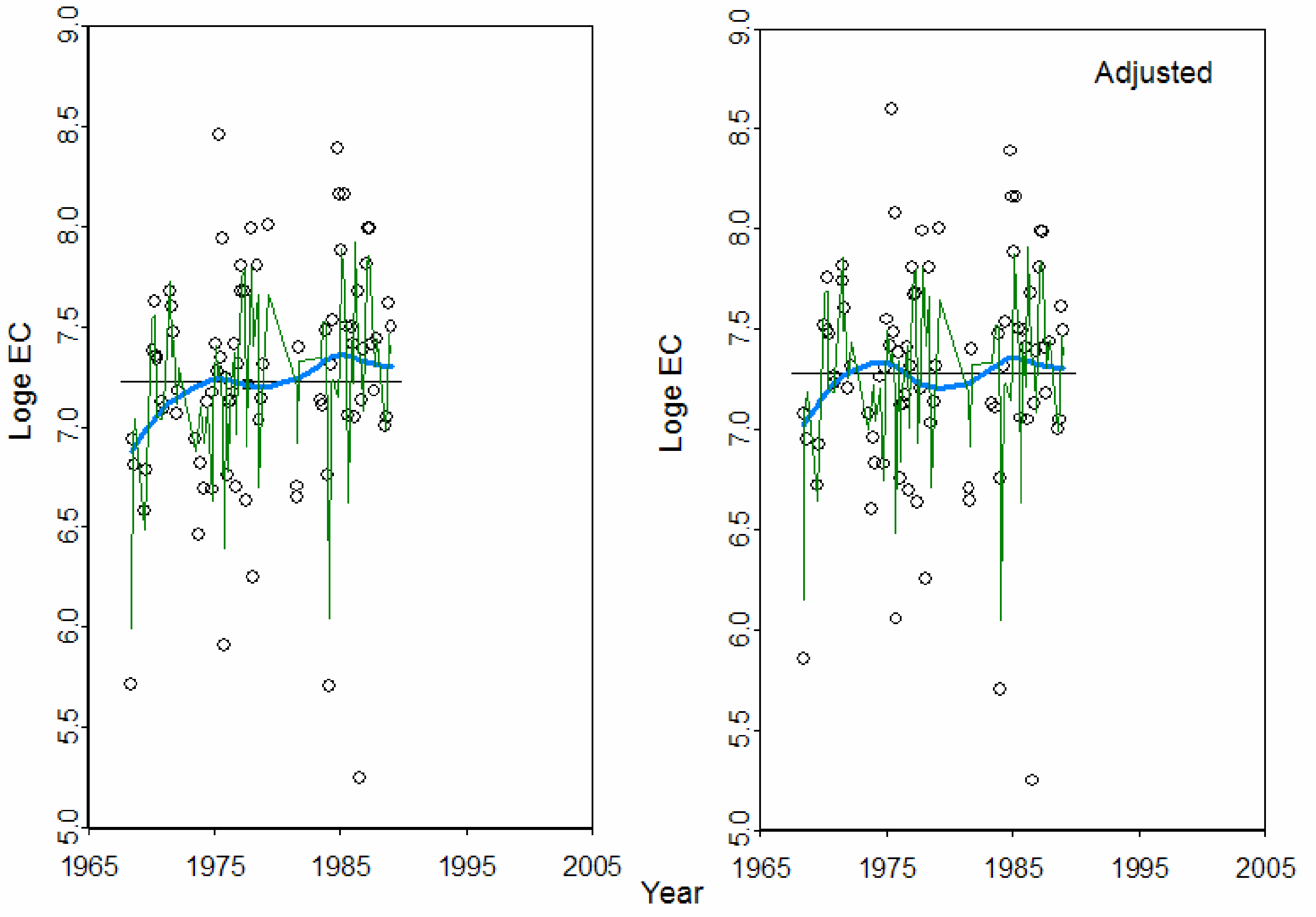
Appendix 2.26 4120055 Belubula R at Bangaroo Bridge



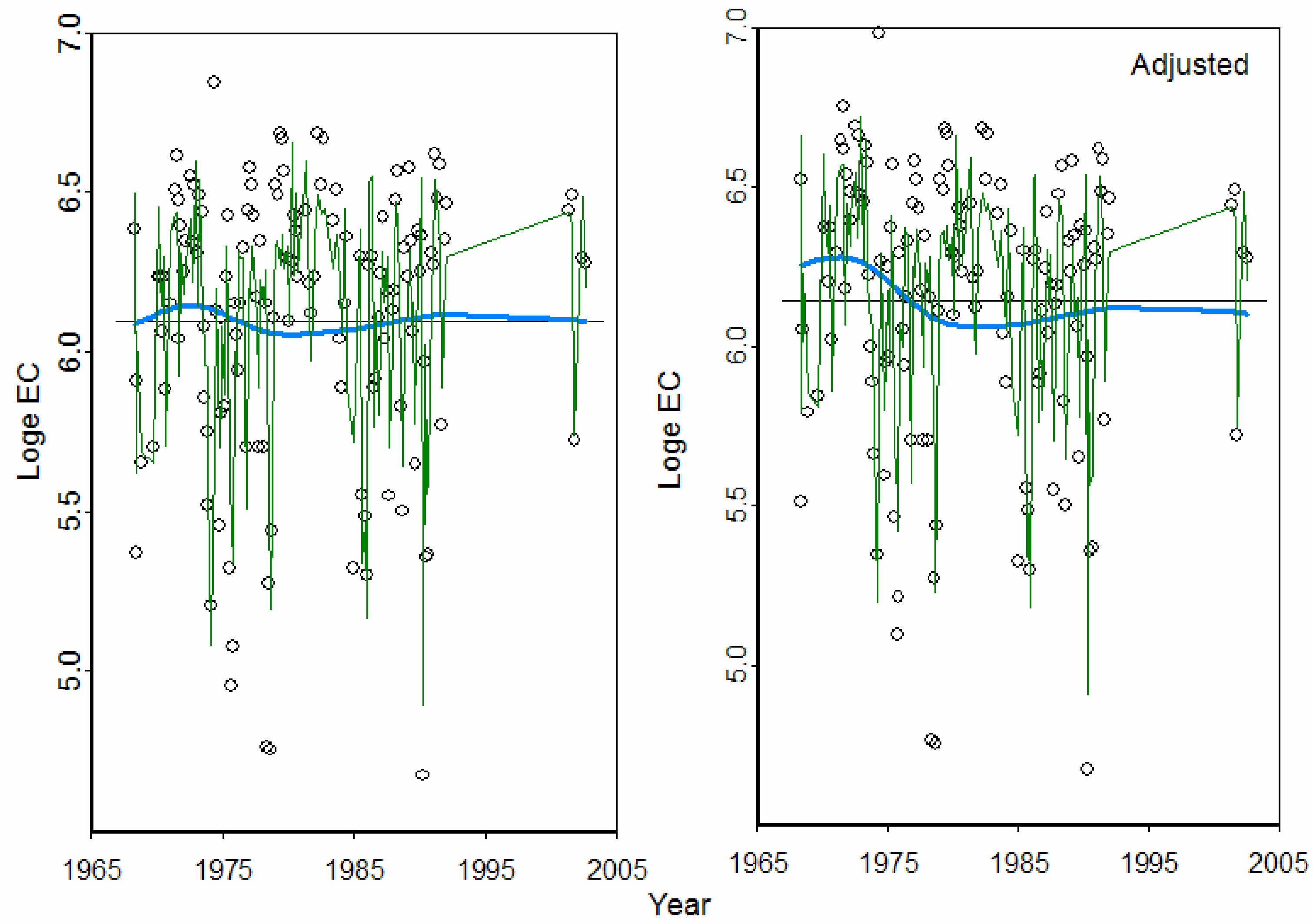
Appendix 2.27 412065 Lachlan R at Narrawa



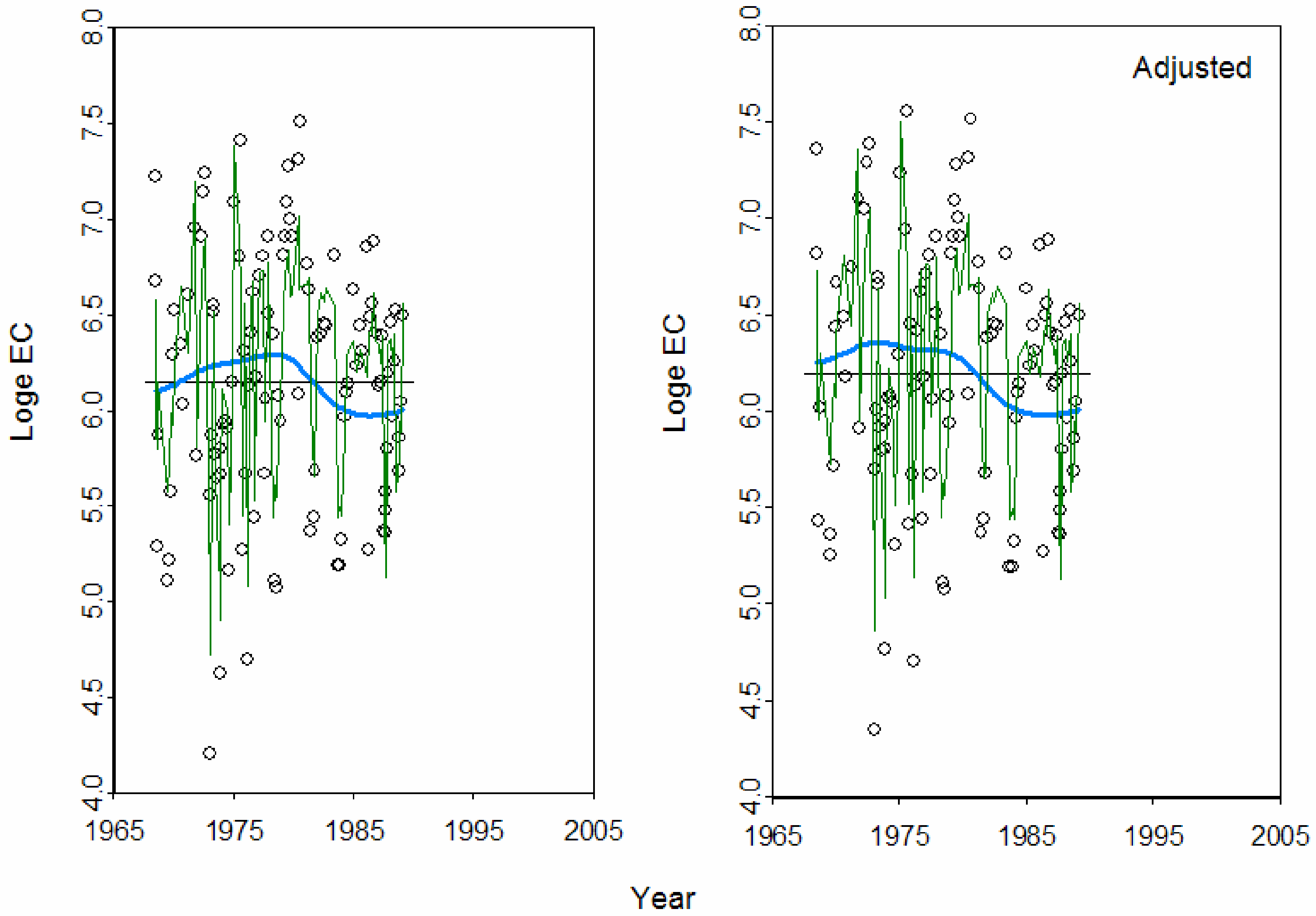
Appendix 2.28 412072 Back Ck at Koorawatha



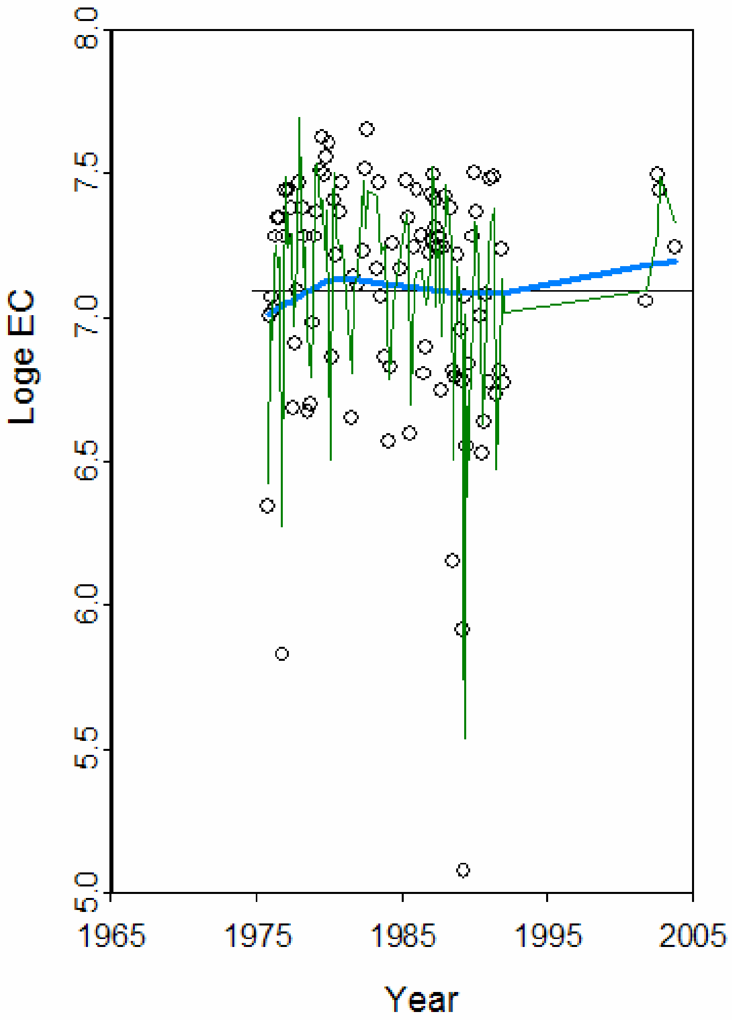
Appendix 2.29 412083 Tuena Ck at Tuena



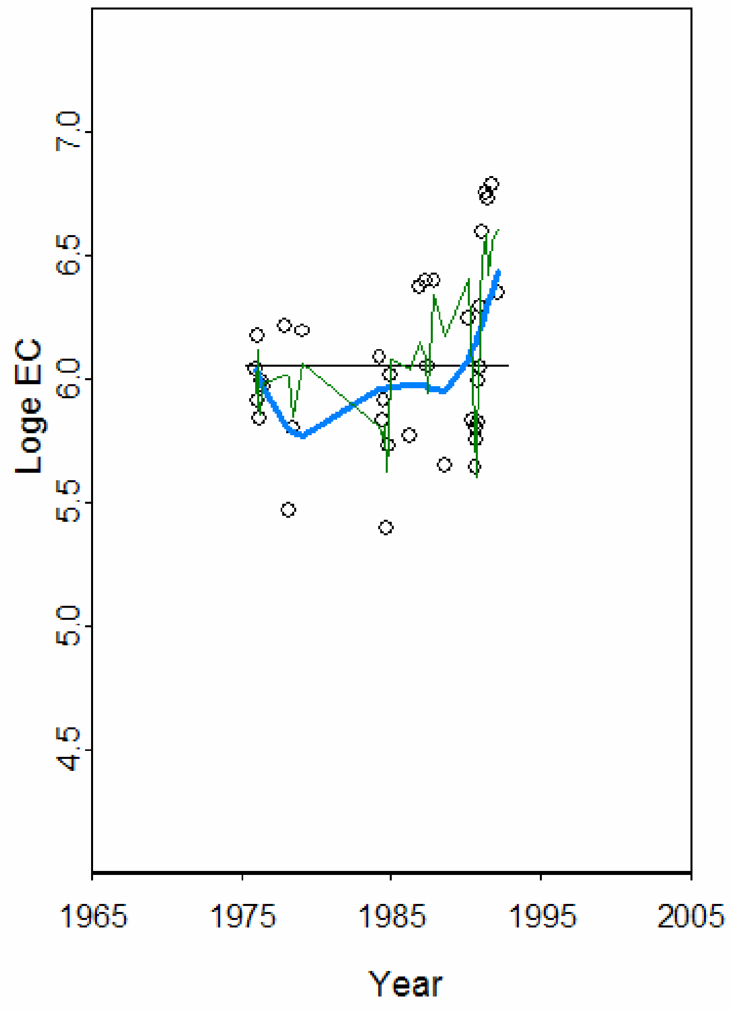
Appendix 2.30 412086 Goobang Ck at Parkes



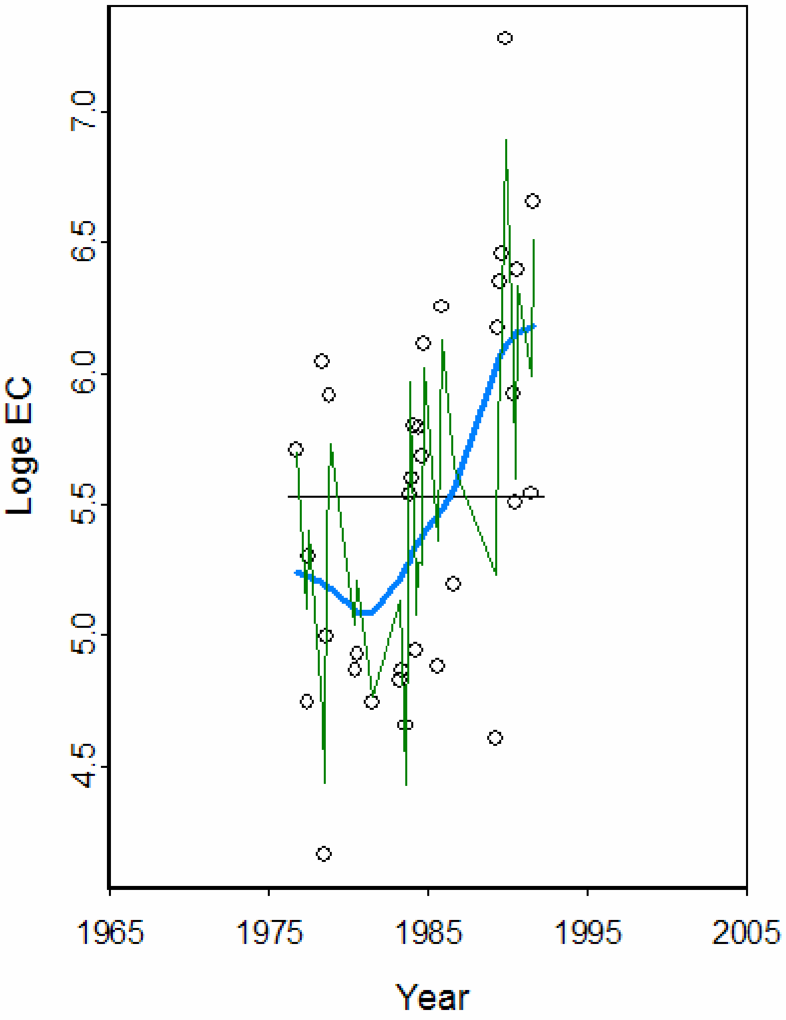
Appendix 2.31 412096 Pudmans Ck at Kennys Rd

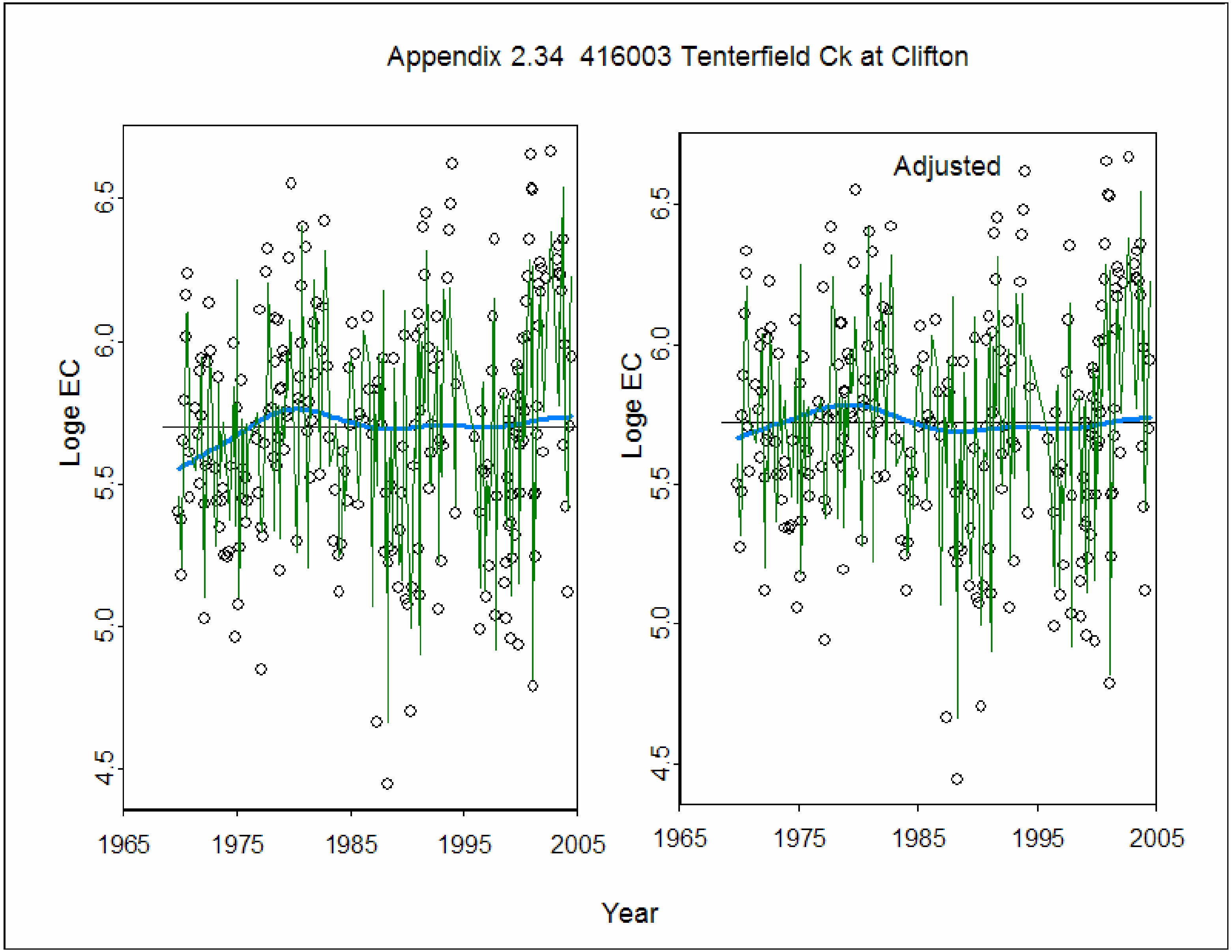


Appendix 2.32 412099 Manna Ck nr Lake Cowal

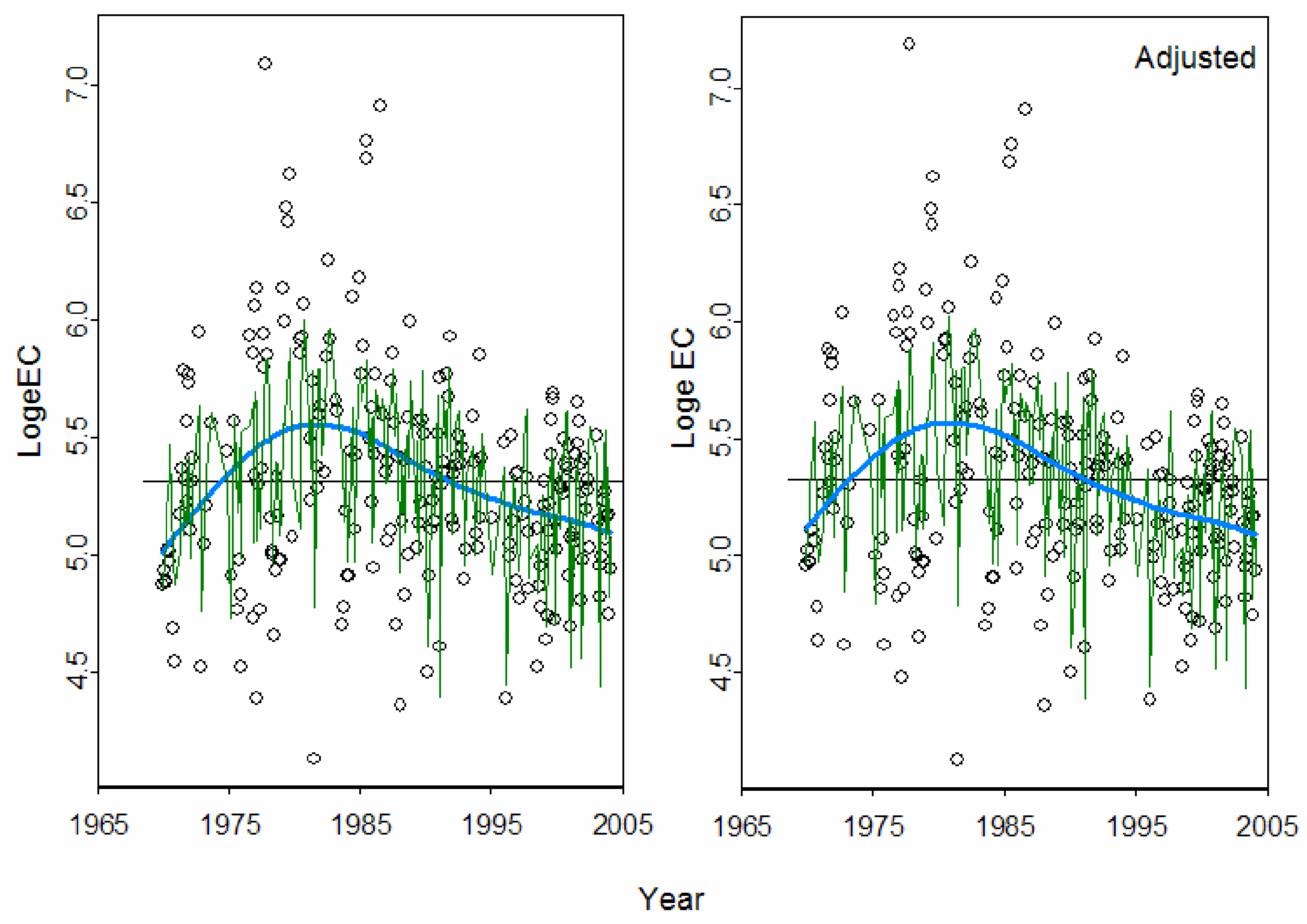


Appendix 2.33 412103 Bland Ck at Morangarell

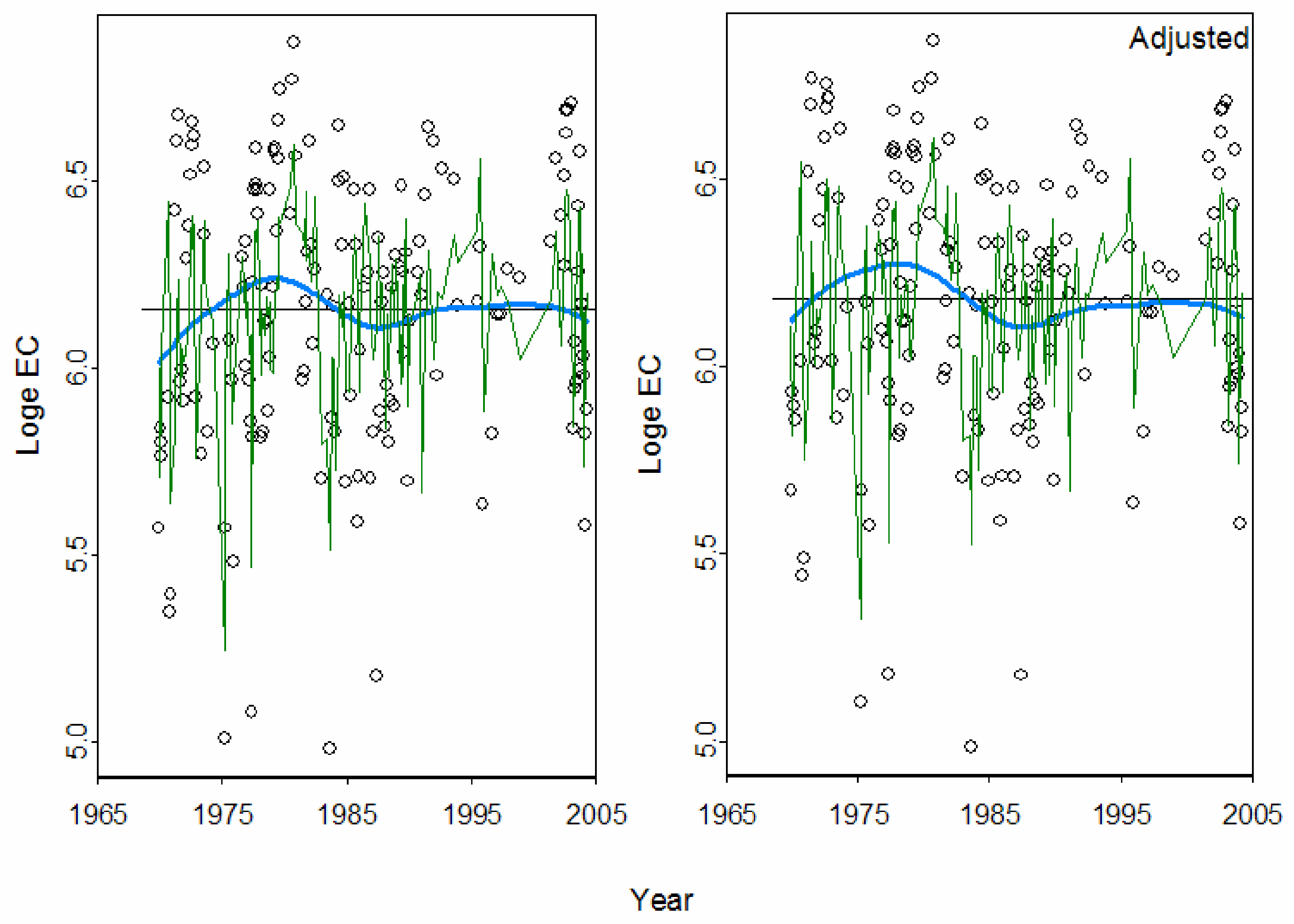



Appendix 2.34 416003 Tenterfield Ck at Clifton
Loge EC
6.5
6.0
5.5
5.0
4.5
1965
1975
1985
1995
2005
Adjusted
Loge EC
6.5
6.0
5.5
5.0
4.5
1965
1975
1985
1995
2005
Year

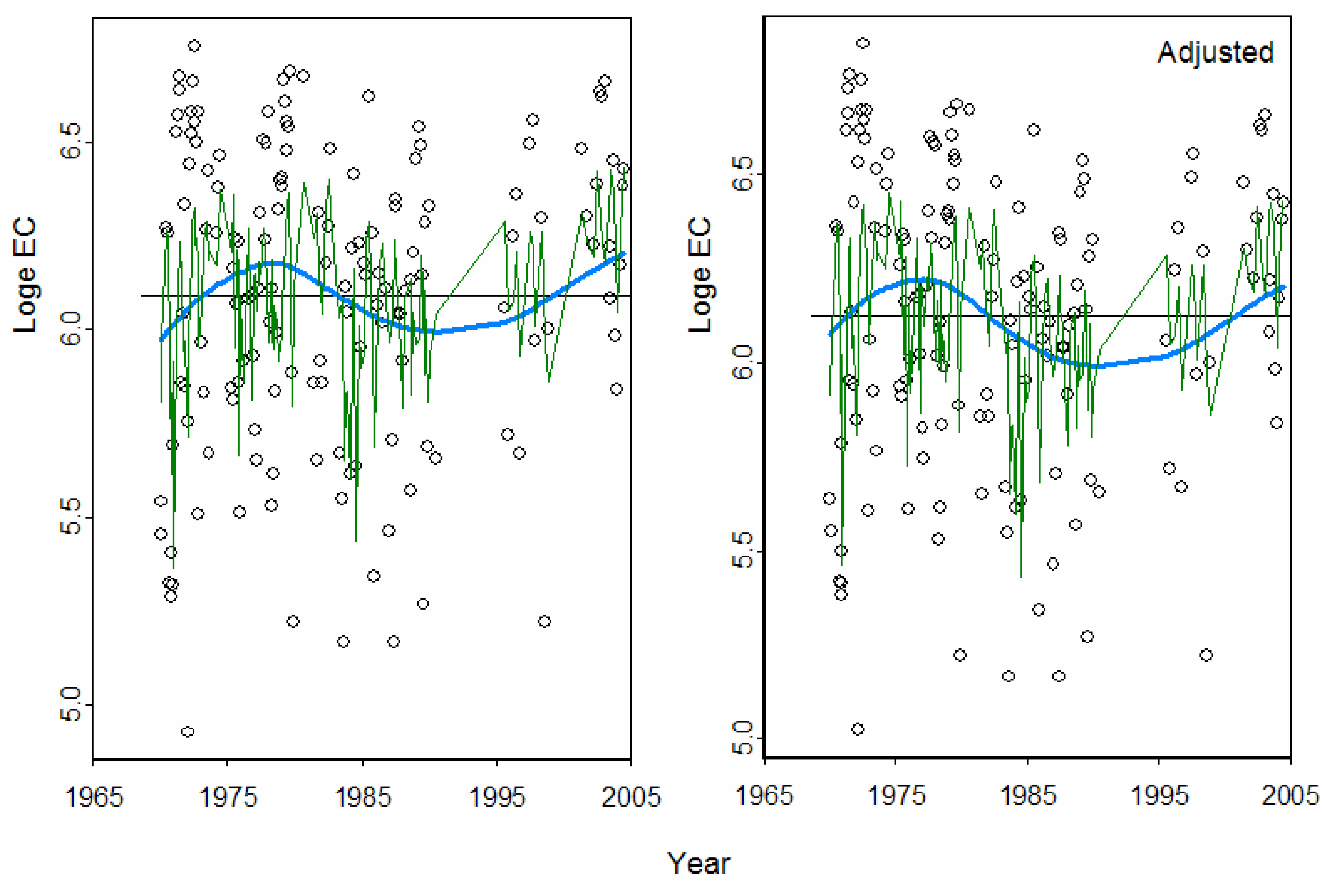
Appendix 2.35 416008 Beardy R at Haystack

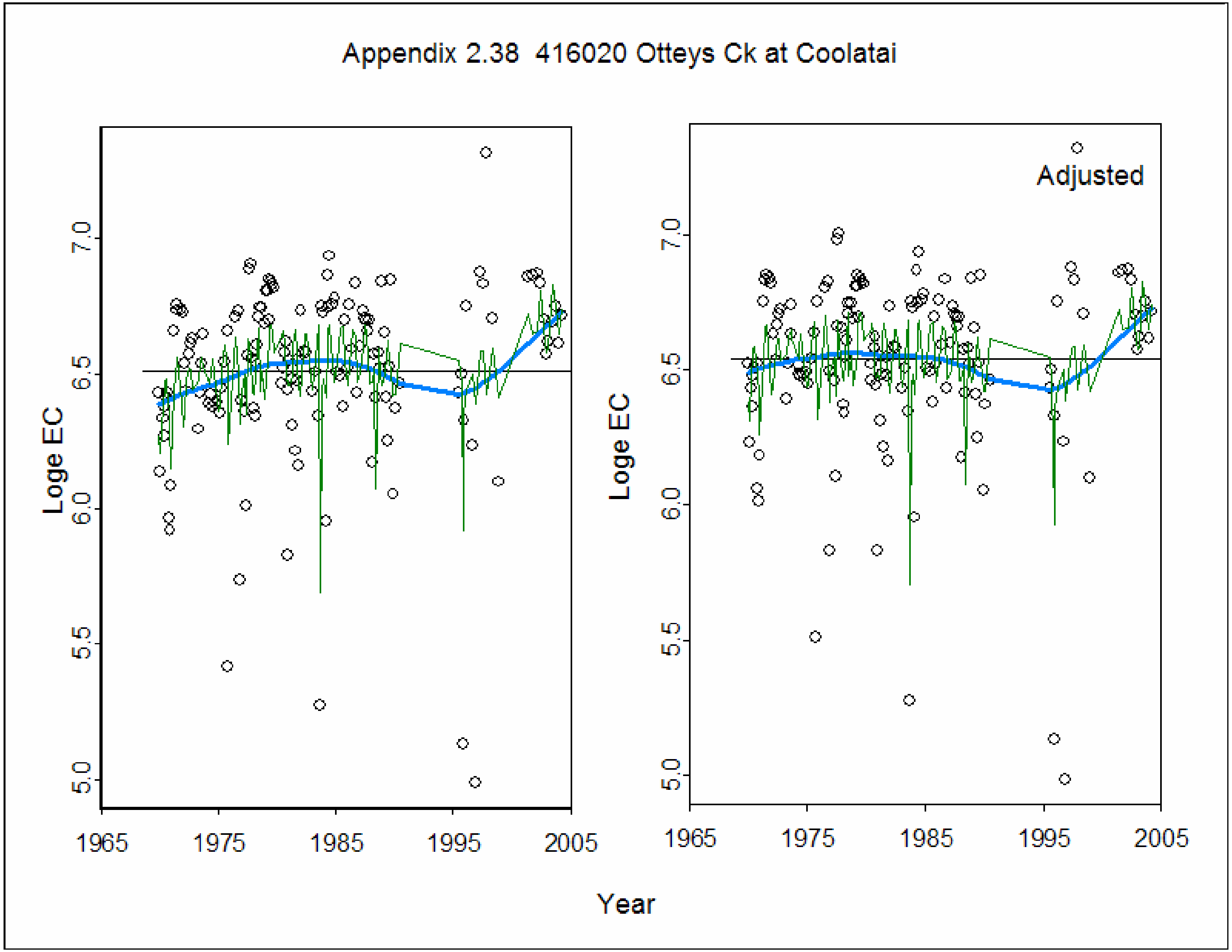


Appendix 2.36 416010 Macintyre R at Wallangara



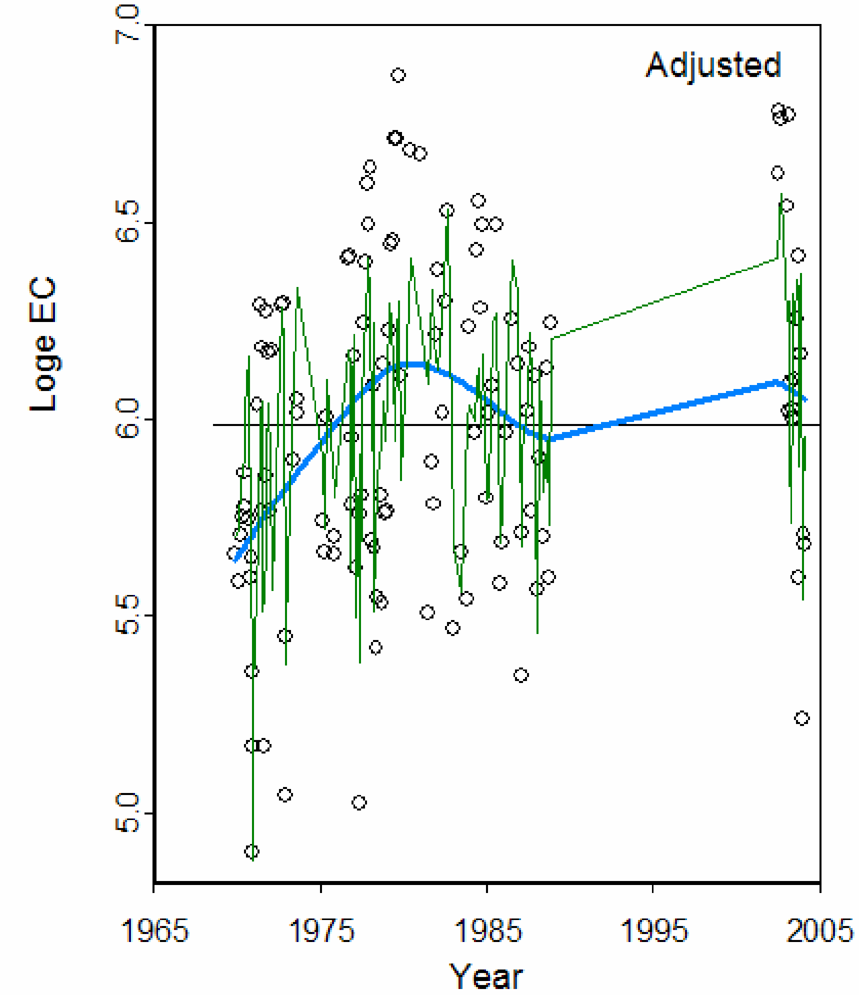
Appendix 2.37 416016 Macintyre R at Inverell



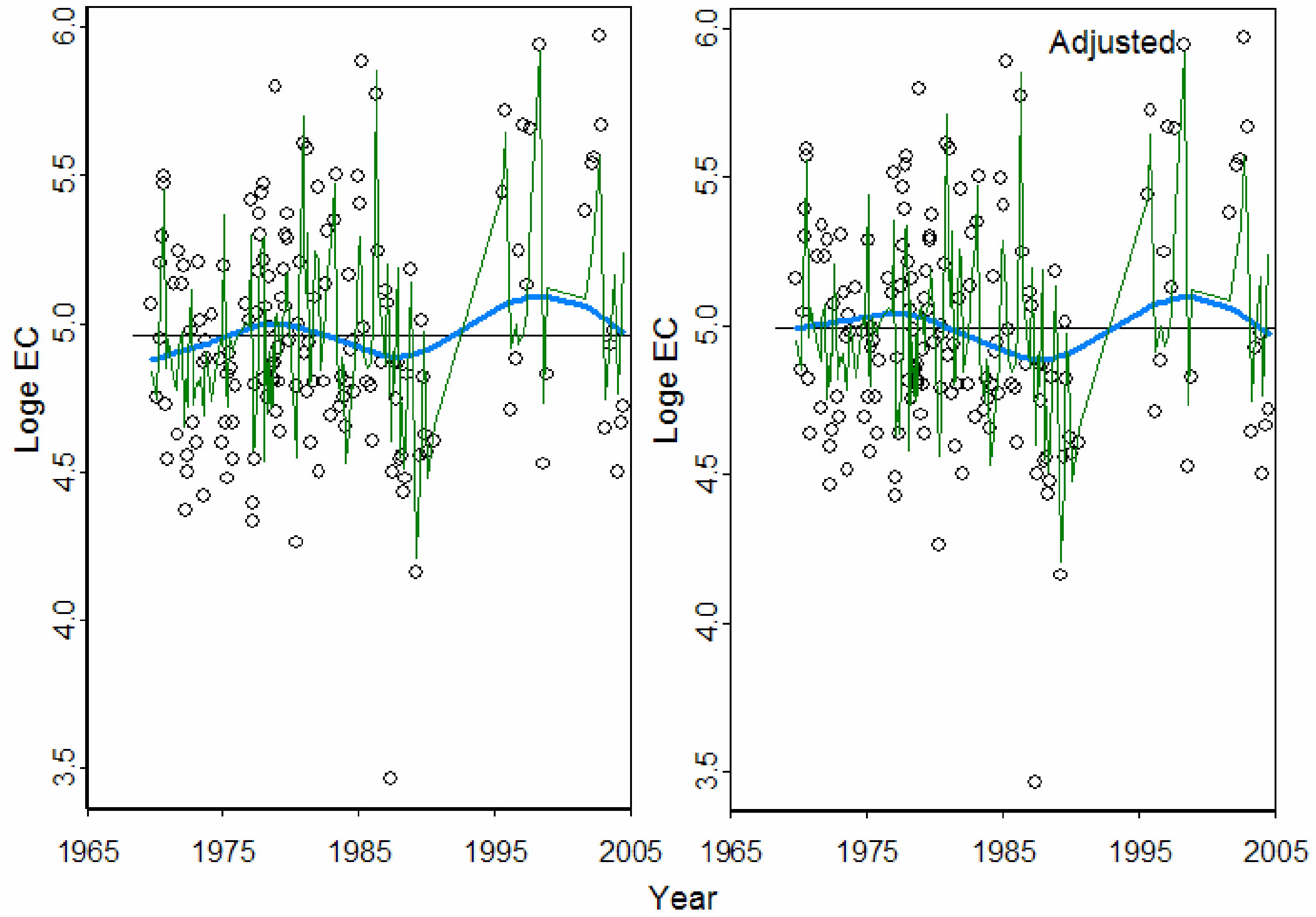


Appendix 2.38 416020 Otteys Ck at Coolatai

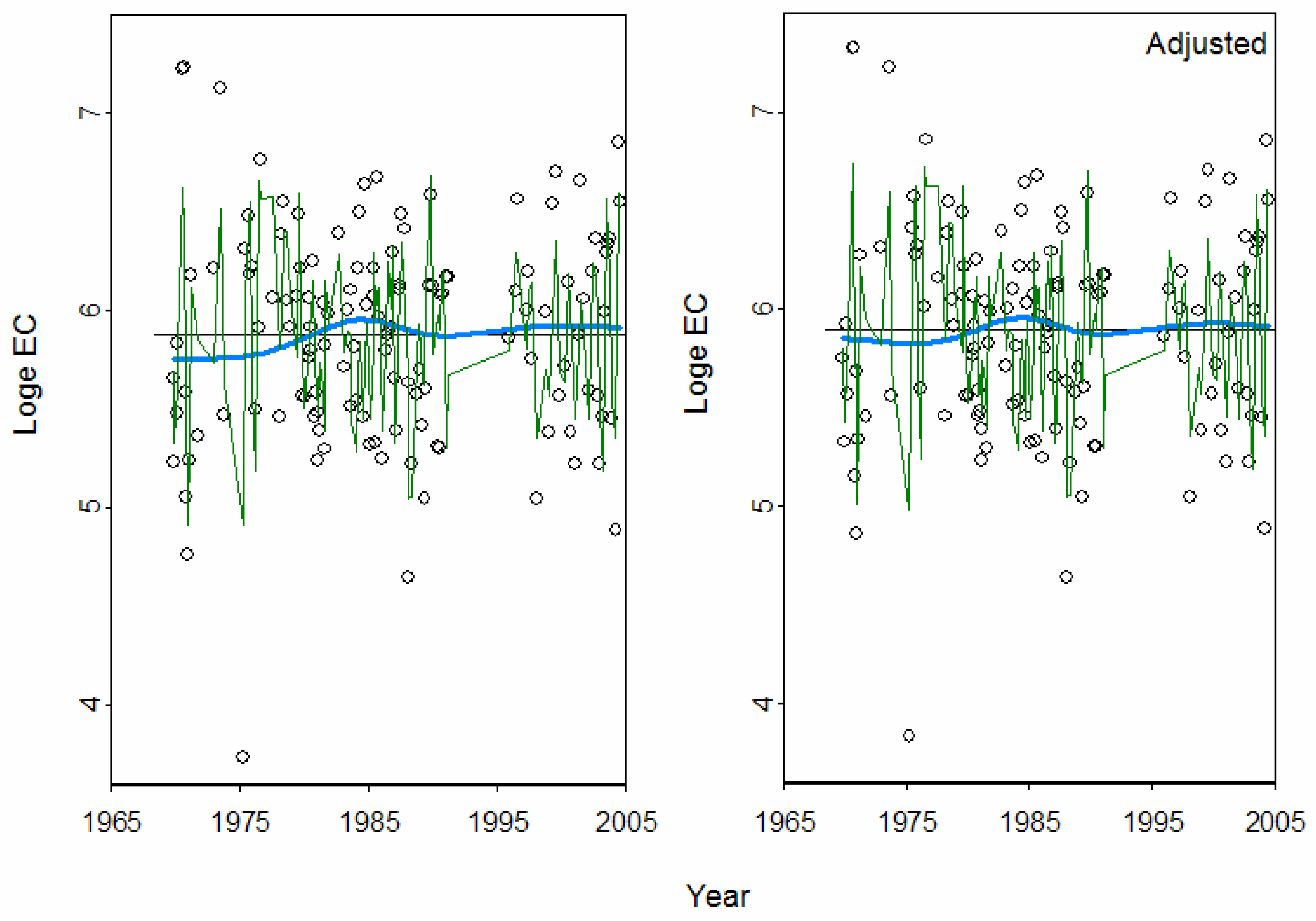
Appendix 2.39 416021 Frasers Ck at Ashford



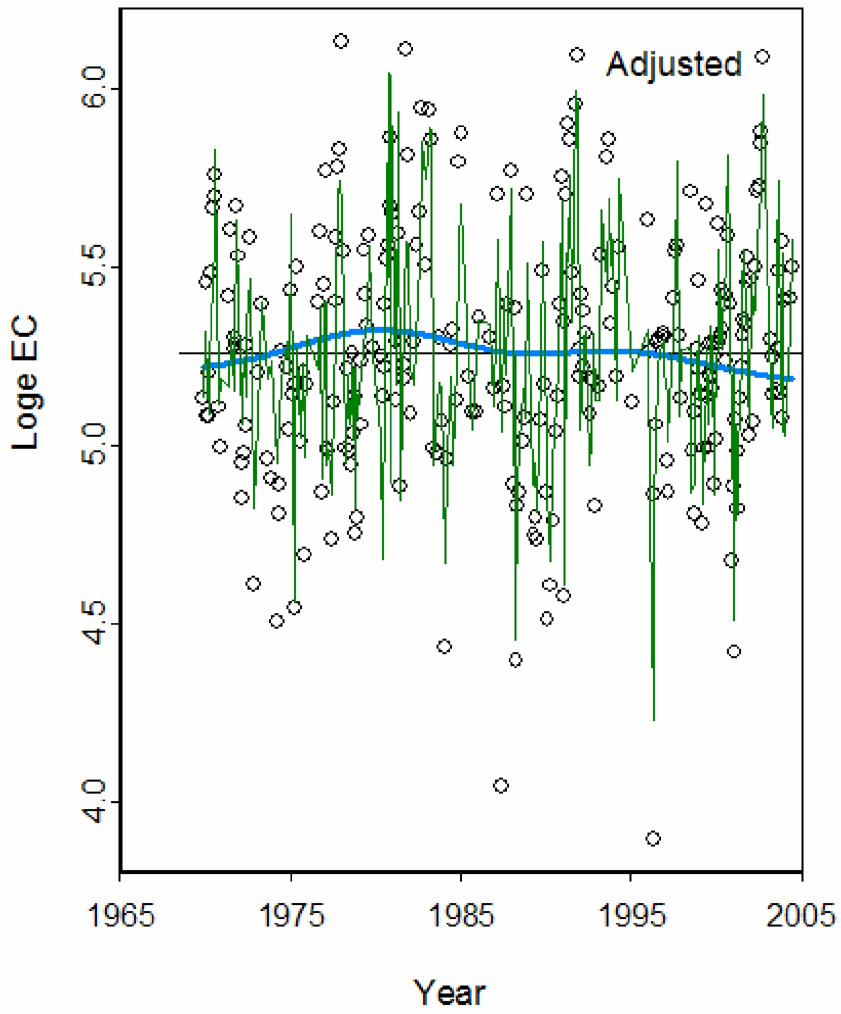
Appendix 2.40 416023 Deepwater Ck at Bolivia



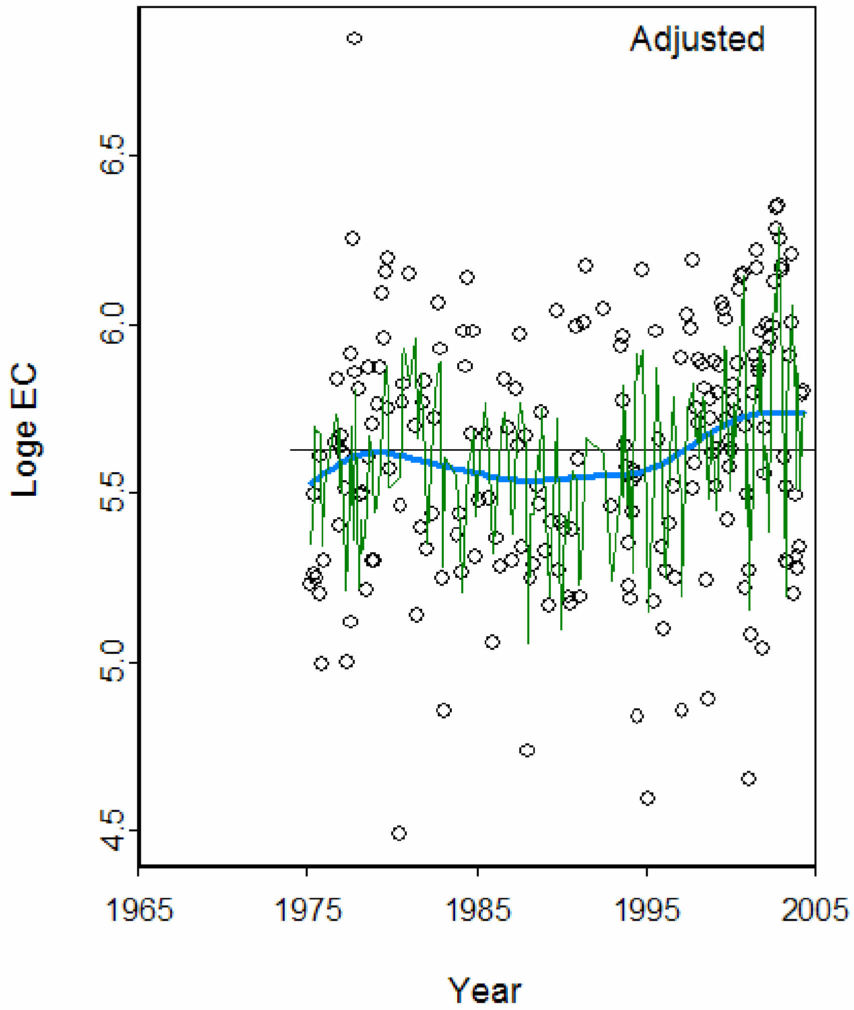
Appendix 2.41 416027 GilGil Ck at Weemelah



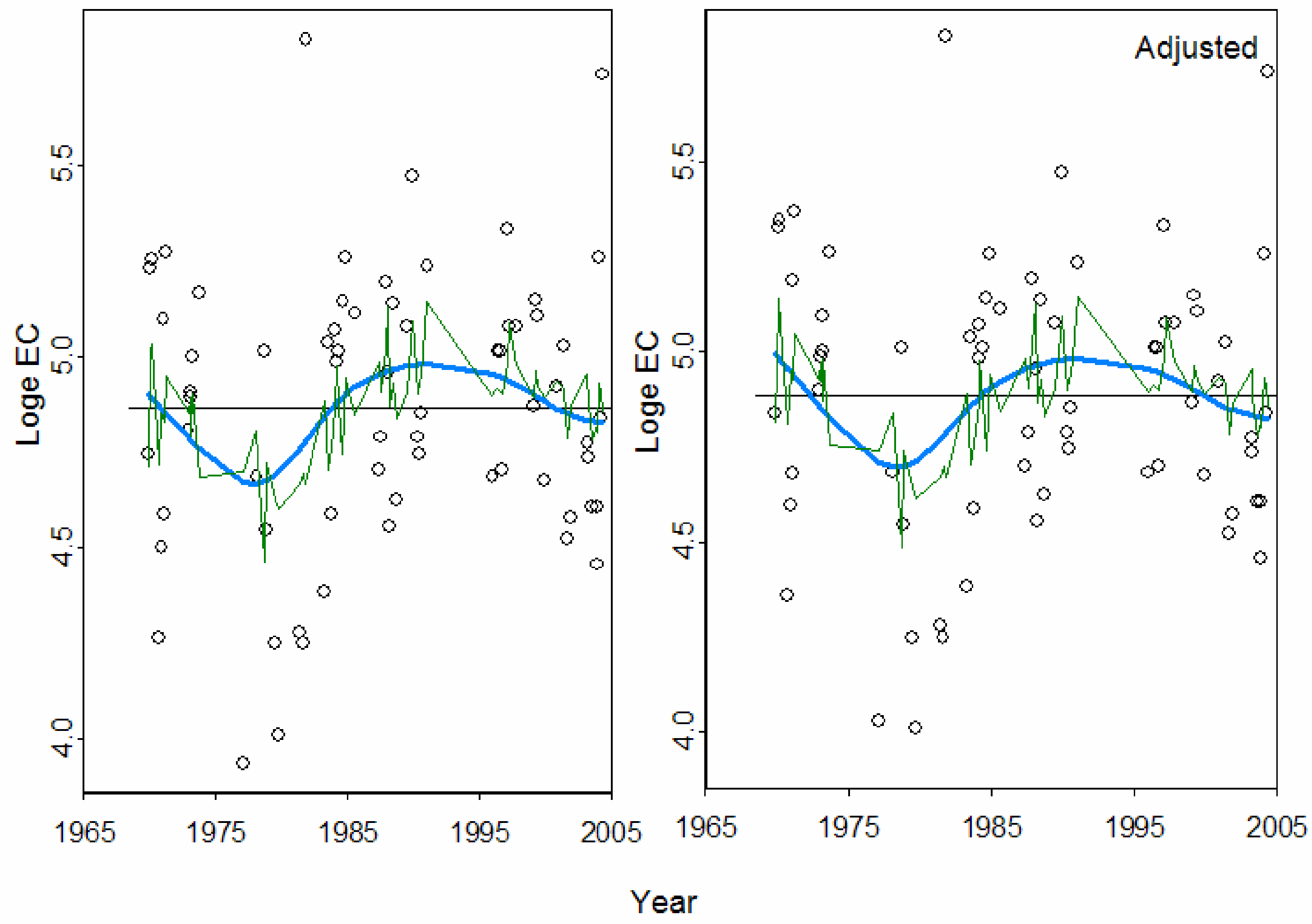
Appendix 2.42 416032 Mole R at Donaldson



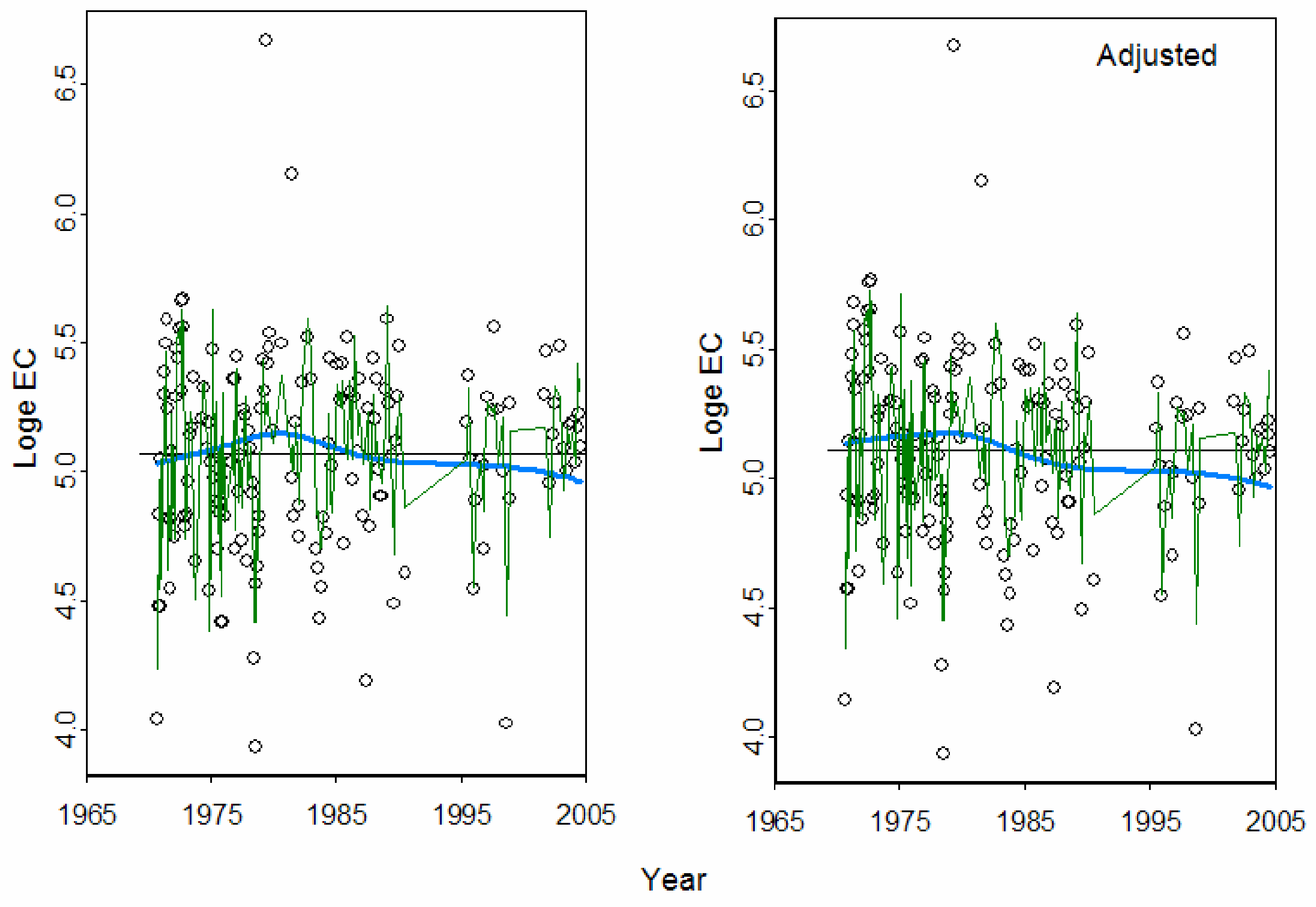
Appendix 2.43 416039 Severn R at Strathbogie



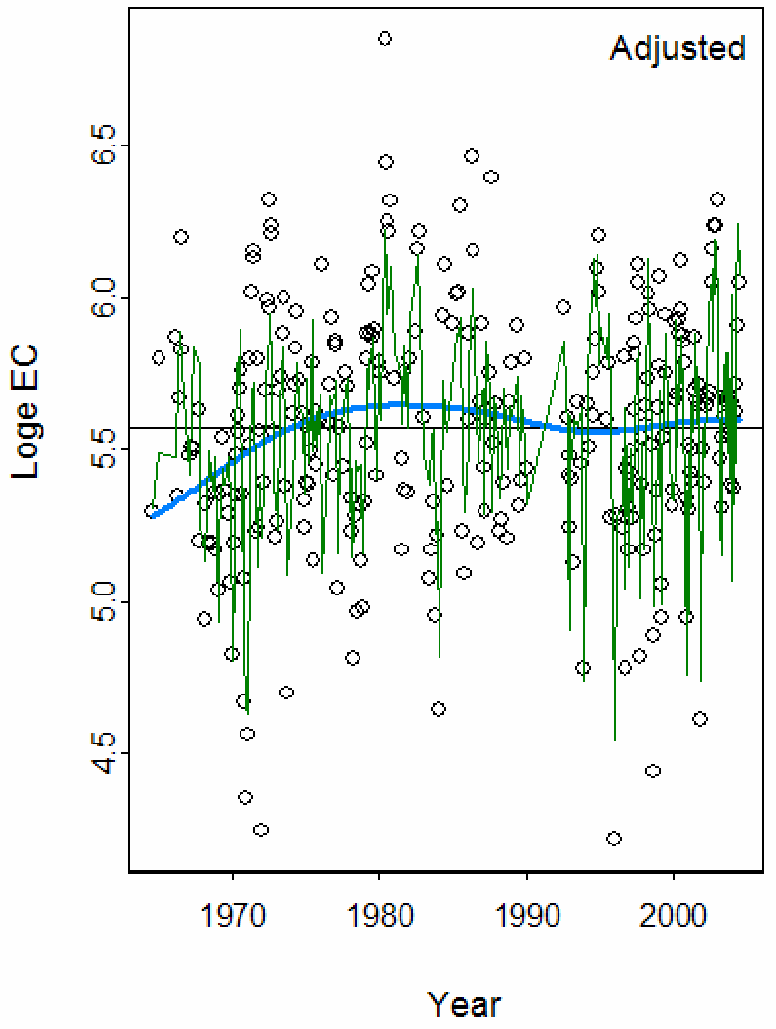
Appendix 2.44 417001 Moonie R at Gundablouie



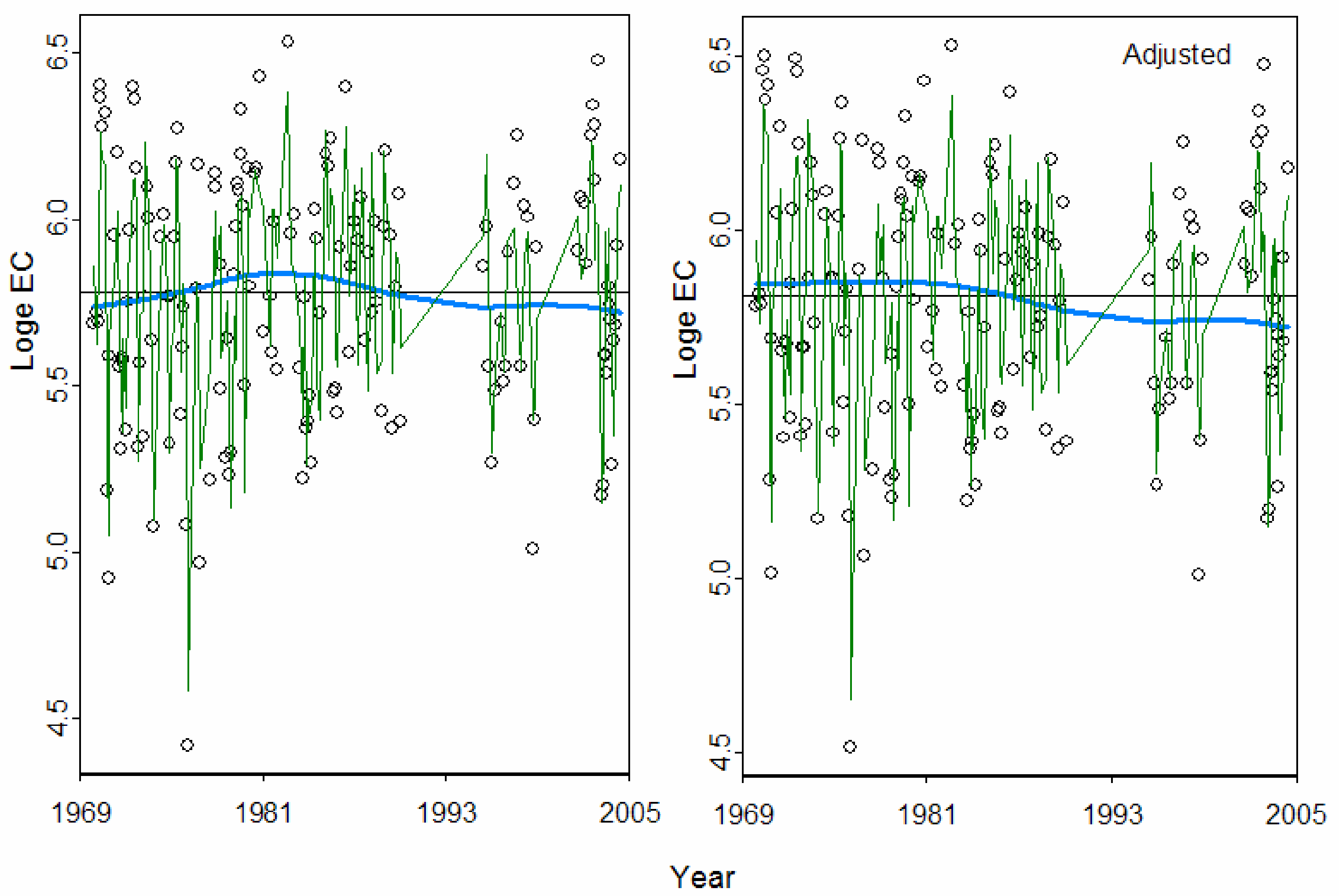
Appendix 2.45 418005 Copes Ck at Kimberley



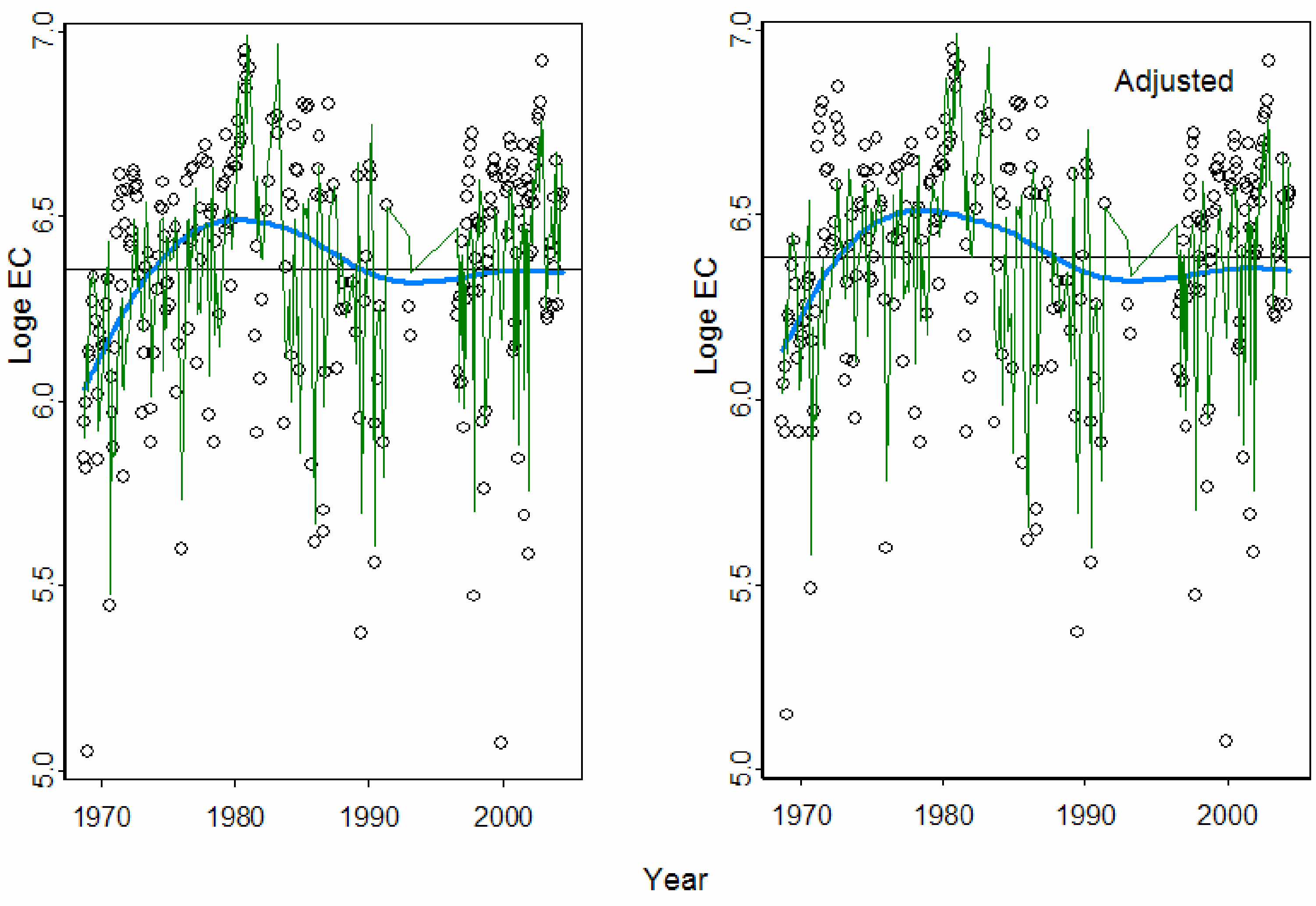
Appendix 2.46 418008 Gwydir R at Bundarra



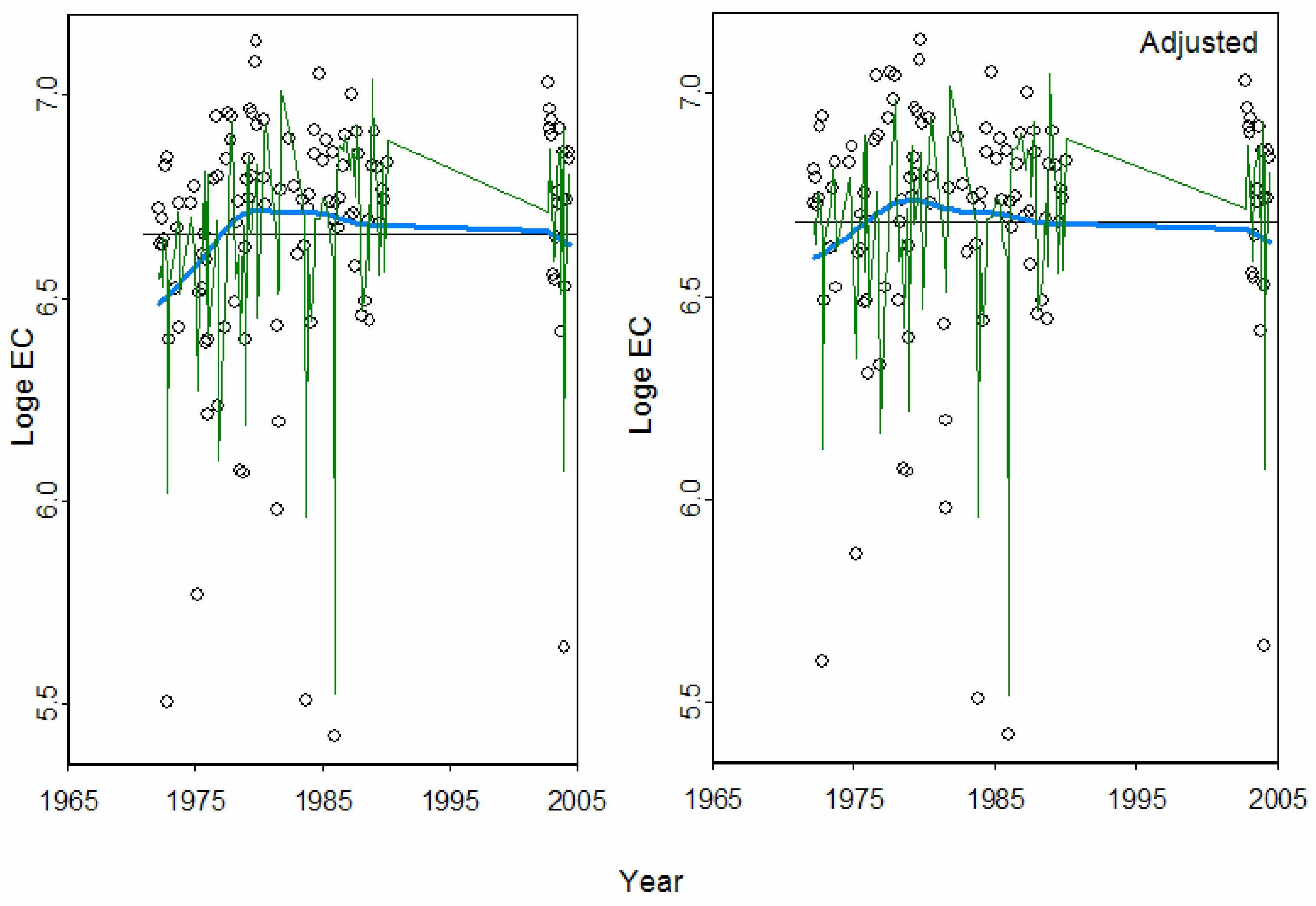
Appendix 2.47 418014 Gwydir R at Yarrowych



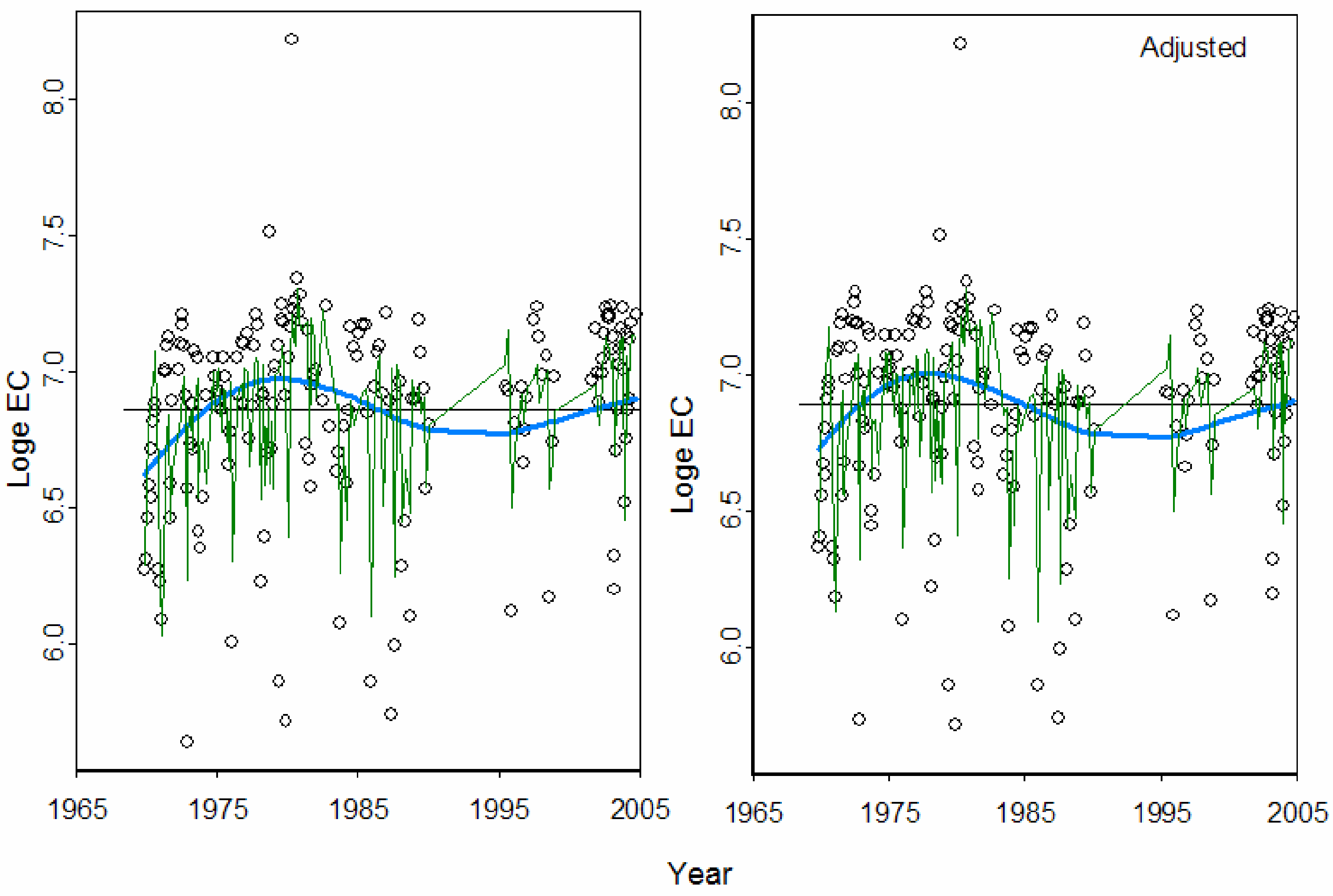
Appendix 2.48 418015 Horton R at Killara / Rider

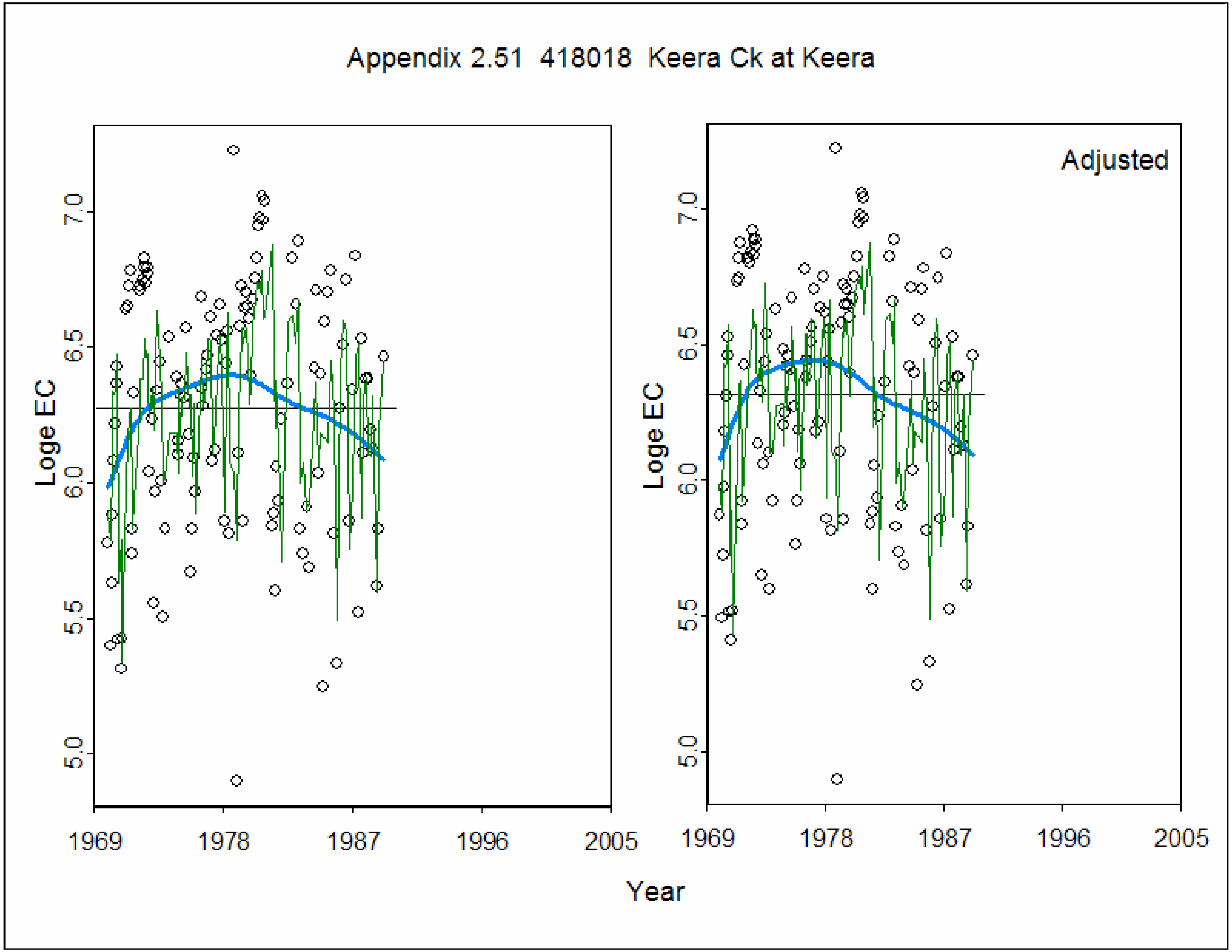


Appendix 2.49 418016 Warialda Ck at Warialda

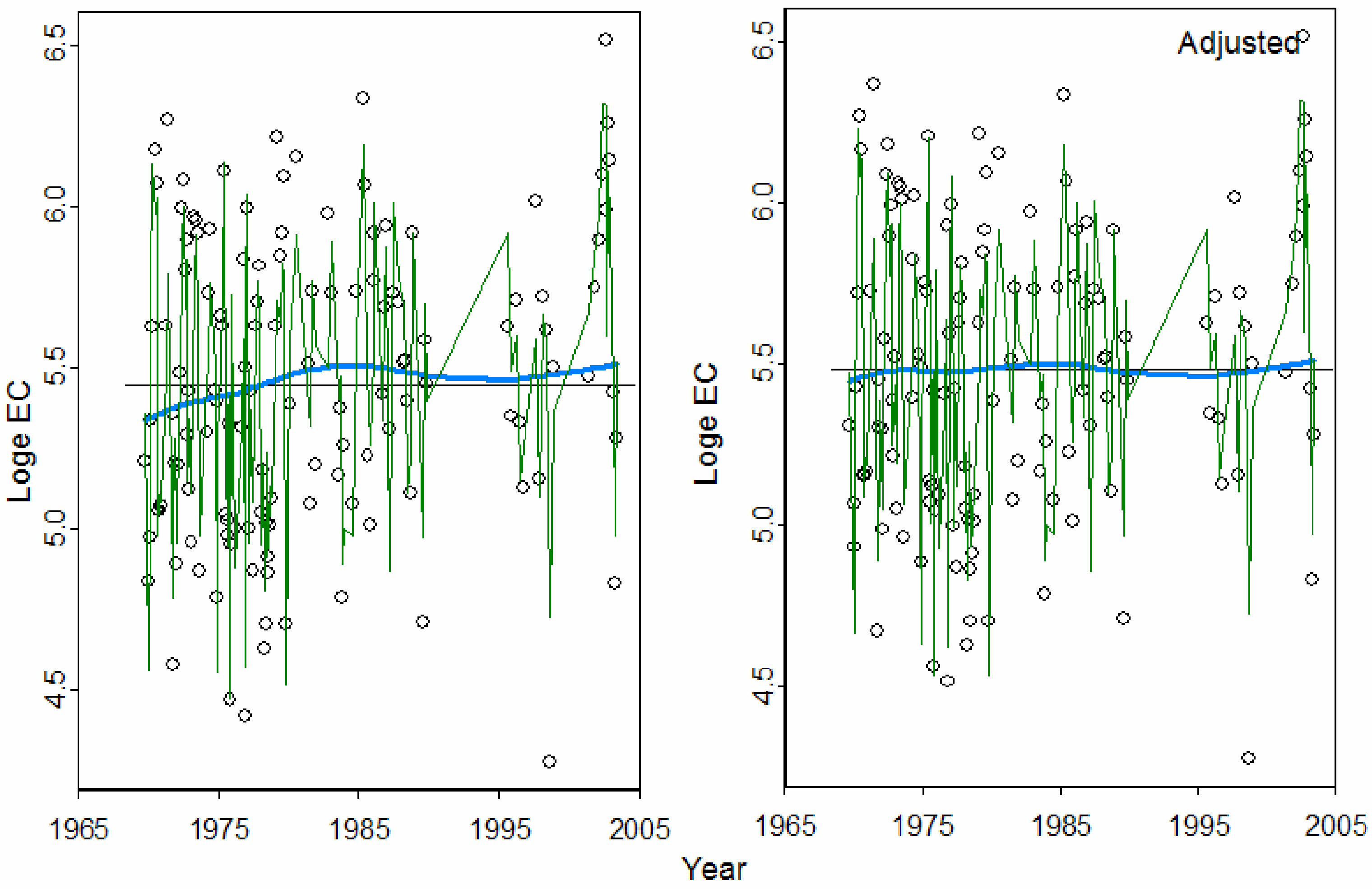


Appendix 2.50 418017 Myall Ck at Molroy

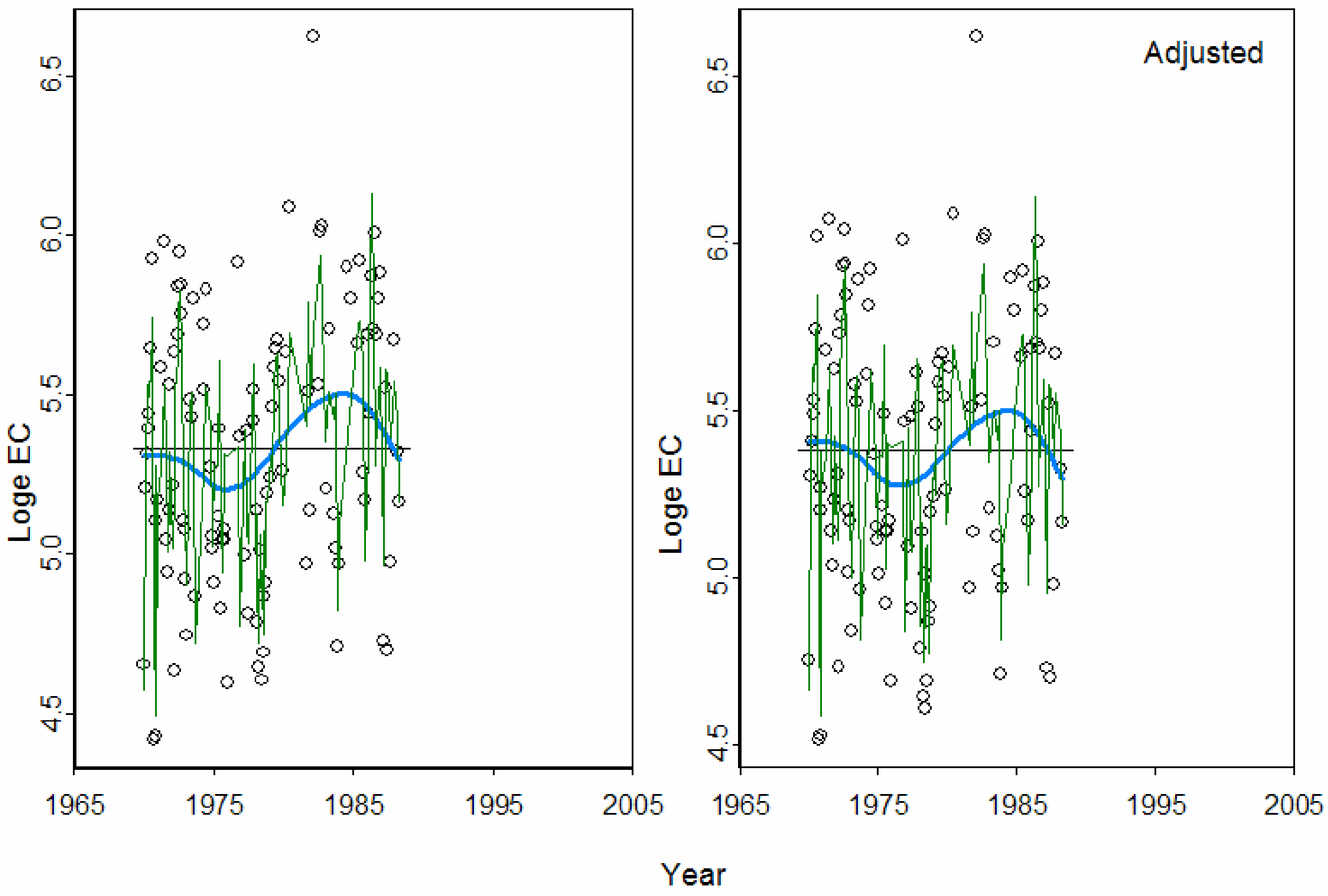



Appendix 2.51 418018 Keera Ck at Keera
Adjusted
Loge EC
Loge EC
7.0
6.5
6.0
5.5
5.0
1969
1978
1987
1996
2005
Year

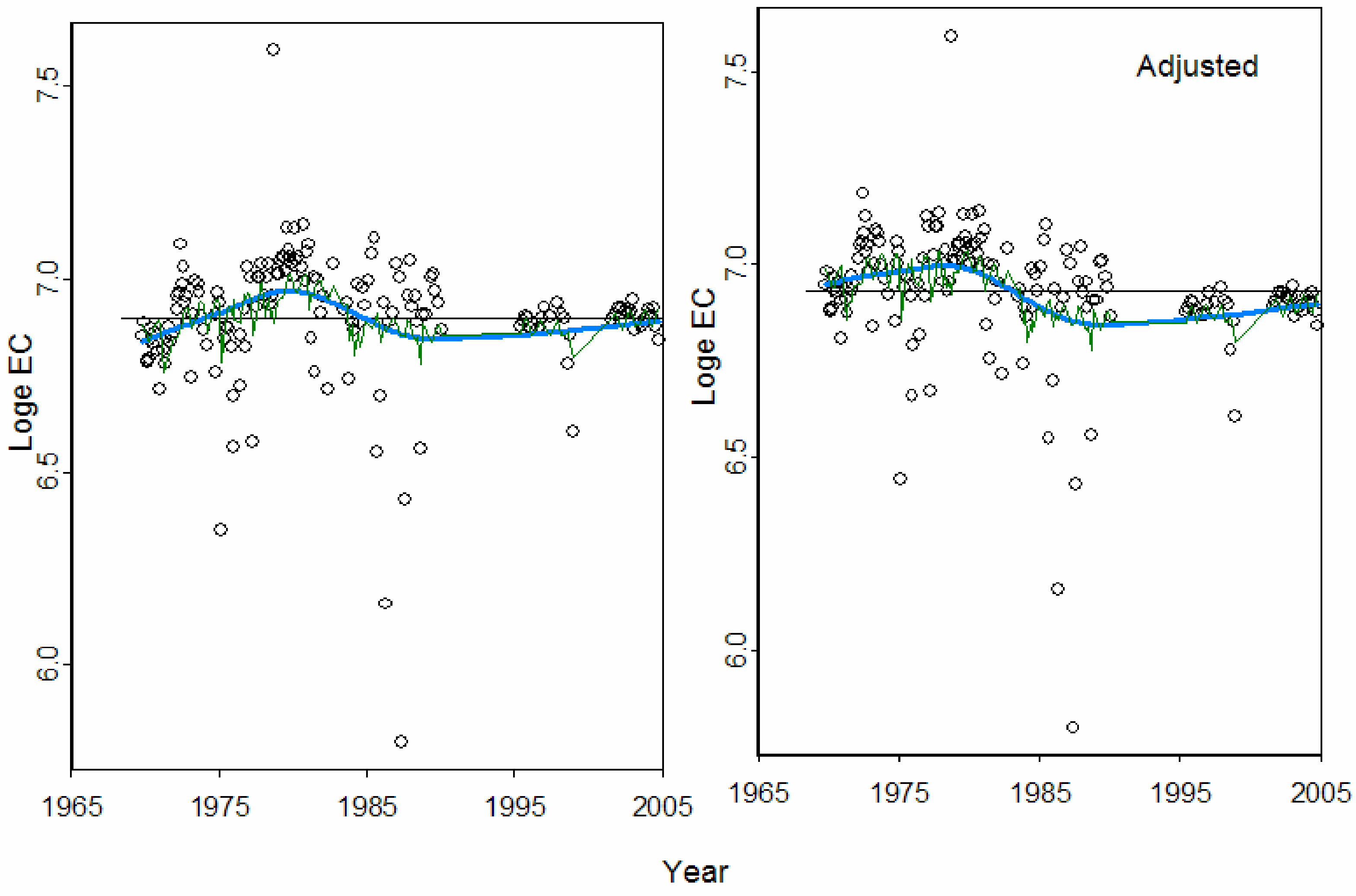
Appendix 2.52 418021 Laura Ck at Laura



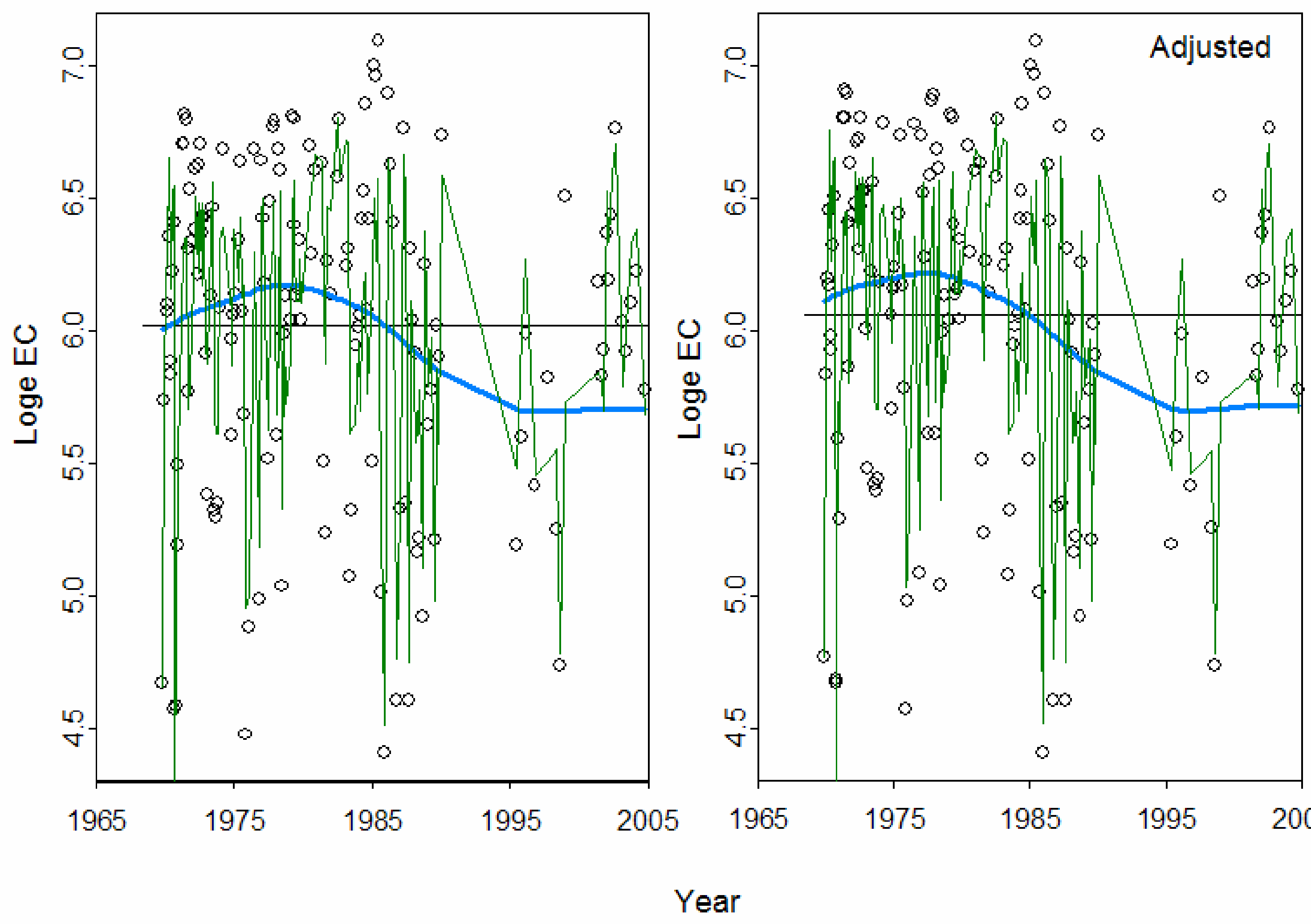
Appendix 2.53 418023 Moredun Ck at Bundarra



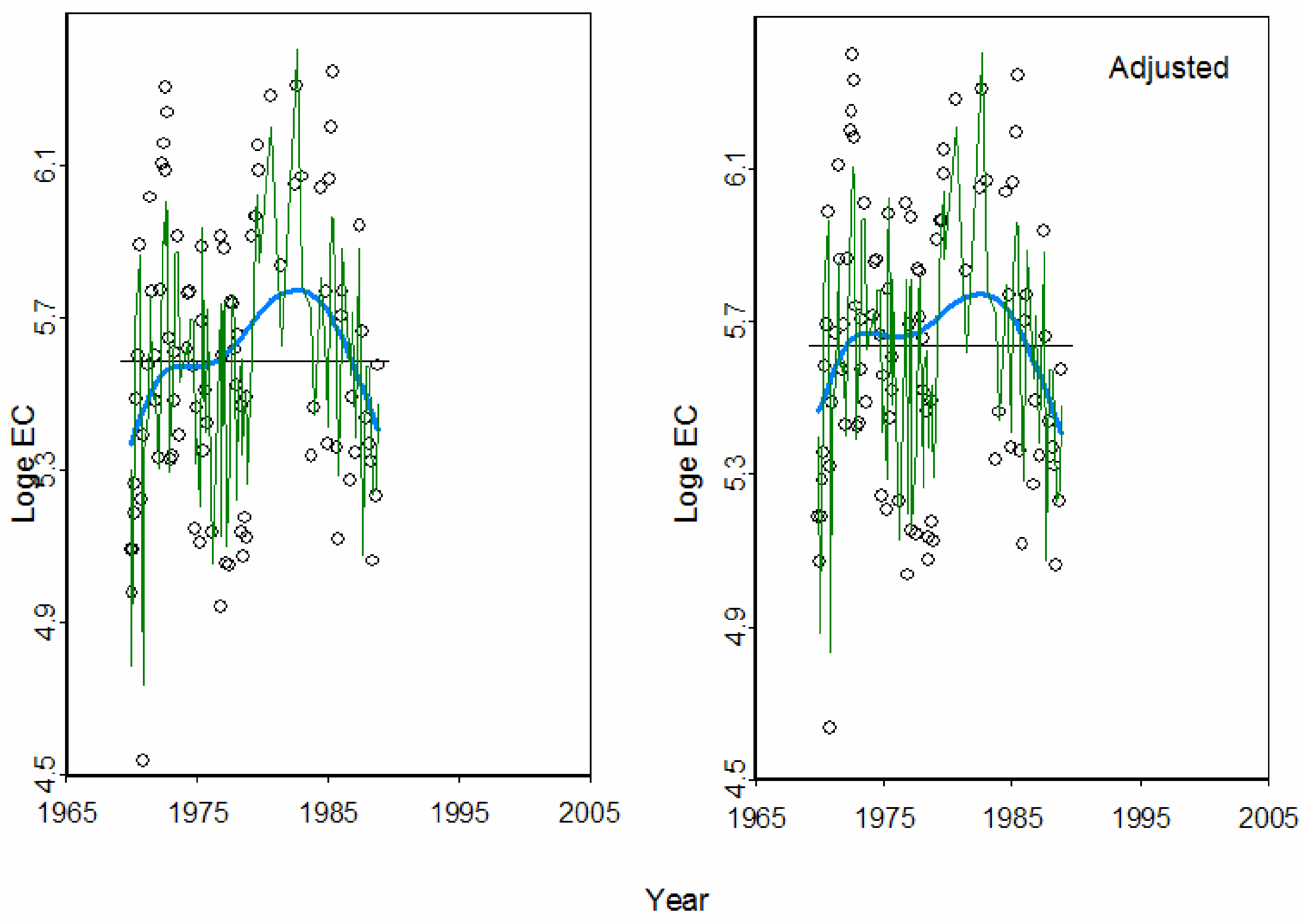
Appendix 2.54 418025 Halls Ck at Bingara



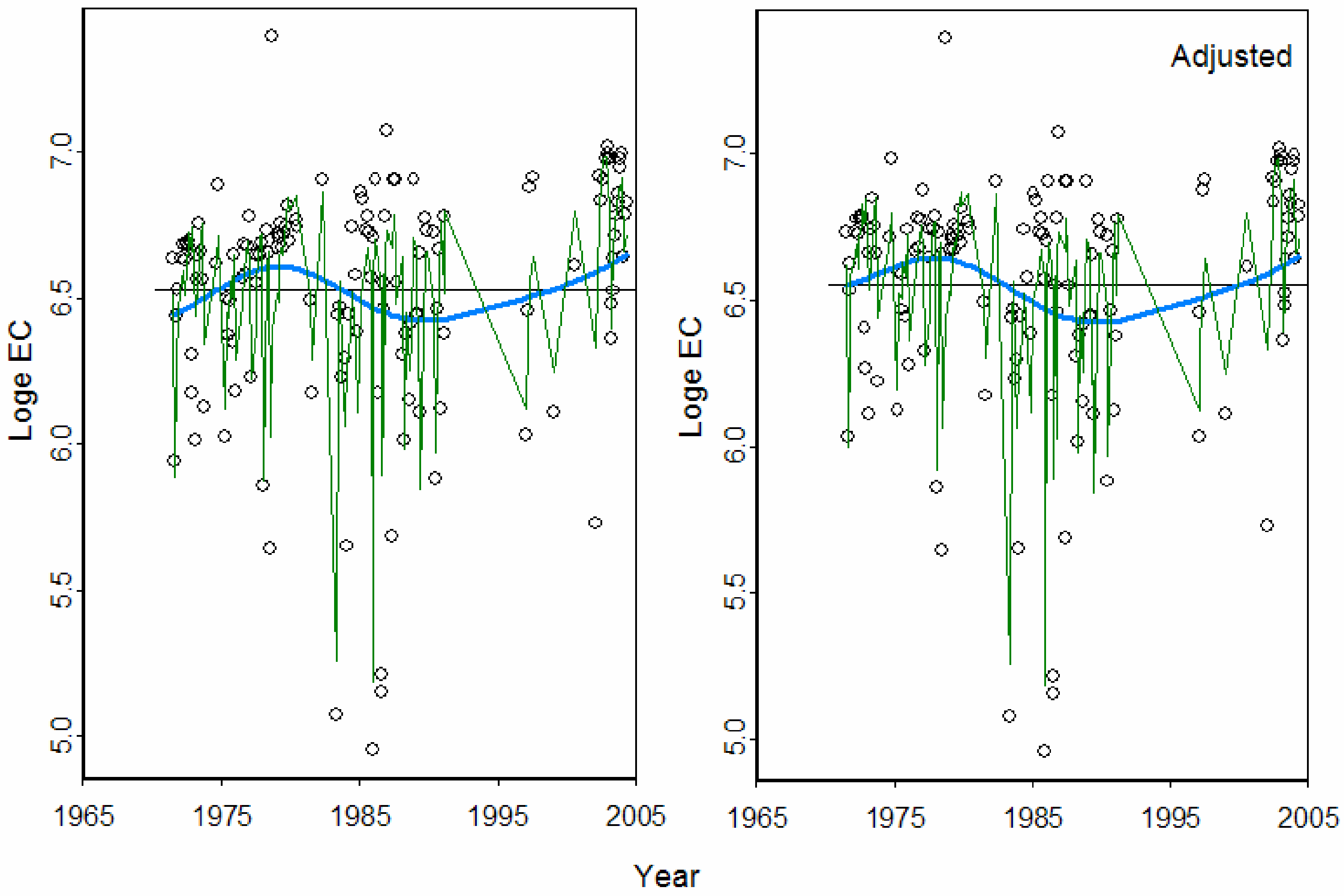
Appendix 2.55 418027 Horton R at Horton Dam Site



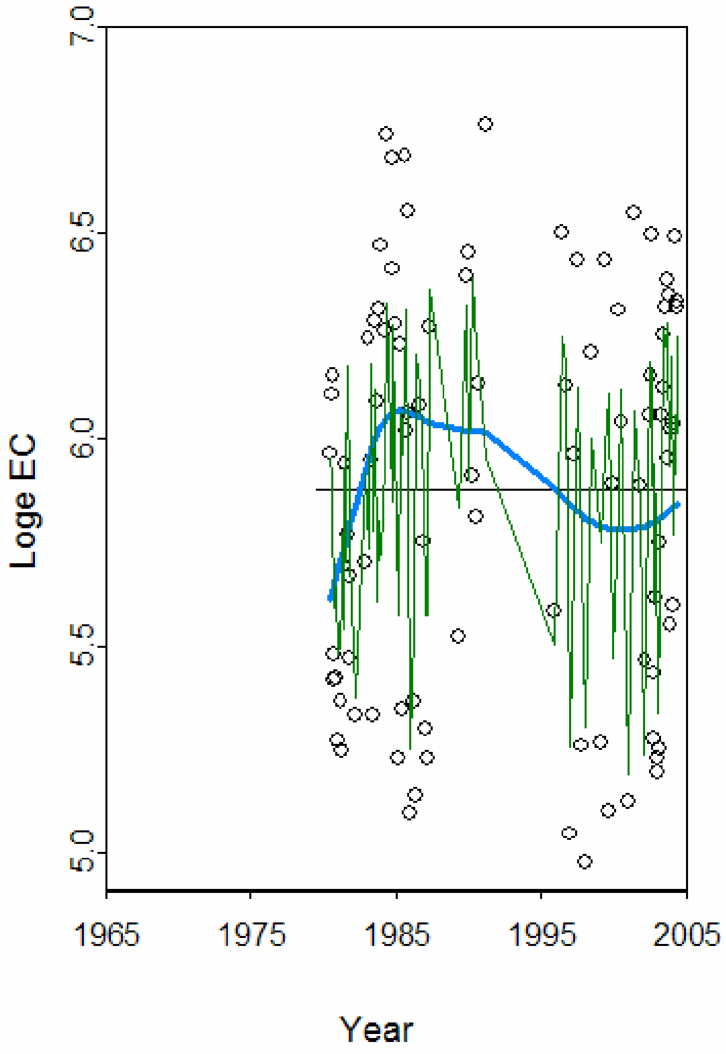
Appendix 2.56 418029 Gwydir R at Stonybatter



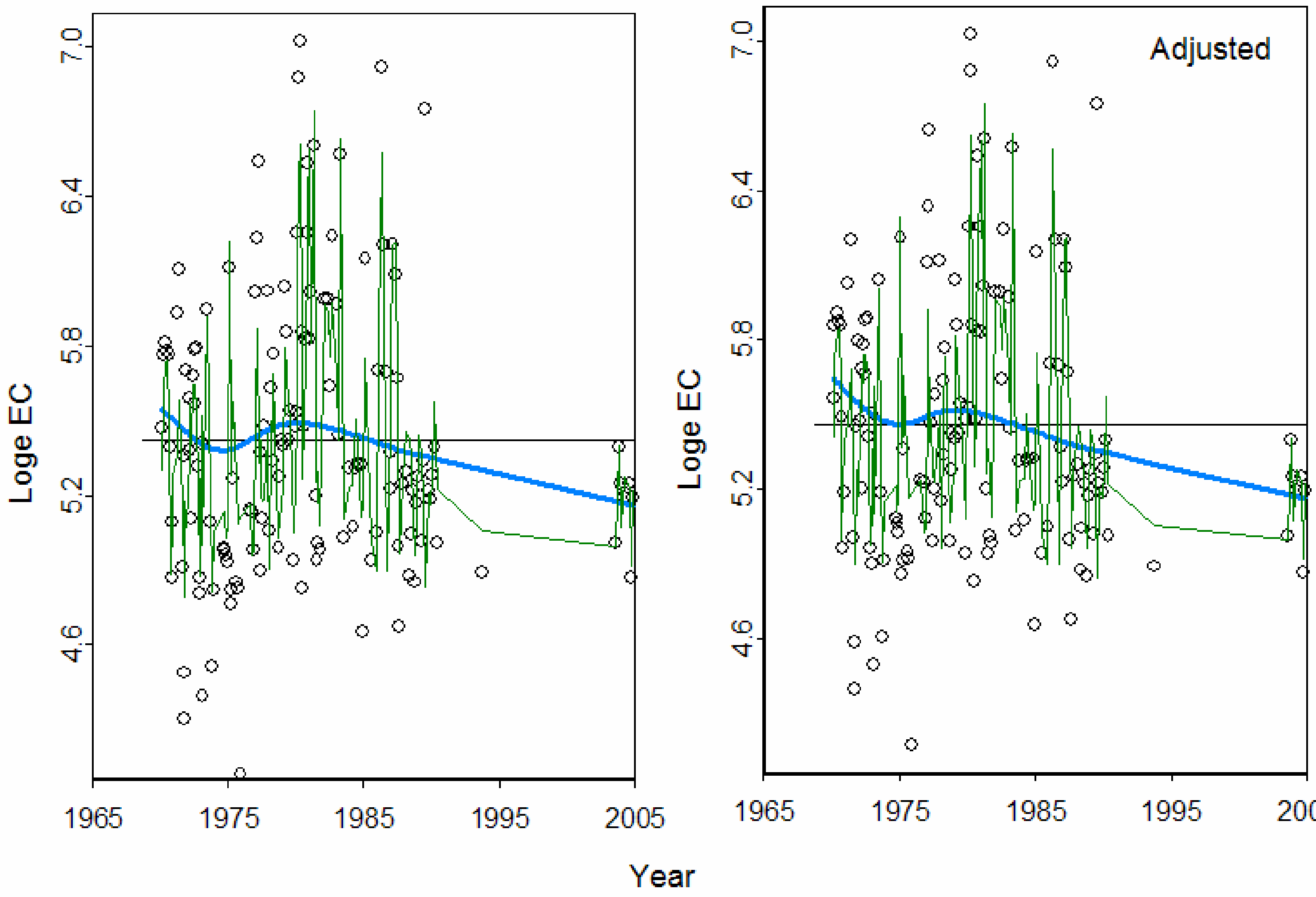
Appendix 2.57 418032 Tycannah Ck at Horseshoe Lagoon



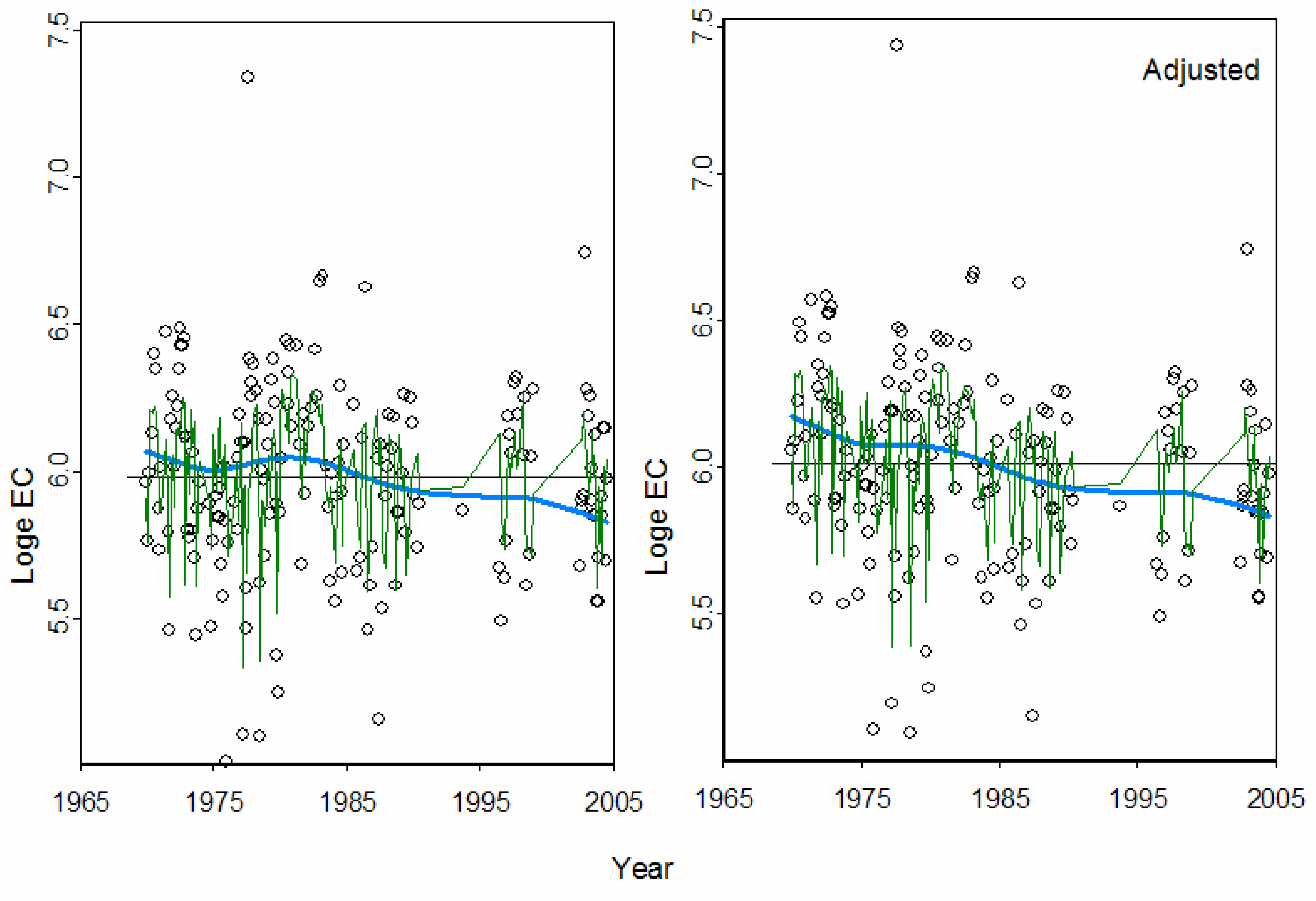
Appendix 2.58 418052 Carole Ck. Nr Garah



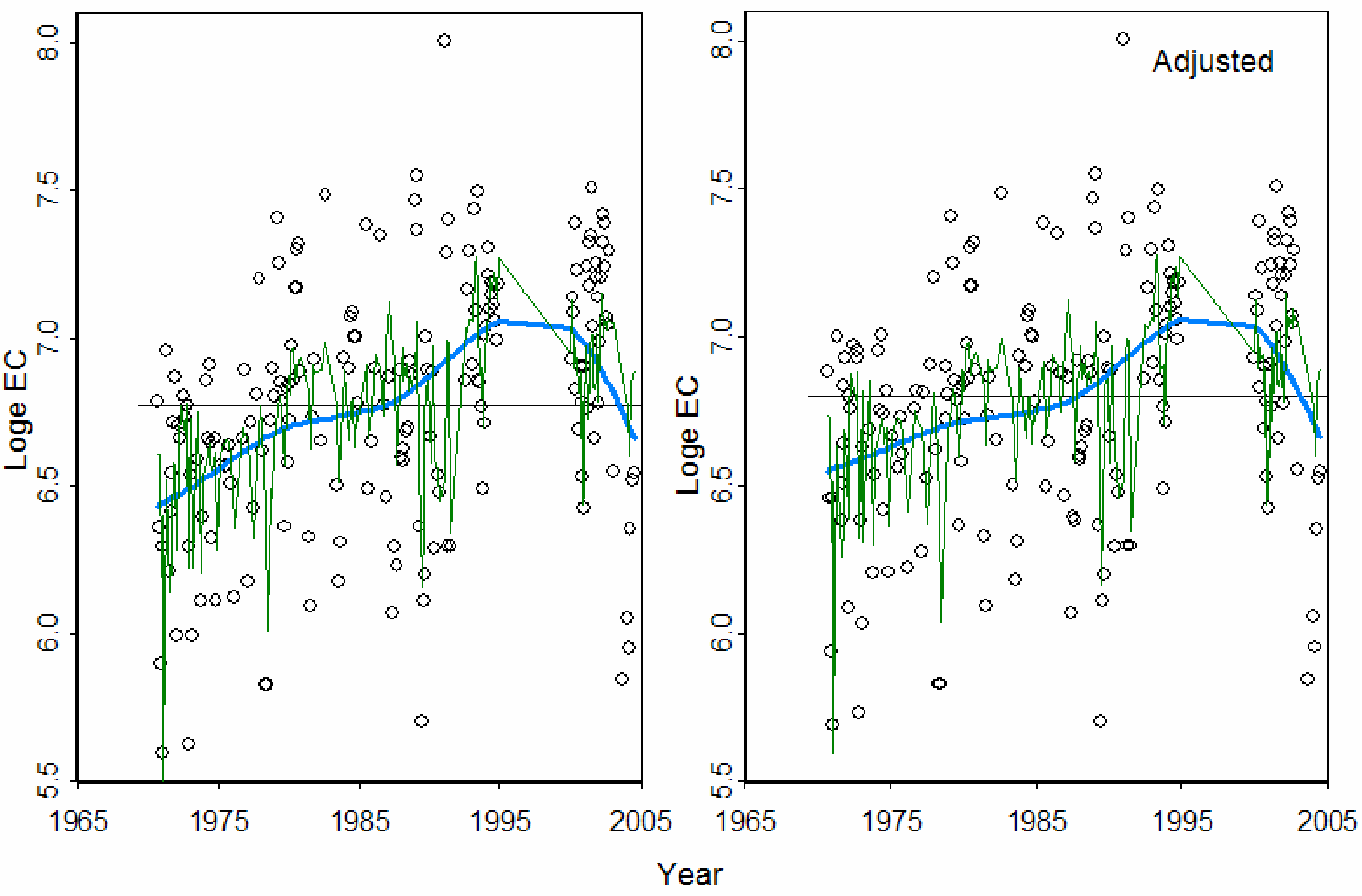
Appendix 2.59 419005 Namoi R at Nth Cuerindi



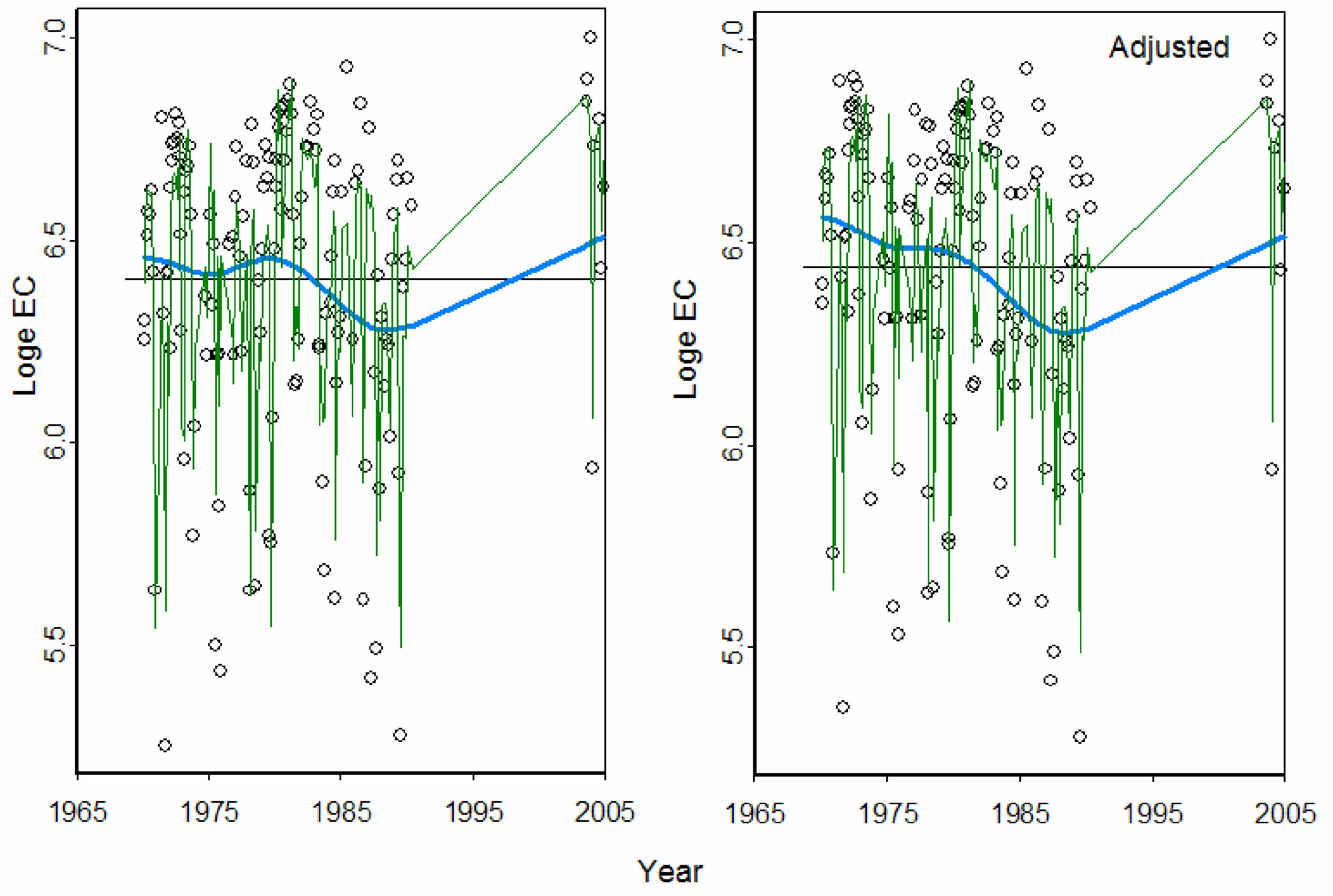
Appendix 2.60 419016 Cockburn R at Mulla Crossing



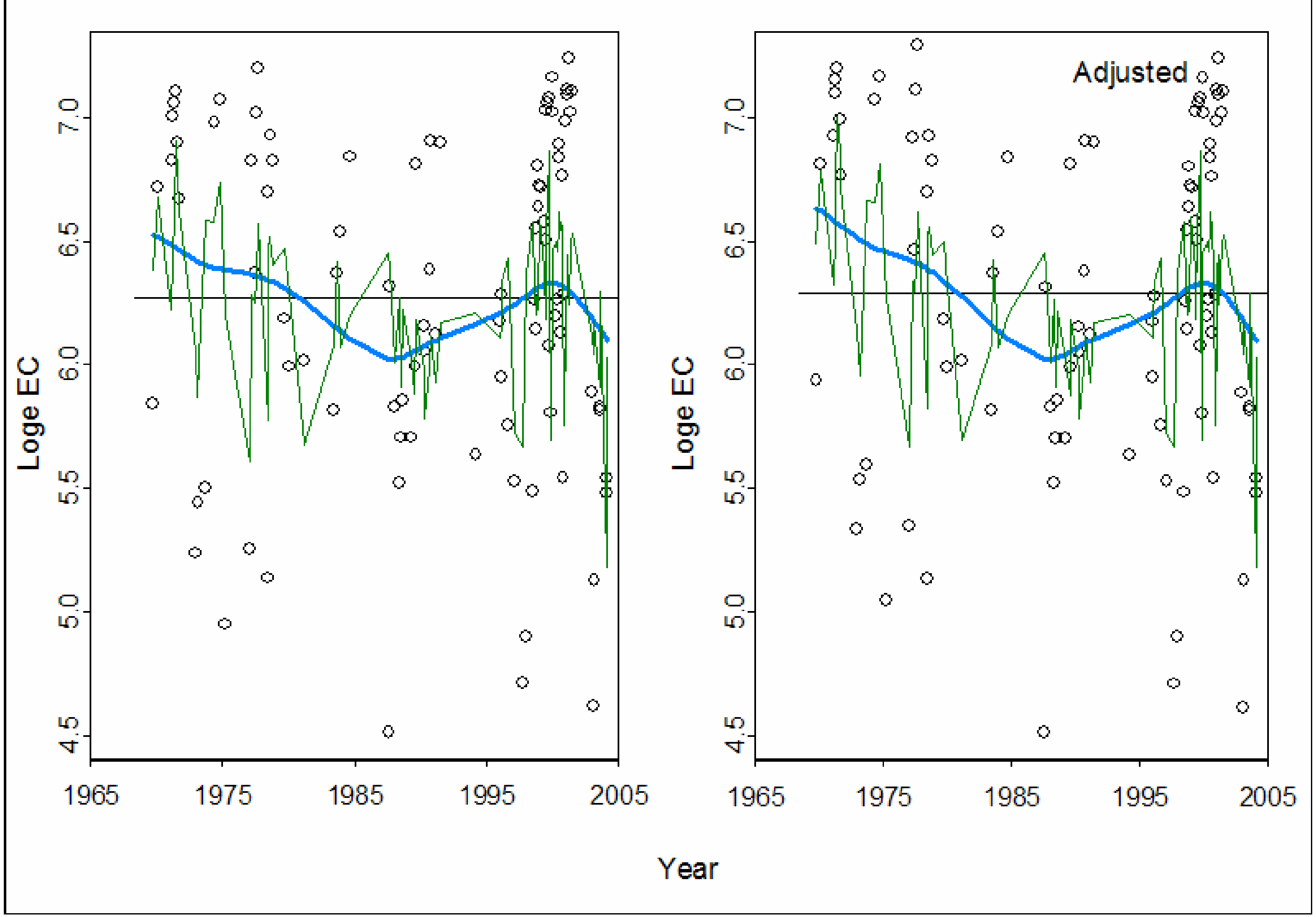
Appendix 2.61 419027 Mooki R at Breeza



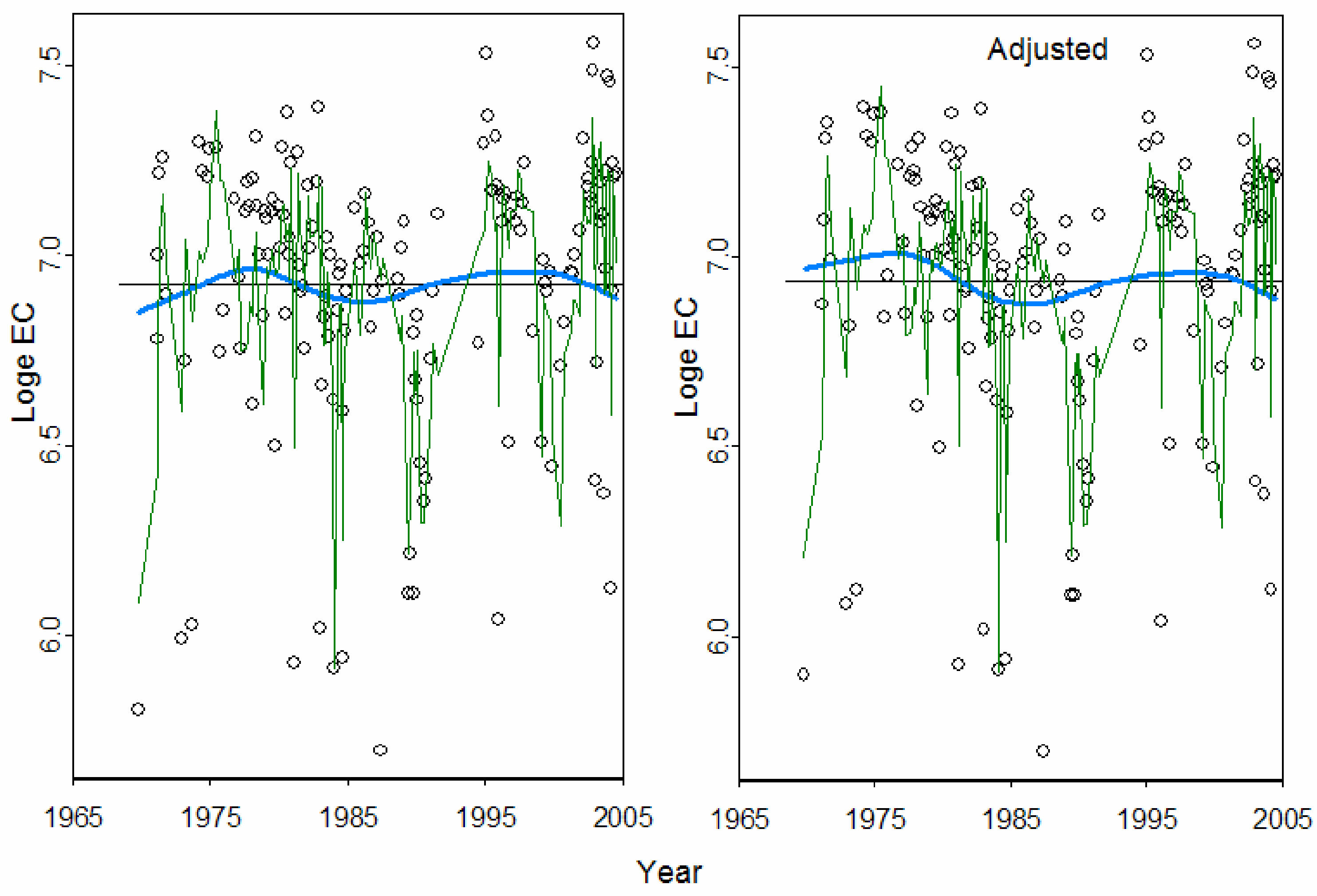
Appendix 2.62 419029 Halls Ck at Ukalon



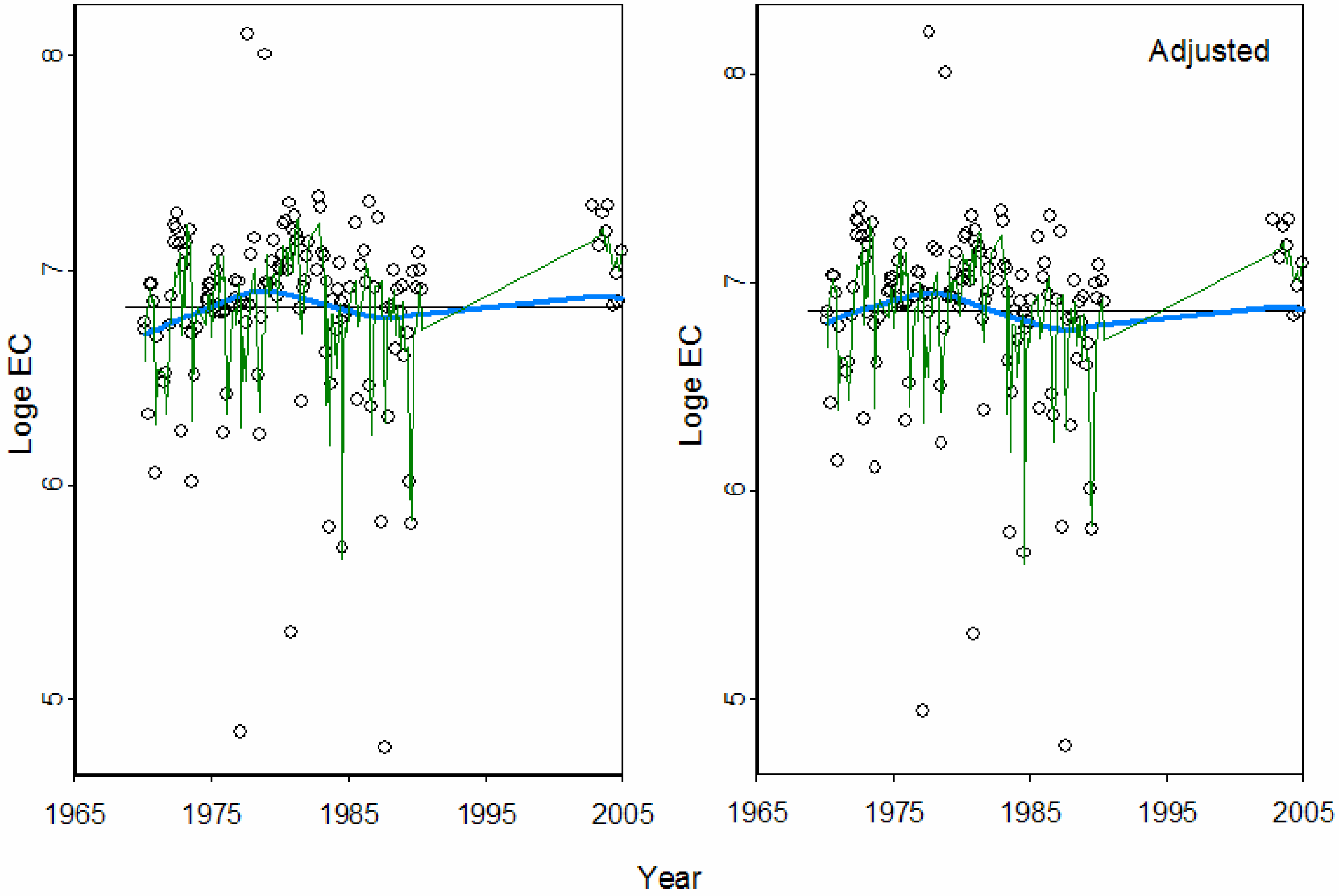
Appendix 2.63 419032 Coxs Ck at Boggabri



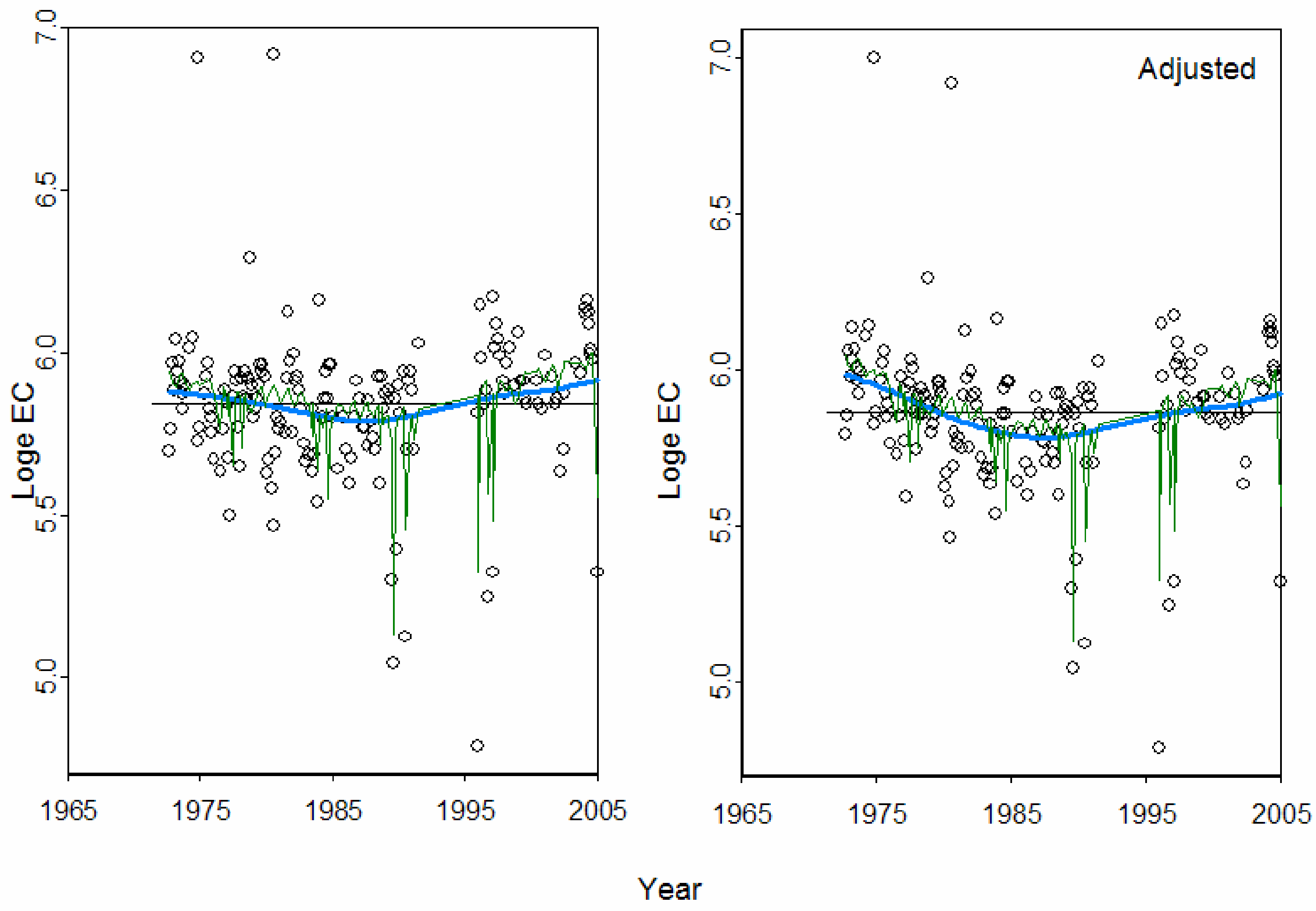
Appendix 2.64 419033 Coxs Ck at Tambar Springs



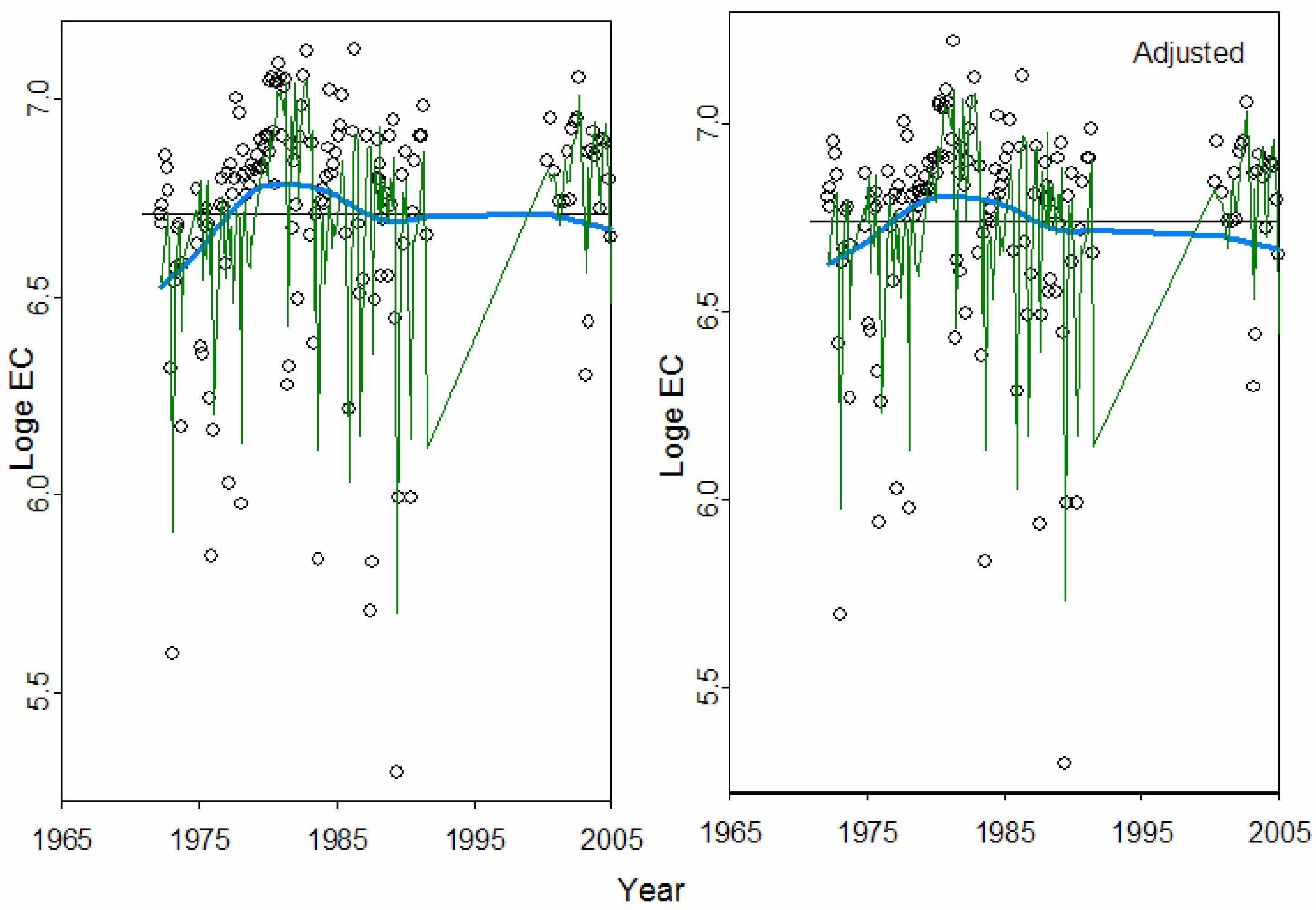
Appendix 2.65 419035 Goonoo Goonoo Ck at Timbumburi



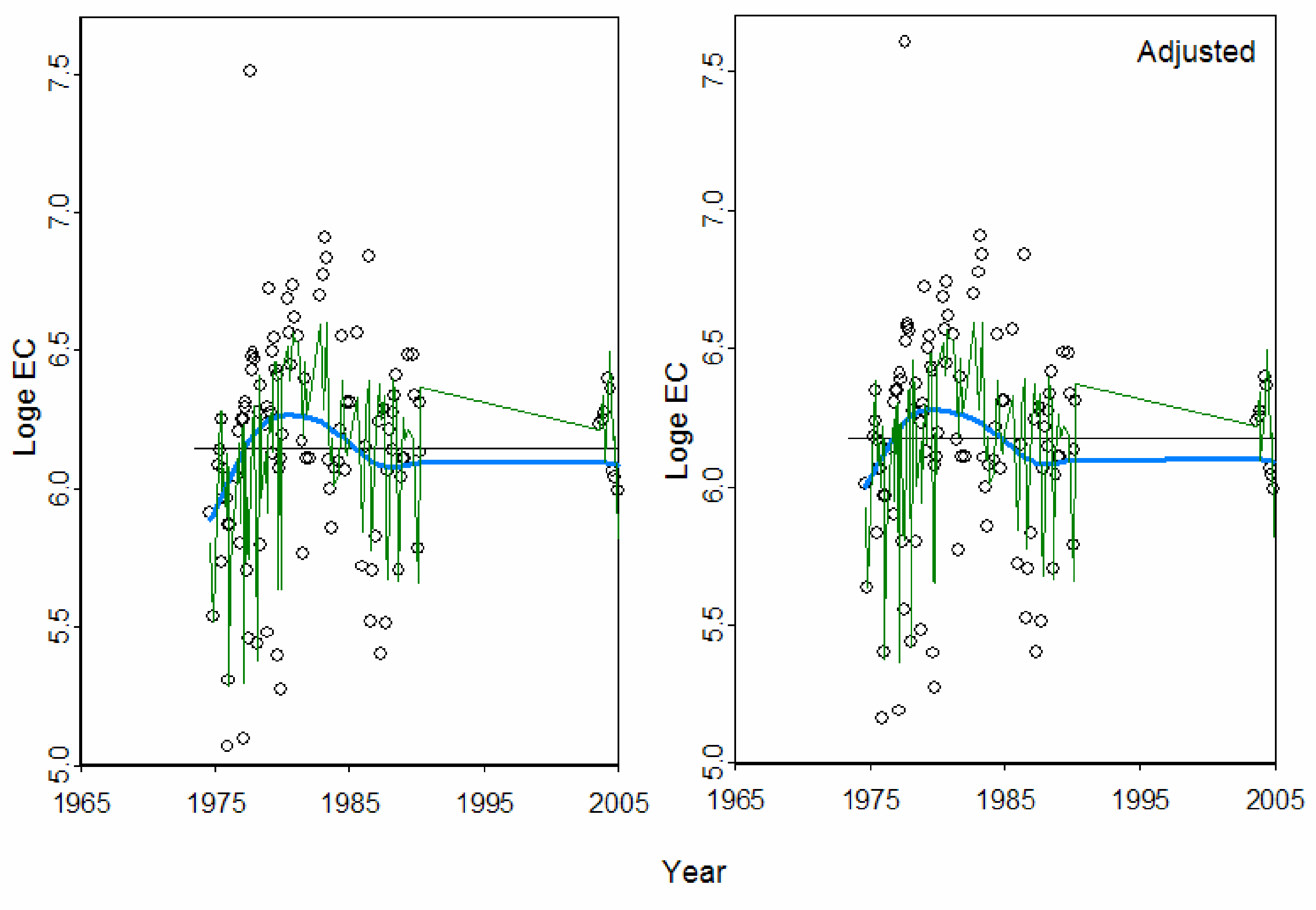
Appendix 2.66 419051 Maules Ck at Avoca



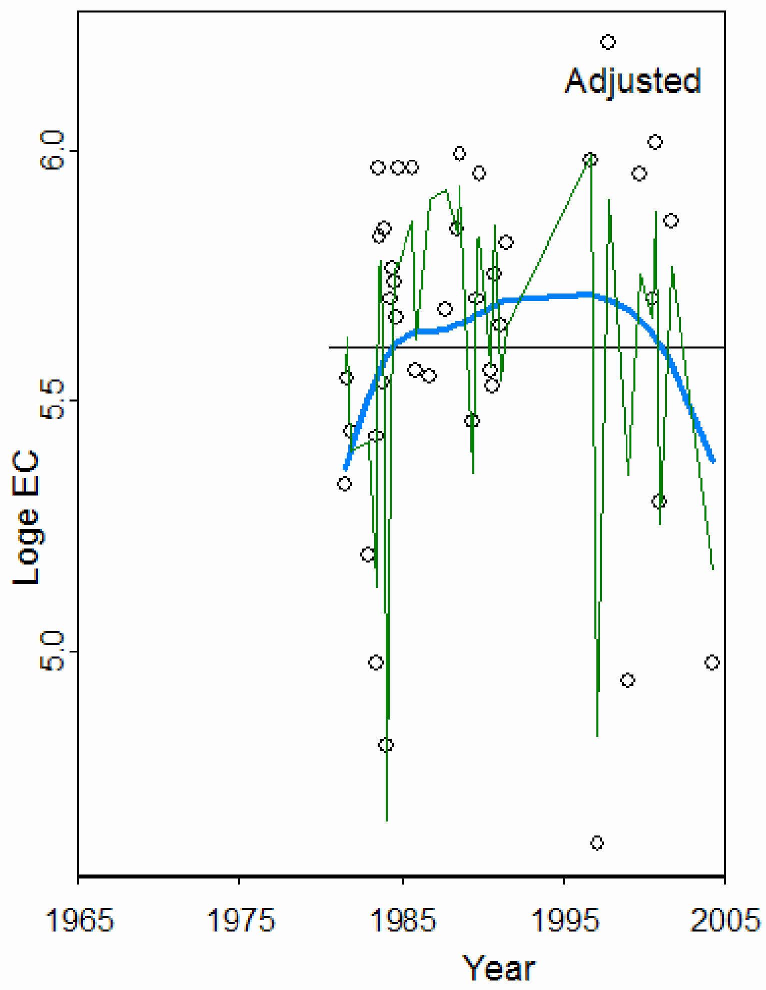
Appendix 2.67 419053 Manilla R at Black Springs



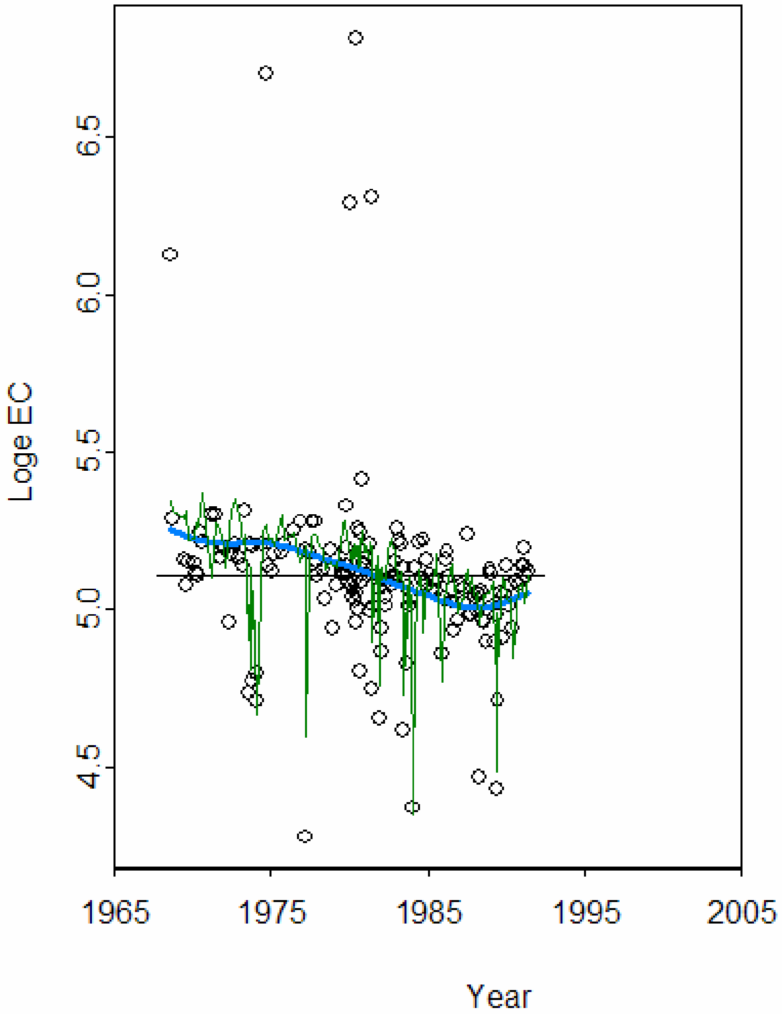
Appendix 2.68 419054 Swamp Oak Ck at Limbri



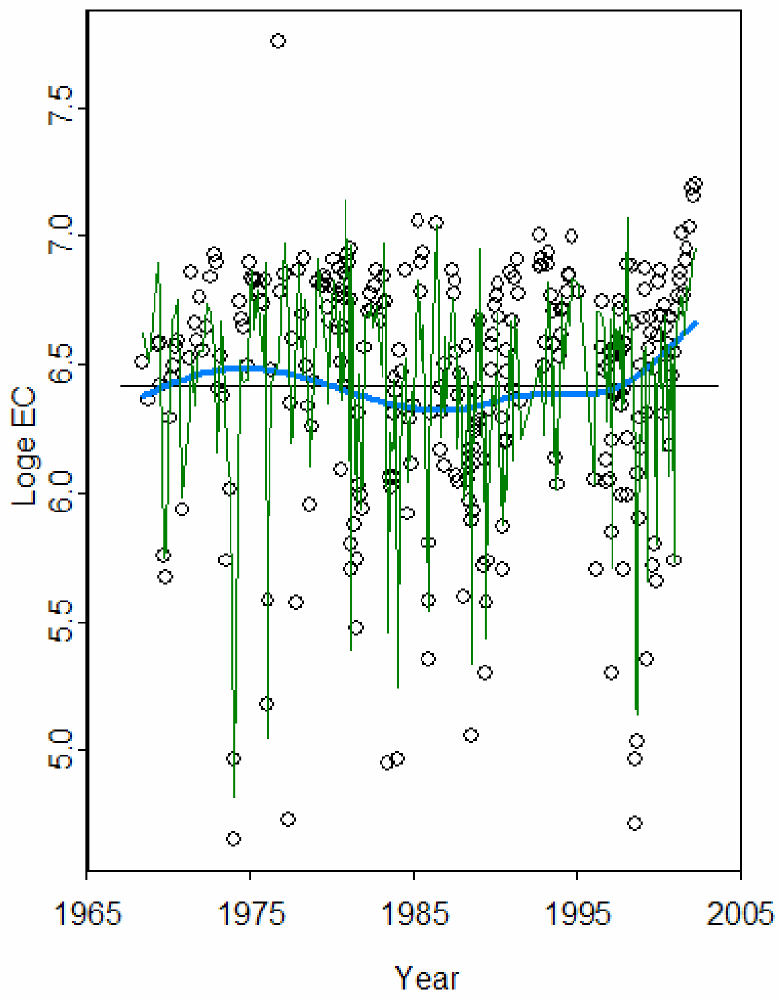
Appendix 2.69 419072 Barradine Ck at Kienbri



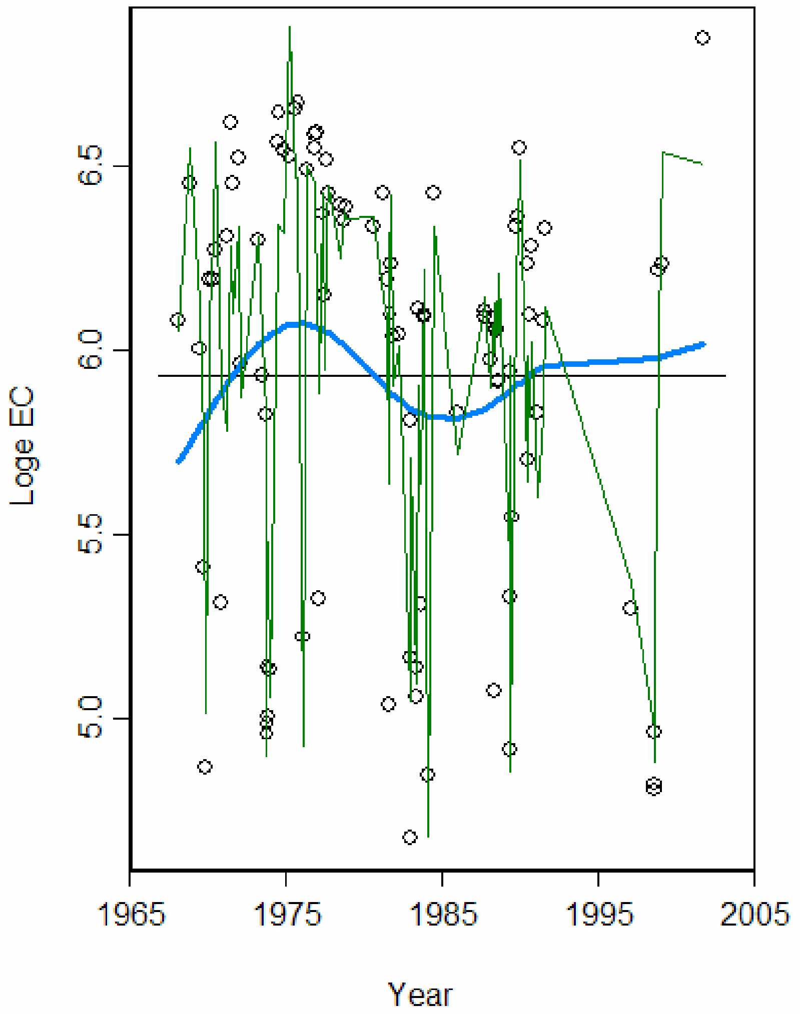
Appendix 2.70 420003 Belar Ck at Warkton



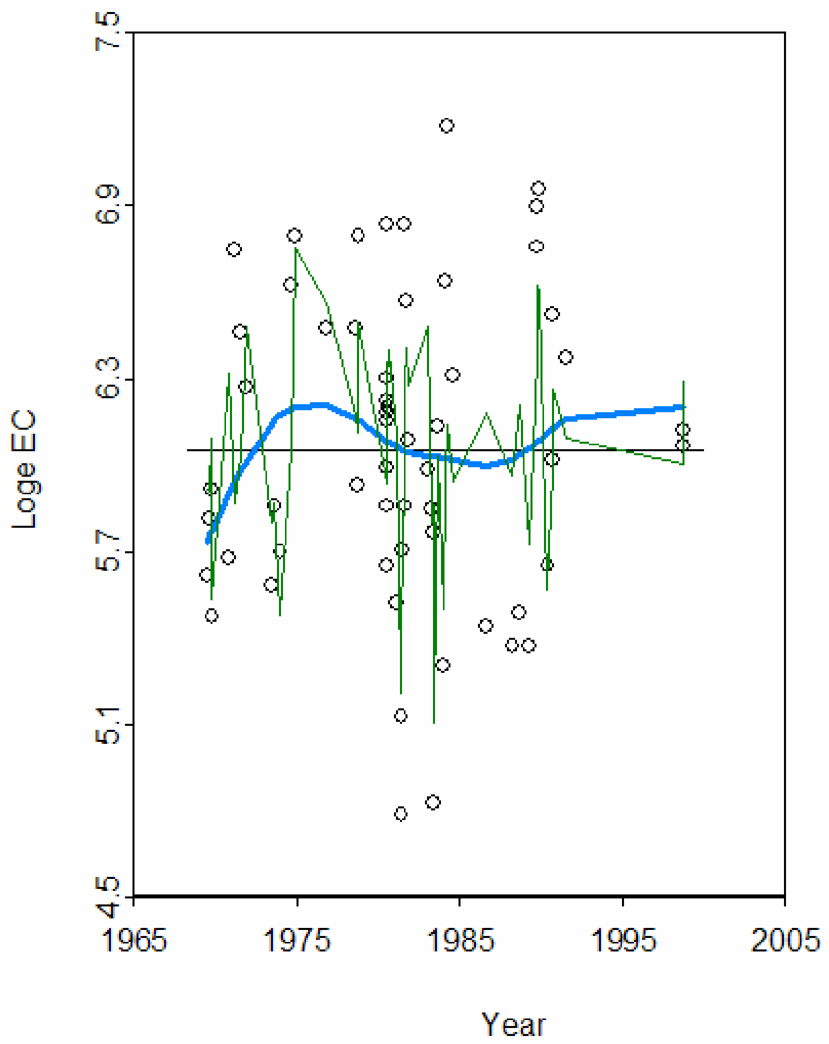
Appendix 2.71 420004 Castlereagh R at Mendooran



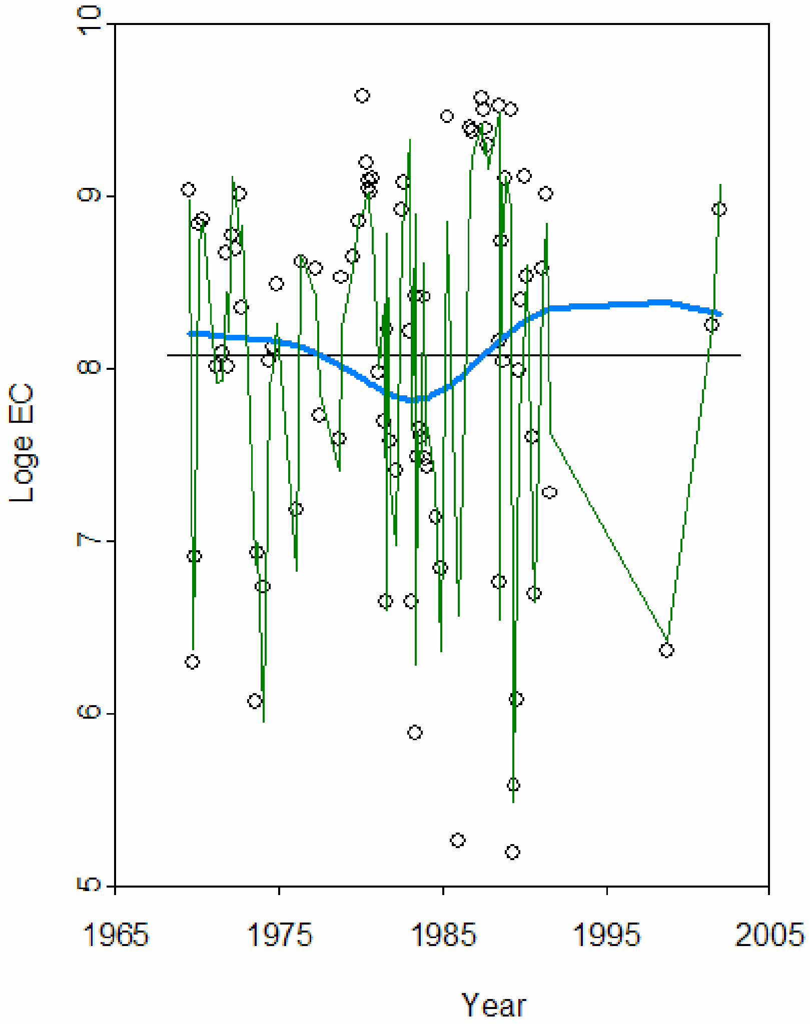
Appendix 2.72 420005 Castlereagh R at Coonamble



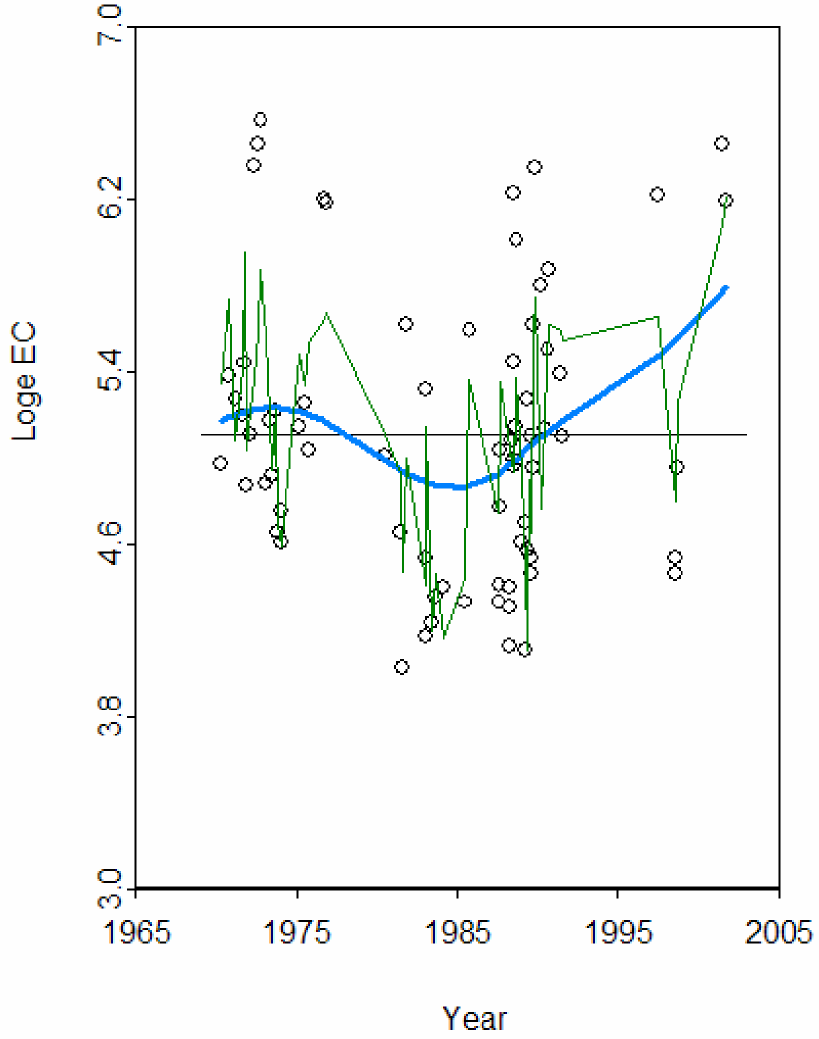
Appendix 2.73 420010 Wallumburrawang Ck at Bearbung



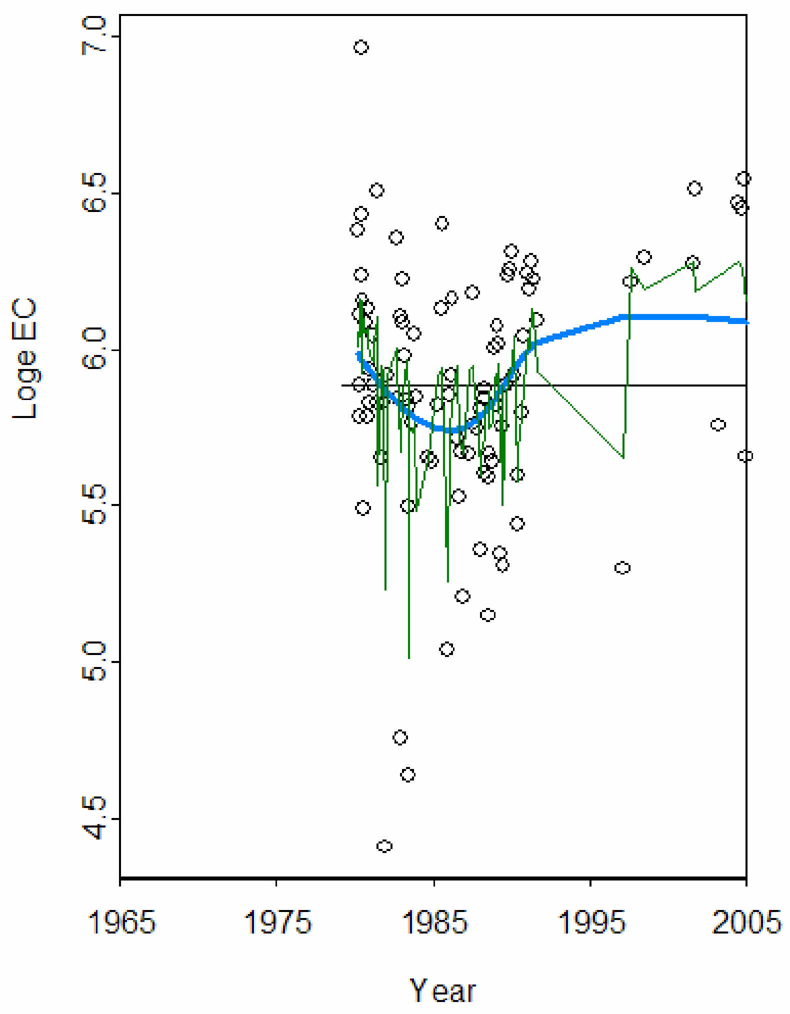
Appendix 2.74 420012 Butheroo Ck at Neilrex



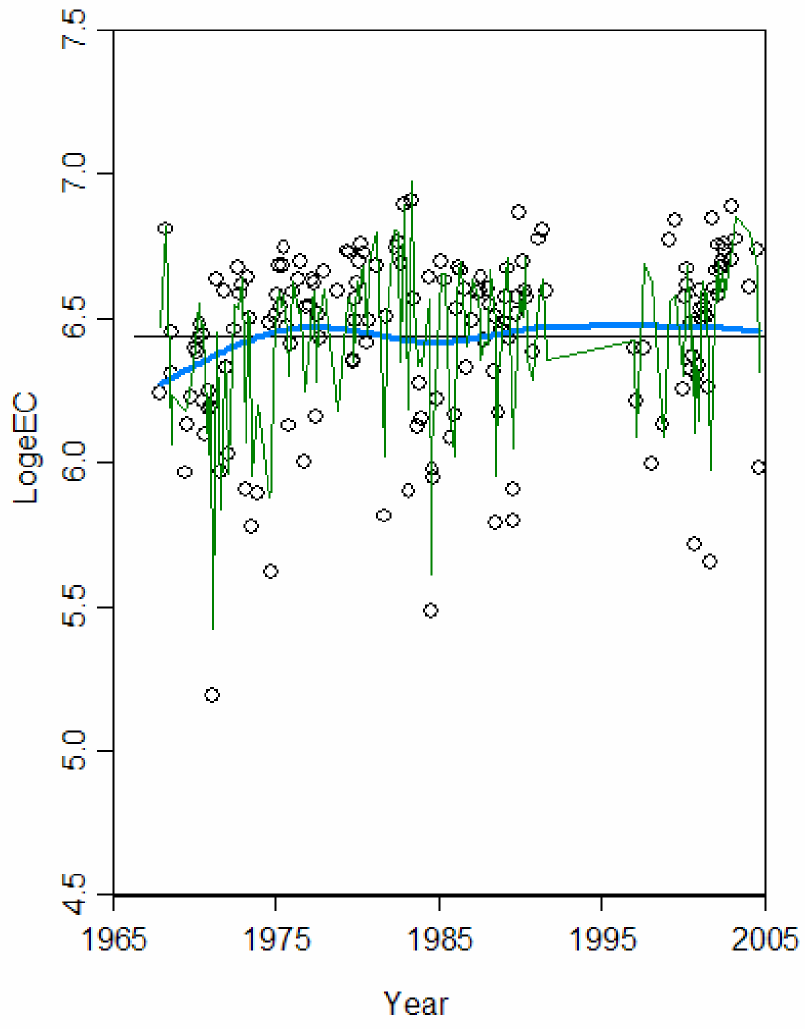
Appendix 2.75 420015 Warrena Ck at Warrana



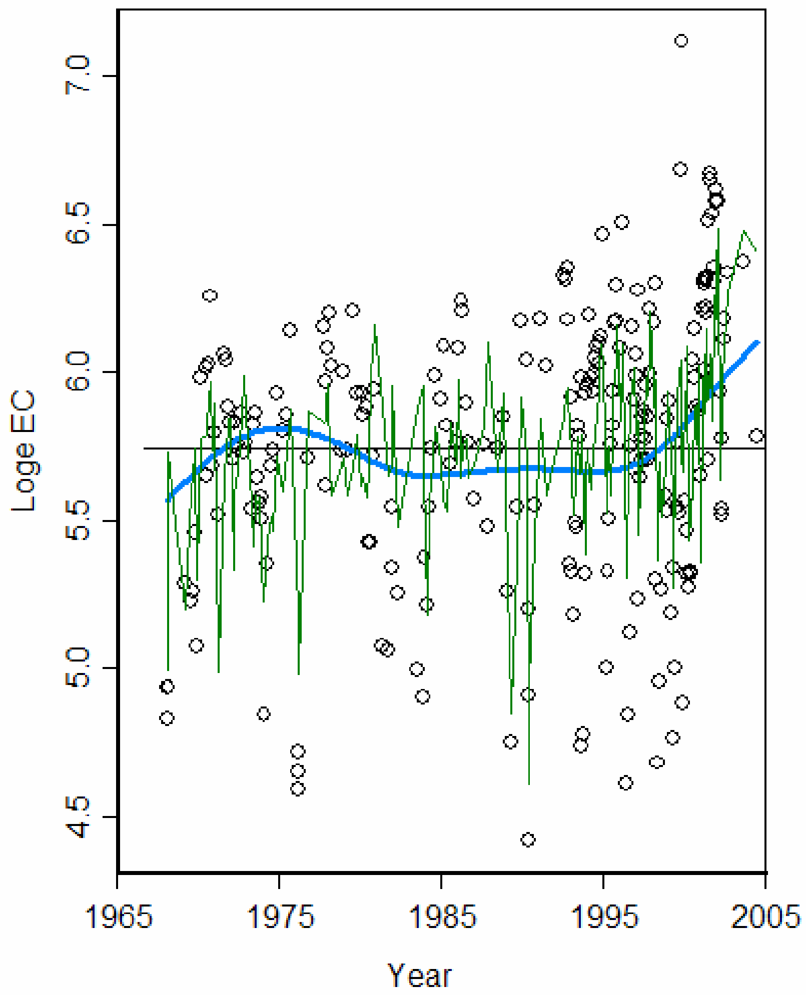
Appendix 2.76 420017 Castlereagh R at Hidden Valley



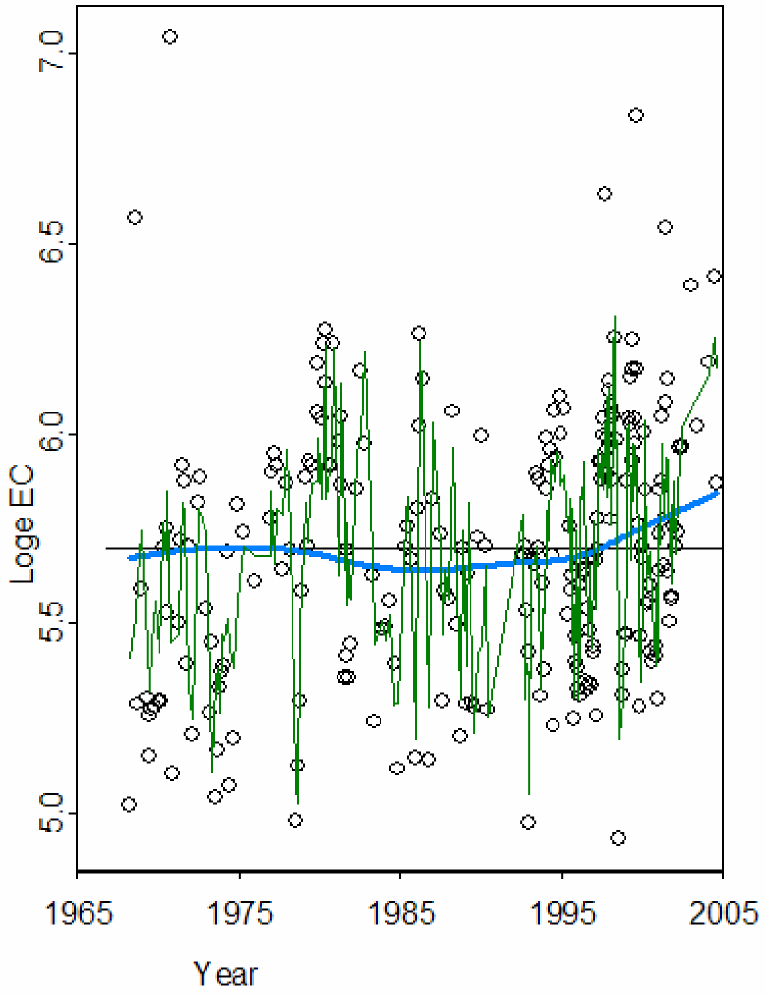
Appendix 2.77 421018 Bell R at Newrea



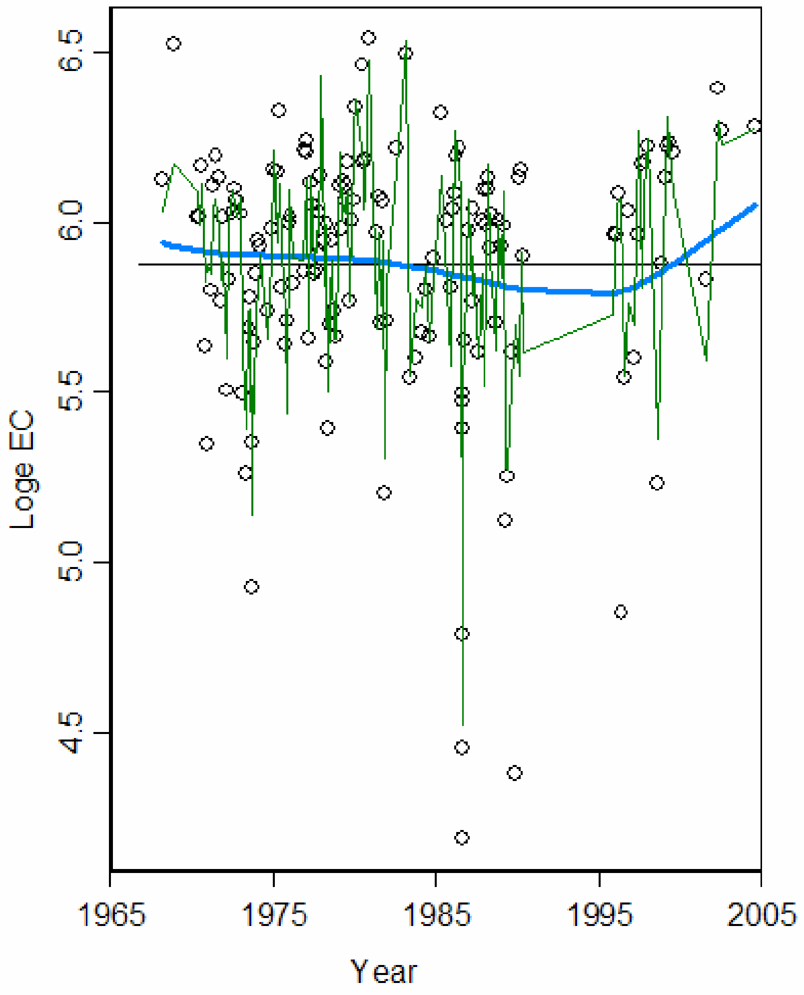
Appendix 2.78 421023 Bogan R at Gongolgon



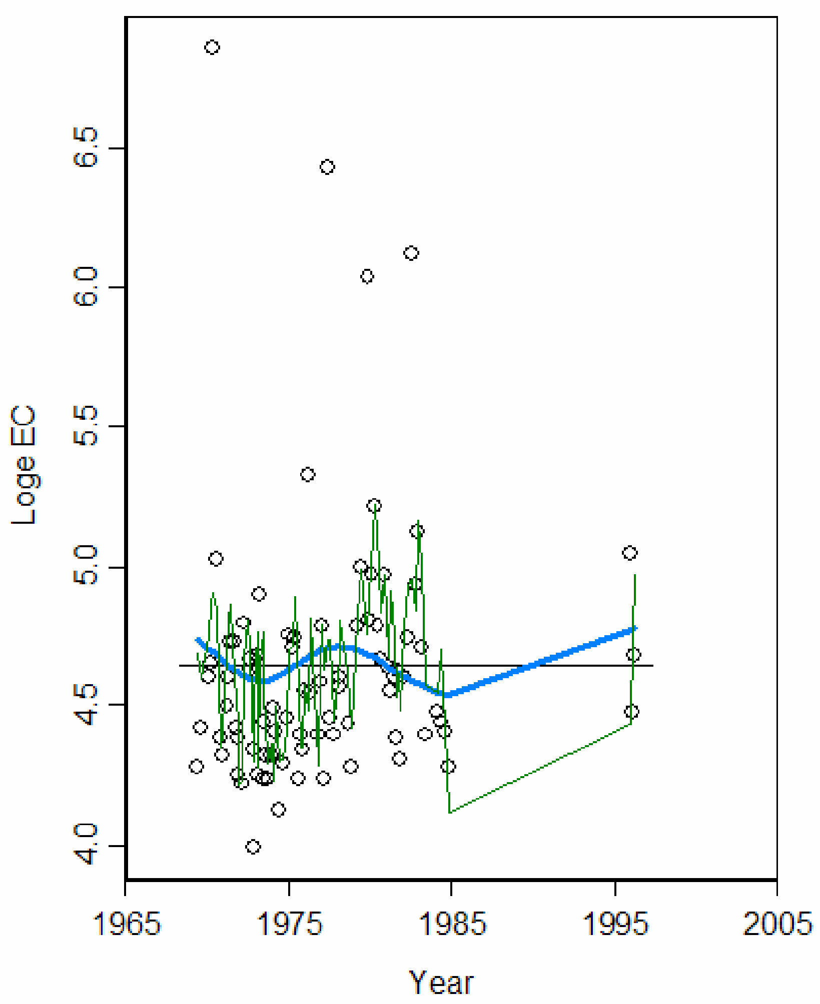
Appendix 2.79 421025 Macquarie R at Bruinbun



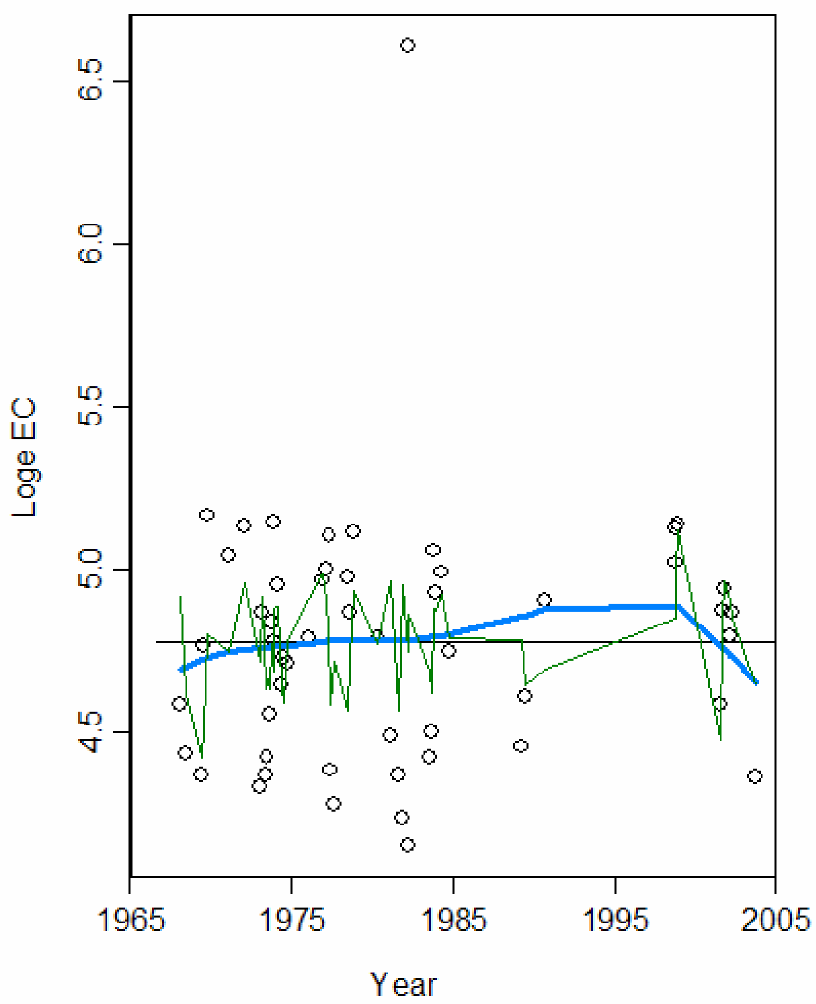
Appendix 2.80 421026 Turon R at Sofala



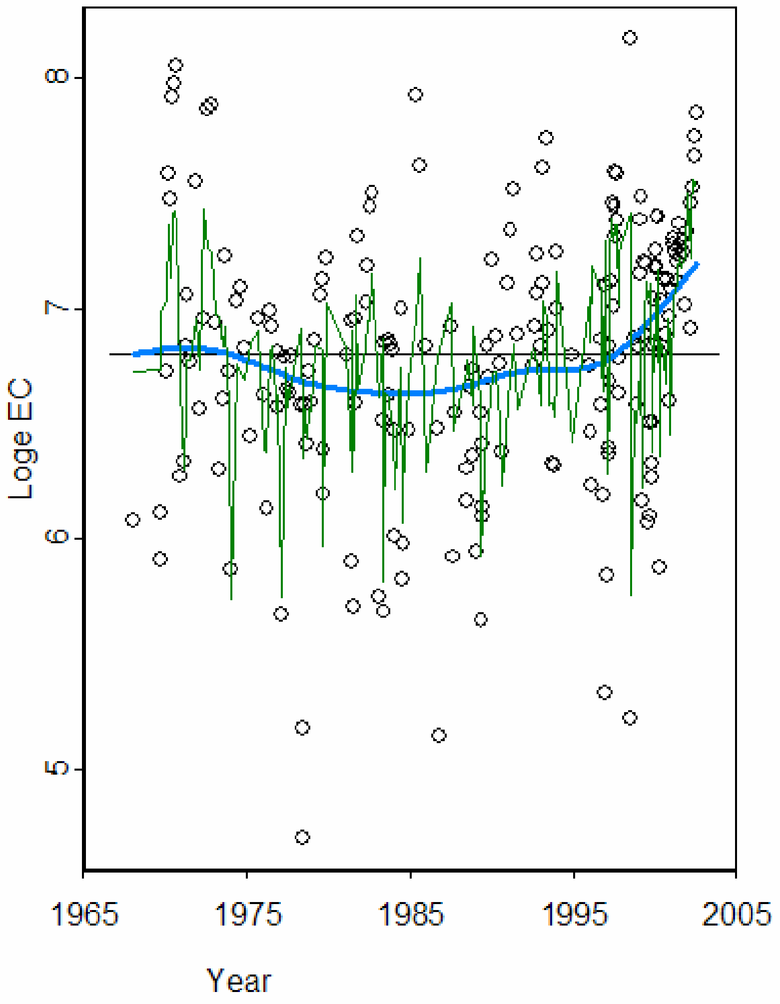
Appendix 2.81 421035 Fish R at Tarana



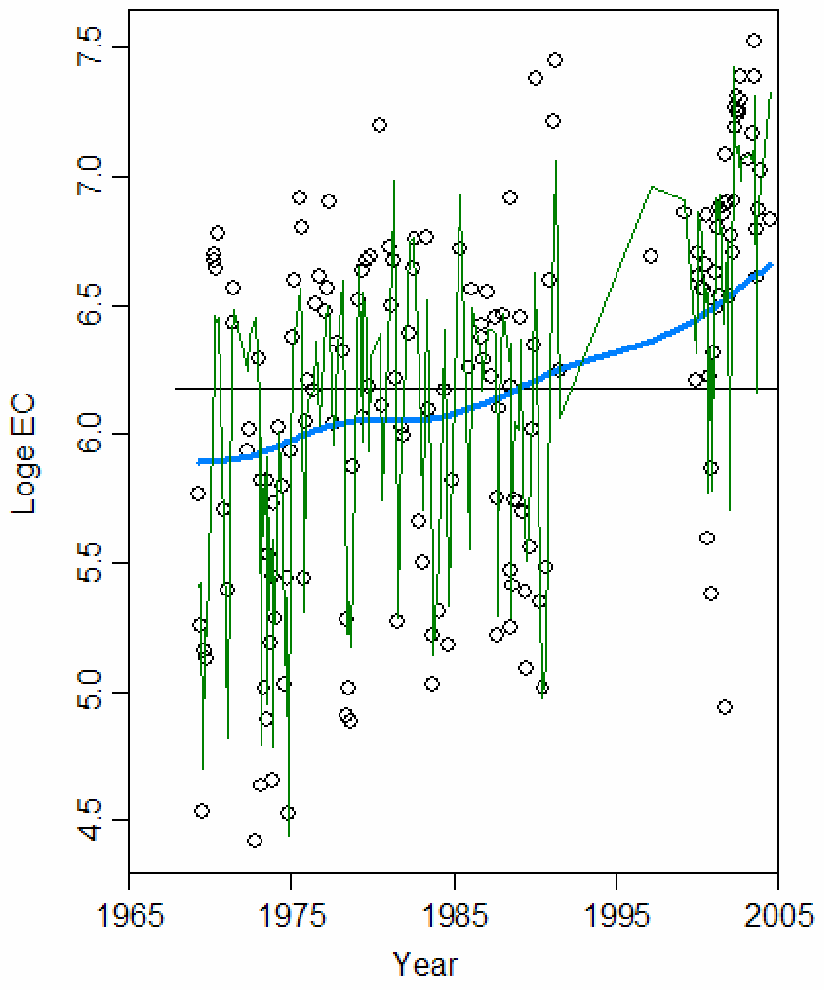
Appendix 2.82 421039 Bogan R at Neurie Plains



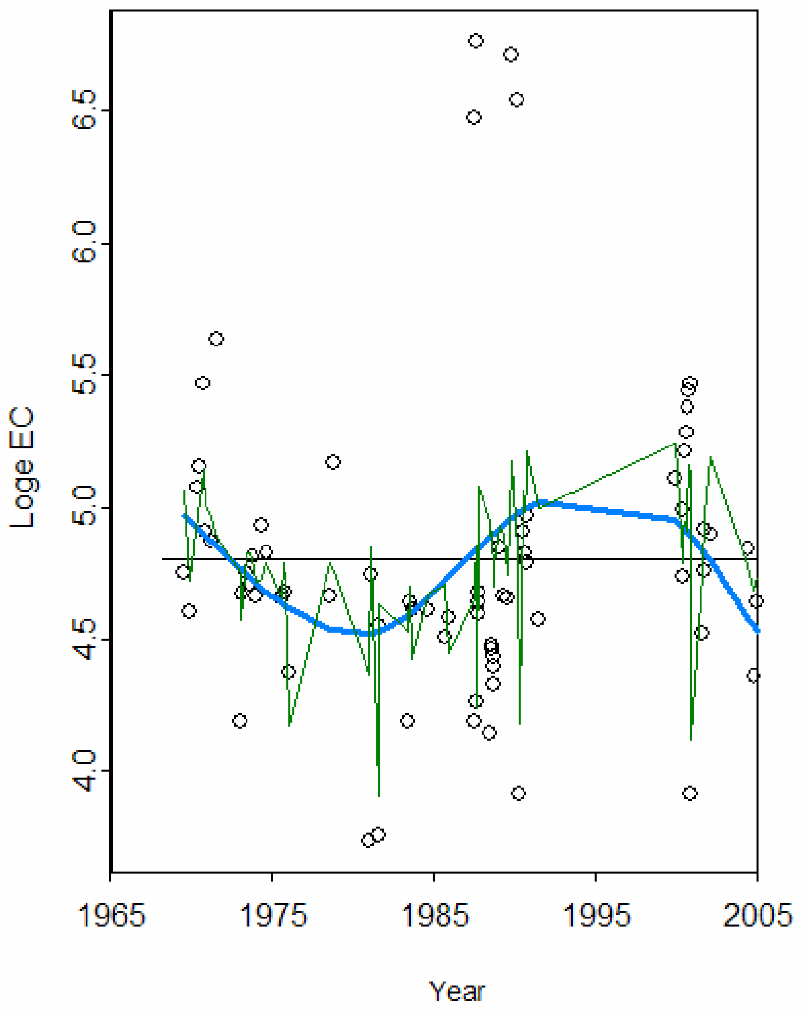
Appendix 2.83 421042 Talbragar R at Elong Elong



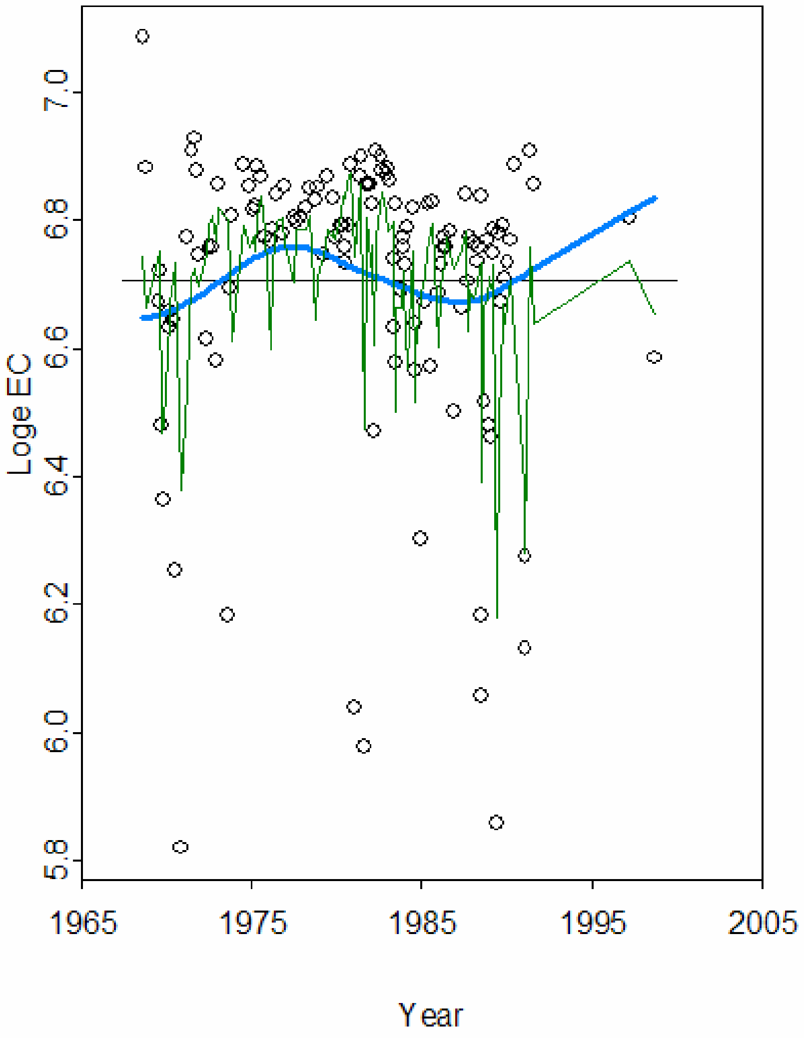
Appendix 2.84 421048 Little R at Obley



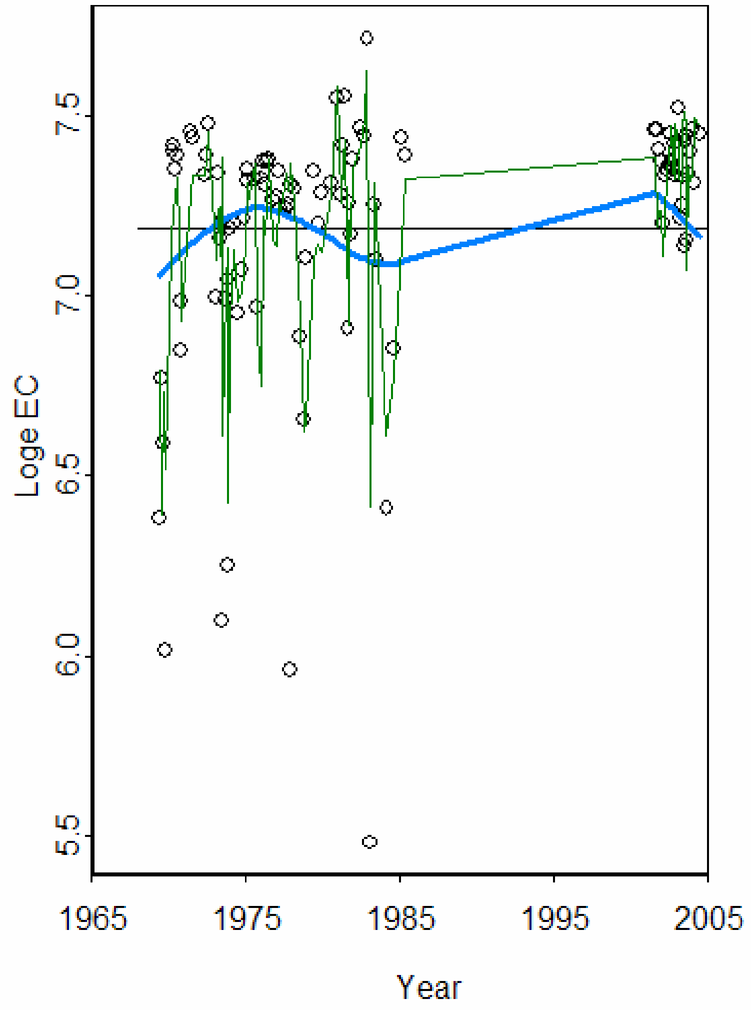
Appendix 2.85 421055 Coolbaggie Ck at Rawsonville



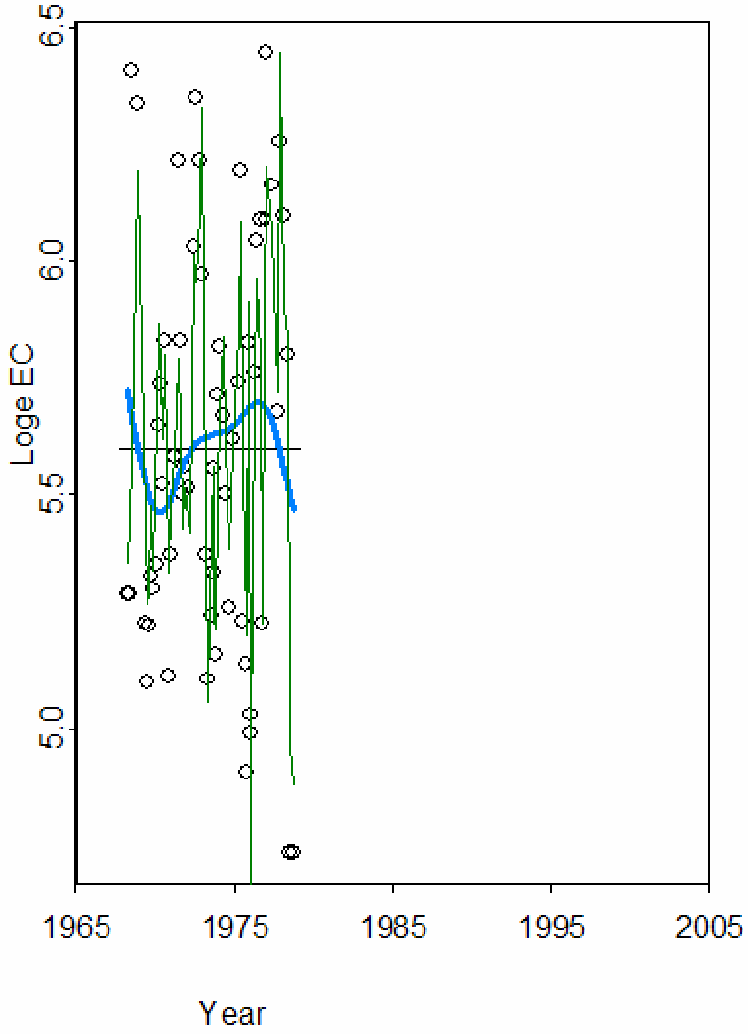
Appendix 2.86 421056 Coolaburragundy Ck at Coolah



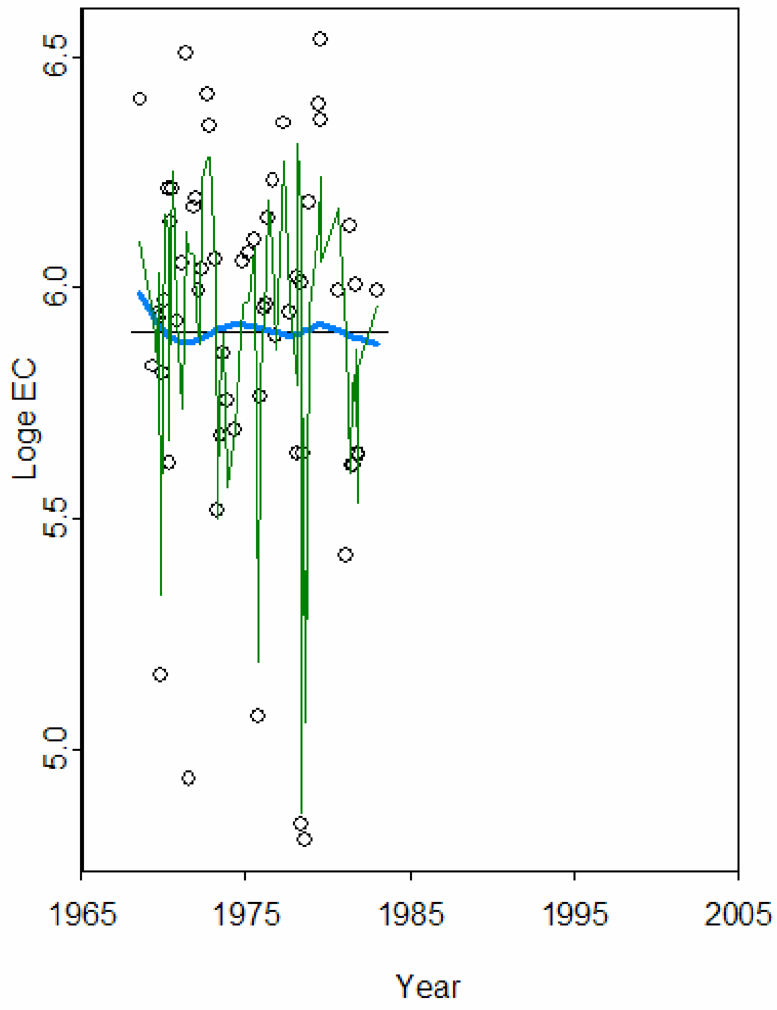
Appendix 2.87 421059 Buckinbar Ck at Yeoval



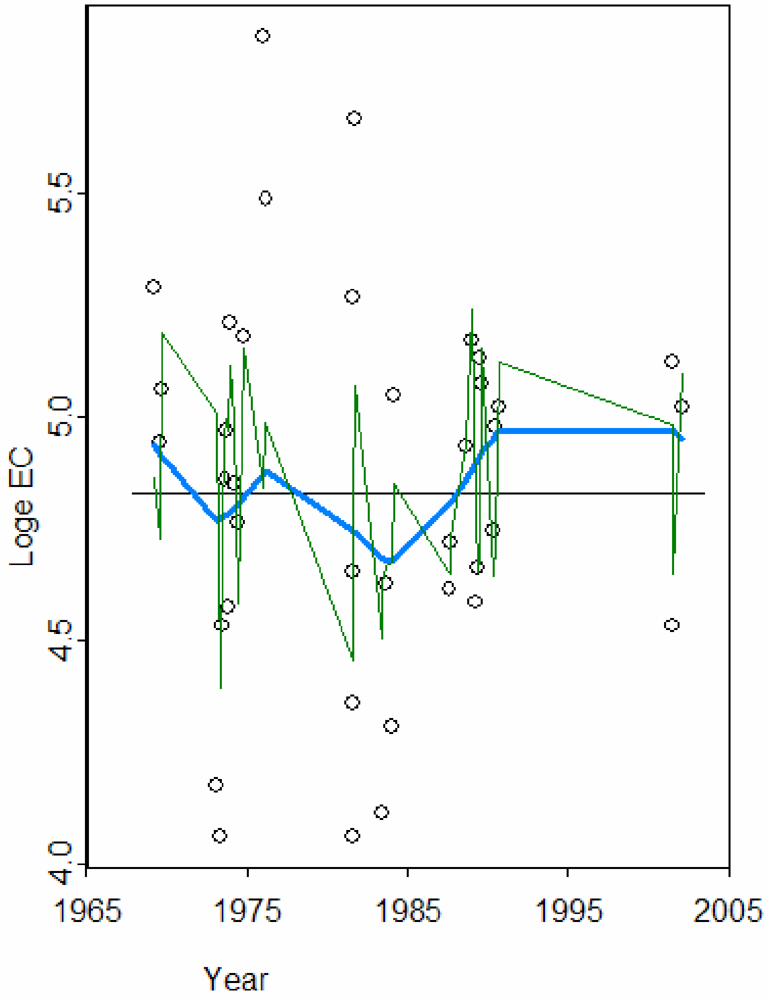
Appendix 2.88 421072 Winburndale Rivulet at Howards Bridge



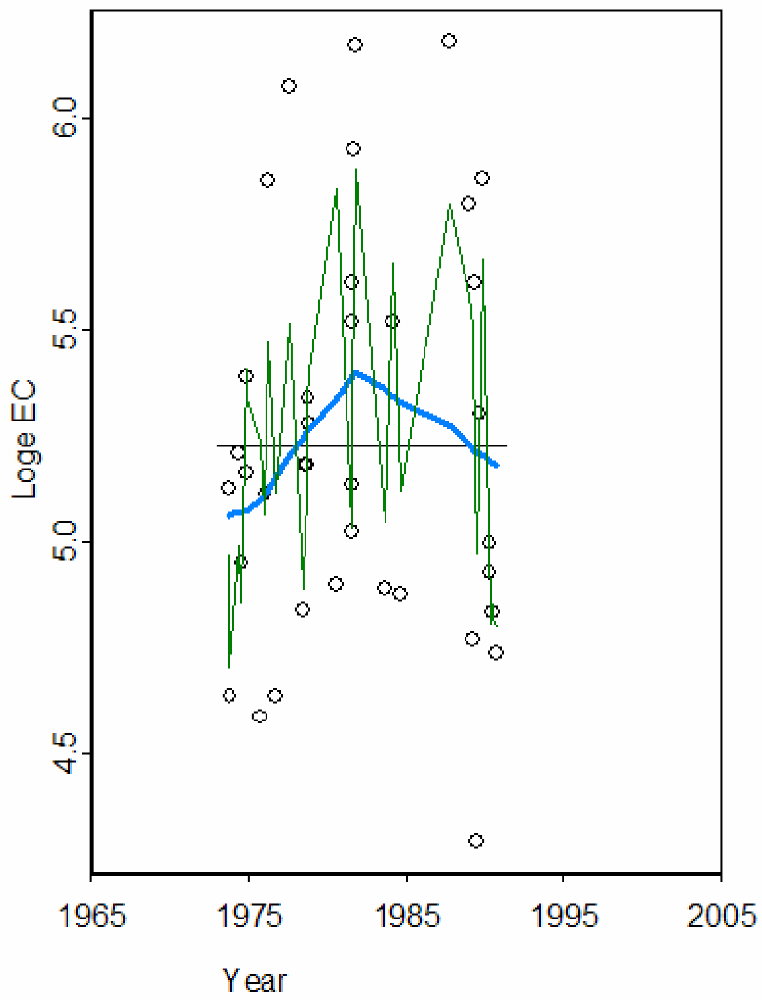
Appendix 2.89 421073 Meroo Ck at Yarrabin 2



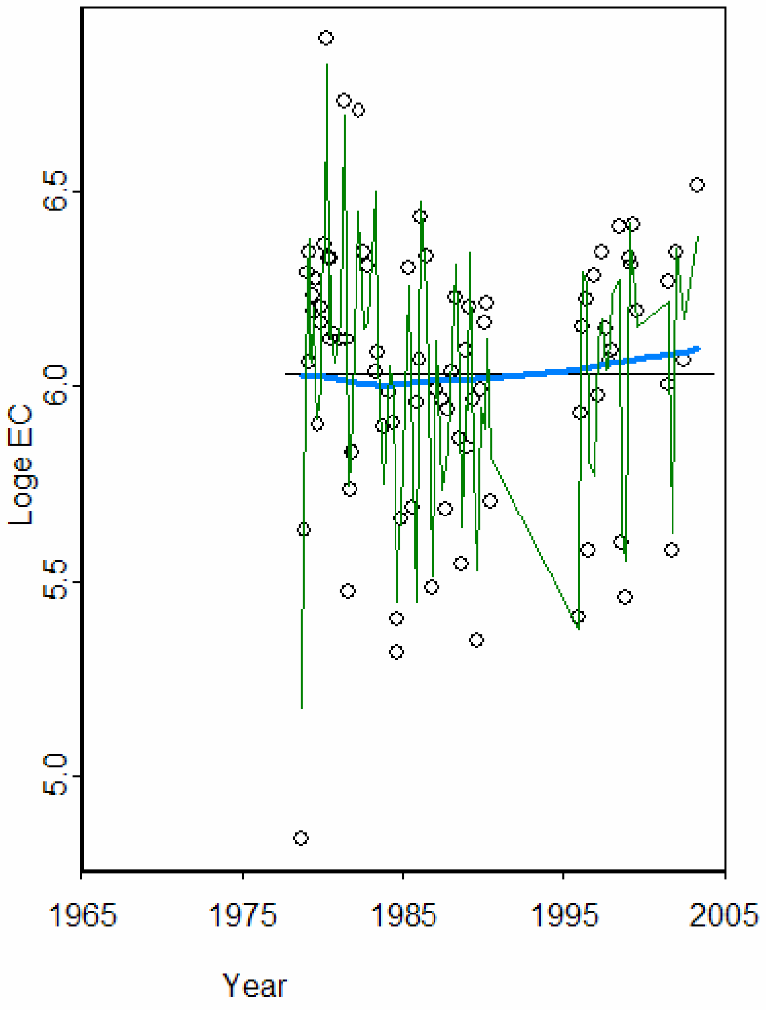
Appendix 2.90 421076 Bogan R at Peak Hill 2



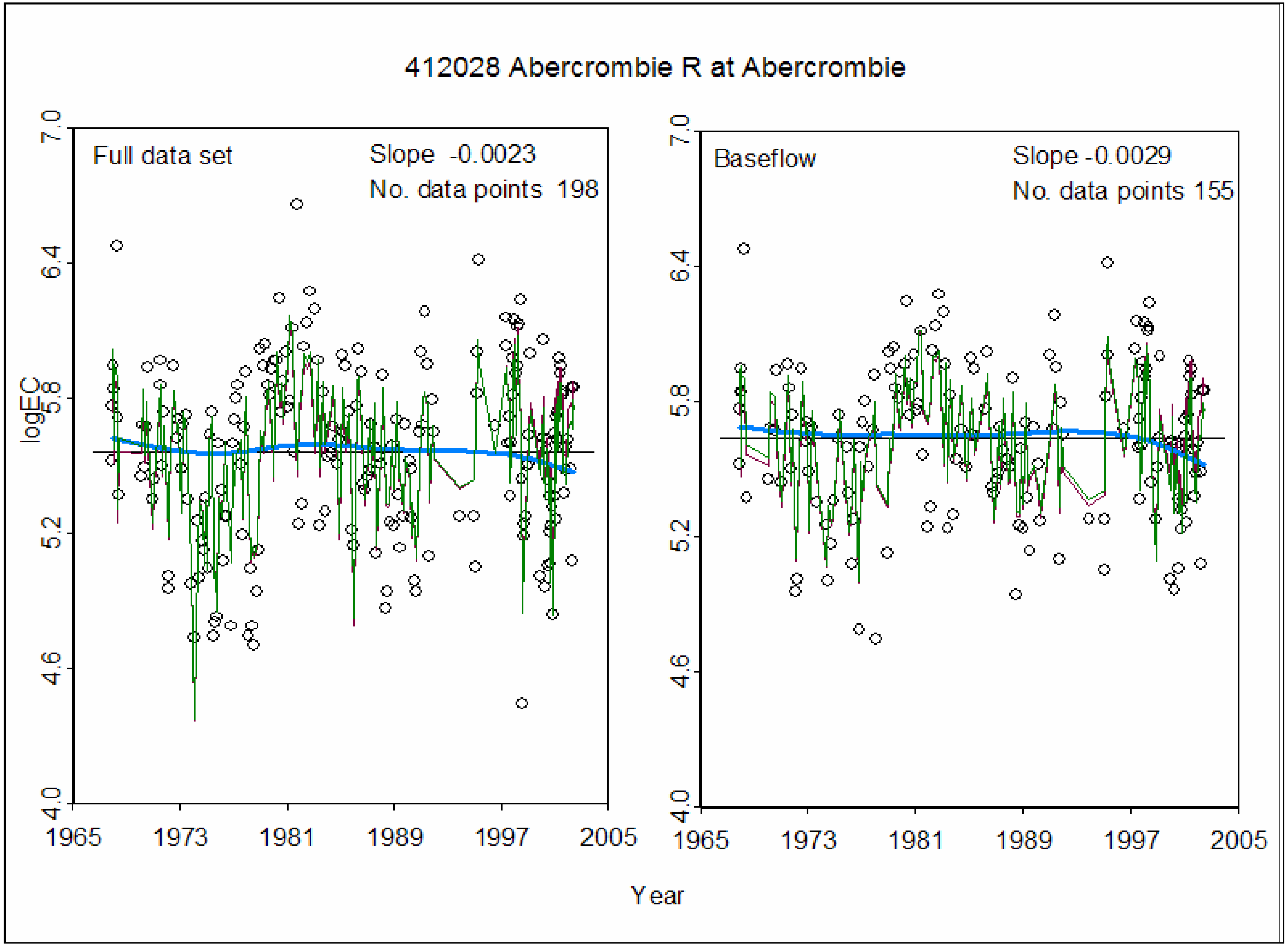
Appendix 2.91 421084 Burrill Ck at Mickibri

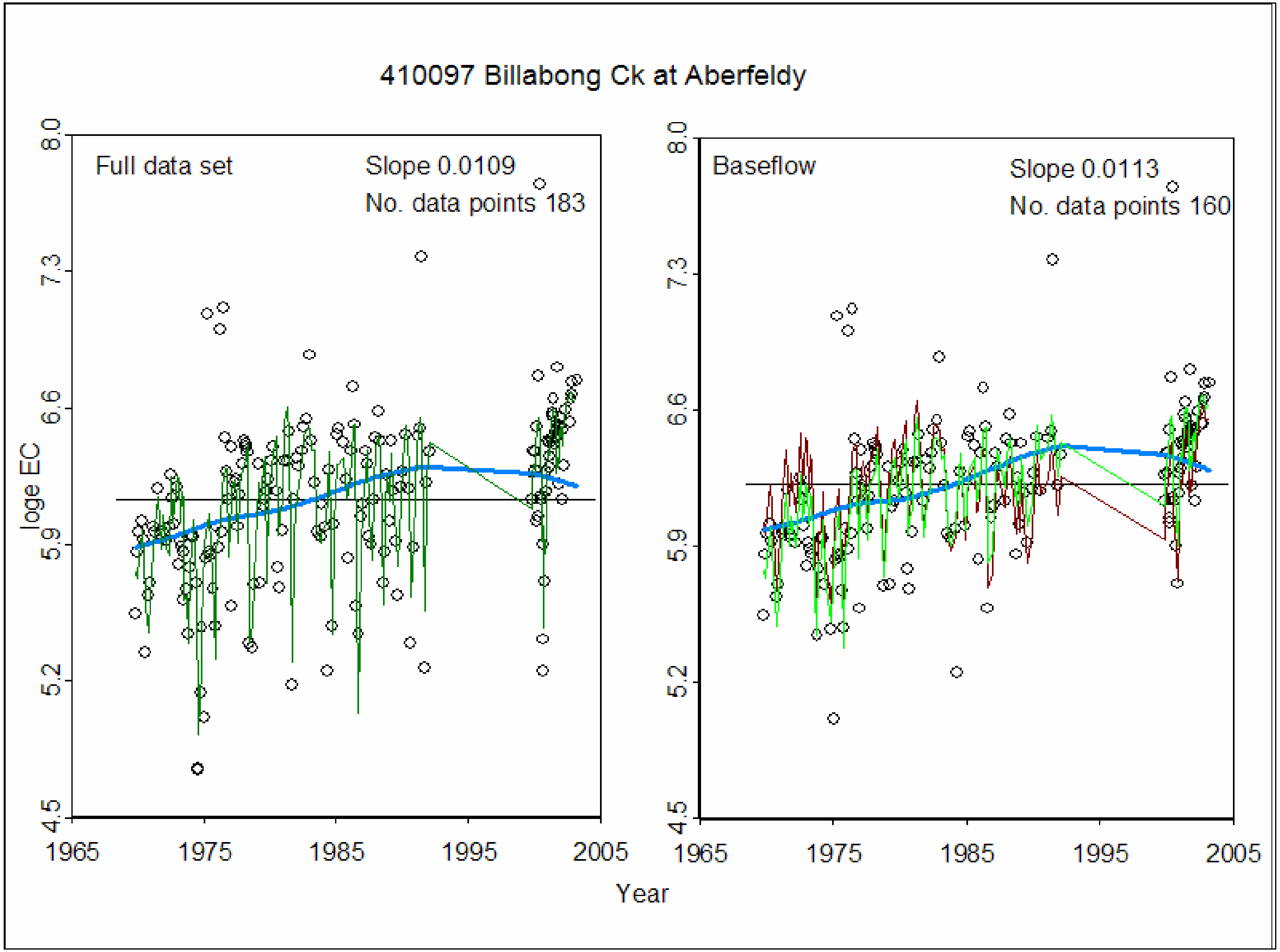


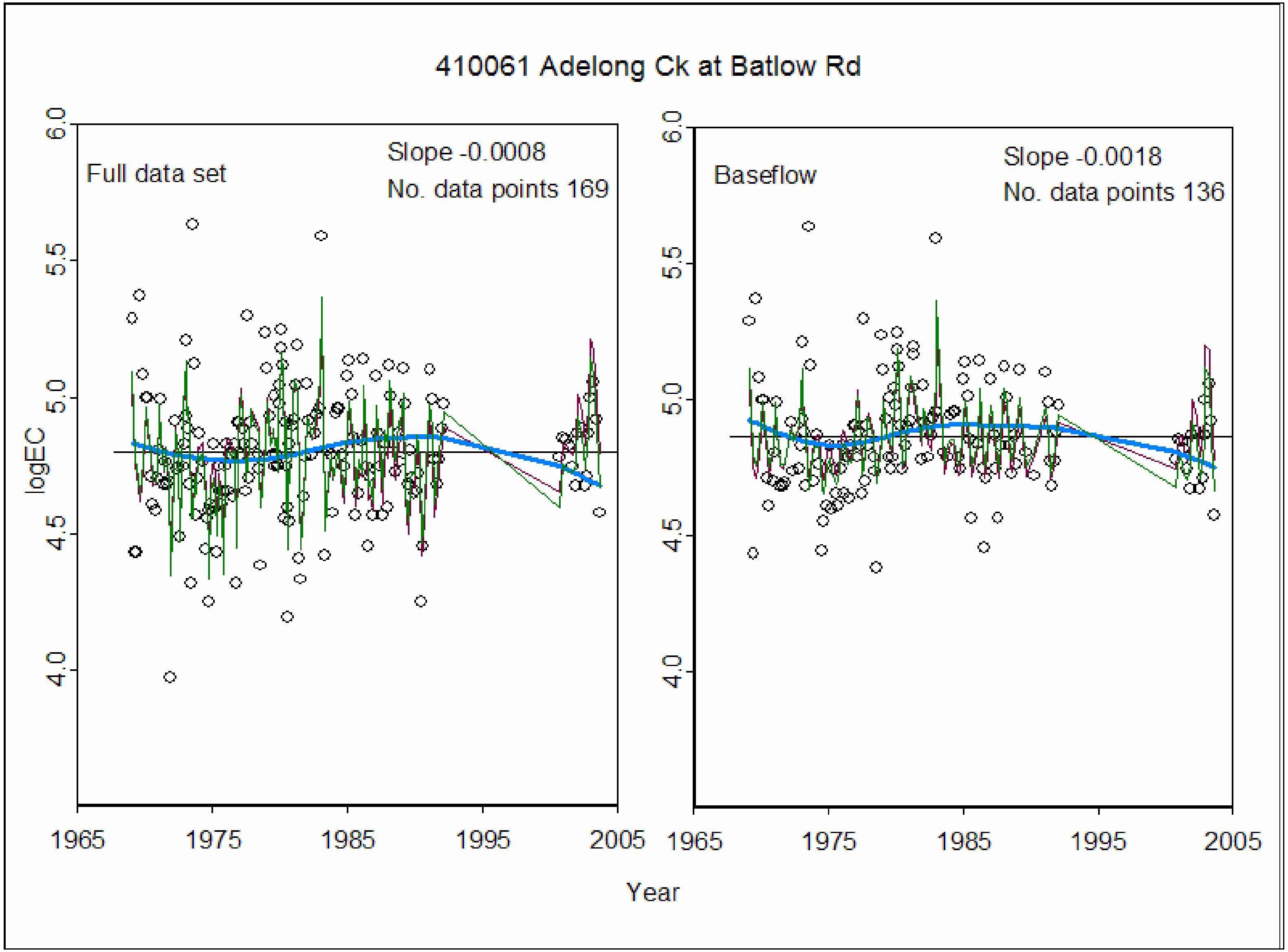
Appendix 2.92 Campbells R Up Stream from Ben Chifley Dam

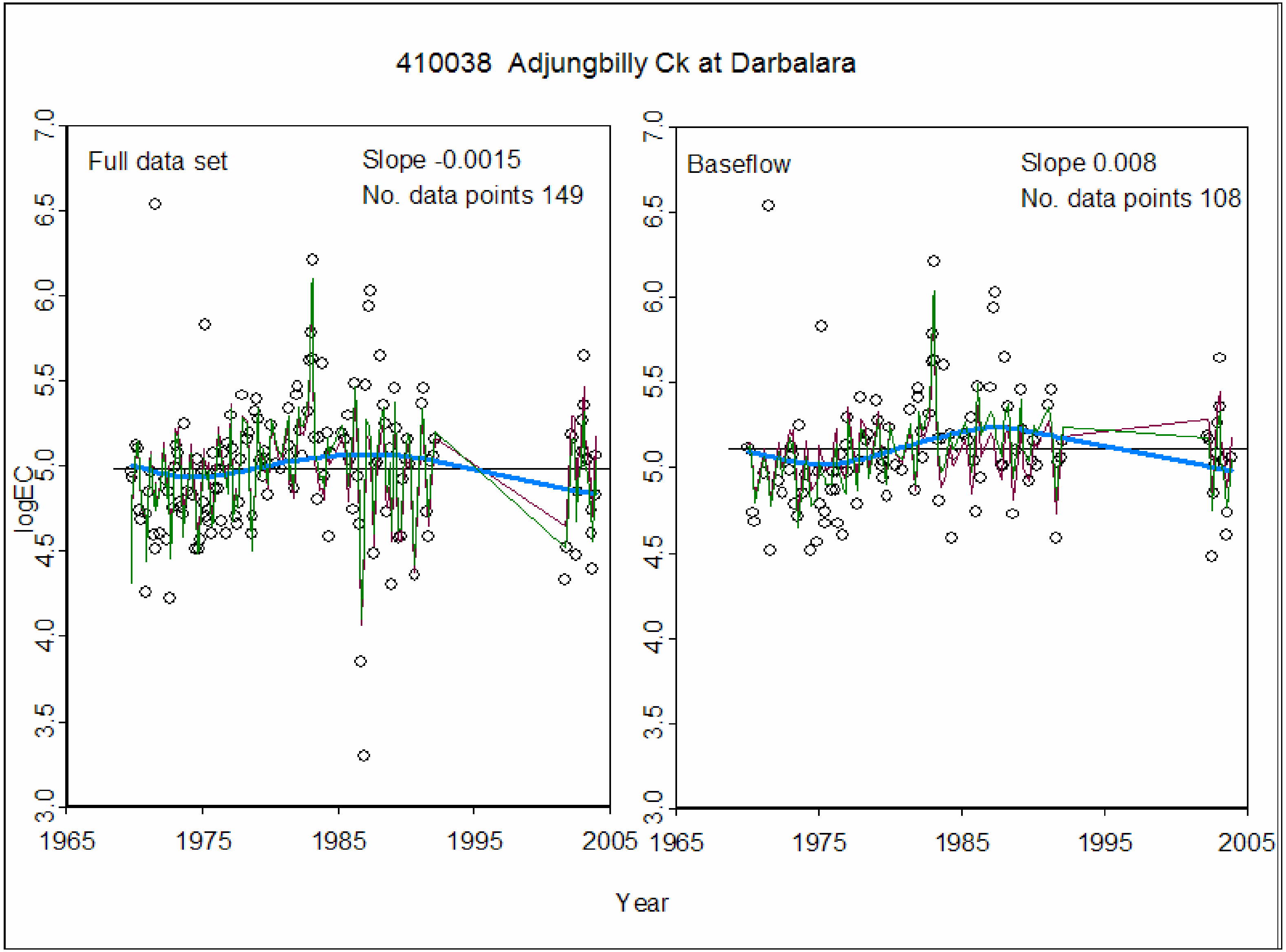


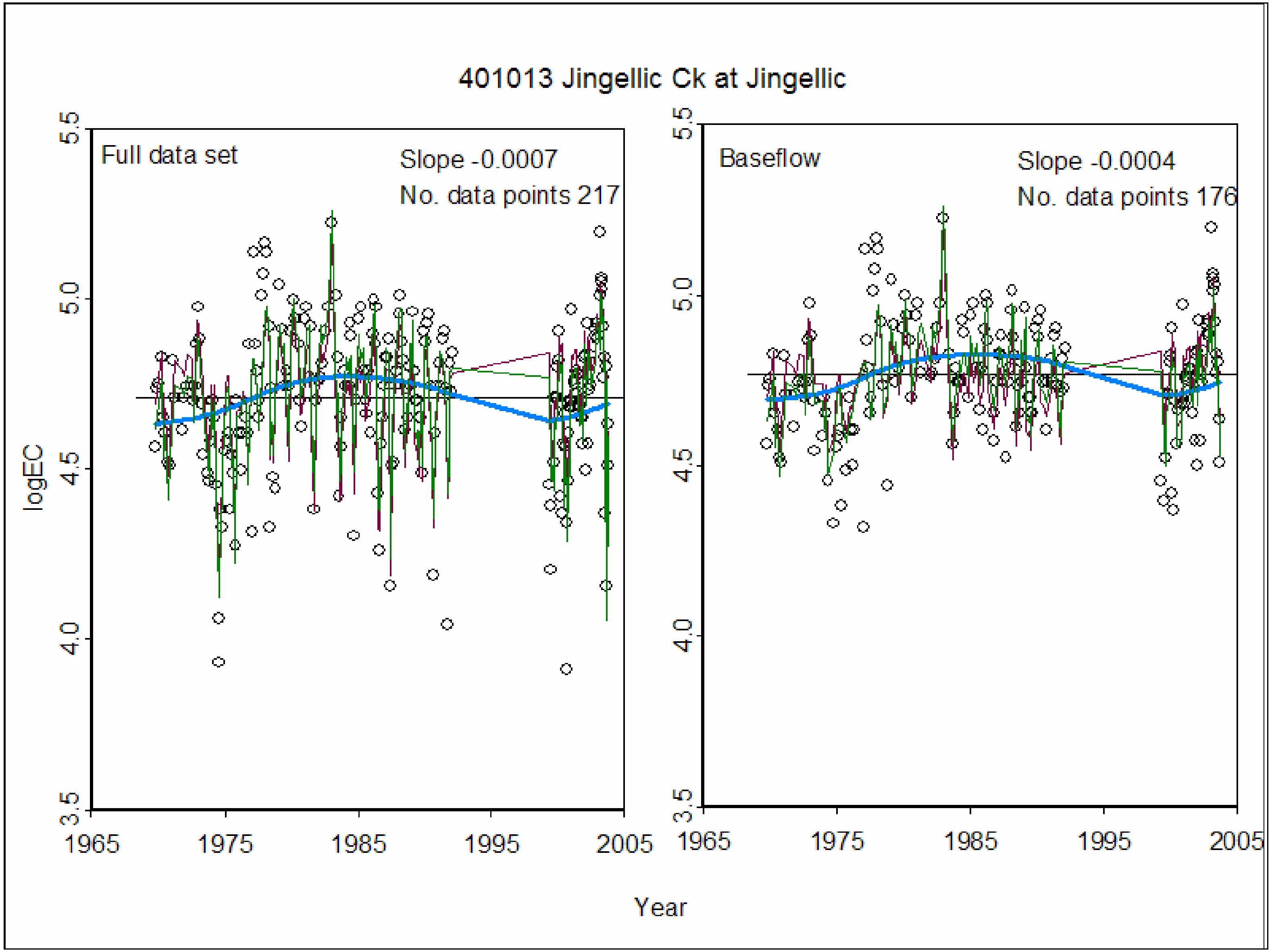
Appendix 3—Base Flow Separation

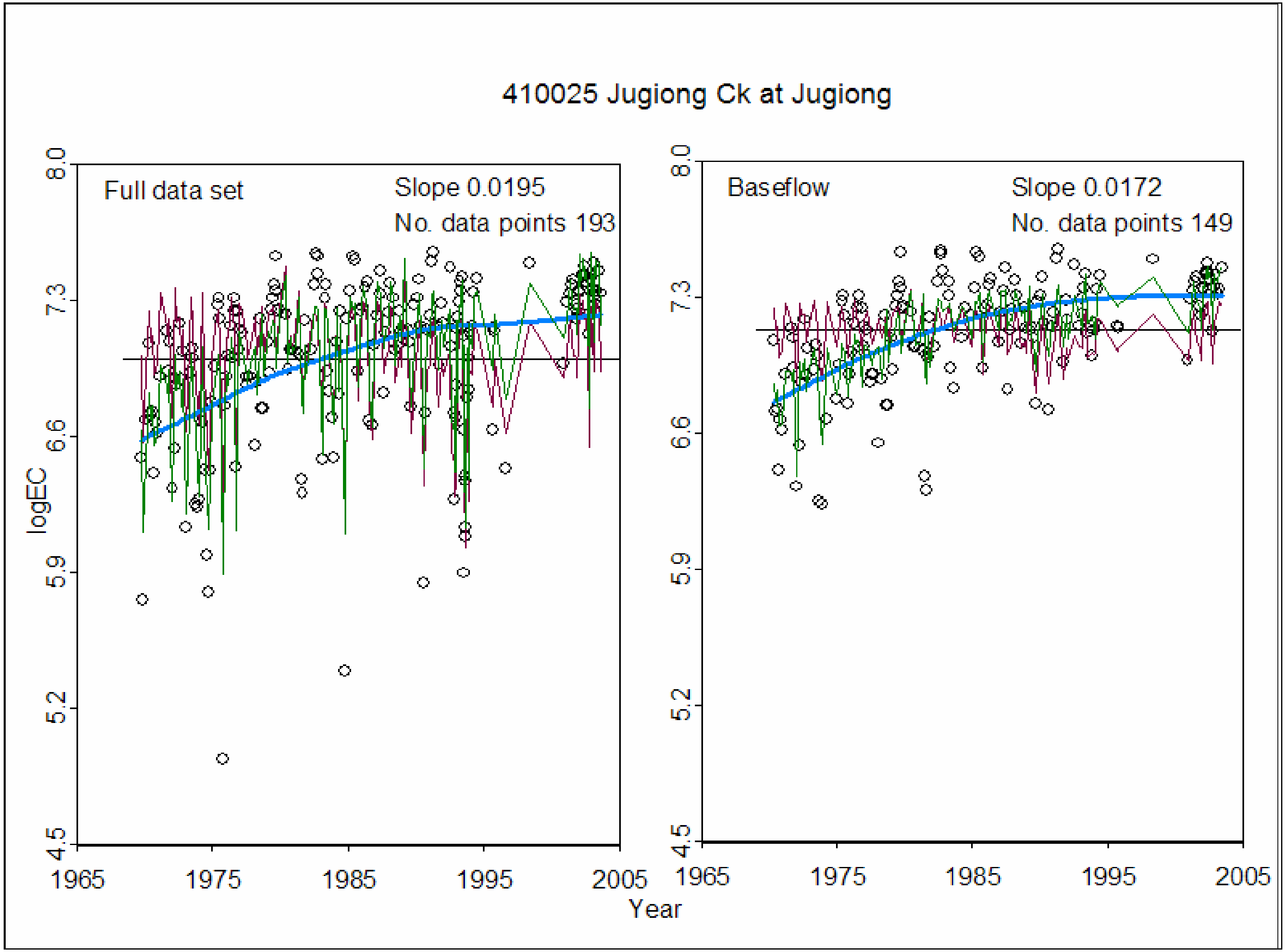


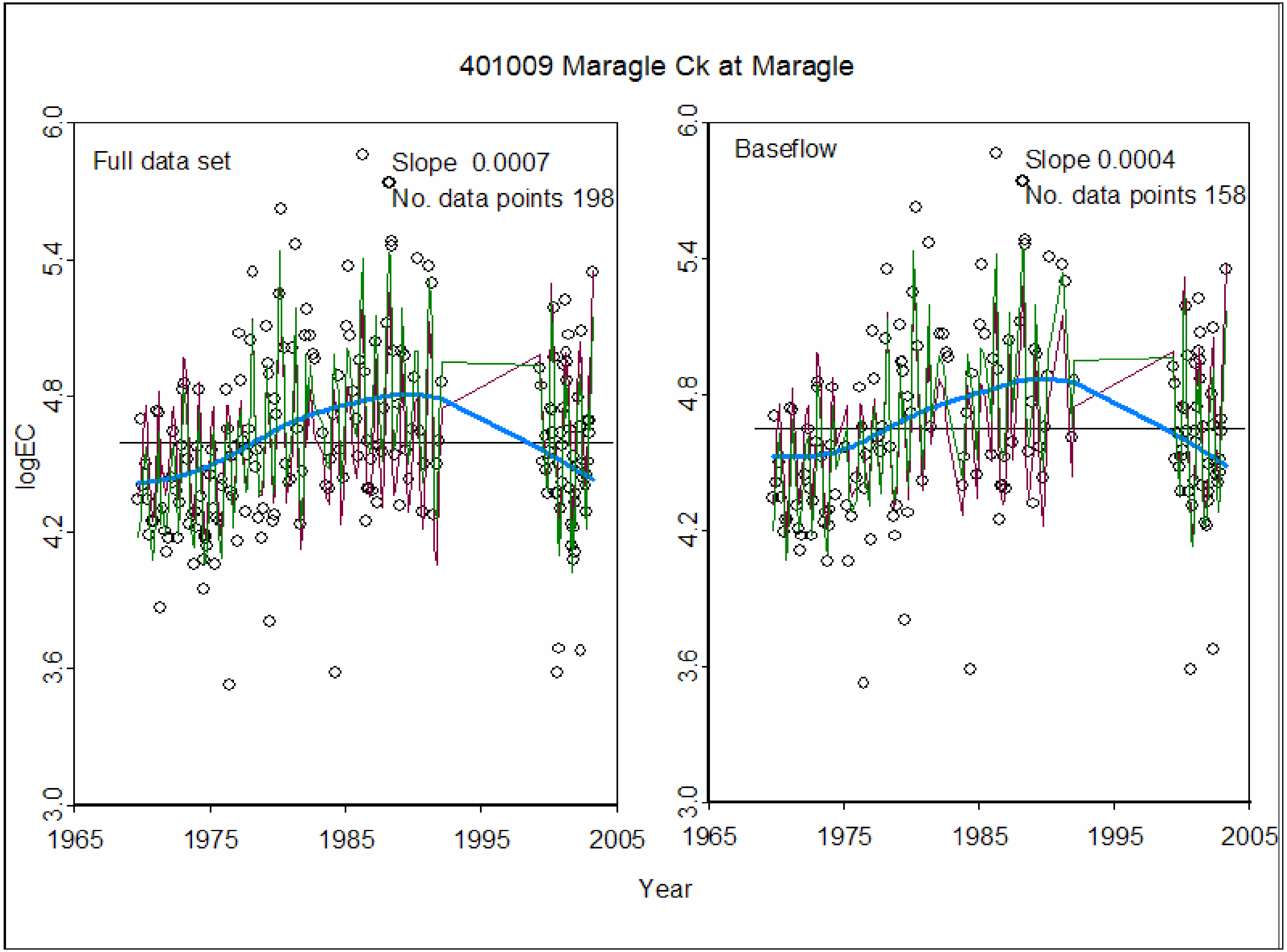

410097 Billabong Ck at Aberfeldy
Full data set
Slope 0.0109
No. data points 183
Baseflow
Slope 0.0113
No. data points 160
loge EC
Year
8.0
7.3
6.6
5.9
5.2
4.5
1965
1975
1985
1995
2005

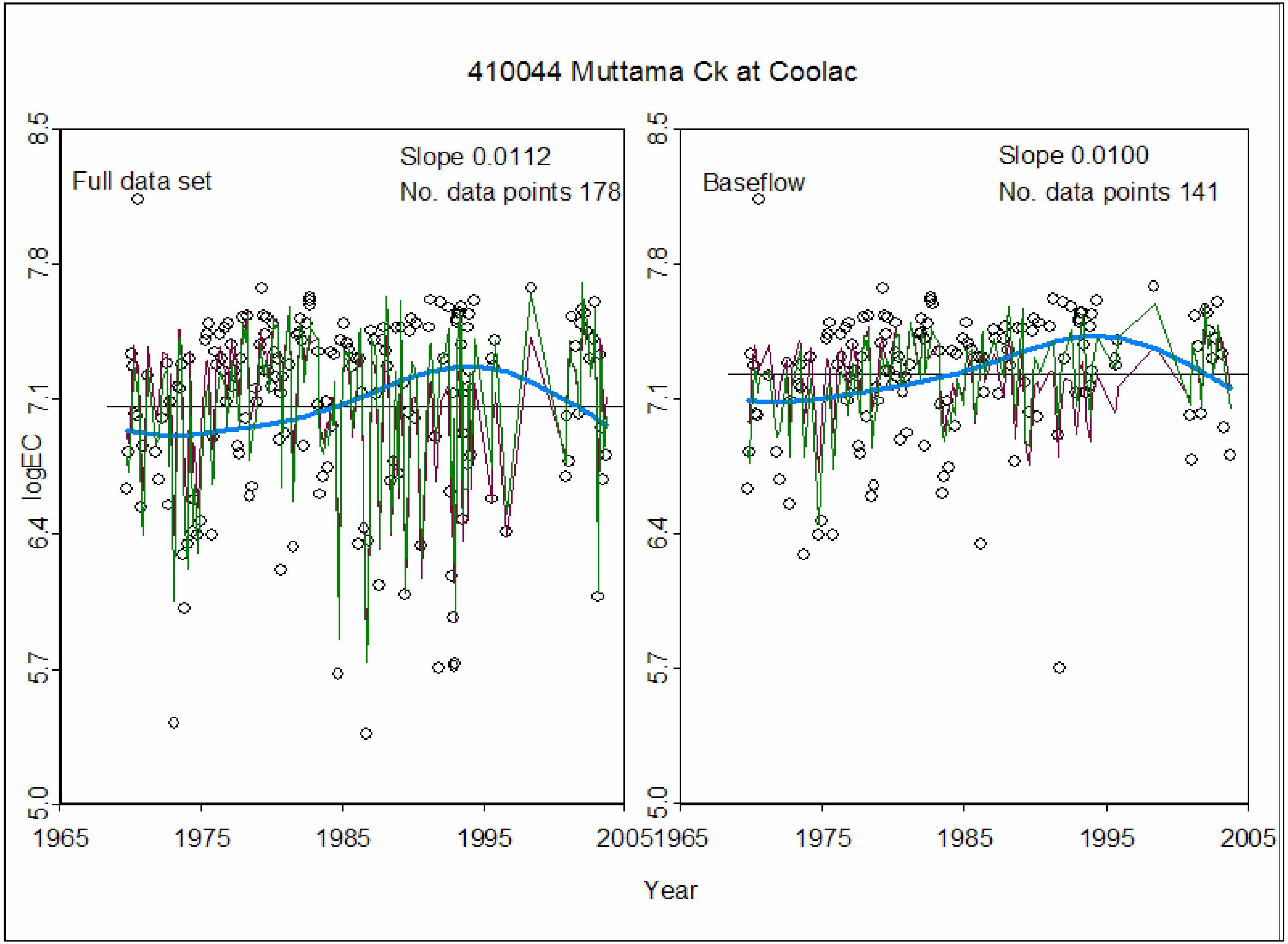

410061 Adelong Ck at Batlow Rd
Full data set
Slope -0.0008
No. data points 169
Baseflow
Slope -0.0018
No. data points 136
logEC
Year
6.0
5.5
5.0
4.5
4.0
1965
1975
1985
1995
2005

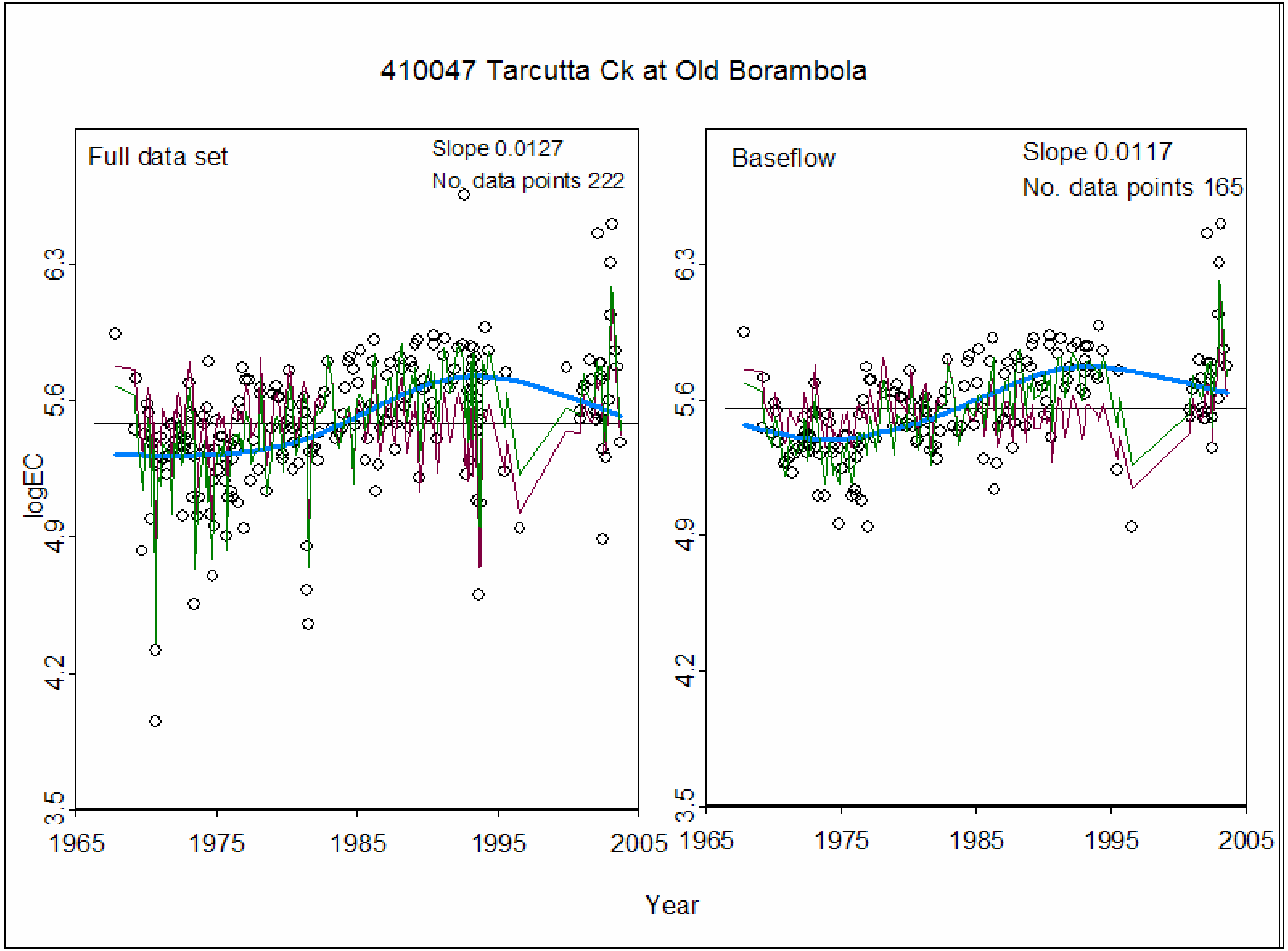

410038 Adjungbilly Ck at Darbalara
Full data set
Slope -0.0015
No. data points 149
Baseflow
Slope 0.008
No. data points 108
logEC
Year
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
1965
1975
1985
1995
2005

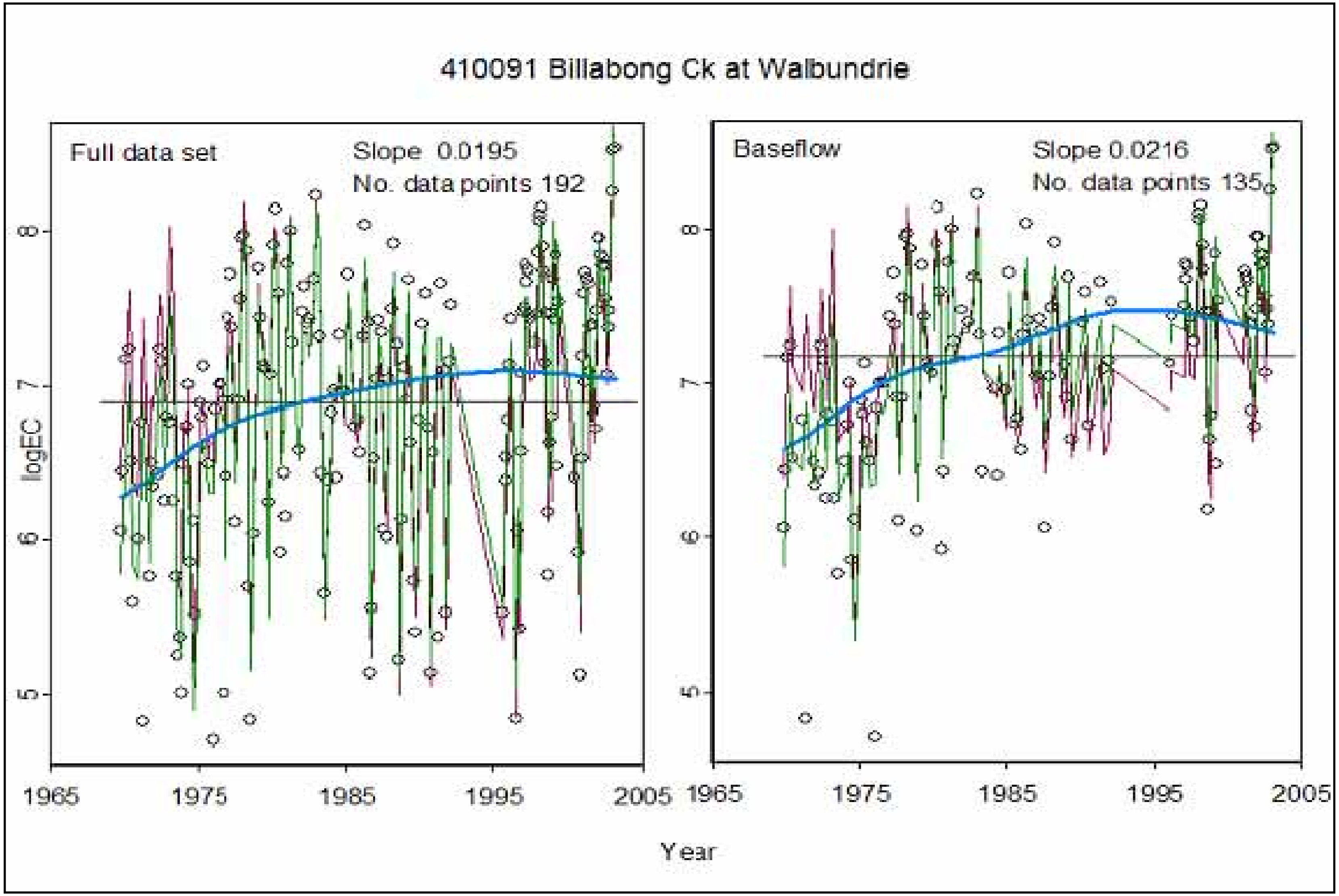

401013 Jingellic Ck at Jingellic
Full data set
Slope -0.0007
No. data points 217
Baseflow
Slope -0.0004
No. data points 176
logEC
5.5
5.0
4.5
4.0
3.5
1965
1975
1985
1995
2005
Year


410025 Jugiong Ck at Jugiong
Full data set
Slope 0.0195
No. data points 193
Baseflow
Slope 0.0172
No. data points 149
logEC
8.0
7.3
6.6
5.9
5.2
4.5
1965
1975
1985
1995
2005
Year


401009 Maragle Ck at Maragle
Full data set
Slope 0.0007
No. data points 198
Baseflow
Slope 0.0004
No. data points 158
logEC
6.0
5.4
4.8
4.2
3.6
3.0
1965
1975
1985
1995
2005
Year

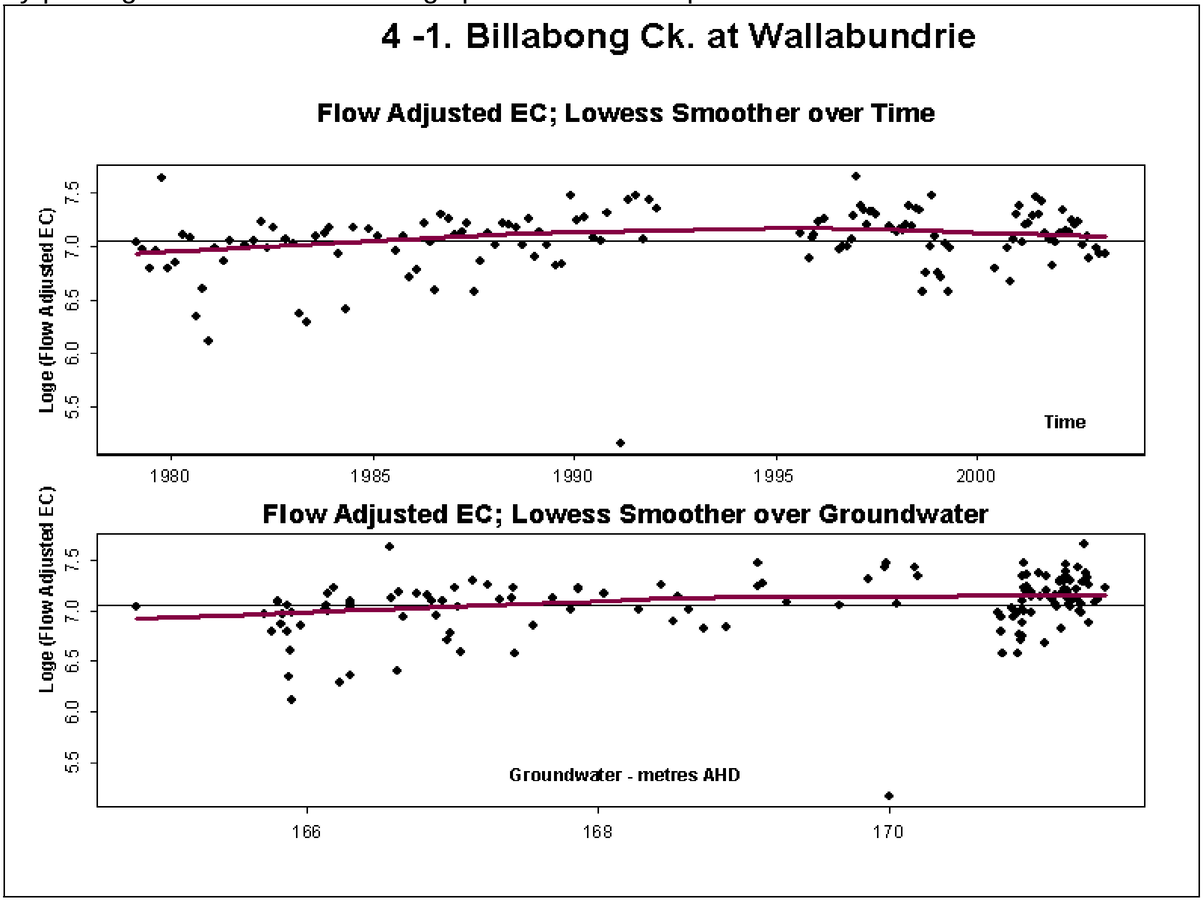

410044 Muttama Ck at Coolac
Full data set
Slope 0.0112
No. data points 178
Baseflow
Slope 0.0100
No. data points 141
logEC
8.5
7.8
7.1
6.4
5.7
5.0
1965
1975
1985
1995
2005
Year


410047 Tarcutta Ck at Old Borambola
Full data set
Slope 0.0127
No. data points 222
Baseflow
Slope 0.0117
No. data points 165
logEC
6.3
5.6
4.9
4.2
3.5
1965
1975
1985
1995
2005
Year

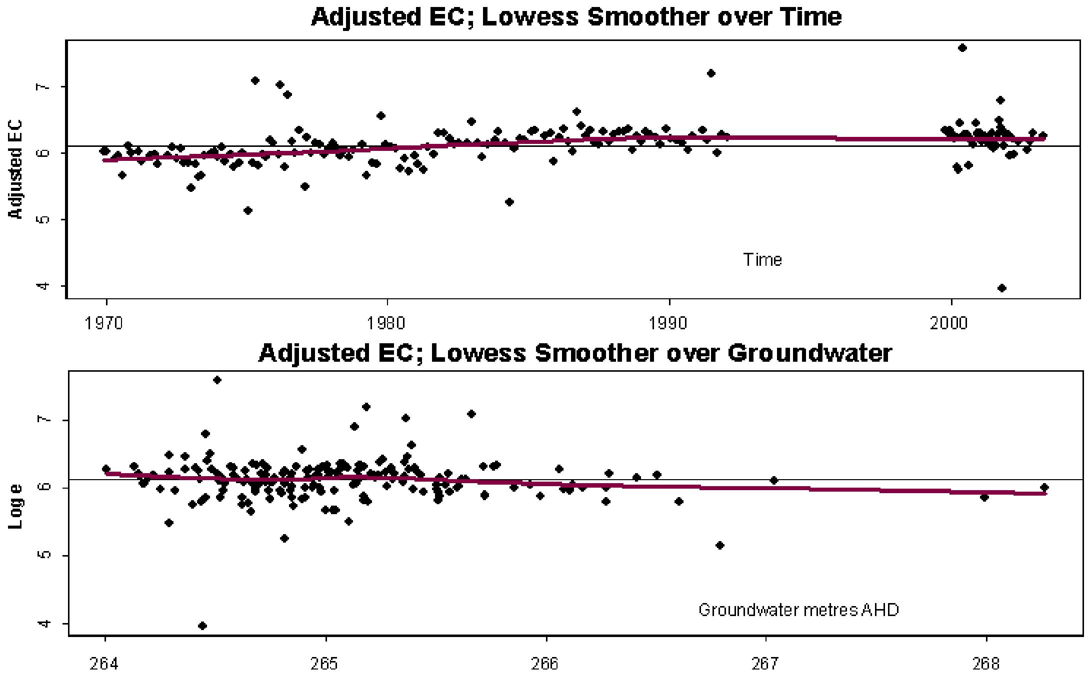

410091 Billabong Ck at Walbundrie
Full data set
Slope 0.0195
No. data points 192
Baseflow
Slope 0.0216
No. data points 135
logEC
5
6
7
8
1965
1975
1985
1995
2005
Year

Appendix 4—Groundwater pilot study

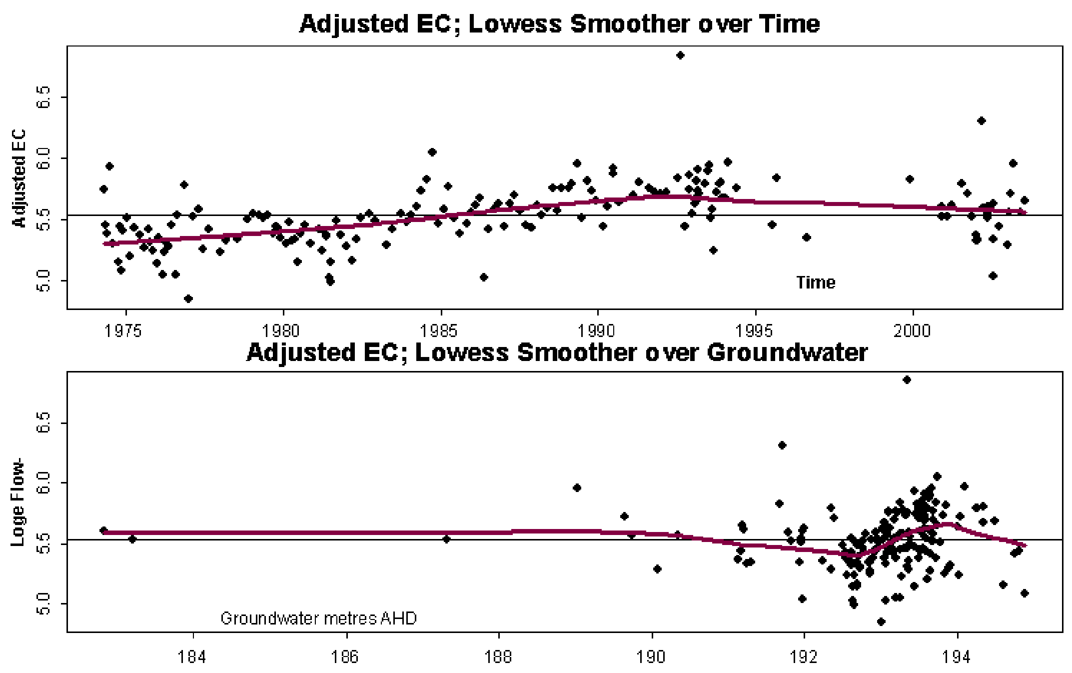
The link between flow-adjusted $\log_e EC$ and either time or groundwater was examined graphically by plotting a LOWESS smoothing spline over the respective data sets.



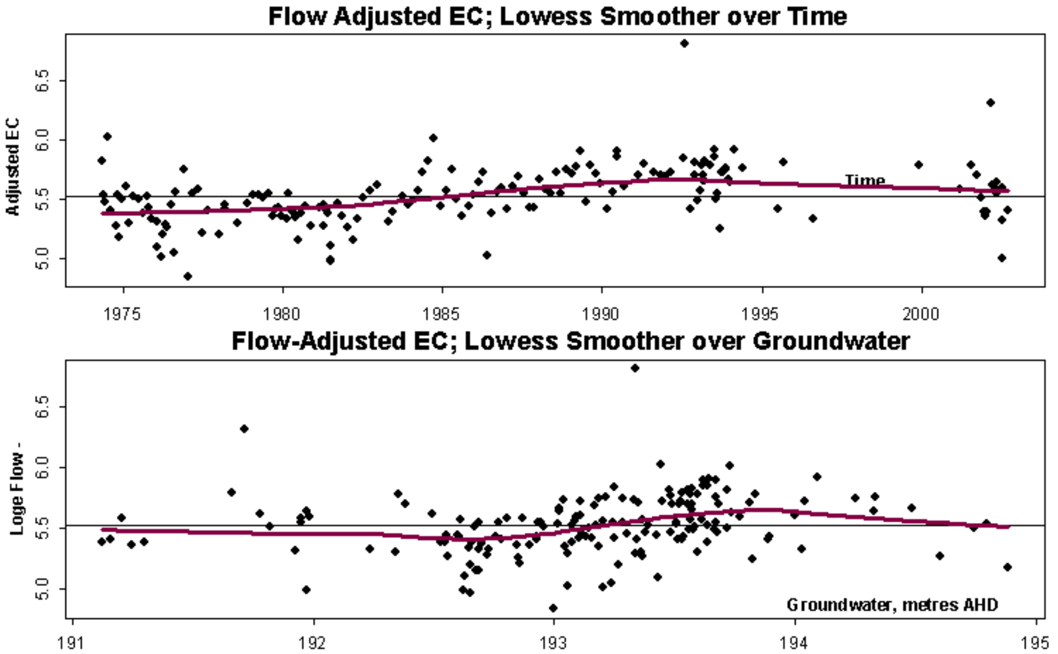
Appendix 4-2. Billabong Ck. at Aberfeldy



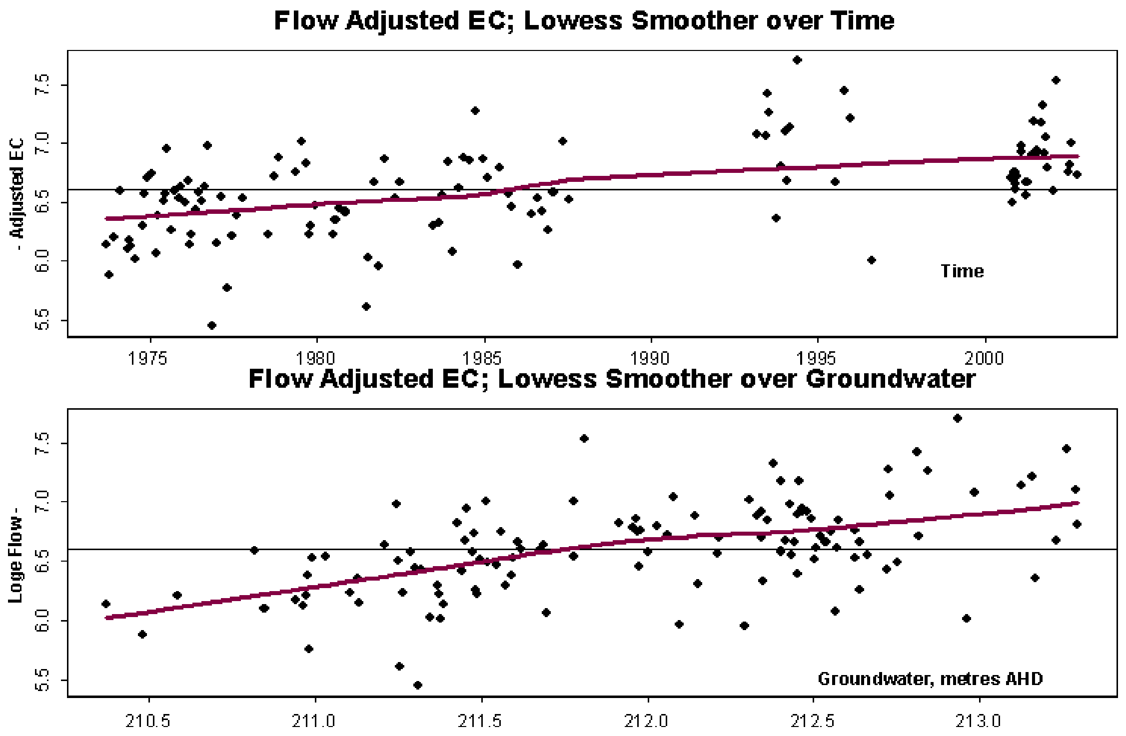
Appendix 4-3a. Tarcutta Ck. at Old Borambola

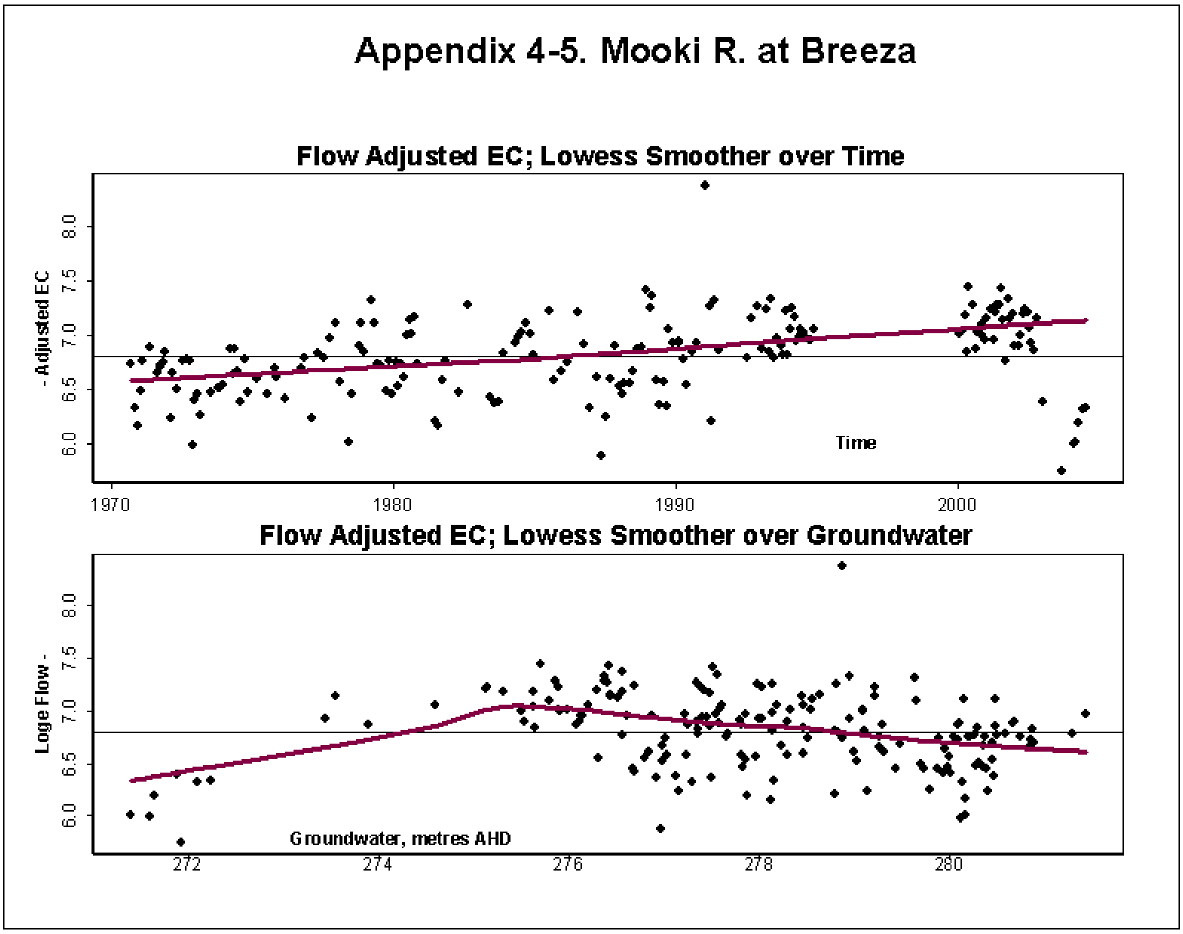


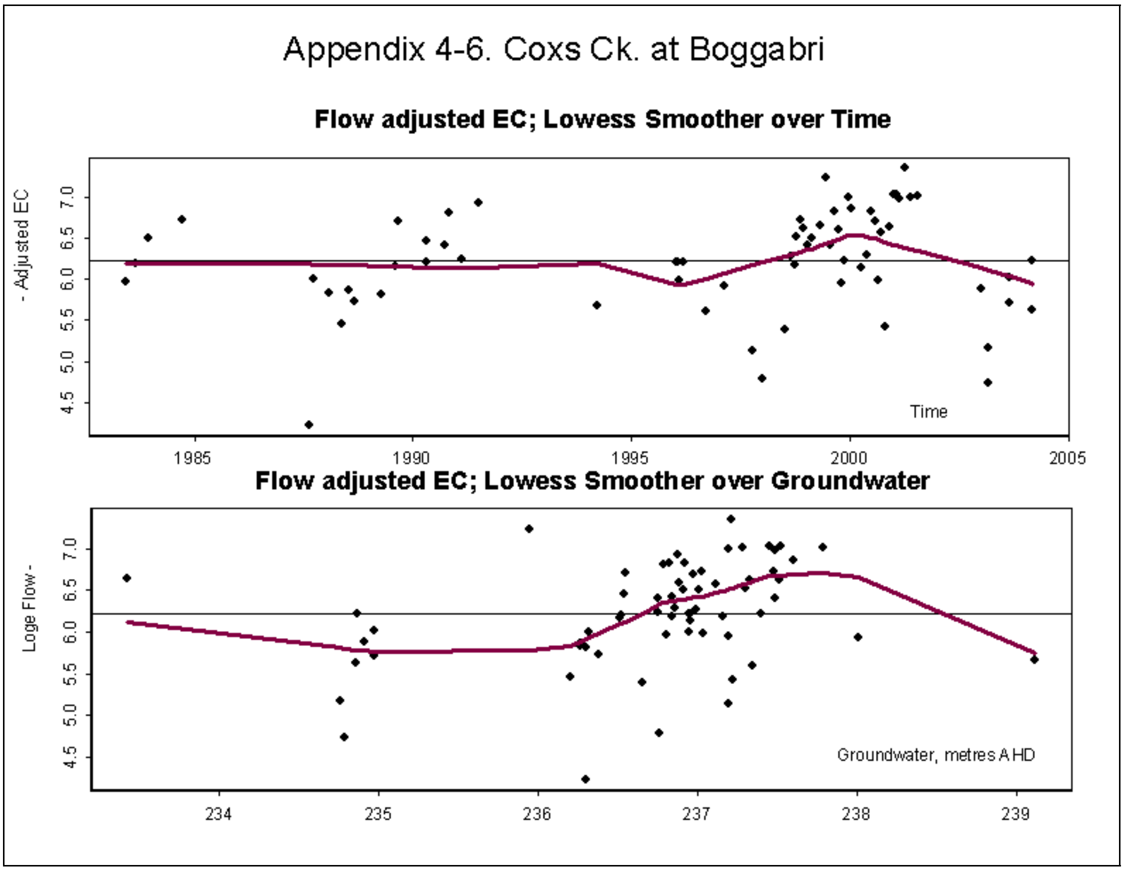
Appendix 4-3b. Tarcutta at Old Borambola

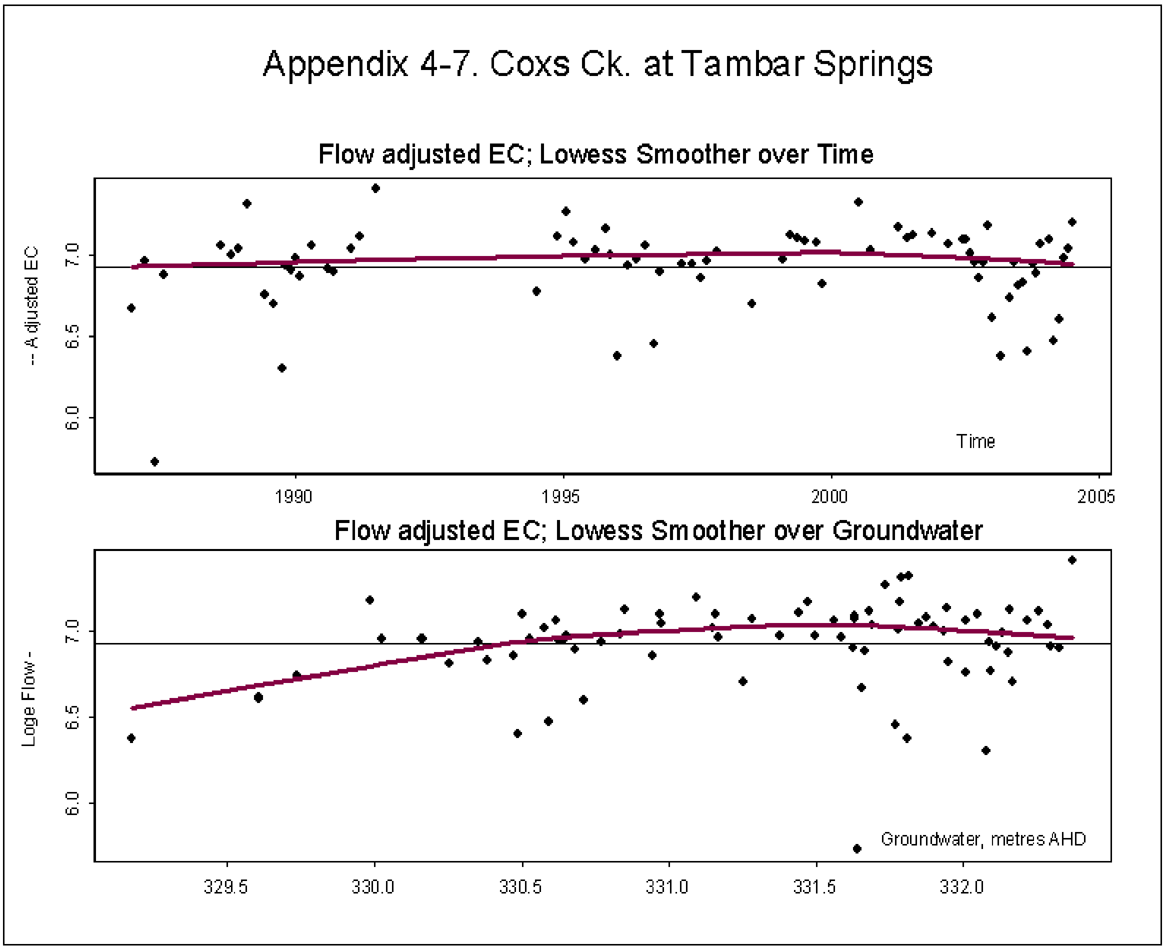


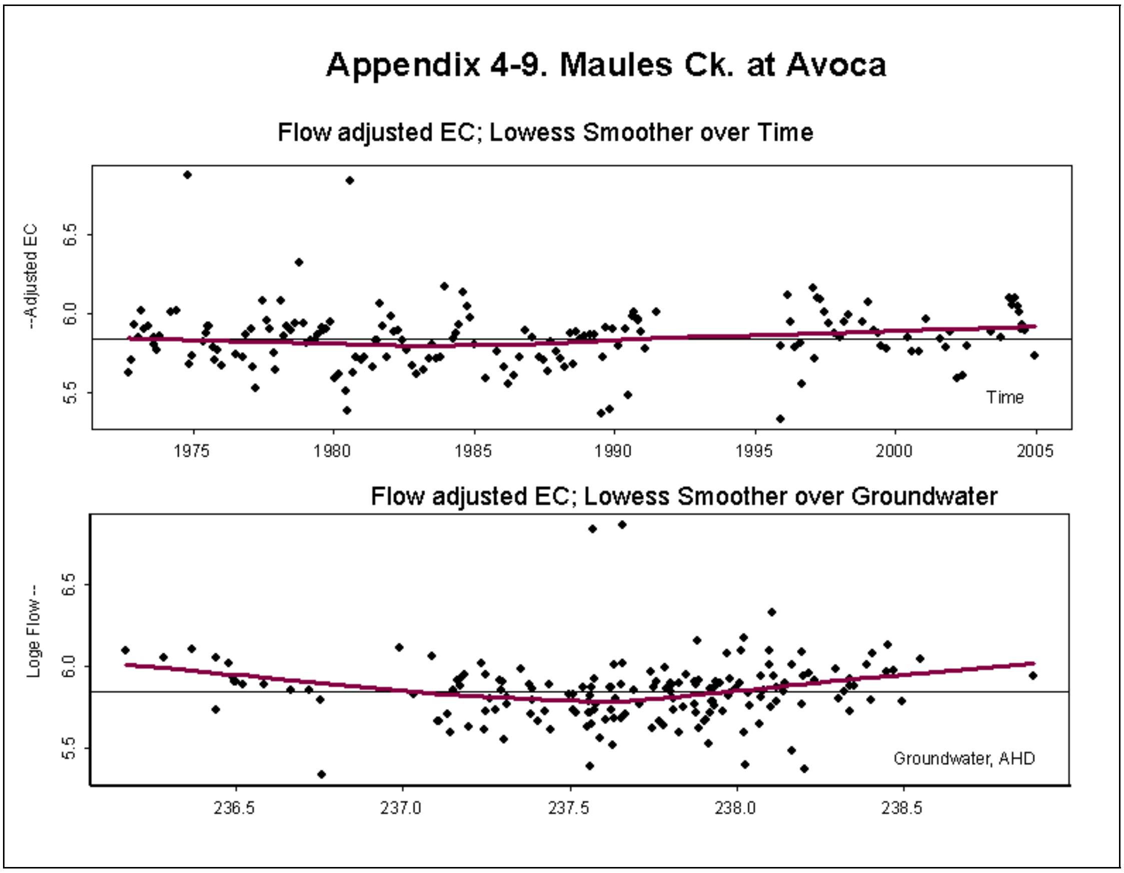
Appendix 4-4. Kyeamba Ck. at Ladysmith




Appendix 4-5. Mooki R. at Breeza
Flow Adjusted EC; Lowess Smoother over Time
Loge Flow - Adjusted EC
6.0
6.5
7.0
7.5
8.0
Time
1970
1980
1990
2000
Flow Adjusted EC; Lowess Smoother over Groundwater
Groundwater, metres AHD
272
274
276
278
280


Appendix 4-6. Coxs Ck. at Boggabri
Flow adjusted EC; Lowess Smoother over Time
Loge Flow - Adjusted EC
4.5
5.0
5.5
6.0
6.5
7.0
Time
1985
1990
1995
2000
2005
Flow adjusted EC; Lowess Smoother over Groundwater
Groundwater, metres AHD
234
235
236
237
238
239


Appendix 4-7. Coxs Ck. at Tambar Springs
Flow adjusted EC; Lowess Smoother over Time
-- Adjusted EC
7.0
6.5
6.0
Time
1990
1995
2000
2005
Flow adjusted EC; Lowess Smoother over Groundwater
Loge Flow -
7.0
6.5
6.0
Groundwater, metres AHD
329.5
330.0
330.5
331.0
331.5
332.0


Appendix 4-9. Maules Ck. at Avoca
Flow adjusted EC; Lowess Smoother over Time
--Adjusted EC
6.5
6.0
5.5
Time
1975
1980
1985
1990
1995
2000
2005
Flow adjusted EC; Lowess Smoother over Groundwater
Loge Flow --
6.5
6.0
5.5
Groundwater, AHD
236.5
237.0
237.5
238.0
238.5

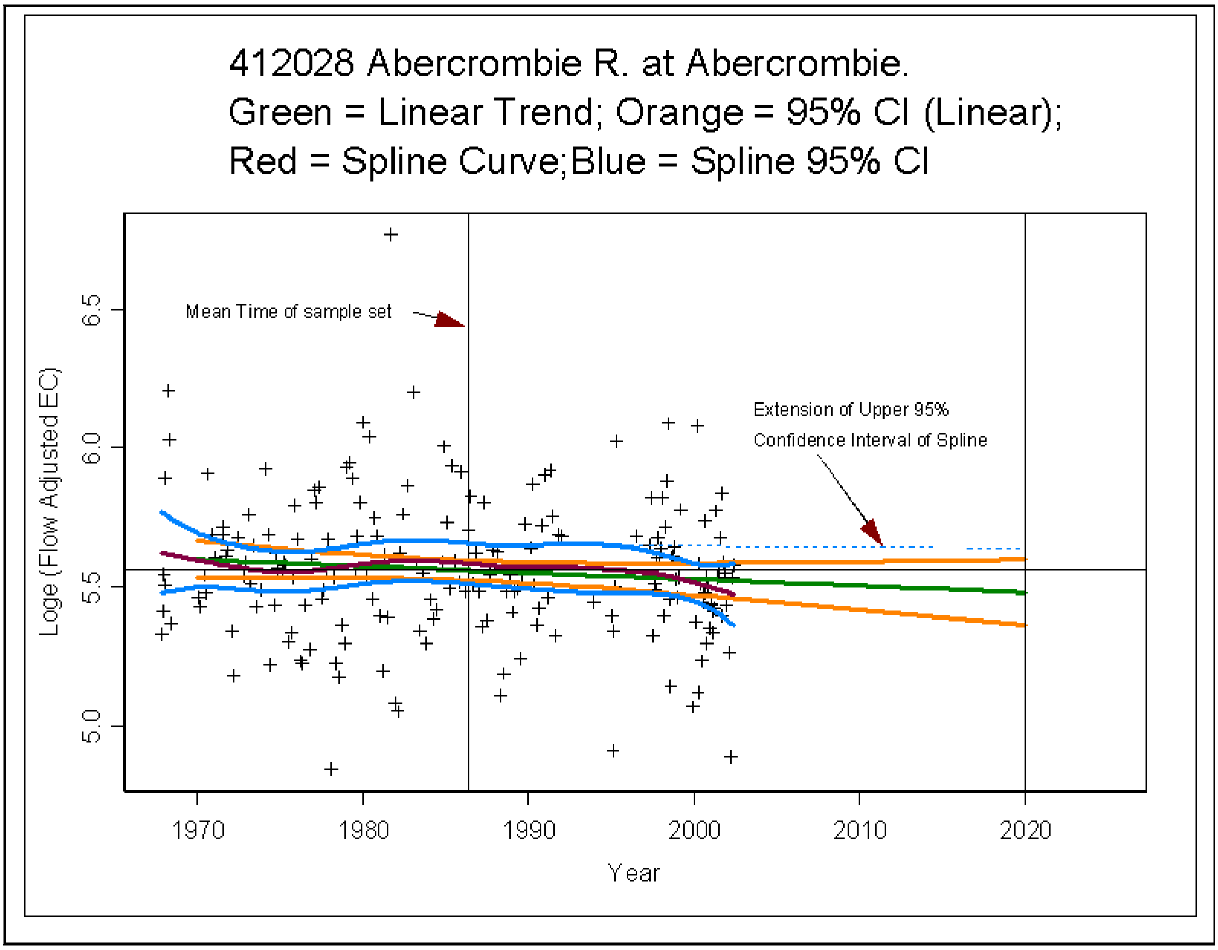
Appendix 5—Forecasting EC for 2020

This appendix contains forecasting techniques that were developed, but not used in the project. As indicated in Section 8.9.1, the GAMs are limited in their ability to forecast, and there are a number of steps associated with satisfactorily forecasting the EC values for 2020.

Linking current work to prior salinity benchmarking

The first stage involves linking the current work to the previously calculated 1975–2000 EC benchmark values. To achieve this link, it is necessary to run the model using: a) the truncated data set used to generate the 1975–2000 benchmark values; and b) the representative flow listed in Appendix 1. The GAM value calculated for the mean time of the benchmark period can then be compared with the current calculations to determine any EC change over time.

At approximately 20% of the sites analysed (Abercrombie River is shown as an example), the non-linear time trend component is statistically non-significant (see last two columns of Table 4). At these sites, the linear component (green and brown lines) becomes the sole driver in forecasting the 2020 values. The upper blue line (dotted) is extended to 2020 purely for interest.



Non-significant cyclic trend component

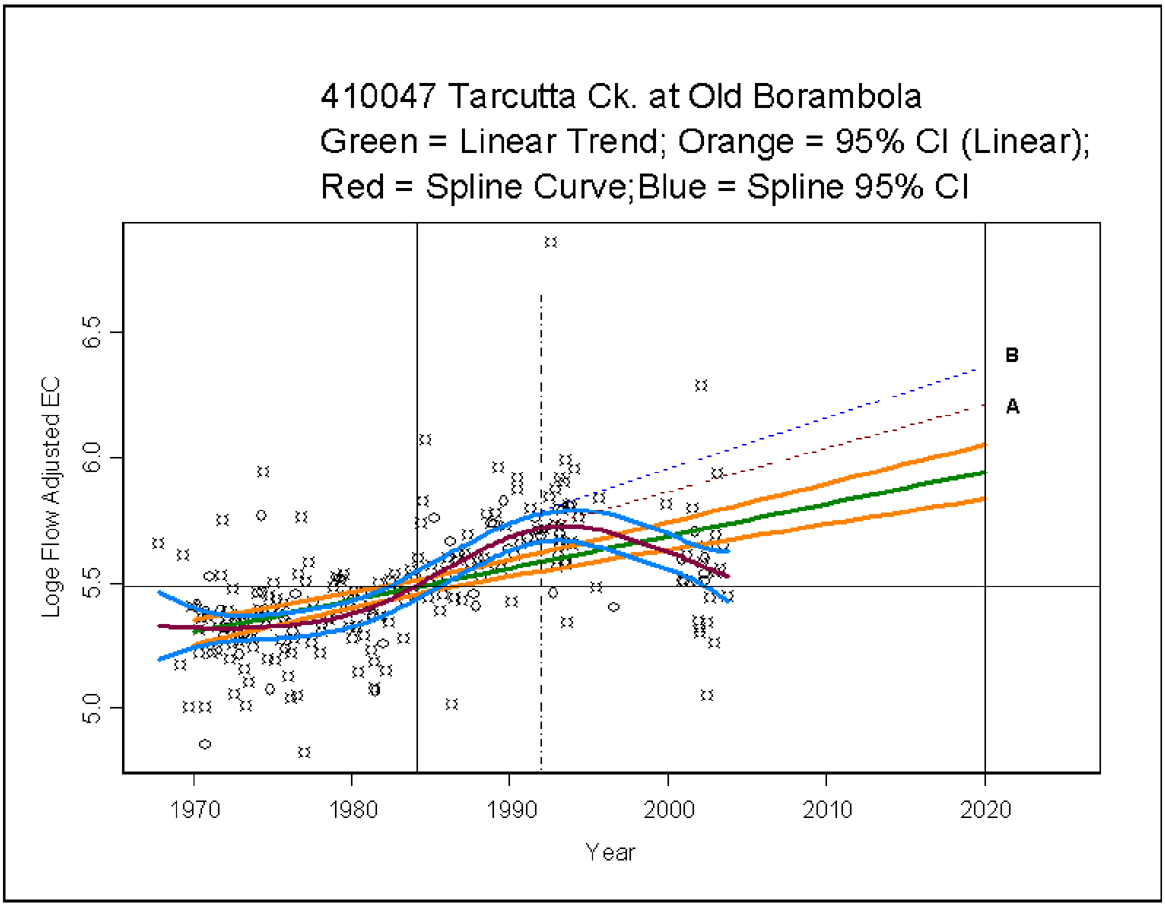
In the above case, the linear trend is negative. In order to plot the worst case scenario, the linear green trend-line and brown confidence belt lines will be pivoted about the 'mean time of the data set' until the green line is horizontal. (If the trend is positive, the pivot adjustment is not undertaken, and the upper orange confidence band would be adopted.) Two values would be provided as part of the 2020 forecasting:

- where the green line cuts the 2020 vertical line (in this case the black vertical line at 2020)
- where the pivoted upper brown confidence limit line cuts the 2020 vertical.

Significant cyclic trend component

At about 80% of sites, the cyclicity of the trend curve is significant. In this situation, the red and blue curves usurp the role of the brown and green lines in interpreting the worst case scenario. However, it is necessary to use the green linear trend-line as the foundation for the extrapolation of the red spline trend curve.

The figure below is an example of the non-linearity being statistically significant. The vertical dashed line indicates the point at which the greatest deviation occurs between the spline and the linear fitted trend curves. Two ratios are calculated here: a $\log_e$ space ratio is derived for (fitted red spline / fitted green linear) and (blue upper limit / fitted green linear). These 2 ratios are projected to the 2020 line at A and B respectively. Point A represents an estimate of the GAM value at 2020. Point B represents the approximate 95% upper confidence band.



Appendix 6 – S-PLUS Script Input File

```
# ######################################################################################
# These are the models being fitted in this program
#
# 1. Data.lm1 <- lm(logEC ~ logFlow )
# 2. Data.lm2 <- lm(logEC ~ logFlow + cost + sint)
# 3. Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
# 3a D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
# 4. Data.lm3 <- lm(AdjEC ~ yrfrac)
# 5. Data.gam2 <- gam(AdjEC ~ s(yrfrac, 4))
# 6. Data.lm4 <- lm(logEC ~ logFlow + cost + sint + yrfrac)
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# 7a D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater, 4)) + s(yrfrac,2)
# ######################################################################################

# =1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1
# ============== Create a "Data" data frame to save having to rename everything ==
# ================================================================================
Data <- wallallgw # use a common data frame name of Data
attach(Data) # attach desired data frame
dim(Data)
Data[1:3,]

mon <- months(Data$dtime) # generate vector of months
yday <- yeardays(Data$dtime) # generate vector of days from start of year
cost <- cos((2 * pi * yday/365)) # dummy variables for season
sint <- sin((2 * pi * yday/365))
yrfrac <- as.numeric(as.character(years(Data$dtime))) + yday/365
Data$yrfrac <- yrfrac

# =2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=
# ============== How regular are the sampling intervals?===================
# =========================================================================
mon
diff(yrfrac)*365 # number of days lapsed between observations
table(years(dtime), mon) # number of observations per month & year
table(years(dtime)) # how many observations per year ?

# =3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=
# ============== EDA to look for possible seasonality =====================
# =========================================================================
par(mfrow=c(2,2))
logEC <- log(TumutEC)
Data$logEC <- log(TumutEC)
min(instFlow)
logFlow <- log(instFlow)
```

```
Data$logFlow <- log(instFlow)
boxplot(split(logEC, mon))
abline(h=mean(logEC)) # reference line at mean of log EC
title("Is there potential seasonality in logEC?")
acf(logEC,lag.max=10)
boxplot(split(logFlow, mon))
abline(h=mean(logFlow)) # reference line at mean of log Flow
title("Is there potential seasonality in logFlow?")
acf(logFlow,lag.max=10)

# =4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=
# ===== Plot the original data; look at EC / Flow dependency ====
# ==========================================================================
par(mfrow=c(2,1))
plot(yrfrac,logEC,type="b",ylim=c(min(min(logFlow),min(logEC)),max(max(logEC),max(logFlow))))
title("log(EC) open circles; log(Flow) solid green circles") # plot original EC data open circles
abline(h=mean(logEC)) # reference line at mean of log EC
points(yrfrac,logFlow,col=4,pch=10,type="b") # overlay the log Flow solid green
abline(h=mean(logFlow))
plot(logFlow, logEC,pch=15) # look at log(Flow) v's log(EC) relationship
title("must correct log(EC) to a constant log(Flow)")

# =5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=
# ===== Start with a linear model on log scale =================
# ===== ... then add sin & cos terms =================
# ===== ... then try adding spline(instFlow) =================
# =========================================================================
Data.lm1 <- lm(logEC ~ logFlow )
Data.lm2 <- lm(logEC ~ logFlow + cost + sint)
Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
Data.lm2a <- lm(logEC ~ cost + sint)
Data$season <- predict(Data.lm2a)

summary(Data.lm1, corr=F) ; anova(Data.lm1) # original linear model
summary(Data.lm2, corr=F) ; anova(Data.lm1, Data.lm2) # adding staggered
summary(Data.gam1, corr=F) ; anova(Data.lm2, Data.gam1) # adding spline for inst Flow
summary.lm(Data.gam1)
summary(lm(logEC ~ predict.gam(Data.gam1)))

# =6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=
# ======= Which model seems more appropriate with smallest AIC ============
# ==========================================================================
AIC(Data.lm1,Data.lm2,Data.lm2a,Data.gam1)
par(mfrow=c(1,1))
acf(Data.gam1$residuals,lag.max=10)

# =7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=
# ======= Create a plot of these models ==================================
# ==========================================================================
plot(logFlow,logEC) # plot the original data
title("Black=linear; Red=F+s+c; Orange=s(Flow,2)+s+c")
```

```
abline(Data.lm2,col=3,lwd=4) # red line is Flow + sin + cos
# create data frame for prediction
dummy <- data.frame(cost = rep(mean(cost), length(cost)))
dummy$sint <- rep(mean(sint), length(sint))
dummy$logFlow <- logFlow
dummy$gam1 <- predict.gam(Data.gam1,dummy,type="response")
points(logFlow, dummy$gam1 , col=5,lwd=4) # orange points are smoothed Flow

# =8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=
# ===== Look at adjusted EC versus time, adjusted for Flow & Seasonality===
# ========================================================================
par(mfrow=c(2,1))
AdjEC <- mean(logEC)+Data.gam1$residuals
Data$AdjEC = AdjEC
#plot(yrfrac,logEC)
plot(yrfrac,AdjEC,pch=16) # now plot EC adjusted for Flow & Seasonality
abline(h=mean(logEC)) # add reference line at mean of log EC
lines(lowess(yrfrac,AdjEC),col=3,lwd=4) # show a lowess smoother over time
title("EC adjusted for Flow & Seasonality; lowess smoother over time")

plot(groundwater,AdjEC,pch=16) # now plot EC adjusted for Flow & Seasonality
abline(h=mean(logEC)) # add reference line at mean of log EC
lines(lowess(groundwater,AdjEC),col=3,lwd=4) # show a lowess smoother over time
title("EC adjusted for Flow & Seasonality; lowess smoother over groundwater")

# =9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=
# ===== Fit Generalized Additive Model to adjusted EC data over time ======
# ===== and plot the linear and {linear + smooth} spline components =======
# =========================================================================
Data.lm3 <- lm(AdjEC ~ yrfrac)
Data.gam2 <- gam(AdjEC ~ s(yrfrac,4))
# Following line added by FJH
Data$Data.gam2 <- predict.gam(Data.gam2) #addition FJH 4th June
summary(Data.lm3); summary(Data.gam2); summary.lm(Data.gam2)
#plot(Data.gam2, se=T)
#abline(h=0) # add reference line at zero
#title("aberall -Zero is the mean (Flow adjusted EC)")
plot(yrfrac,AdjEC) # Plot EC adjusted for Flow & Seasonality
abline(h=mean(logEC)) # add reference line at mean of log EC
lines(yrfrac, predict(Data.lm3), col=4,lwd=4) # show the linear part in green
lines(yrfrac, predict.gam(Data.gam2) , col=5,lwd=4) # add the GAM fitted model in orange
title("Adjusted EC data: Green is linear fit; Orange is spline")
#acf(Data.gam2$residuals,lag.max=10) # check for autocorrelation in residuals

D.lm3a <- lm(AdjEC ~ groundwater)
D.gam2a <- gam(AdjEC ~ s(groundwater,2))
summary(D.lm3a); summary(D.gam2a); summary.lm(D.gam2a)
#plot(D.gam2a, se=T)
#abline(h=0) # add reference line at zero
#title("Zero is the mean (Flow adjusted EC)")
plot(groundwater,AdjEC) # Plot EC adjusted for Flow & Seasonality
```

```
abline(h=mean(logEC)) # add reference line at mean of log EC
wallallgw$AdjEC <- AdjEC
wallallgw$lm3a <- predict(D.lm3a)
wallallgw$gam2a <- predict.gam(D.gam2a)
lines(groundwater, predict(D.lm3a), col=4,lwd=4) # show the linear part in green
lines(groundwater, predict.gam(D.gam2a) , col=5,lwd=4) # add the GAM fitted model in orange
title("Adjusted EC data: Green is linear fit; Orange is spline 2")
#acf(D.gam2a$residuals,lag.max=10) # check for autocorrelation in residuals

AIC(Data.lm1,Data.lm2,Data.lm2a,Data.gam1,Data.lm3,D.lm3a,Data.gam2,D.gam2a)

# ==========================================================================
# ===== display the effect of different degrees of smoothing =======
# ==========================================================================
fit <- smooth.spline(yrfrac,AdjEC)
fit
Data.gam2 <- gam(AdjEC ~ s(yrfrac, 4))
Data.gam22 <- gam(AdjEC ~ s(yrfrac, 2))
Data.gam26 <- gam(AdjEC ~ s(yrfrac, 6))
Data.gam210 <- gam(AdjEC ~ s(yrfrac, 10))

par(mfrow=c(2,2))
plot(yrfrac,AdjEC, xlab="Year") # Plot EC adjusted for Flow & Seasonality
abline(h=mean(logEC)) # add reference line at mean of log EC
lines(yrfrac, predict(Data.lm3), col=4,lwd=4) # show the linear part in green
lines(yrfrac, predict.gam(Data.gam22) , col=5,lwd=4) # add the GAM fitted model in orange
title("Adjusted EC data: Degree of smoothing = 2")

plot(yrfrac,AdjEC, xlab="Year") # Plot EC adjusted for Flow & Seasonality
abline(h=mean(logEC)) # add reference line at mean of log EC
lines(yrfrac, predict(Data.lm3), col=4,lwd=4) # show the linear part in green
lines(yrfrac, predict.gam(Data.gam2) , col=5,lwd=4) # add the GAM fitted model in orange
title("Adjusted EC data: Degree of smoothing = 4")

plot(yrfrac,AdjEC, xlab="Year") # Plot EC adjusted for Flow & Seasonality
abline(h=mean(logEC)) # add reference line at mean of log EC
lines(yrfrac, predict(Data.lm3), col=4,lwd=4) # show the linear part in green
lines(yrfrac, predict.gam(Data.gam26) , col=5,lwd=4) # add the GAM fitted model in orange
title("Adjusted EC data: Degree of smoothing = 6")

plot(yrfrac,AdjEC, xlab="Year") # Plot EC adjusted for Flow & Seasonality
abline(h=mean(logEC)) # add reference line at mean of log EC
lines(yrfrac, predict(Data.lm3), col=4,lwd=4) # show the linear part in green
lines(yrfrac, predict.gam(Data.gam210) , col=5,lwd=4) # add the GAM fitted model in orange
title("Adjusted EC data: Degree of smoothing = 10")

# 10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10
# ===== Predict log EC for the first day of each year ====================
# ==========================================================================
years <- 2003 - 1970 + 2
yr.margin <- data.frame(yrfrac=seq(from=1970, to=2004, length=years))
```

```
yr.margin$yrfrac[35] <- mean(yrfrac)
yr.margin$gam2 <- predict.gam(Data.gam2,yr.margin,type="response")
yr.margin[]

# 11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11
# ==========================================================================
# ===== Repeat above using full model in one hit ==========================
# ==========================================================================
Data.lm4 <- lm(logEC ~ logFlow + cost + sint + yrfrac)
Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
AIC(Data.lm1,Data.lm2,Data.gam1,Data.lm4,Data.gam3)
mean(TumutEC)

summary(Data.lm4)
summary(Data.gam3)
summary.lm(Data.gam3)
Data.gam4 <- gam(logEC ~ s(logFlow,2) + s(yrfrac, 4))
anova(Data.gam4, Data.gam3) # shows additional reduction in deviance due to Sin & Cos
summary(lm(logEC ~ predict.gam(Data.gam3)))

par(mfrow=c(1,1))
plot(Data.gam3, se=T) # note, this gives 2 plots , one of which has
# 2 * standard error of predictions
abline(h=0) # add a reference line at origin
title("aberall Zero is the mean (Adjusted EC)")
acf(Data.gam3$residuals,lag.max=10) # check for autocorrelation in residuals

# 12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12
# == Plot original data, ============================
# == ..... then Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint) ===================
# == ..... then Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4)) ====
# == ..... therefore, Data.gam3 - Data.gam1 = {linear + smooth} * yrfrac component
# == ..... but must add on the grand mean, back to proper scale =================
# ========================================================================================
smoothEC <- mean(logEC)+ predict.gam(Data.gam3) - predict.gam(Data.gam1)
plot(yrfrac, logEC) # plot original data
abline(h=mean(logEC)) # add a reference line at mean
title("original log(EC); Red: gam1; Green: gam3; Orange: smooth yrfrac trend")
title(sub="BLUE curve is from fitting AdjEC ~ s(yrfrac,4) in 2-step approach")
lines(yrfrac, predict.gam(Data.gam1), col=3) # add RED fitted curve from spline(Flow,2)+s+c
lines(yrfrac, predict.gam(Data.gam2) , col=6,lwd=4) # add BLUE fitted from 2 step approach
lines(yrfrac, predict.gam(Data.gam3), col=4) #add GREEN curve: spl(Flow,2)+s+c + spl(yrfrac,4)
lines(yrfrac, smoothEC, col=5,lwd=4) # show the smoothed part

yr.margin$logFlow <- rep(mean(logFlow), length(yr.margin$yrfrac))
yr.margin$cost <- rep(mean(cost), length(yr.margin$yrfrac))
yr.margin$sint <- rep(mean(sint), length(yr.margin$yrfrac))
yr.margin$gam3 <- predict.gam(Data.gam3,yr.margin,type="response")
yr.margin$diff <- yr.margin$gam3 - yr.margin$gam2
yr.margin[,]
```

```
full.data <-predict.gam(Data.gam3,se.fit=T,type="response")
Data$gam3fit <- full.data$fit
Data$gam3se <- full.data$se.fit
hist(full.data$se.fit)
min(full.data$se.fit); Data[Data$gam3se==min(full.data$se.fit),]
max(full.data$se.fit); Data[Data$gam3se==max(full.data$se.fit),]

full.limits <- pointwise(full.data,coverage=0.95) # Pointwise calculates 95% confidence intervals
Data$lower <- full.limits$lower
Data$upper <- full.limits$upper
Data[,c("yrfrac","instFlow","TumutEC","gam3fit","gam3se","lower","upper")]

plot(yrfrac, logEC) # plot original data
abline(h=mean(logEC)) # add a reference line at mean
title("original log(EC); Blue: gam3; Red: Upper & Lower 95% CI")
lines(yrfrac, full.data$fit, col=6,lwd=4) # add BLUE fitted curve
lines(yrfrac, full.limits$lower , col=3,lwd=2) # add RED lower 95% limits
lines(yrfrac, full.limits$upper , col=3,lwd=2) # add RED upper 95% limits

# ==========================================================================================
# =13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13
#===========================================================================================
# Look at impact of including groundwater by comparing these models
#
# 3. Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
# 3a D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
#
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# 7a D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater, 4)) + s(yrfrac,2)
# ==========================================================================================
par(mfrow=c(2,1))
plot(yrfrac, AdjEC, pch=16)
abline(h = mean(logEC))
lines(lowess(yrfrac, AdjEC), col=3, lwd=4)
title("Adjusted EC; lowess smoother over time")

plot(groundwater, AdjEC, pch=16)
abline(h = mean(logEC))
lines(lowess(groundwater, AdjEC), col=3, lwd=4)
title("Adjusted EC; lowess smoother over groundwater")

# ========== Alternative models ================================================
# 3. Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
# 3a D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# ==============================================================================
D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
summary.lm(D.gam1a); summary.lm(D.gam1a, corr=F)
anova (Data.gam1, D.gam1a); anova (Data.gam1, Data.gam3)
summary(lm(logEC ~ predict.gam(D.gam1a)))
```

```
# ========== Alternative models ================================================
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# 7a D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater, 4)) + s(yrfrac,2)
# ==============================================================================
D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac,4) + s(groundwater,2),
control = gam.control(bf.maxit = 100) )
summary.lm(D.gam3a); summary.lm(D.gam3a, corr=F); anova (Data.gam3, D.gam3a)
summary(lm(logEC ~ predict.gam(D.gam3a)))

AIC(Data.lm1,Data.lm2,Data.gam1,D.gam1a,Data.gam3,D.gam3a)

# 1. Data.lm1 <- lm(logEC ~ logFlow )
# 2. Data.lm2 <- lm(logEC ~ logFlow + cost + sint)
# 3. Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
# 3a D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# 7a D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater, 4)) + s(yrfrac,2)
```

Appendix 7 – S-PLUS Script Output File

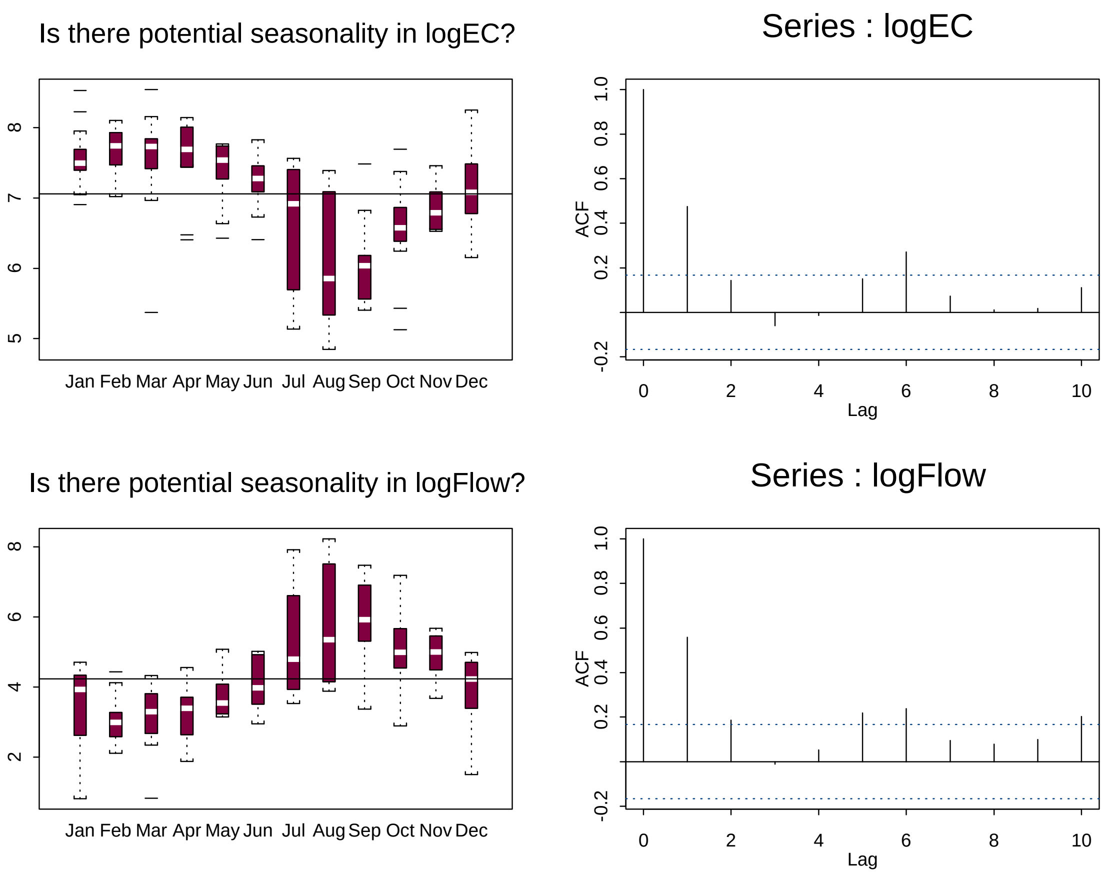
The GREEN numbers in Section 11 (`# 11=11=`) indicate values which may be useful additions to a summary table for these analyses.

```
                # BLUE text is comment #
                # RED text is program code #
                # BLACK text is output #

> # #####################################################################################
# These are the models being fitted in this program
#
# 1. Data.lm1 <- lm(logEC ~ logFlow )
# 2. Data.lm2 <- lm(logEC ~ logFlow + cost + sint)
# 3. Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
# 3a D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
# 4. Data.lm3 <- lm(AdjEC ~ yrfrac)
# 5. Data.gam2 <- gam(AdjEC ~ s(yrfrac, 4))
# 6. Data.lm4 <- lm(logEC ~ logFlow + cost + sint + yrfrac)
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# 7a D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater, 4)) + s(yrfrac,2)
# #####################################################################################

# =1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1=1
# ============== Create a "Data" data frame to save having to rename everything ==
# ================================================================================

> Data <- wallallgw                         # use a common data frame name of Data
> attach(Data)                          # attach desired data frame

> dim(Data)
[1] 138 7

> Data[1:3, ]
dtime jday instFlow AccVol TumutEC EC76 groundwater
1 02/15/1979 10:00:00.000 28901.42 18.0 1995757 2350 2350 164.819
2 04/12/1979 10:00:00.000 28957.42 30.3 1997038 1700 1700 165.704
3 06/22/1979 11:00:00.000 29028.46 34.6 1999603 1250 1250 165.752

> mon <- months(Data$dtime)                 # generate vector of months
> yday <- yeardays(Data$dtime)              # generate vector of days from start of year
> cost <- cos(((2 * pi * yday)/365))        # dummy variables for season
> sint <- sin(((2 * pi * yday)/365))
> yrfrac <- as.numeric(as.character(years(Data$dtime))) + yday/365
> Data$yrfrac <- yrfrac

> # =2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=2=
# ============== How regular are the sampling intervals?===================
# =========================================================================
```

```
> mon
[1] Feb Apr Jun Aug Oct Dec Feb Apr Jun Aug Oct Dec Feb Apr Jun Oct Jan Mar
[19] May Jul Oct Jan Mar May Jul Oct Dec Mar Apr Jul Nov Feb Jul Oct Dec Feb
[37] Apr Jun Jul Sep Nov Jan Mar May Jul Sep Nov Jan Mar May Jul Sep Nov Jan
[55] Feb May Jul Sep Nov Jan Apr Jun Aug Oct Mar May Jul Sep Nov Jan Aug Oct
[73] Nov Dec Jan Mar Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jun Oct Nov
[91] Dec Feb Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May
[109] Jun Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
[127] Feb Mar Apr May Jun Jul Aug Sep Oct Dec Jan Mar

Jan < Feb < Mar < Apr < May < Jun < Jul < Aug < Sep < Oct < Nov < Dec

> diff(yrfrac) * 365                    # number of days lapsed between observations
[1] 56 71 55 56 57 69 63 64 56 56 63 54 70 57
[15] 140 76 68 58 63 99 69 61 65 77 91 42 84 60
[29] 65 138 87 166 71 55 64 63 55 49 55 64 57 61
[43] 49 63 63 63 64 70 56 65 56 54 62 43 69 76
[57] 49 85 55 77 77 63 63 126 63 64 70 56 69 1295
[71] 83 27 21 35 57 139 28 36 34 21 34 28 28 35
[85] 28 28 28 119 28 34 36 21 35 28 28 35 28 28
[99] 28 35 21 28 28 28 35 28 21 399 112 35 28 21
[113] 27 28 28 28 35 35 21 35 28 35 35 21 35 28
[127] 28 35 28 29 27 35 36 21 62 35 56

> table(years(dtime), mon)              # number of observations per month & year
integer matrix: 23 rows, 12 columns.
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1979 0 1 0 1 0 1 0 1 0 1 0 1
1980 0 1 0 1 0 1 0 1 0 1 0 1
1981 0 1 0 1 0 1 0 0 0 1 0 0
1982 1 0 1 0 1 0 1 0 0 1 0 0
1983 1 0 1 0 1 0 1 0 0 1 0 1
1984 0 0 1 1 0 0 1 0 0 0 1 0
1985 0 1 0 0 0 0 1 0 0 1 0 1
1986 0 1 0 1 0 1 1 0 1 0 1 0
1987 1 0 1 0 1 0 1 0 1 0 1 0
1988 1 0 1 0 1 0 1 0 1 0 1 0
1989 1 1 0 0 1 0 1 0 1 0 1 0
1990 1 0 0 1 0 1 0 1 0 1 0 0
1991 0 0 1 0 1 0 1 0 1 0 1 0
1992 1 0 0 0 0 0 0 0 0 0 0 0
1995 0 0 0 0 0 0 0 1 0 1 1 1
1996 1 0 1 0 0 0 0 1 1 1 1 1
1997 1 1 1 1 1 2 0 0 0 1 1 1
1998 0 2 1 1 1 1 1 1 1 1 1 1
1999 1 1 1 1 1 0 0 0 0 0 0 0
2000 0 0 0 0 0 1 0 0 1 1 1 1
2001 1 1 1 1 1 1 1 1 1 1 1 1
2002 1 1 1 1 1 1 1 1 1 1 0 1
2003 1 0 1 0 0 0 0 0 0 0 0 0
```

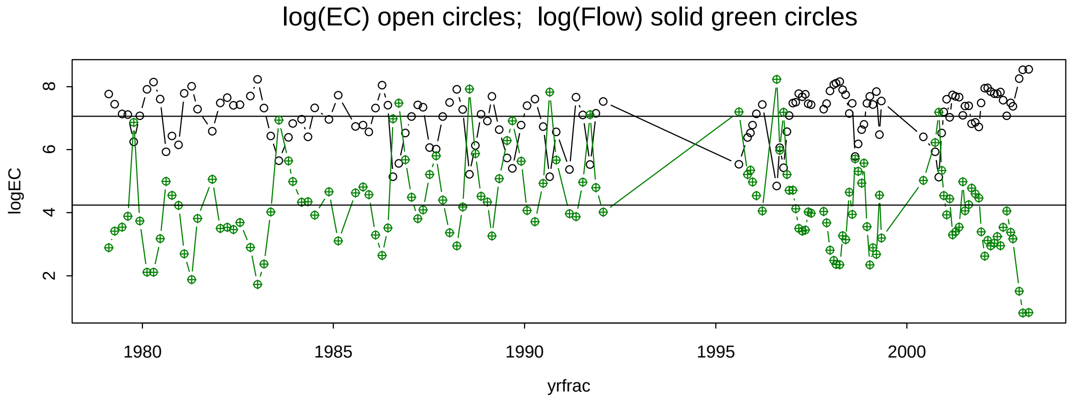
```
> table(years(dtime))                        # how many observations per year ?
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1995
6 6 4 5 6 4 4 6 6 6 6 5 5 1 4

1996 1997 1998 1999 2000 2001 2002 2003
7 10 12 5 5 12 11 2

> # =3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=3=
# ============== EDA to look for possible seasonality =====================
# ==========================================================================
> par(mfrow = c(2, 2))
> logEC <- log(TumutEC)
> Data$logEC <- log(TumutEC)
> min(instFlow)
[1] 2.26

> logFlow <- log(instFlow)
> Data$logFlow <- log(instFlow)
> boxplot(split(logEC, mon))
> abline(h = mean(logEC))                    # reference line at mean of log EC
> title("Is there potential seasonality in logEC?")

> acf(logEC, lag.max = 10)
Call: acf(x = logEC, lag.max = 10)

Autocorrelation matrix:
lag logEC
1 0 1.0000
2 1 0.4753
3 2 0.1428
4 3 -0.0598
5 4 -0.0145
6 5 0.1504
7 6 0.2715
8 7 0.0726
9 8 0.0104
10 9 0.0174
11 10 0.1107
```

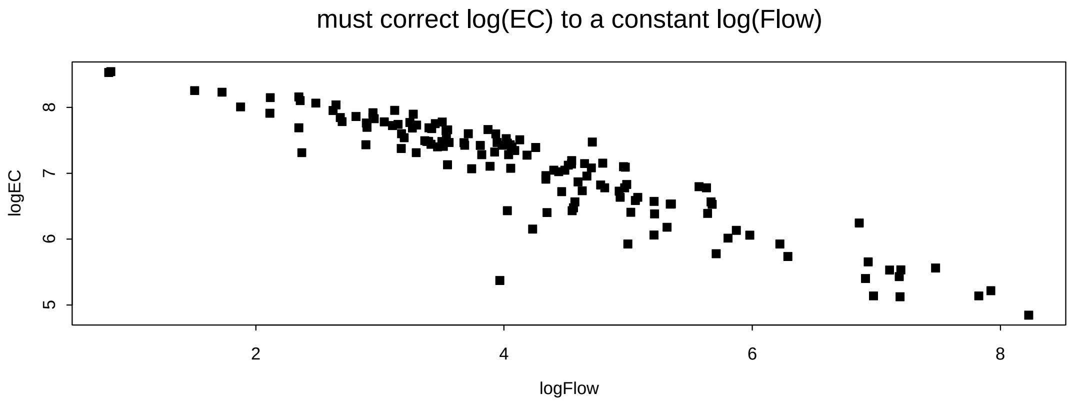
```
> boxplot(split(logFlow, mon))
> abline(h = mean(logFlow))                    # reference line at mean of log Flow
```




```
> title("Is there potential seasonality in logFlow?")

> acf(logFlow, lag.max = 10)
Call: acf(x = logFlow, lag.max = 10)

Autocorrelation matrix:
lag logFlow
1 0 1.0000
2 1 0.5583
3 2 0.1867
4 3 -0.0116
5 4 0.0525
6 5 0.2182
7 6 0.2382
8 7 0.0954
9 8 0.0792
10 9 0.0995
11 10 0.2028

> # =4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=4=
# ===== Plot the original data; look at EC / Flow dependency ====
# ==============================================================
> par(mfrow = c(2, 1))
```

```
> plot(yrfrac, logEC, type = "b", ylim = c(min(min(logFlow), min(logEC)), max( max(logEC),
   max(logFlow))))
> title("log(EC) open circles; log(Flow) solid green circles") # plot original EC data open circles
> abline(h = mean(logEC))                                      # reference line at mean of log EC
> points(yrfrac, logFlow, col = 4, pch = 10, type = "b")       # overlay the log Flow solid green
> abline(h = mean(logFlow))
> plot(logFlow, logEC, pch = 15)                               # look at log(Flow)/log(EC)
   relationship
> title("must correct log(EC) to a constant log(Flow)")
```





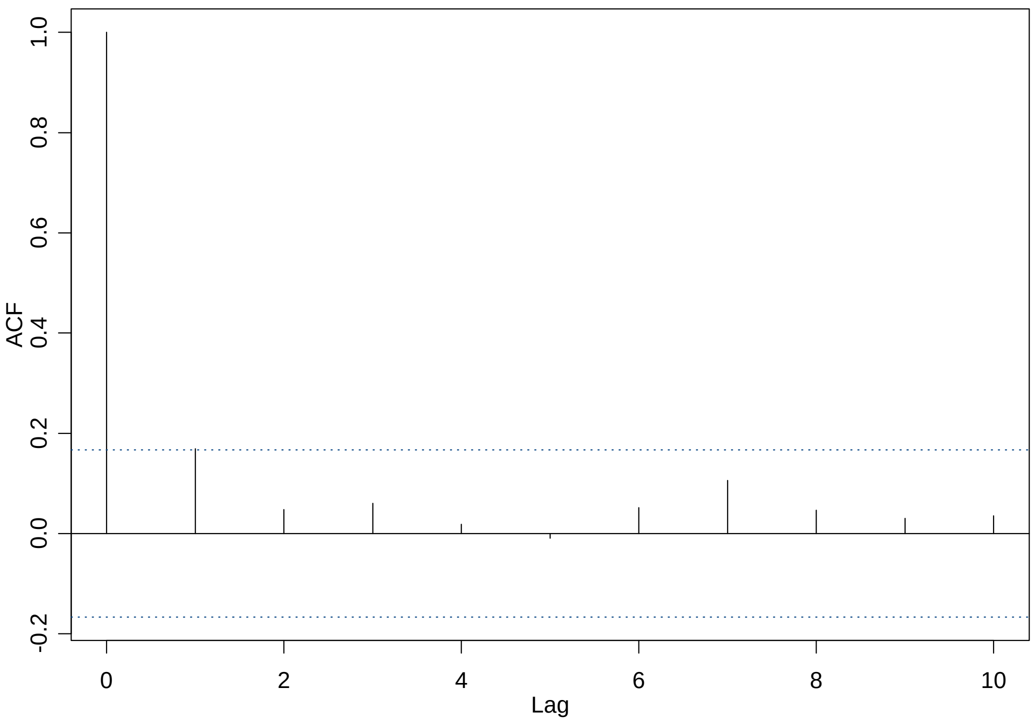

```
> # =5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=5=
# ===== Start with a linear model on log scale =================
# ===== ... then add sin & cos terms =================
# ===== ... then try adding spline(instFlow) =================
# ========================================================================
> Data.lm1 <- lm(logEC ~ logFlow)
> Data.lm2 <- lm(logEC ~ logFlow + cost + sint)
> Data.gam1 <- gam(logEC ~ s(logFlow, 2) + cost + sint)
> Data.lm2a <- lm(logEC ~ cost + sint)
> Data$season <- predict(Data.lm2a)

> summary(Data.lm1, corr = F); anova(Data.lm1)            # original linear model

Call: lm(formula = logEC ~ logFlow)
Residuals:
Min 1Q Median 3Q Max
-1.828 -0.1164 0.04352 0.1972 0.6607
```

```
Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 9.2488 0.0842 109.8285 0.0000
logFlow -0.5171 0.0189 -27.4275 0.0000

Residual standard error: 0.3132 on 136 degrees of freedom
0Multiple R-Squared: 0.8469
F-statistic: 752.3 on 1 and 136 degrees of freedom, the p-value is 0

Analysis of Variance Table
Response: logEC

Terms added sequentially (first to last)
Df Sum of Sq Mean Sq F Value Pr(F)
logFlow 1 73.77783 73.77783 752.2702 0
Residuals 136 13.33801 0.09807

> summary(Data.lm2, corr = F); anova(Data.lm1, Data.lm2)    # adding staggered

Call: lm(formula = logEC ~ logFlow + cost + sint)
Residuals:
Min 1Q Median 3Q Max
-1.877 -0.1055 0.03911 0.1861 0.622

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 9.1660 0.1125 81.4738 0.0000
logFlow -0.4982 0.0254 -19.5840 0.0000
cost 0.0274 0.0400 0.6847 0.4947
sint 0.0507 0.0497 1.0213 0.3090

Residual standard error: 0.314 on 134 degrees of freedom
Multiple R-Squared: 0.8483
F-statistic: 249.8 on 3 and 134 degrees of freedom, the p-value is 0

Analysis of Variance Table
Response: logEC

Terms Resid. Df RSS Test Df Sum of Sq F Value Pr(F)
1 logFlow 136 13.33801
2 logFlow + cost + sint 134 13.21405 +cost+sint 2 0.1239577 0.6285104 0.5349506

> summary(Data.gam1, corr = F); anova(Data.lm2, Data.gam1)  # adding spline for inst Flow

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint)
Deviance Residuals:
Min 1Q Median 3Q Max
-1.899777 -0.08394454 0.04062478 0.1687246 0.6001848

(Dispersion Parameter for Gaussian family taken to be 0.0964553 )
```

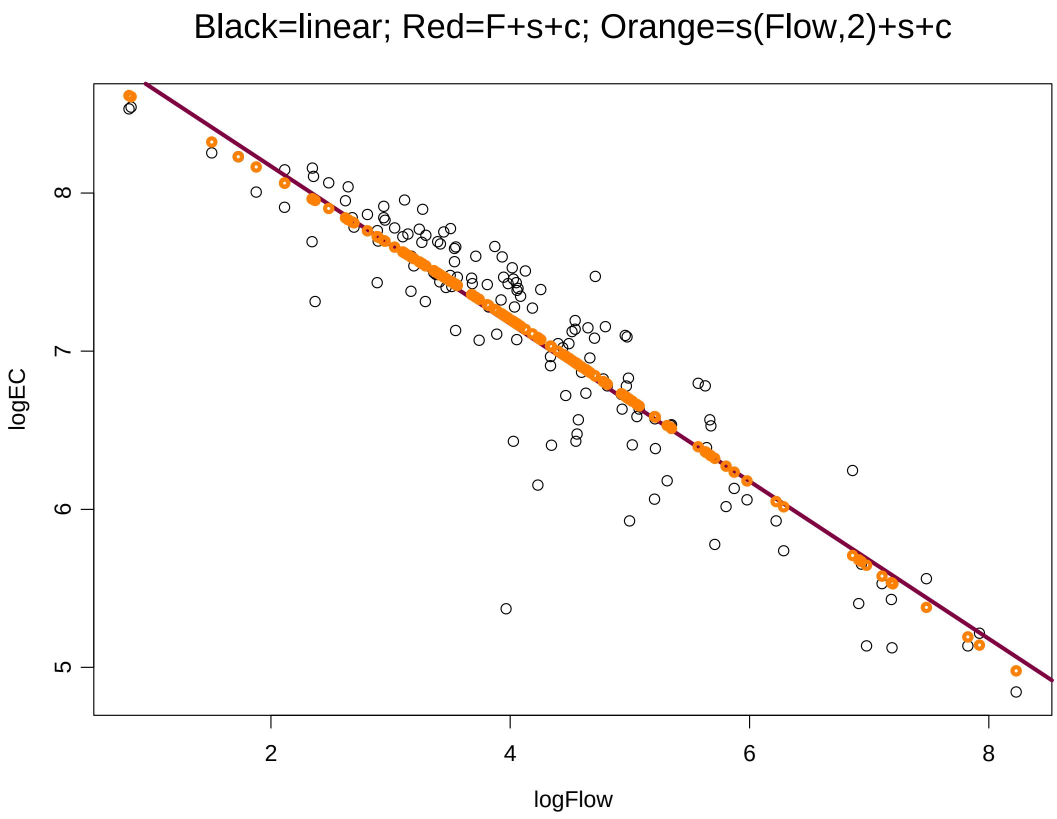
```
Null Deviance: 87.11584 on 137 degrees of freedom

Residual Deviance: 12.82857 on 133.0002 degrees of freedom

Number of Local Scoring Iterations: 1

DF for Terms and Chi-squares for Nonparametric Effects

Df Npar Df Npar Chisq P(Chi)
(Intercept) 1
s(logFlow, 2) 1 1 3.996404 0.04558675
cost 1
sint 1

Analysis of Variance Table
Response: logEC

Terms Resid. Df RSS Test Df Sum of Sq F Value Pr(F)
1 logFlow + cost + sint 134.0000 13.21405
2 s(logFlow, 2) + cost + sint 133.0002 12.82857 1 vs. 2 0.9998424 0.3854744 3.997034 0.04762443

> summary.lm(Data.gam1)

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint)
Residuals:
Min 1Q Median 3Q Max
-1.9 -0.08394 0.04062 0.1687 0.6002

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 9.1691 0.1113 82.4082 0.0000
s(logFlow, 2) -0.4989 0.0252 -19.8319 0.0000
cost 0.0288 0.0396 0.7272 0.4684
sint 0.0477 0.0491 0.9711 0.3333

Residual standard error: 0.3106 on 133.000157644148 degrees of freedom
Multiple R-Squared: 0.8501
F-statistic: 256.3 on 3 and 133.000157644148 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept) s(logFlow, 2) cost
s(logFlow, 2) -0.9711
cost -0.3413 0.3287
sint -0.6291 0.6427 0.2295

> summary(lm(logEC ~ predict.gam(Data.gam1)))

Call: lm(formula = logEC ~ predict.gam(Data.gam1))
Residuals:
Min 1Q Median 3Q Max
```

```
-1.9 -0.08393 0.04004 0.1688 0.6005

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -0.0110 0.2532 -0.0433 0.9655
predict.gam(Data.gam1) 1.0016 0.0357 28.0634 0.0000

Residual standard error: 0.3071 on 136 degrees of freedom
Multiple R-Squared: 0.8527
F-statistic: 787.6 on 1 and 136 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept)
predict.gam(Data.gam1) -0.9947

> # =6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=6=
# ======= Which model seems more appropriate with smallest AIC ============
# =========================================================================
> AIC(Data.lm1, Data.lm2, Data.lm2a, Data.gam1)
df AIC
Data.lm1 3 75.17125
Data.lm2 5 77.88274
Data.lm2a 4 262.35254
Data.gam1 5 73.79718

> par(mfrow = c(1, 1))
> acf(Data.gam1$residuals, lag.max = 10)
Call: acf(x = Data.gam1$residuals, lag.max = 10)

Autocorrelation matrix:
lag Data.gam1
1 0 1.0000
2 1 0.1693
3 2 0.0481
4 3 0.0600
5 4 0.0184
6 5 -0.0094
7 6 0.0515
8 7 0.1056
9 8 0.0466
10 9 0.0303
11 10 0.0355
```

Series : Data.gam1$residuals

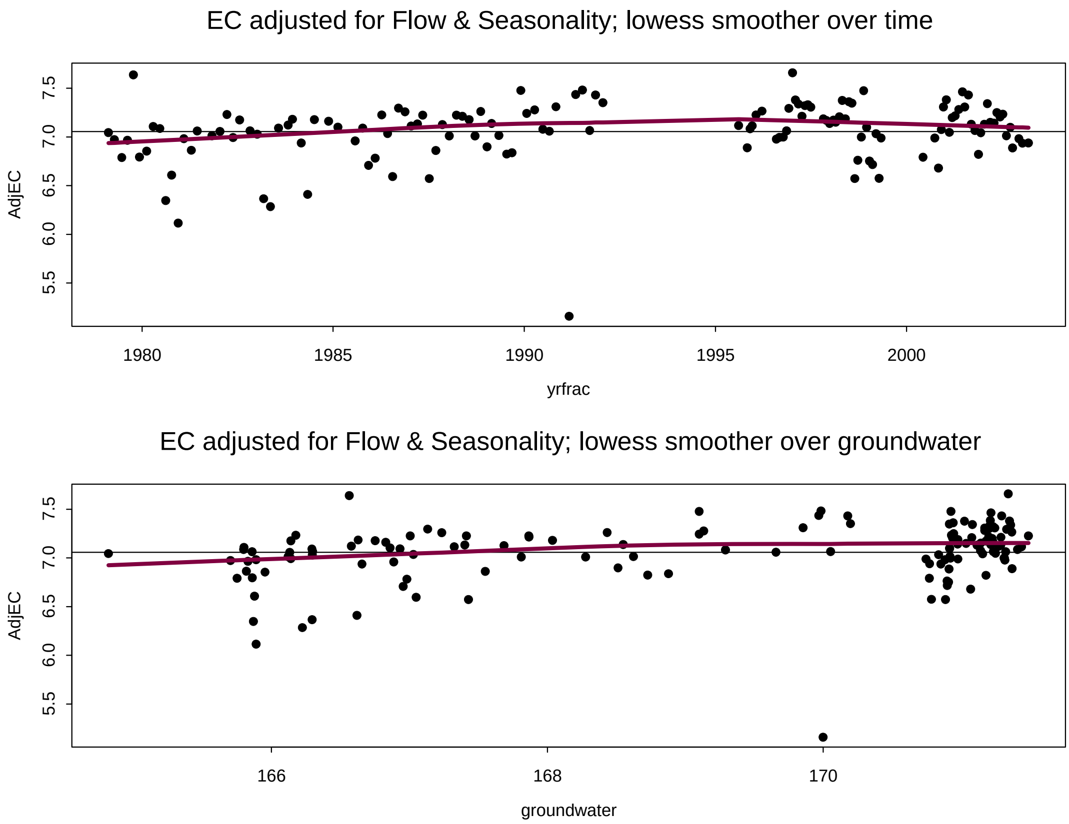


```
 > # =7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=7=
# ======= Create a plot of these models =================================
# ======================================================================
> plot(logFlow, logEC)                                    # plot the original data
> title("Black=linear; Red=F+s+c; Orange=s(Flow,2)+s+c")
> abline(Data.lm2, col = 3, lwd = 4)                      # red line is Flow + sin + cos
                                                      # create data frame for prediction
> dummy <- data.frame(cost = rep(mean(cost), length(cost)))
```




```
> dummy$sint <- rep(mean(sint), length(sint))
> dummy$logFlow <- logFlow
> dummy$gam1 <- predict.gam(Data.gam1, dummy, type = "response")
> points(logFlow, dummy$gam1, col = 5, lwd = 4)           # orange points are smoothed Flow
```

```
> # =8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=8=
# ===== Look at adjusted EC versus time, adjusted for Flow & Seasonality ===
# ========================================================================
> par(mfrow = c(2, 1))
> AdjEC <- mean(logEC) + Data.gam1$residuals
> Data$AdjEC = AdjEC
> # plot(yrfrac,logEC)
> plot(yrfrac, AdjEC, pch = 16)                          # now plot EC adjusted for Flow &
  Seasonality
> abline(h = mean(logEC))                                # add reference line at mean of log EC
> lines(lowess(yrfrac, AdjEC), col = 3, lwd = 4)         # show a lowess smoother over time
```



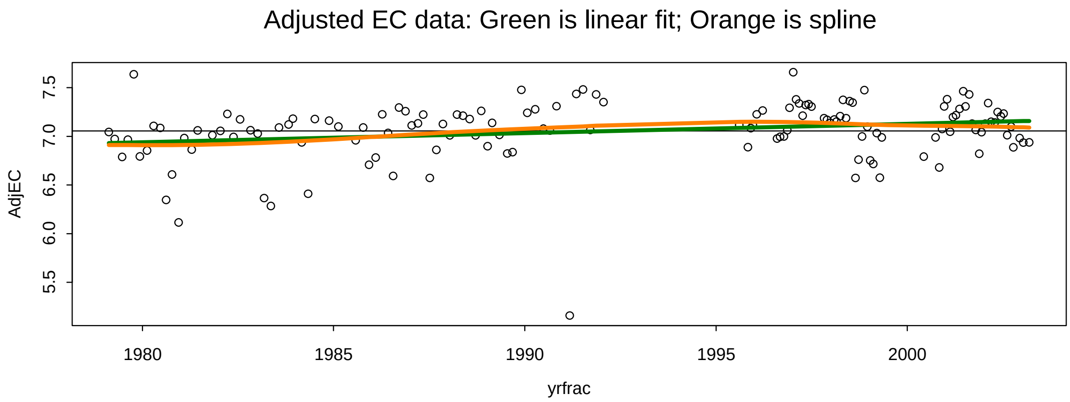

```
> title("EC adjusted for Flow & Seasonality; lowess smoother over time")

> plot(groundwater, AdjEC, pch = 16)                     # now plot EC adjusted for Flow &
  Groundwater
> abline(h = mean(logEC))                                # add reference line at mean of log EC
> lines(lowess(groundwater, AdjEC), col = 3, lwd = 4)    # show a lowess smoother over time
> title("EC adjusted for Flow & Seasonality; lowess smoother over groundwater")
```

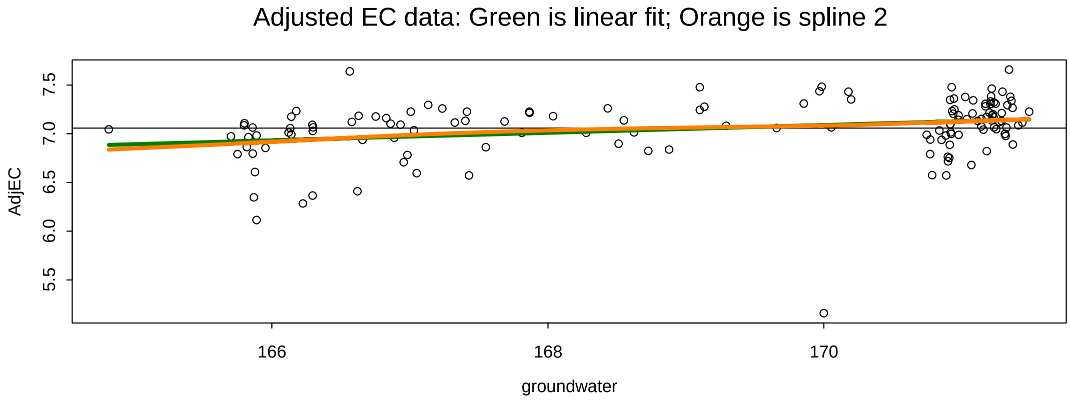
```
> # =9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=9=
# ===== Fit Generalized Additive Model to adjusted EC data over time ======
# ===== and plot the linear and {linear + smooth} spline components =======
# ========================================================================
> Data.lm3 <- lm(AdjEC ~ yrfrac)
> Data.gam2 <- gam(AdjEC ~ s(yrfrac, 4))
                                                        # Following line added by FJH
> Data$Data.gam2 <- predict.gam(Data.gam2)                  # addition FJH 4th June
> summary(Data.lm3)

Call: lm(formula = AdjEC ~ yrfrac)
Residuals:
Min 1Q Median 3Q Max
-1.888 -0.1162 0.04685 0.1882 0.7018

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -11.8912 6.6213 -1.7959 0.0747
yrfrac 0.0095 0.0033 2.8619 0.0049

Residual standard error: 0.2983 on 136 degrees of freedom
Multiple R-Squared: 0.0568
F-statistic: 8.19 on 1 and 136 degrees of freedom, the p-value is 0.004878

Correlation of Coefficients:
(Intercept)
yrfrac -1

> summary(Data.gam2)

Call: gam(formula = AdjEC ~ s(yrfrac, 4))
Deviance Residuals:
Min 1Q Median 3Q Max
-1.940155 -0.115644 0.05524887 0.1766916 0.727667

(Dispersion Parameter for Gaussian family taken to be 0.0888215 )

Null Deviance: 12.82857 on 137 degrees of freedom

Residual Deviance: 11.81326 on 133.0001 degrees of freedom

Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

Df Npar Df Npar F Pr(F)
(Intercept) 1
s(yrfrac, 4) 1 3 1.075704 0.3617306

> summary.lm(Data.gam2)
```

```
Call: gam(formula = AdjEC ~ s(yrfrac, 4))
Residuals:
Min 1Q Median 3Q Max
-1.94 -0.1156 0.05525 0.1767 0.7277

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -11.8912 6.6158 -1.7974 0.0745
s(yrfrac, 4) 0.0095 0.0033 2.8643 0.0049

Residual standard error: 0.298 on 133.000097500532 degrees of freedom
Multiple R-Squared: 0.07181
F-statistic: 10.9 on 1 and 133.000097500532 degrees of freedom, the p-value is 0.001234

Correlation of Coefficients:
(Intercept)
s(yrfrac, 4) -1

> #plot(Data.gam2, se=T)
> #abline(h=0) # add reference line at zero
> #title("aberall -Zero is the mean (Flow adjusted EC)")

> plot(yrfrac, AdjEC)                                       # Plot EC adjusted for Flow &
   Seasonality
> abline(h = mean(logEC))                                   # add reference line at mean of log EC
> lines(yrfrac, predict(Data.lm3), col = 4, lwd = 4)        # show the linear part in green
> lines(yrfrac, predict.gam(Data.gam2), col = 5, lwd = 4)   # add the GAM fitted model in orange
> title("Adjusted EC data: Green is linear fit; Orange is spline")
> #acf(Data.gam2$residuals,lag.max=10)                      # check for autocorrelation in residuals
> D.lm3a <- lm(AdjEC ~ groundwater)
> D.gam2a <- gam(AdjEC ~ s(groundwater, 2))
> summary(D.lm3a)

Call: lm(formula = AdjEC ~ groundwater)
Residuals:
Min 1Q Median 3Q Max
-1.932 -0.1294 0.05291 0.1798 0.6843

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 0.4098 1.9852 0.2064 0.8368
groundwater 0.0393 0.0117 3.3492 0.0010

Residual standard error: 0.2952 on 136 degrees of freedom
Multiple R-Squared: 0.07619
F-statistic: 11.22 on 1 and 136 degrees of freedom, the p-value is 0.001049

Correlation of Coefficients:
(Intercept)
groundwater -0.9999
```

```
> summary(D.gam2a)

Call: gam(formula = AdjEC ~ s(groundwater, 2))
Deviance Residuals:
Min 1Q Median 3Q Max
-1.925528 -0.1125483 0.06120973 0.1824931 0.6802358

(Dispersion Parameter for Gaussian family taken to be 0.0868339 )

Null Deviance: 12.82857 on 137 degrees of freedom

Residual Deviance: 11.72266 on 135.001 degrees of freedom

Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

Df Npar Df Npar F Pr(F)
(Intercept) 1
s(groundwater, 2) 1 1 1.480972 0.2257211

> summary.lm(D.gam2a)

Call: gam(formula = AdjEC ~ s(groundwater, 2))
Residuals:
Min 1Q Median 3Q Max
-1.926 -0.1125 0.06121 0.1825 0.6802

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 0.4098 1.9817 0.2068 0.8365
s(groundwater, 2) 0.0393 0.0117 3.3551 0.0010

Residual standard error: 0.2947 on 135.000976573578 degrees of freedom
Multiple R-Squared: 0.07789
F-statistic: 12.12 on 1 and 135.000976573578 degrees of freedom, the p-value is 0.0006719

Correlation of Coefficients:
(Intercept)
s(groundwater, 2) -0.9999

> #plot(D.gam2a, se=T)
> #abline(h=0)                                  # add reference line at zero
> #title("Zero is the mean (Flow adjusted EC)")
> plot(groundwater, AdjEC)                      # Plot EC adjusted for Flow &
   Seasonality
> abline(h = mean(logEC))                       # add reference line at mean of log EC
> wallallgw$AdjEC <- AdjEC
> wallallgw$lm3a <- predict(D.lm3a)
> wallallgw$gam2a <- predict.gam(D.gam2a)
> lines(groundwater, predict(D.lm3a), col = 4, lwd = 4)       # show the linear part in green
```

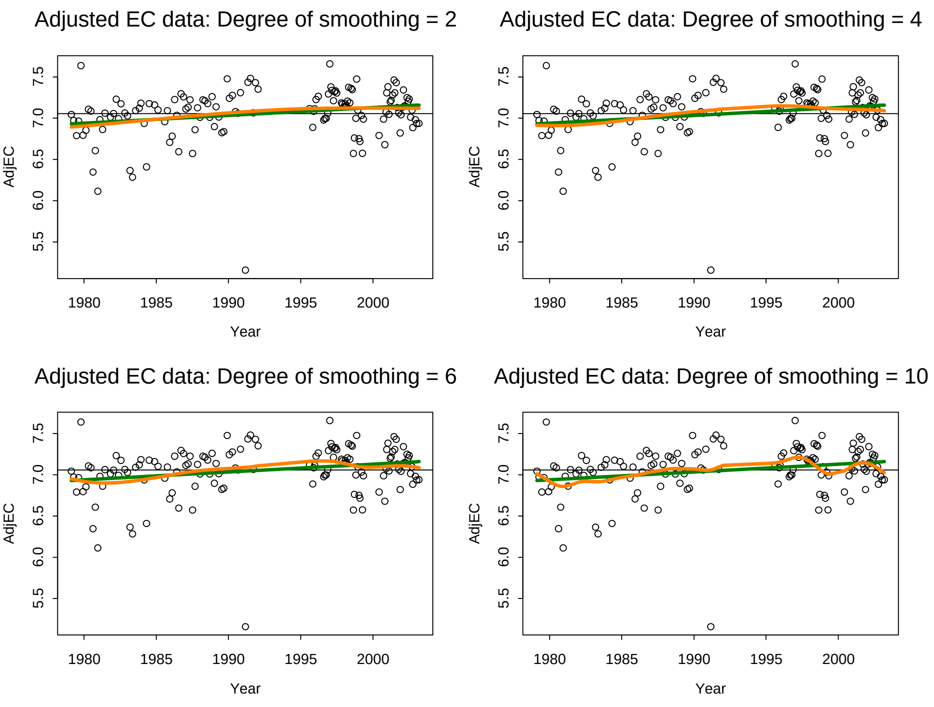
```
> lines(groundwater, predict.gam(D.gam2a), col = 5, lwd = 4)     # add the GAM fitted model in orange
> title("Adjusted EC data: Green is linear fit; Orange is spline 2")
```






```
> #acf(D.gam2a$residuals,lag.max=10)                        # check for autocorrelation in
    residuals

> AIC(Data.lm1, Data.lm2, Data.lm2a, Data.gam1, Data.lm3, D.lm3a, Data.gam2,D.gam2a)
df AIC
Data.lm1 3 75.17125
Data.lm2 5 77.88274
Data.lm2a 4 262.35254
Data.gam1 5 73.79718
Data.lm3 3 61.72711
D.lm3a 3 58.86047
Data.gam2 3 58.41877
D.gam2a 3 57.35630
```

```
> # ==========================================================================
# ===== display the effect of different degrees of smoothing =======
# ==========================================================================
> fit <- smooth.spline(yrfrac, AdjEC)
> fit
Call:
smooth.spline(x = yrfrac, y = AdjEC)

Smoothing Parameter (Spar): 0.5722725
Equivalent Degrees of Freedom (Df): 2.413857
Penalized Criterion: 12.0448
GCV: 0.09012851

> Data.gam2 <- gam(AdjEC ~ s(yrfrac, 4))
> Data.gam22 <- gam(AdjEC ~ s(yrfrac, 2))
> Data.gam26 <- gam(AdjEC ~ s(yrfrac, 6))
> Data.gam210 <- gam(AdjEC ~ s(yrfrac, 10))

> par(mfrow = c(2, 2))
> plot(yrfrac, AdjEC, xlab = "Year")                          # Plot EC adjusted for Flow &
    Seasonality
> abline(h = mean(logEC))                                     # add reference line at mean of log EC
> lines(yrfrac, predict(Data.lm3), col = 4, lwd = 4)          # show the linear part in green
> lines(yrfrac, predict.gam(Data.gam22), col = 5, lwd = 4)    # add the GAM fitted model in orange
> title("Adjusted EC data: Degree of smoothing = 2")

> plot(yrfrac, AdjEC, xlab = "Year")                          # Plot EC adjusted for Flow &
    Seasonality
> abline(h = mean(logEC))                                     # add reference line at mean of log EC
> lines(yrfrac, predict(Data.lm3), col = 4, lwd = 4)          # show the linear part in green
> lines(yrfrac, predict.gam(Data.gam2), col = 5, lwd = 4)     # add the GAM fitted model in orange
> title("Adjusted EC data: Degree of smoothing = 4")

> plot(yrfrac, AdjEC, xlab = "Year")                          # Plot EC adjusted for Flow &
    Seasonality
> abline(h = mean(logEC))                                     # add reference line at mean of log EC
> lines(yrfrac, predict(Data.lm3), col = 4, lwd = 4)          # show the linear part in green
> lines(yrfrac, predict.gam(Data.gam26), col = 5, lwd = 4)    # add the GAM fitted model in orange
> title("Adjusted EC data: Degree of smoothing = 6")

> plot(yrfrac, AdjEC, xlab = "Year")                          # Plot EC adjusted for Flow &
    Seasonality
> abline(h = mean(logEC))                                     # add reference line at mean of log EC
> lines(yrfrac, predict(Data.lm3), col = 4, lwd = 4)          # show the linear part in green
> lines(yrfrac, predict.gam(Data.gam210), col = 5, lwd = 4) # add the GAM fitted model in orange
> title("Adjusted EC data: Degree of smoothing = 10")
```


Adjusted EC data: Degree of smoothing = 2
Adjusted EC data: Degree of smoothing = 4
Adjusted EC data: Degree of smoothing = 6
Adjusted EC data: Degree of smoothing = 10
AdjEC
5.5
6.0
6.5
7.0
7.5
1980
1985
1990
1995
2000
Year

```
> # 10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10=10
# ===== Predict log EC for the first day of each year ======================
# ==========================================================================
> years <- 2003 - 1970 + 2
> yr.margin <- data.frame(yrfrac = seq(from = 1970, to = 2004, length = years))
> yr.margin$yrfrac[35] <- mean(yrfrac)
> yr.margin$gam2 <- predict.gam(Data.gam2, yr.margin, type = "response")
> yr.margin[]
yrfrac gam2
1 1970.000 6.932072
2 1971.000 6.929936
3 1972.000 6.927801
4 1973.000 6.925665
5 1974.000 6.923529
6 1975.000 6.921394
7 1976.000 6.919258
8 1977.000 6.917123
9 1978.000 6.914987
10 1979.000 6.912851
11 1980.000 6.910882
12 1981.000 6.911939
13 1982.000 6.919938
14 1983.000 6.932158
15 1984.000 6.949488
16 1985.000 6.971271
17 1986.000 6.995059
18 1987.000 7.019379
19 1988.000 7.041986
20 1989.000 7.061857
21 1990.000 7.079195
22 1991.000 7.095223
23 1992.000 7.112181
yrfrac gam2
24 1993.000 7.127173
25 1994.000 7.138876
26 1995.000 7.146719
27 1996.000 7.150127
28 1997.000 7.147736
29 1998.000 7.136819
30 1999.000 7.121997
31 2000.000 7.112684
32 2001.000 7.108636
33 2002.000 7.103532
34 2003.000 7.094415
35 1992.461 7.119458
```

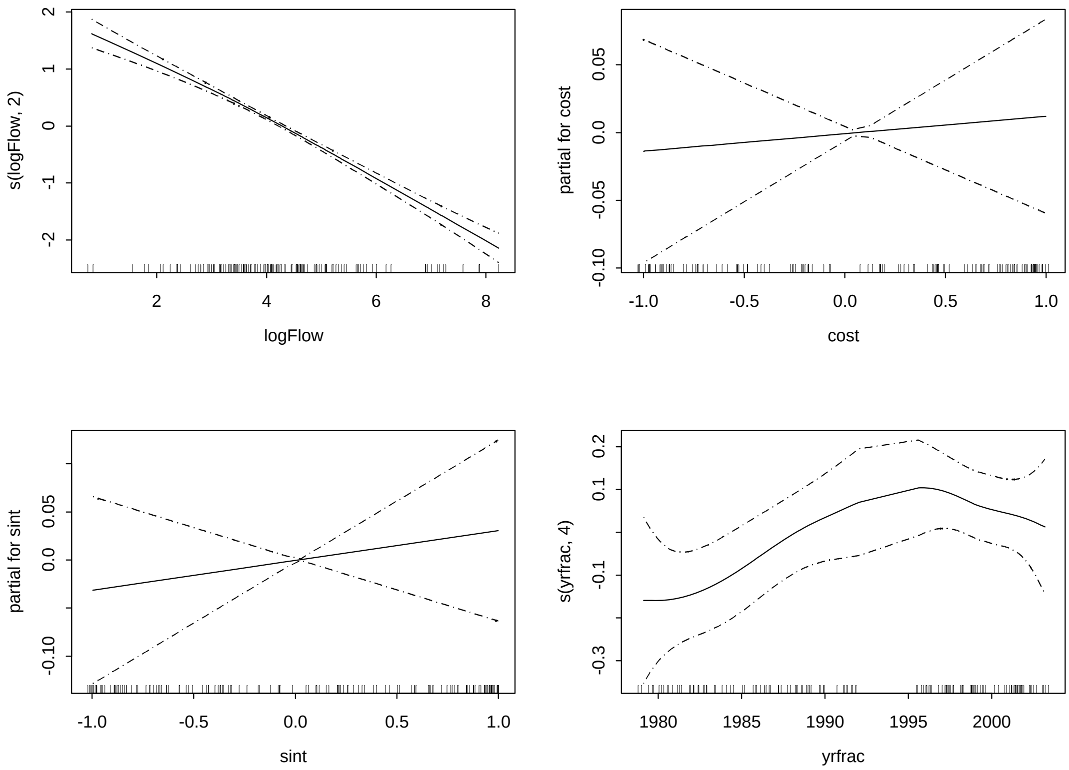
```
> # 11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11=11
# ==========================================================================
# ===== Repeat above using full model in one hit ==========================
# ==========================================================================

> Data.lm4 <- lm(logEC ~ logFlow + cost + sint + yrfrac)
> Data.gam3 <- gam(logEC ~ s(logFlow, 2) + cost + sint + s(yrfrac, 4))
> AIC(Data.lm1, Data.lm2, Data.gam1, Data.lm4, Data.gam3)
df AIC
Data.lm1 3 75.17125
Data.lm2 5 77.88274
Data.gam1 5 73.79718
Data.lm4 6 72.21068
Data.gam3 6 63.95890

> mean(TumutEC)
[1] 1502.268 ← 8

> summary(Data.lm4)

Call: lm(formula = logEC ~ logFlow + cost + sint + yrfrac)
Residuals:
Min 1Q Median 3Q Max
-1.871 -0.1129 0.04921 0.2006 0.6553

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -9.7299 6.8536 -1.4197 0.1580
logFlow -0.4920 0.0249 -19.7322 0.0000
cost 0.0252 0.0391 0.6455 0.5197
sint 0.0601 0.0486 1.2366 0.2184
yrfrac 0.0095 0.0034 2.7574 0.0066

Residual standard error: 0.3066 on 133 degrees of freedom
Multiple R-Squared: 0.8565
F-statistic: 198.5 on 4 and 133 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept) logFlow cost sint
logFlow -0.1053
cost 0.0147 0.3255
sint -0.0801 0.6448 0.2275
yrfrac -0.9999 0.0898 -0.0202 0.0700

> summary(Data.gam3)

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint + s(yrfrac, 4))
Deviance Residuals:
Min 1Q Median 3Q Max
-1.937644 -0.1042951 0.04775693 0.1726274 0.7676619
```

```
(Dispersion Parameter for Gaussian family taken to be 0.0912708 )

Null Deviance: 87.11584 on 137 degrees of freedom

Residual Deviance: 11.77396 on 129.0003 degrees of freedom

Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

Df Npar Df Npar F Pr(F)
(Intercept) 1
s(logFlow, 2) 1 1 3.916259 0.0499573
```
← 6
```
cost 1
sint 1
s(yrfrac, 4) 1 3 1.185677 0.3178680
```
← 5

```
> summary.lm(Data.gam3)

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint + s(yrfrac, 4))
Residuals:
Min 1Q Median 3Q Max
-1.938 -0.1043 0.04776 0.1726 0.7677

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -9.3717 6.7540 -1.3876 0.1677
s(logFlow, 2) -0.5164 0.0246 -21.0140 0.0000
cost 0.0129 0.0385 0.3345 0.7386
sint 0.0310 0.0479 0.6480 0.5181
s(yrfrac, 4) 0.0093 0.0034 2.7605 0.0066
--------------1------2------------3-----

Residual standard error: 0.3021 on 129.00025514468 degrees of freedom
Multiple R-Squared: 0.8611
F-statistic: 205.9 on 4 and 129.00025514468 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept) s(logFlow, 2) cost sint
s(logFlow, 2) -0.1053
cost 0.0147 0.3255
sint -0.0801 0.6448 0.2275
s(yrfrac, 4) -0.9999 0.0898 -0.0202 0.0700

> Data.gam4 <- gam(logEC ~ s(logFlow, 2) + s(yrfrac, 4))
> anova(Data.gam4, Data.gam3)                # shows additional reduction in deviance due to Sin &
    Cos
Analysis of Deviance Table

Response: logEC

Terms Resid. Df Resid. Dev Test Df Deviance
1 s(logFlow, 2) + s(yrfrac, 4) 131.0003 11.80148
2 s(logFlow, 2) + cost + sint + s(yrfrac, 4) 129.0003 11.77396 +cost+sint 2 0.02751376 ← 7


> summary(lm(logEC ~ predict.gam(Data.gam3)))

Call: lm(formula = logEC ~ predict.gam(Data.gam3))
Residuals:
Min 1Q Median 3Q Max
-1.938 -0.104 0.04588 0.1718 0.7711

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -0.0154 0.2411 -0.0637 0.9493
predict.gam(Data.gam3) 1.0022 0.0340 29.5008 0.0000
```

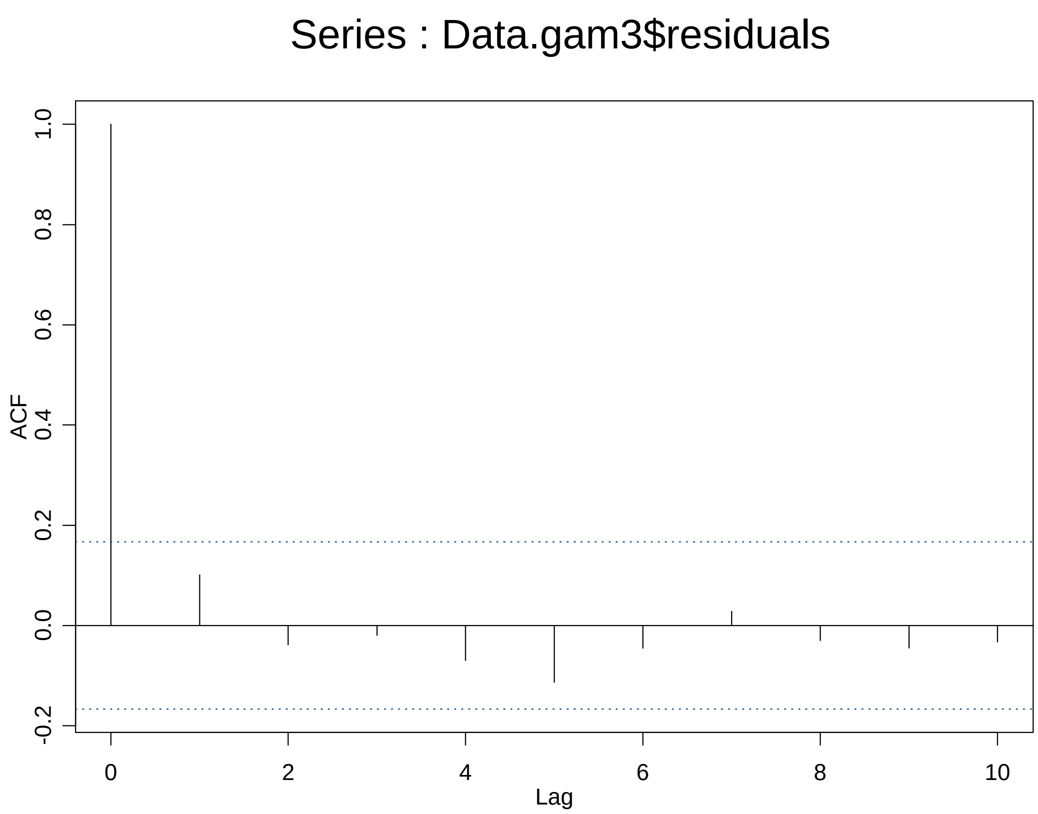
```
Residual standard error: 0.2942 on 136 degrees of freedom
Multiple R-Squared: 0.8649
F-statistic: 870.3 on 1 and 136 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept)
predict.gam(Data.gam3) -0.9946
```

```
> par(mfrow = c(1, 1))
> plot(Data.gam3, se = T)                      # note, this gives 2 plots , one of which has
                                            # 2 * standard error of predictions
```



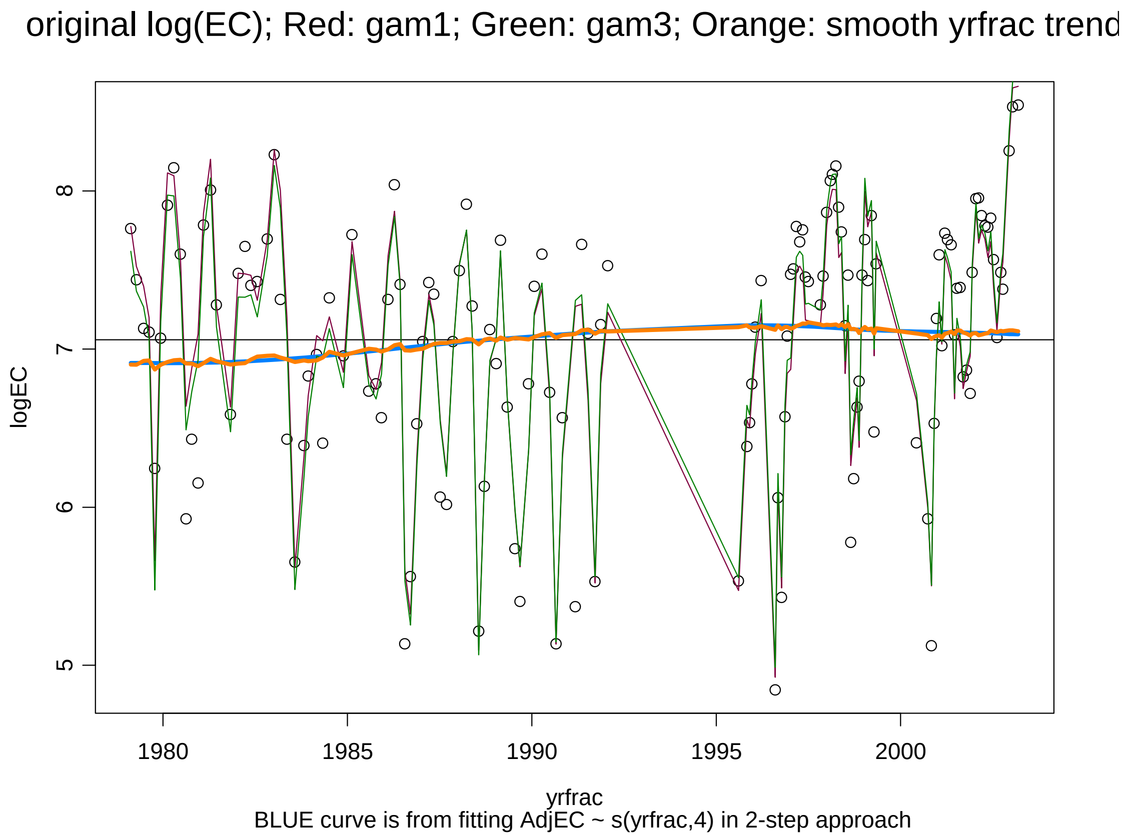

```
> abline(h = 0)                                # add a reference line at origin
> title("aberall Zero is the mean (Adjusted EC)")
```

```
> acf(Data.gam3$residuals, lag.max = 10)            # check for autocorrelation in residuals

Call: acf(x = Data.gam3$residuals, lag.max = 10)

Autocorrelation matrix:
lag Data.gam3
1 0 1.0000
2 1 0.1015 ← 4
3 2 -0.0383
4 3 -0.0192
5 4 -0.0698
```




```
6 5 -0.1130
7 6 -0.0452
8 7 0.0287
9 8 -0.0298
10 9 -0.0445
11 10 -0.0326
```

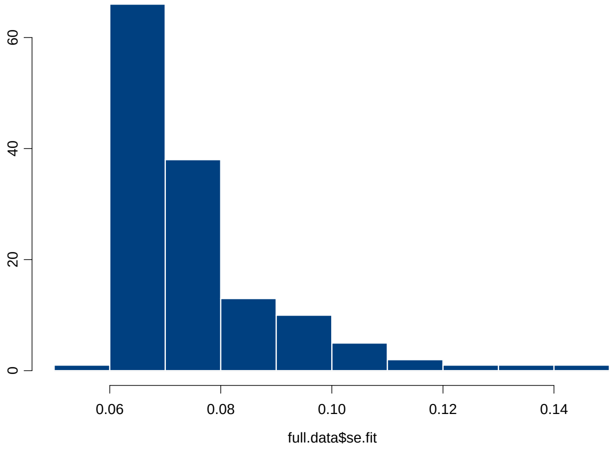
```
>  # 12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12=12
# == Plot original data, ============================
# == ..... then Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint) ===================
# == ..... then Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4)) ====
# == ..... therefore, Data.gam3 - Data.gam1 = {linear + smooth} * yrfrac component
# == ..... but must add on the grand mean, back to proper scale ==============================
#
   ================================================================================================
   ===

> smoothEC <- mean(logEC) + predict.gam(Data.gam3) - predict.gam(Data.gam1)
```




```
> plot(yrfrac, logEC)                                        # plot original data
> abline(h = mean(logEC))                                    # add a reference line at mean
> title("original log(EC); Red: gam1; Green: gam3; Orange: smooth yrfrac trend")
> title(sub = "BLUE curve is from fitting AdjEC ~ s(yrfrac,4) in 2-step approach")
> lines(yrfrac, predict.gam(Data.gam1), col = 3)         # add RED fitted curve from
   spline(Flow,2)+s+c
> lines(yrfrac, predict.gam(Data.gam2), col = 6, lwd = 4)   # add BLUE fitted from 2 step approach
> lines(yrfrac, predict.gam(Data.gam3), col = 4)         # add GREEN curve: spl(Flow,2)+s+c +
   spl(yrfrac,4)
> lines(yrfrac, smoothEC, col = 5, lwd = 4)                 # show the smoothed part
```

```
> yr.margin$logFlow <- rep(mean(logFlow), length(yr.margin$yrfrac))
> yr.margin$cost <- rep(mean(cost), length(yr.margin$yrfrac))
> yr.margin$sint <- rep(mean(sint), length(yr.margin$yrfrac))
> yr.margin$gam3 <- predict.gam(Data.gam3, yr.margin, type = "response")
> yr.margin$diff <- yr.margin$gam3 - yr.margin$gam2
> yr.margin[, ]

yrfrac gam2 logFlow cost sint gam3 diff
1 1970.000 6.932072 4.23717 0.06910815 0.01728406 6.921398 -0.0106736821
2 1971.000 6.929936 4.23717 0.06910815 0.01728406 6.921430 -0.0085065681
3 1972.000 6.927801 4.23717 0.06910815 0.01728406 6.921461 -0.0063394542
4 1973.000 6.925665 4.23717 0.06910815 0.01728406 6.921493 -0.0041723403
5 1974.000 6.923529 4.23717 0.06910815 0.01728406 6.921524 -0.0020052264
6 1975.000 6.921394 4.23717 0.06910815 0.01728406 6.921556 0.0001618876
7 1976.000 6.919258 4.23717 0.06910815 0.01728406 6.921587 0.0023290015
8 1977.000 6.917123 4.23717 0.06910815 0.01728406 6.921619 0.0044961154
9 1978.000 6.914987 4.23717 0.06910815 0.01728406 6.921650 0.0066632294
10 1979.000 6.912851 4.23717 0.06910815 0.01728406 6.921682 0.0088303433
11 1980.000 6.910882 4.23717 0.06910815 0.01728406 6.921894 0.0110115380
12 1981.000 6.911939 4.23717 0.06910815 0.01728406 6.925276 0.0133364219
13 1982.000 6.919938 4.23717 0.06910815 0.01728406 6.935876 0.0159380050
14 1983.000 6.932158 4.23717 0.06910815 0.01728406 6.951007 0.0188486419
15 1984.000 6.949488 4.23717 0.06910815 0.01728406 6.971466 0.0219784717
16 1985.000 6.971271 4.23717 0.06910815 0.01728406 6.996211 0.0249397751
17 1986.000 6.995059 4.23717 0.06910815 0.01728406 7.022797 0.0277381088
18 1987.000 7.019379 4.23717 0.06910815 0.01728406 7.049749 0.0303702367
19 1988.000 7.041986 4.23717 0.06910815 0.01728406 7.074685 0.0326994572
20 1989.000 7.061857 4.23717 0.06910815 0.01728406 7.096611 0.0347540918
21 1990.000 7.079195 4.23717 0.06910815 0.01728406 7.115580 0.0363851784
22 1991.000 7.095223 4.23717 0.06910815 0.01728406 7.132721 0.0374975530
23 1992.000 7.112181 4.23717 0.06910815 0.01728406 7.150320 0.0381392305
yrfrac gam2 logFlow cost sint gam3 diff
24 1993.000 7.127173 4.23717 0.06910815 0.01728406 7.165444 0.0382714051
25 1994.000 7.138876 4.23717 0.06910815 0.01728406 7.176623 0.0377469833
26 1995.000 7.146719 4.23717 0.06910815 0.01728406 7.183135 0.0364162860
27 1996.000 7.150127 4.23717 0.06910815 0.01728406 7.184258 0.0341306918
28 1997.000 7.147736 4.23717 0.06910815 0.01728406 7.178604 0.0308680612
29 1998.000 7.136819 4.23717 0.06910815 0.01728406 7.164031 0.0272110158
30 1999.000 7.121997 4.23717 0.06910815 0.01728406 7.145902 0.0239049277
31 2000.000 7.112684 4.23717 0.06910815 0.01728406 7.133203 0.0205198414
32 2001.000 7.108636 4.23717 0.06910815 0.01728406 7.124675 0.0160388670
33 2002.000 7.103532 4.23717 0.06910815 0.01728406 7.113353 0.0098209841
34 2003.000 7.094415 4.23717 0.06910815 0.01728406 7.096962 0.0025472476
35 1992.461 7.119458 4.23717 0.06910815 0.01728406 7.157730 0.0382721263

> full.data <- predict.gam(Data.gam3, se.fit = T, type = "response")
> Data$gam3fit <- full.data$fit
> Data$gam3se <- full.data$se.fit
```

```
> hist(full.data$se.fit)
```



```
> min(full.data$se.fit)
[1] 0.05998097

> Data[Data$gam3se == min(full.data$se.fit), ]
dtime jday instFlow AccVol TumutEC EC76
105 02/08/1999 13:00:00.000 36199.54 17.957 4972145 1690 1690

groundwater AdjEC lm3a gam2a yrfrac logEC logFlow season
105 170.9 6.716427 7.125082 7.118388 1999.107 7.432484 2.88798 7.670008

Data.gam2 gam3fit gam3se
105 7.120683 7.84086 0.05998097

> max(full.data$se.fit)
[1] 0.1409031

> Data[Data$gam3se == max(full.data$se.fit), ]
dtime jday instFlow AccVol TumutEC EC76
137 01/13/2003 09:00:00.000 37634.38 2.26 5270352 5070 5070

groundwater AdjEC lm3a gam2a yrfrac logEC logFlow
137 170.853 6.936688 7.123235 7.115925 2003.036 8.531096 0.8153648

season Data.gam2 gam3fit gam3se
137 7.45426 7.094019 8.712717 0.1409031

> full.limits <- pointwise(full.data, coverage = 0.95)      # Pointwise calculates 95% confidence
    intervals
> Data$lower <- full.limits$lower
> Data$upper <- full.limits$upper
> Data[, c("yrfrac", "instFlow", "TumutEC", "gam3fit", "gam3se", "lower", "upper")]

yrfrac instFlow TumutEC gam3fit gam3se lower upper
1 1979.126 18.000 2350 7.619119 0.10789777 7.405640 7.832597
2 1979.279 30.300 1700 7.367065 0.10239058 7.164483 7.569648
3 1979.474 34.600 1250 7.265906 0.10175919 7.064573 7.467239
4 1979.625 48.800 1220 7.069561 0.10445379 6.862897 7.276225
5 1979.778 955.000 515 5.476505 0.09882643 5.280975 5.672036
6 1979.934 42.100 1175 7.174896 0.08860564 6.999587 7.350204
7 1980.123 8.280 2725 7.974203 0.09209611 7.791989 8.156417
8 1980.296 8.300 3450 7.968552 0.09070900 7.789082 8.148022
9 1980.471 23.900 2000 7.447640 0.08629355 7.276906 7.618374
10 1980.625 148.000 375 6.489115 0.07992999 6.330972 6.647259
11 1980.778 94.500 620 6.731176 0.08019801 6.572503 6.889850
12 1980.951 68.800 470 6.929524 0.07353971 6.784024 7.075024
13 1981.099 14.800 2400 7.711637 0.07383562 7.565551 7.857722
14 1981.290 6.540 3000 8.081380 0.08824108 7.906793 8.255967
15 1981.447 45.585 1450 7.140731 0.07227695 6.997729 7.283733
16 1981.830 157.425 725 6.476440 0.07116623 6.335636 6.617245
17 1982.038 33.087 1770 7.330104 0.06837437 7.194824 7.465385
18 1982.225 34.274 2100 7.328006 0.06889187 7.191702 7.464310
```

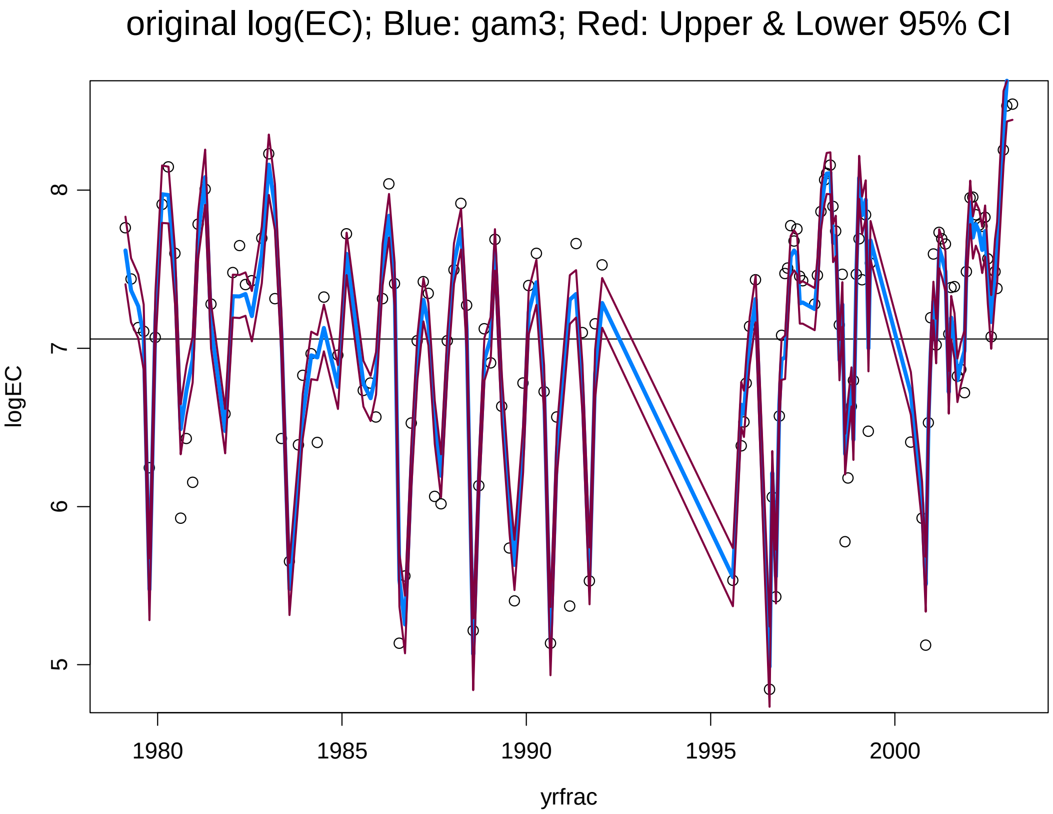
19 1982.384 31.968 1640 7.343125 0.06919790 7.206215 7.480034
20 1982.556 39.805 1680 7.202753 0.08036520 7.043749 7.361758
21 1982.827 18.095 2200 7.590280 0.09067480 7.410878 7.769682
22 1983.016 5.628 3750 8.160992 0.09633654 7.970388 8.351596
23 1983.184 10.699 1500 7.893272 0.07347576 7.747898 8.038645
yrfrac instFlow TumutEC gam3fit gam3se lower upper
24 1983.362 56.094 620 7.080422 0.06930723 6.943296 7.217549
25 1983.573 1028.000 285 5.479287 0.08352734 5.314026 5.644547
26 1983.822 281.828 595 6.194166 0.07131529 6.053067 6.335265
27 1983.937 146.832 925 6.570944 0.07144003 6.429598 6.712289
28 1984.167 76.427 1060 6.955518 0.07621368 6.804727 7.106308
29 1984.332 77.137 605 6.942043 0.07222603 6.799142 7.084944
30 1984.510 50.578 1515 7.129302 0.07455221 6.981799 7.276805
31 1984.888 106.367 1050 6.755818 0.06974703 6.617822 6.893814
32 1985.126 22.237 2260 7.596883 0.06768951 7.462957 7.730808
33 1985.581 102.700 840 6.776582 0.07304970 6.632052 6.921113
34 1985.775 122.975 880 6.683866 0.07186531 6.541678 6.826053
35 1985.926 96.585 710 6.842225 0.06821334 6.707263 6.977187
36 1986.101 26.892 1500 7.529358 0.06637613 7.398031 7.660685
37 1986.274 14.106 3100 7.838033 0.06924817 7.701023 7.975042
38 1986.425 33.497 1650 7.404613 0.06944363 7.267217 7.542009
39 1986.559 1072.786 170 5.533821 0.08413628 5.367356 5.700287
40 1986.710 1768.319 260 5.254179 0.09194408 5.072266 5.436093
41 1986.885 292.290 683 6.265016 0.07095568 6.124629 6.405404
42 1987.041 89.210 1150 6.936892 0.07049117 6.797424 7.076361
43 1987.208 45.117 1670 7.306930 0.06870375 7.170998 7.442862
44 1987.342 59.595 1550 7.153473 0.06772819 7.019471 7.287475
45 1987.515 182.570 430 6.530991 0.06882430 6.394820 6.667161
46 1987.688 331.784 410 6.193804 0.06883561 6.057611 6.329997
yrfrac instFlow TumutEC gam3fit gam3se lower upper
47 1987.860 81.501 1150 6.968855 0.06817244 6.833974 7.103736
48 1988.036 28.824 1800 7.536319 0.06492144 7.407870 7.664768
49 1988.227 18.974 2740 7.753868 0.06562139 7.624034 7.883701
50 1988.381 65.742 1440 7.120440 0.06754868 6.986793 7.254087
51 1988.559 2759.165 184 5.065924 0.11451616 4.839351 5.292497
52 1988.712 355.432 460 6.180287 0.06928774 6.043200 6.317375
53 1988.860 91.610 1240 6.929898 0.06828601 6.794792 7.065003
54 1989.030 76.530 1000 7.061861 0.06924876 6.924851 7.198872
55 1989.148 26.083 2180 7.622007 0.06634971 7.490733 7.753282
56 1989.337 160.485 760 6.676419 0.07892923 6.520255 6.832582
57 1989.545 537.225 310 5.983613 0.07638041 5.832492 6.134733
58 1989.679 1005.241 222 5.630979 0.08012194 5.472456 5.789502
59 1989.912 279.000 880 6.363327 0.07472370 6.215484 6.511169
60 1990.063 58.306 1630 7.228005 0.07119123 7.087152 7.368859
61 1990.274 40.940 2000 7.416835 0.07146536 7.275439 7.558231
62 1990.485 138.286 834 6.747380 0.07368009 6.601602 6.893158
63 1990.658 2505.000 170 5.148755 0.10901901 4.933058 5.364452
64 1990.830 289.598 710 6.343269 0.07482188 6.195232 6.491306
65 1991.175 52.751 215 7.308282 0.07792153 7.154112 7.462451
66 1991.348 48.001 2125 7.343976 0.07570555 7.194191 7.493762
67 1991.523 143.004 1210 6.740101 0.07822232 6.585336 6.894865

```
68 1991.715 1220.000 252 5.561219 0.09089050 5.381390 5.741048
69 1991.868 120.949 1280 6.838856 0.07784214 6.684843 6.992868
yrfrac instFlow TumutEC gam3fit gam3se lower upper
70 1992.058 55.522 1857 7.287082 0.07906743 7.130645 7.443519
71 1995.605 1336.895 253 5.554008 0.09278712 5.370426 5.737589
72 1995.833 183.833 592 6.644267 0.07225298 6.501312 6.787221
73 1995.907 210.449 688 6.585332 0.07390836 6.439102 6.731561
74 1995.964 144.282 879 6.800519 0.07396834 6.654171 6.946867
75 1996.060 94.001 1260 7.045898 0.07581266 6.895901 7.195895
76 1996.216 57.446 1690 7.311876 0.07444257 7.164589 7.459162
77 1996.597 3746.886 127 4.987600 0.12801680 4.734316 5.240885
78 1996.674 395.283 428 6.212827 0.06992153 6.074485 6.351168
79 1996.773 1319.144 228 5.557734 0.08574746 5.388080 5.727387
80 1996.866 183.201 714 6.647355 0.06625399 6.516270 6.778440
81 1996.923 110.414 1190 6.929553 0.06507105 6.800808 7.058298
82 1997.016 111.259 1760 6.943592 0.06958538 6.805915 7.081268
83 1997.093 61.949 1820 7.261654 0.06807079 7.126974 7.396333
84 1997.170 33.202 2380 7.582251 0.06459837 7.454441 7.710060
85 1997.266 30.486 2160 7.619264 0.06393360 7.492770 7.745758
86 1997.342 31.380 2330 7.593348 0.06369345 7.467329 7.719367
87 1997.419 56.095 1730 7.284715 0.06492653 7.156256 7.413173
88 1997.496 53.726 1680 7.289853 0.06755409 7.156196 7.423511
89 1997.822 56.653 1450 7.247117 0.06742489 7.113716 7.380519
90 1997.899 39.554 1740 7.442687 0.06394411 7.316172 7.569202
91 1997.992 16.561 2600 7.880415 0.06461822 7.752566 8.008264
92 1998.090 11.980 3180 8.043944 0.06436844 7.916589 8.171298
yrfrac instFlow TumutEC gam3fit gam3se lower upper
93 1998.148 10.559 3310 8.105323 0.06558905 7.975553 8.235092
94 1998.244 10.454 3490 8.107020 0.06672681 7.974999 8.239041
95 1998.321 26.295 2690 7.666670 0.06159060 7.544811 7.788528
96 1998.397 23.234 2300 7.710570 0.06482080 7.582321 7.838820
97 1998.493 104.536 1271 6.925570 0.06463754 6.797683 7.053457
98 1998.570 51.656 1750 7.278295 0.07107707 7.137668 7.418923
99 1998.647 301.872 323 6.331362 0.06496705 6.202823 6.459901
100 1998.723 202.973 483 6.544774 0.06399342 6.418162 6.671387
101 1998.819 139.077 760 6.756436 0.06221191 6.633349 6.879524
102 1998.877 262.855 895 6.422440 0.06486230 6.294108 6.550771
103 1998.953 35.099 1750 7.494664 0.06030006 7.375358 7.613969
104 1999.030 10.442 2190 8.080386 0.06895098 7.943965 8.216808
105 1999.107 17.957 1690 7.840860 0.05998097 7.722186 7.959534
106 1999.203 14.595 2550 7.939712 0.06195782 7.817127 8.062297
107 1999.279 95.546 649 6.999507 0.07276812 6.855533 7.143480
108 1999.337 24.441 1880 7.681912 0.06207421 7.559097 7.804727
109 2000.430 151.585 606 6.714943 0.06847464 6.579464 6.850422
110 2000.737 504.666 375 6.026490 0.06664022 5.894641 6.158340
111 2000.833 1326.714 168 5.508433 0.08730471 5.335698 5.681167
112 2000.910 208.489 685 6.531955 0.06519072 6.402974 6.660937
113 2000.967 94.104 1330 6.968906 0.06229516 6.845654 7.092159
114 2001.041 51.114 1990 7.299745 0.06155526 7.177956 7.421533
115 2001.118 84.791 1120 7.046607 0.07148097 6.905180 7.188034
yrfrac instFlow TumutEC gam3fit gam3se lower upper
```

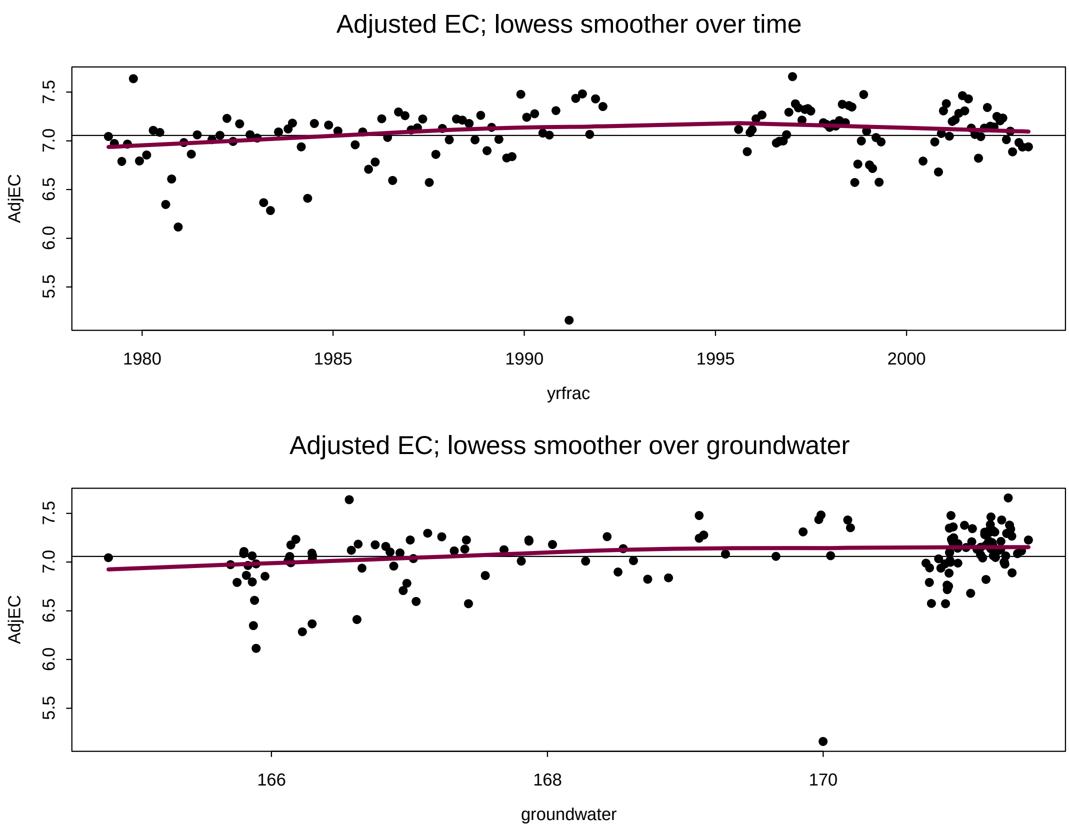
```
116 2001.195 27.020 2280 7.629351 0.06221255 7.506262 7.752440
117 2001.271 29.814 2190 7.576212 0.06306605 7.451434 7.700990
118 2001.367 34.685 2120 7.486056 0.06391199 7.359604 7.612507
119 2001.463 145.130 1200 6.722163 0.06839003 6.586852 6.857475
120 2001.521 57.818 1610 7.194550 0.06923530 7.057567 7.331534
121 2001.616 70.505 1620 7.077084 0.07267117 6.933302 7.220866
122 2001.693 118.917 919 6.797646 0.06969949 6.659744 6.935549
123 2001.789 99.154 960 6.899373 0.06820677 6.764424 7.034322
124 2001.885 86.876 828 6.983824 0.06560092 6.854031 7.113617
125 2001.942 29.768 1780 7.540929 0.06683779 7.408689 7.673170
126 2002.038 13.778 2840 7.922678 0.06959783 7.784977 8.060379
127 2002.115 22.611 2850 7.700278 0.06722387 7.567274 7.833282
128 2002.192 18.974 2550 7.785490 0.06933769 7.648303 7.922676
129 2002.288 20.803 2390 7.734172 0.07159256 7.592524 7.875820
130 2002.364 25.554 2370 7.622452 0.07387213 7.476294 7.768610
131 2002.444 19.199 2510 7.740990 0.08181227 7.579122 7.902857
132 2002.518 34.286 1930 7.445185 0.08346400 7.280049 7.610320
133 2002.614 57.676 1180 7.166600 0.08592583 6.996594 7.336606
134 2002.712 29.321 1780 7.501851 0.09549534 7.312911 7.690790
135 2002.770 23.837 1600 7.604956 0.09653518 7.413959 7.795953
136 2002.940 4.511 3840 8.390398 0.11928652 8.154386 8.626409
137 2003.036 2.260 5070 8.712717 0.14090308 8.433937 8.991497
138 2003.189 2.298 5130 8.716846 0.13794577 8.443916 8.989775
```

```
> plot(yrfrac, logEC)                                  # plot original data
> abline(h = mean(logEC))                              # add a reference line at mean
> title("original log(EC); Blue: gam3; Red: Upper & Lower 95% CI")
> lines(yrfrac, full.data$fit, col = 6, lwd = 4)       # add BLUE fitted curve
> lines(yrfrac, full.limits$lower, col = 3, lwd = 2)   # add RED lower 95% limits
```

```
> lines(yrfrac, full.limits$upper, col = 3, lwd = 2)                # add RED upper 95% limits
```



```
> # ===================================================================================
# =13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13=13
#==================================================================================
# Look at impact of including groundwater by comparing these models
#
# 3. Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
# 3a D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
#
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# 7a D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater, 4)) + s(yrfrac,2)
# ==================================================================================
> par(mfrow = c(2, 1))
> plot(yrfrac, AdjEC, pch = 16)
```




```
> abline(h = mean(logEC))
> lines(lowess(yrfrac, AdjEC), col = 3, lwd = 4)
> title("Adjusted EC; lowess smoother over time")
> plot(groundwater, AdjEC, pch = 16)
> abline(h = mean(logEC))
> lines(lowess(groundwater, AdjEC), col = 3, lwd = 4)
> title("Adjusted EC; lowess smoother over groundwater")
```

```
> # ========== Alternative models ================================================
# 3. Data.gam1 <- gam(logEC ~ s(logFlow,2) + cost + sint)
# 3a D.gam1a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater,2))
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# ==============================================================================
> D.gam1a <- gam(logEC ~ s(logFlow, 2) + cost + sint + s(groundwater, 2))
> summary.lm(D.gam1a)

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint + s(groundwater, 2))
Residuals:
Min 1Q Median 3Q Max
-1.92 -0.1193 0.0499 0.1817 0.6991

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 2.4648 2.0171 1.2219 0.2239
s(logFlow, 2) -0.5074 0.0242 -20.9468 0.0000
cost 0.0151 0.0382 0.3964 0.6925
sint 0.0437 0.0473 0.9237 0.3573
s(groundwater, 2) 0.0398 0.0119 3.3393 0.0011

Residual standard error: 0.2988 on 131.001134217726 degrees of freedom
Multiple R-Squared: 0.8617
F-statistic: 210.7 on 4 and 131.001134217726 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept) s(logFlow, 2) cost sint
s(logFlow, 2) -0.0098
cost 0.0675 0.3308
sint -0.0396 0.6419 0.2282
s(groundwater, 2) -0.9986 -0.0417 -0.0856 0.0062

> summary.lm(D.gam1a, corr = F)

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint + s(groundwater, 2))
Residuals:
Min 1Q Median 3Q Max
-1.92 -0.1193 0.0499 0.1817 0.6991

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 2.4648 2.0171 1.2219 0.2239
s(logFlow, 2) -0.5074 0.0242 -20.9468 0.0000
cost 0.0151 0.0382 0.3964 0.6925
sint 0.0437 0.0473 0.9237 0.3573
s(groundwater, 2) 0.0398 0.0119 3.3393 0.0011

Residual standard error: 0.2988 on 131.001134217726 degrees of freedom
Multiple R-Squared: 0.8617
F-statistic: 210.7 on 4 and 131.001134217726 degrees of freedom, the p-value is 0
```

```
> anova(Data.gam1, D.gam1a)
Analysis of Deviance Table

Response: logEC

Terms Resid. Df Resid. Dev
1 s(logFlow, 2) + cost + sint 133.0002 12.82857
2 s(logFlow, 2) + cost + sint + s(groundwater, 2) 131.0011 11.69496

Test Df Deviance
1
2 +s(groundwater, 2) 1.999023 1.133614
```

```
> anova(Data.gam1, Data.gam3)
Analysis of Deviance Table

Response: logEC

Terms Resid. Df Resid. Dev Test Df Deviance
1 s(logFlow, 2) + cost + sint 133.0002 12.82857
2 s(logFlow, 2) + cost + sint + s(yrfrac, 4) 129.0003 11.77396 +s(yrfrac, 4) 3.999902 1.054613

> summary(lm(logEC ~ predict.gam(D.gam1a)))

Call: lm(formula = logEC ~ predict.gam(D.gam1a))
Residuals:
Min 1Q Median 3Q Max
-1.921 -0.1188 0.0497 0.1815 0.7026

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -0.0165 0.2402 -0.0688 0.9453
predict.gam(D.gam1a) 1.0023 0.0338 29.6159 0.0000

Residual standard error: 0.2932 on 136 degrees of freedom
Multiple R-Squared: 0.8658
F-statistic: 877.1 on 1 and 136 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept)
predict.gam(D.gam1a) -0.9946


> # ========== Alternative models ================================================
# 7. Data.gam3 <- gam(logEC ~ s(logFlow,2) + cost + sint + s(yrfrac, 4))
# 7a D.gam3a <- gam(logEC ~ s(logFlow,2) + cost + sint + s(groundwater, 4)) + s(yrfrac,2)
# ===============================================================================
> D.gam3a <- gam(logEC ~ s(logFlow, 2) + cost + sint + s(yrfrac, 4) +
    s(groundwater, 2), control = gam.control(bf.maxit = 100))
> summary.lm(D.gam3a)

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint + s(yrfrac, 4) + s(
    groundwater, 2), control = gam.control(bf.maxit = 100))
Residuals:
Min 1Q Median 3Q Max
-1.994 -0.1021 0.03352 0.1645 0.623

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 51.3341 18.2040 2.8199 0.0056
s(logFlow, 2) -0.5273 0.0271 -19.4671 0.0000
cost -0.0015 0.0393 -0.0377 0.9700
sint 0.0274 0.0487 0.5624 0.5748
s(yrfrac, 4) -0.0352 0.0128 -2.7503 0.0068
```

```
s(groundwater, 2) 0.1658 0.0456 3.6358 0.0004

Residual standard error: 0.2991 on 127.001231718258 degrees of freedom
Multiple R-Squared: 0.8642
F-statistic: 168.8 on 5 and 127.001231718258 degrees of freedom, the p-value is 0

Correlation of Coefficients:
(Intercept) s(logFlow, 2) cost sint s(yrfrac, 4)
s(logFlow, 2) -0.4436
cost -0.2233 0.3914
sint -0.2406 0.6642 0.2707
s(yrfrac, 4) -0.9938 0.4454 0.2320 0.2378
s(groundwater, 2) 0.9301 -0.4396 -0.2458 -0.2279 -0.9651
```

```
> summary.lm(D.gam3a, corr = F)

Call: gam(formula = logEC ~ s(logFlow, 2) + cost + sint + s(yrfrac, 4) + s(
    groundwater, 2), control = gam.control(bf.maxit = 100))
Residuals:
Min 1Q Median 3Q Max
-1.994 -0.1021 0.03352 0.1645 0.623

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) 51.3341 18.2040 2.8199 0.0056
s(logFlow, 2) -0.5273 0.0271 -19.4671 0.0000
cost -0.0015 0.0393 -0.0377 0.9700
sint 0.0274 0.0487 0.5624 0.5748
s(yrfrac, 4) -0.0352 0.0128 -2.7503 0.0068
s(groundwater, 2) 0.1658 0.0456 3.6358 0.0004

Residual standard error: 0.2991 on 127.001231718258 degrees of freedom
Multiple R-Squared: 0.8642
F-statistic: 168.8 on 5 and 127.001231718258 degrees of freedom, the p-value is 0

> anova(Data.gam3, D.gam3a)
Analysis of Deviance Table

Response: logEC

Terms Resid. Df
1 s(logFlow, 2) + cost + sint + s(yrfrac, 4) 129.0003
2 s(logFlow, 2) + cost + sint + s(yrfrac, 4) + s(groundwater, 2) 127.0012

Resid. Dev Test Df Deviance
1 11.77396
2 11.36316 +s(groundwater, 2) 1.999023 0.4108005

> summary(lm(logEC ~ predict.gam(D.gam3a)))

Call: lm(formula = logEC ~ predict.gam(D.gam3a))
Residuals:
Min 1Q Median 3Q Max
-1.995 -0.1009 0.03245 0.1641 0.6274

Coefficients:
Value Std. Error t value Pr(>|t|)
(Intercept) -0.0217 0.2364 -0.0919 0.9269
predict.gam(D.gam3a) 1.0031 0.0333 30.1116 0.0000

Residual standard error: 0.289 on 136 degrees of freedom
Multiple R-Squared: 0.8696
F-statistic: 906.7 on 1 and 136 degrees of freedom, the p-value is 0

Correlation of Coefficients:
```

```
(Intercept)
predict.gam(D.gam3a) -0.9946

> AIC(Data.lm1, Data.lm2, Data.gam1, D.gam1a, Data.gam3, D.gam3a)
df AIC
Data.lm1 3 75.17125
Data.lm2 5 77.88274
Data.gam1 5 73.79718
D.gam1a 6 63.02983
Data.gam3 6 63.95890
D.gam3a 7 61.05800
```

Appendix 8—Derivation of $\{100 \times (e^{\eta} - 1)\}$

The linear coefficient of *time*, η, was used to calculate the percentage change in EC per annum using the formula $\{100 \times (e^{\eta} - 1)\}$. Derivation of this formula is now presented.

For simplicity, we can ignore terms in our model such as $\log_e$flow and the seasonality sin and cos terms. Doing this, the form of the equation we are fitting is:

$$\log_e(EC) = a + b \cdot \text{time} + \text{error},$$

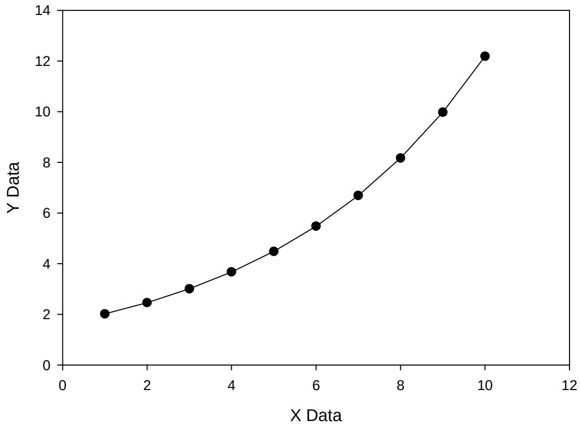
but for ease of manipulation, let us write it as

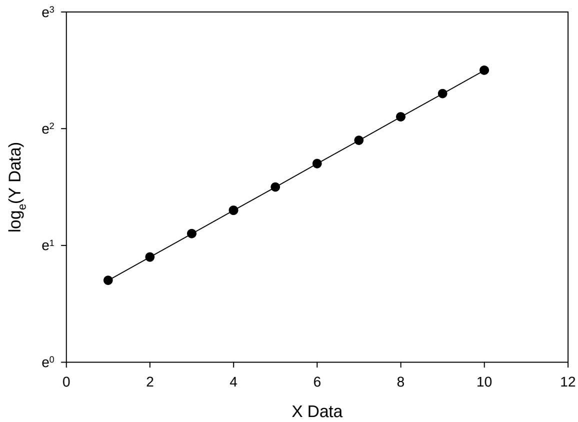
$$\log_e(Y) = a + b \cdot X,$$

which can be represented on the natural *Y* scale by

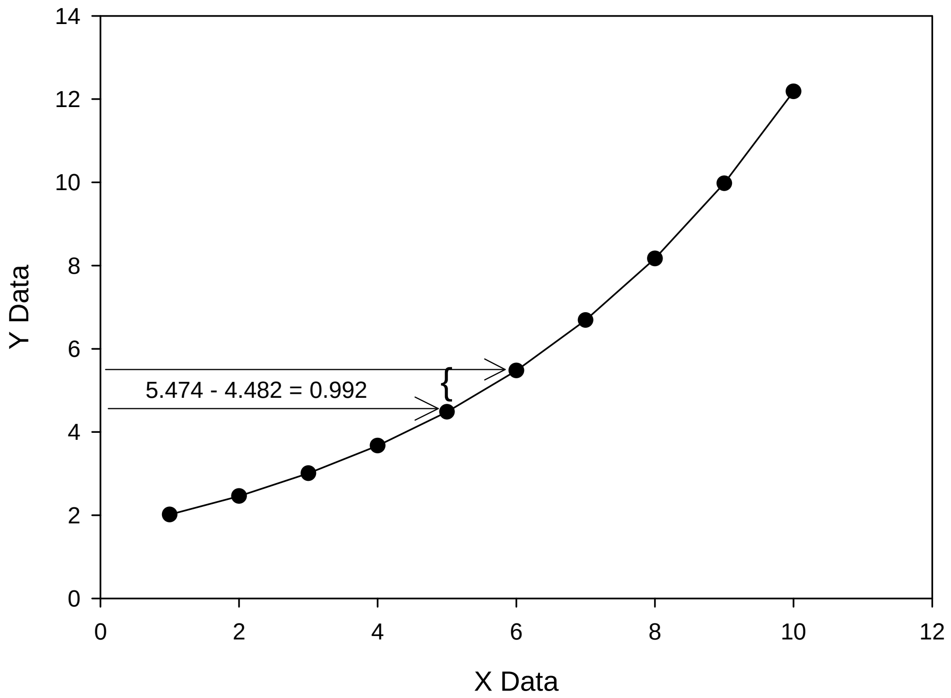
$$Y = \exp\{a + b \cdot X\}.$$

Let's make up an example data set using $a = 0.5$ and $b = 0.2$; that is, $Y = \exp(0.5 + 0.2X)$. On the natural *Y* scale, the relationship is curvilinear (left graph), and on the $\log_e(Y)$ scale, the relationship is linear (right graph).





Looking at this curve (enlarged for clarity below), we note the change in *Y* per unit of *X*, which, when using the 5th and 6th values, is an additional (5.474 – 4.482 =) 0.992 units of *Y* per unit of *X*. This amount will, of course, change with various selections of *X* values (seen in the table below). However, the proportional change does not vary; that is, 0.992 units change as a proportion of its 'starting value' of 4.482 is a 0.221 proportional increase.



Note this consistency in the following table.

X	*Y*	**Difference: $Y_i - Y_{i-1}$**	**Diff as proportion of Y_i**
1	exp{0.5 + 0.2 × 1} = 2.014		
2	2.460	2.460 – 2.014 = 0.446	0.446 / 2.014 = 0.221
3	3.004	0.545	0.545 / 2.460 = 0.221
4	3.669	0.665	0.665 / 3.004 = 0.221
5	4.482	0.812	0.812 / 3.669 = 0.221
6	5.474	0.992	0.992 / 4.482 = 0.221
7	6.686	1.212	1.212 / 5.474 = 0.221
8	8.166	1.480	1.480 / 6.686 = 0.221
9	9.974	1.808	1.808 / 8.166 = 0.221
10	12.182	12.182 – 9.974 = 2.208	2.208 / 9.974 = 0.221

… so we note that the proportional change in *Y* per unit change in *X* is 0.221.

This constancy can be shown algebraically as a difference between 2 *Y* values, divided by the lesser of the 2 *Y* numbers:

$$(Y_2 - Y_1) / Y_1$$

… or

$$[\ \exp\{a + b \cdot X_2\} - \exp\{a + b \cdot X_1\}\ ] / \exp\{a + b \cdot X_1\}.$$

Allowing the exponentiation into the bracketed terms, 'sum' terms become 'products':

$$[\ \{e^a \times e^{b \cdot X2}\} - \{\ e^a \times e^{b \cdot X1}\}\ ] / \{\ e^a \times e^{b \cdot X1}\}.$$

Dividing top and bottom by e^a we get:

$$[\ \{e^{b \cdot X2}\} - \{e^{b \cdot X1}\}\ ] / \{e^{b \cdot X1}\},$$

and then dividing top and bottom by $e^{b \cdot X1}$ we get (when dividing terms with exponents, division becomes difference):

$$[\ e^{b \cdot X2 - b \cdot X1} - 1\ ],$$

which equals:

$$[\ e^{b\ (X2 - X1)} - 1\ ].$$

Since $X_2 - X_1$ is unity, this can be rewritten as:

$$[\ e^{b} - 1\ ].$$

Since for this example $b = 0.2$, then we note:

$$[\ e^{0.2} - 1\ ] = 0.221.$$

So the proportional change in Y per unit of X is $(e^{\eta} - 1)$, and the percentage change in Y per unit of X is $\{100 \times (e^{\eta} - 1)\}$.

Annexure A—Aspects of Archived Electrical Conductivity Data in TRITON

By F. J. Harvey

Acknowledgments

Rodger Grayson, who provided advice on the various drafts. Terry Koen and Sarah McGeoch, who proof-read and edited this document and provided advice. The staff of the Armidale and Tumut hydrographic offices who assisted in the data evaluation.

Department of Environment and Climate Change NSW
Wagga Wagga Research Centre

March 2006

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Abstract

This report is an annexure to ‘2006 Stream EC Trends for Inland NSW ’. One of the first steps in this investigation was an examination of the data. Most of the electrical conductivity (EC) data was obtained from the Department of Water and Energy’s (DWE) TRITON database.

This report investigates data sources in the northern and southern parts of NSW. It flags a potential major anomaly in the TRITON archive and describes how it was handled in ‘2006 Stream EC Trends for Inland NSW’. The anomaly took the form of a possible systematic error in the earlier data record. The implications for trend analysis are discussed. The report also flags a number of other minor issues that will need to be addressed by the archive manager.

1 Introduction

As a prelude to the stream EC trends investigation, a review was undertaken of the EC data collected during (regular) visits to water quality monitoring sites. Here, these data are termed ‘discrete data’. The TRITON database holds most of this data and its ancillary information. The data investigation revealed a number of issues with profound implications for the way that this EC data is (and has previously been) used in trend analysis.

The grab-sampling programs that generated the discrete data have been considered in two blocks. The first block was operated by hydrographic staff from the late 1960s to the early 1990s and is termed ’historical’ here. At most sites, there is a second block of data (starting in the early 1990s). This second block was mostly (but not always) generated under the one collection program.

2 TRITON Archive—Historical EC 1960s to 1992

EC meters were used in the Tumut and Armidale offices to measure the grab samples taken in the field by departmental hydrographic teams. The sampling program was in its infancy and required a checking procedure of the Tumut/Armidale instruments – sometimes duplicate samples were sent to Sydney for laboratory analysis. Gauging stations used in the data checking procedure are listed in old records at the Armidale and Tumut offices. The dates (before the early 1990s) when the comparisons occurred can usually be identified in TRITON because they contain two different EC readings.

The exercise of separating the 2 data strands (Armidale/Tumut and laboratory data) has led to the conclusion that a bias exists in the historical dataset before 1992. The apparent bias has implications for the comparison of EC trends at different sites.

2.1 Southern districts record

Most of the historical EC data from the Murray, Murrumbidgee and Lachlan valleys was measured in the Tumut office. The TRITON archive is ambiguous on this fact, describing all the early data under a ‘Laboratory Codes’ heading as ‘unknown / not recorded’. This labelling is misleading, as it is open to an interpretation that the data were analysed under accredited laboratory conditions, but that the details have been lost. However, this investigation has found that the data was not analysed under accredited laboratory conditions, and the source (Tumut office) is known.

As most historical readings can be traced back to Tumut, the TRITON database could be vastly improved by creating a specific code for the Tumut (and Armidale) EC meters. Such a step would clarify a large proportion of the samples currently labelled as ‘unknown’.

2.1.1 Tumut sampling program

In the historical program, grab samples were obtained during site visits and brought back to Tumut to be measured. They were then processed in batches, and the results were recorded there. In some instances, duplicate samples were sent to Sydney for laboratory analysis for the purpose of checking the Tumut meter. Of the sites selected as suitable for the stream EC trend study, only a few were part of the historical checking. The TRITON record suggests that gauging station 401009 Maragle Creek at Maragle was the subject of an extensive checking program. This study identified 5 other stations with occasional duplicate readings—410061 Adelong Creek at Batlow Road, 401013 Jingellic Creek at Jingellic, 410044 Muttama Creek at Coolac, 410047 Tarcutta Creek at Old Borambola and 410048 Kyeamba Creek at Ladysmith. A cursory investigation suggests that there are other duplicate sites, but these were not listed for inclusion in the EC trend study, and there were no additional resources to invest in the data editing.

By comparing the TRITON archive with the results held at Tumut, it is possible to isolate the Tumut readings. It was assumed that the remainder were Sydney laboratory readings. After editing for gross errors, the performance of the Tumut EC meter can be compared with the Sydney laboratory (Figures 1a, b). These figures are based on the premise that the laboratory results are correct (time constraints prevented confirmation of this).

Based on the 6 sites listed above, Figure 1 shows the corrections that should be applied to the Tumut EC meter data in µS/cm (Figure 1a) and as a percentage of the instrument reading (Figure 1b). The plots suggest that compared with the laboratory analysis, the Tumut meter could have been underestimating EC throughout the early 1970s (i.e. overestimating rising trends), and briefly overestimating EC in some sample batches around 1977. In additional, R. Boyton (DIPNR, pers. comm. 19 Aug 2003) indicates that quality assurance was a problem in the early stages of the program. It was not until the late 1970s that independent checks were regularly carried out, and the Tumut meter was incorporated into a wider formal program.

Figure 1a. Correction (µS/cm) to Tumut data using laboratory analyses as datum.

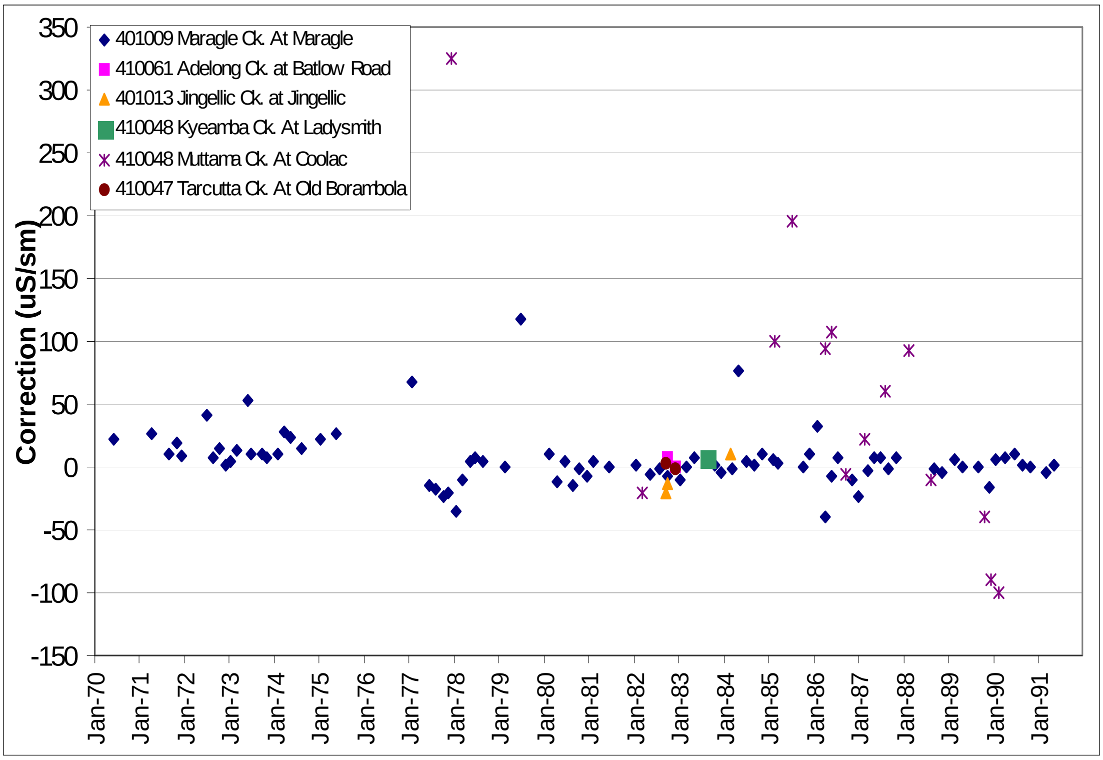
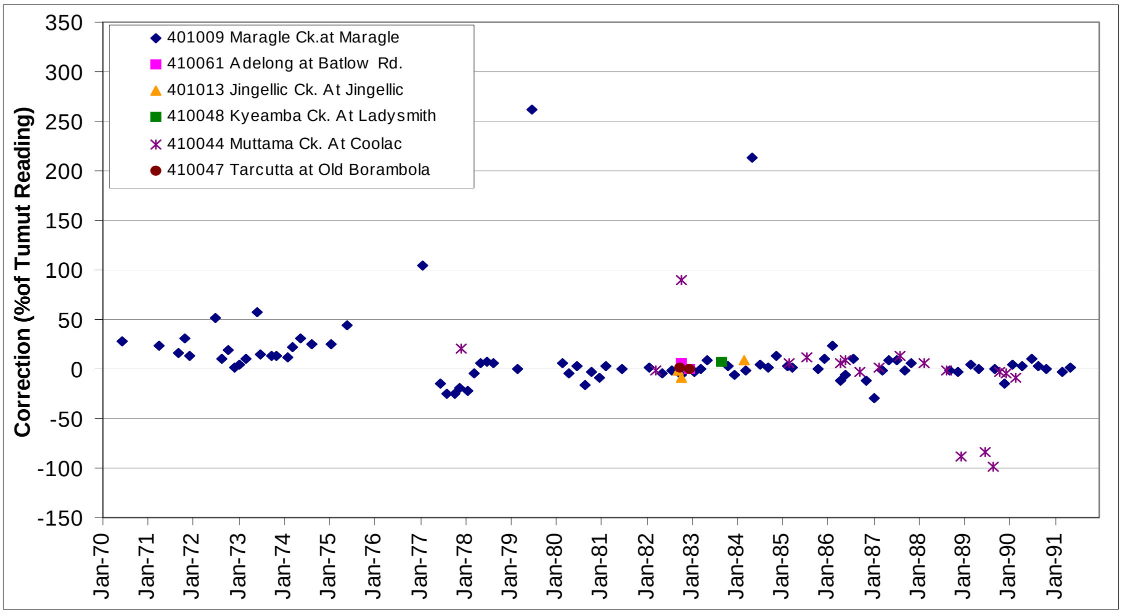


Figure 1b. Correction (percentage) to Tumut data using laboratory analyses as datum.



The hypothesis that the early record was an underestimate is far from conclusive. Nearly all the comparisons in the early years (1969–1975) were done for the 1 gauging station, 401009 Maragle Creek at Maragle, where the EC range was low. There would have been more confidence about widespread underestimation had there been more sites with laboratory comparisons, and if such sites contained high EC readings. Muttama at Coolac (410044) is the only site with the potential to fulfil the high EC requirement. As can be seen from Figure 1a, the Muttama corrections are large when expressed in µS/cm. However, the corrections are comparable with those at the Maragle site when expressed as a percentage of the laboratory readings. Unfortunately, there is only 1 duplicate in Muttama's early record, and it did not help to clarify the situation.

Most of the archived historical EC data from southern NSW was measured using the Tumut meter. In view of the above information, it is possible that there is a bias in the earlier data. An assessment was made (based solely on Figure 1) that the early record might have underestimated EC by approximately 15%. However, this could not be verified without extensive investigation, and it was not considered prudent to adjust the data on the basis of such limited evidence.

To test the implications of such an anomaly, trends calculated using the adjusted and non-adjusted datasets were compared. The results are outlined in Section 4.

2.2 Northern districts record

Most of the historical EC data from the Border, Gwydir and Namoi valleys was under the coordination of the Armidale office.

2.2.1 Armidale sampling program

The EC sampling program was active as early as 1962 at some sites in northern NSW. Before 1969, some measurements were obtained using portable meters, which were considered unreliable (Water Conservation and Irrigation Commission 1968). Other samples were forwarded to Sydney for laboratory analysis. 418008 Gwydir at Bundarra is the earliest EC trend site, dating from 1964.

In 1969, an EC meter was installed at the Armidale office. Duplicate samples were taken at a number of the sites used in the salinity trend study: The Armidale meter data strand in TRITON was separated from the Sydney laboratory analyses.

During the data collation phase of the stream EC trend study, a gap was noted in the Armidale hardcopy records, generally from the mid 1970s to the mid 1980s. The reason for this gap is not clear, but the gap made it virtually impossible to identify the Armidale data in TRITON. Consequently, there was no easy way to compare the 2 data sets over that period.

In the preliminary selection of the stream EC trends sites, there were 11 data sets in which the Armidale data could be compared with the Sydney laboratory results. Figure 2 shows the corrections that should be applied to the Armidale data if the Sydney laboratory results are assumed correct. These corrections are expressed in µS/cm (Figure 2a) and as a percentage of the reading (Figure 2b). These figures show all data from the 11 sites and contain too much information to be used for standalone evaluation. However, in Figure 2b, outliers differing by >60% occur at more than 1 site at particular times in the 1970s. A possible explanation is that batches of samples were measured badly in either the Armidale office or Sydney laboratory. This raises the idea that the instrument differences might vary from batch to batch as well as long-term.

Figure 2a. Correction (µS/cm) to Armidale data using laboratory analyses as datum.

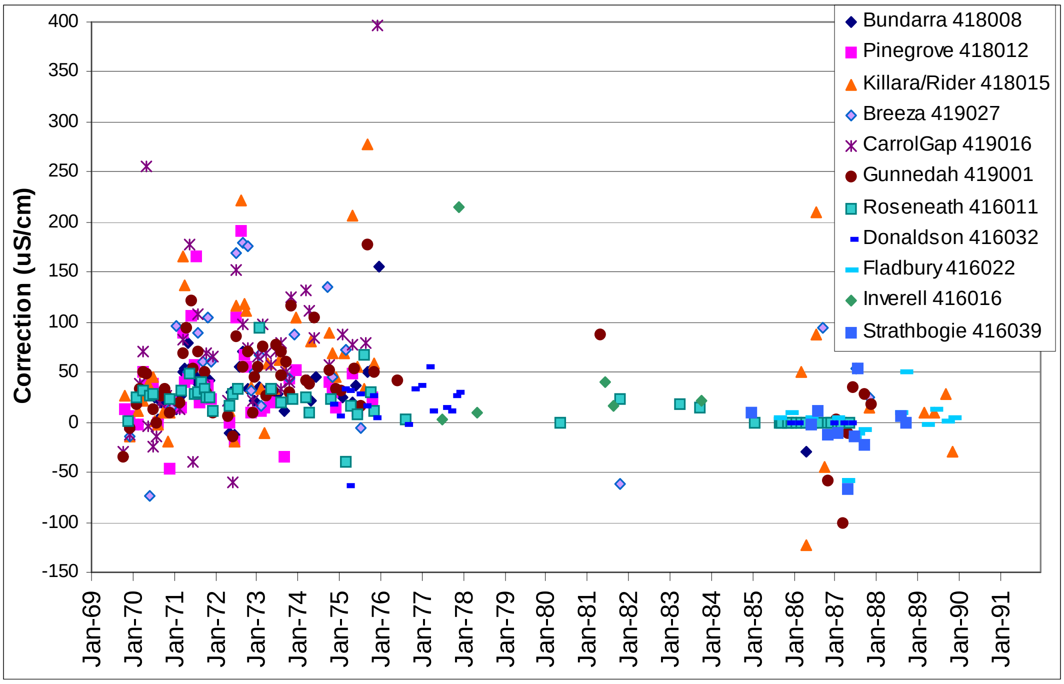
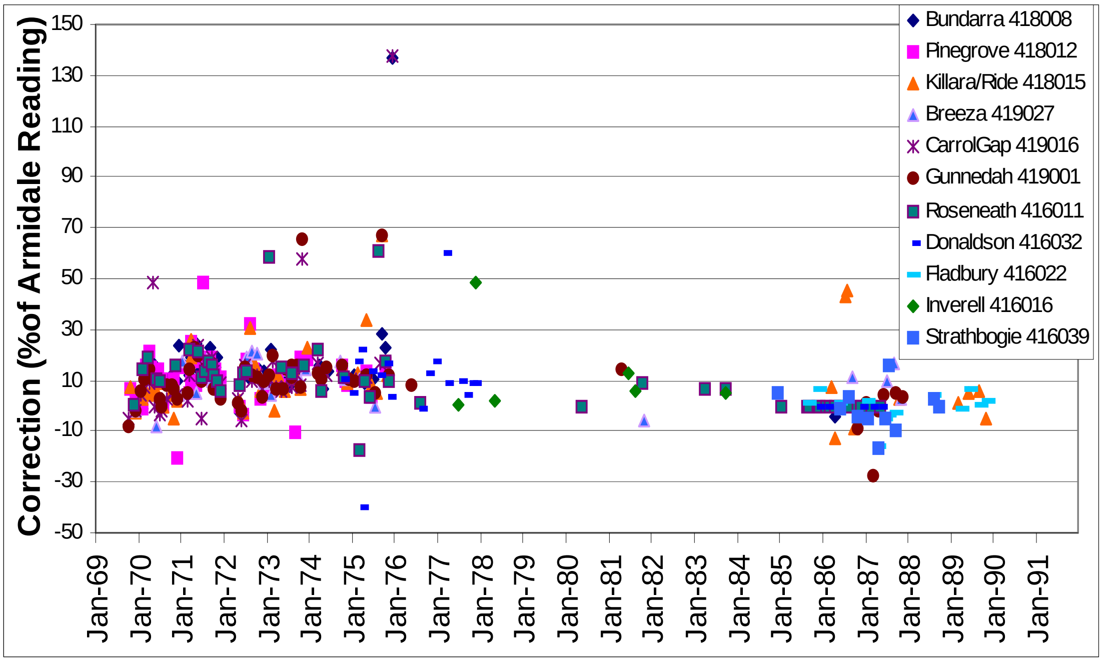
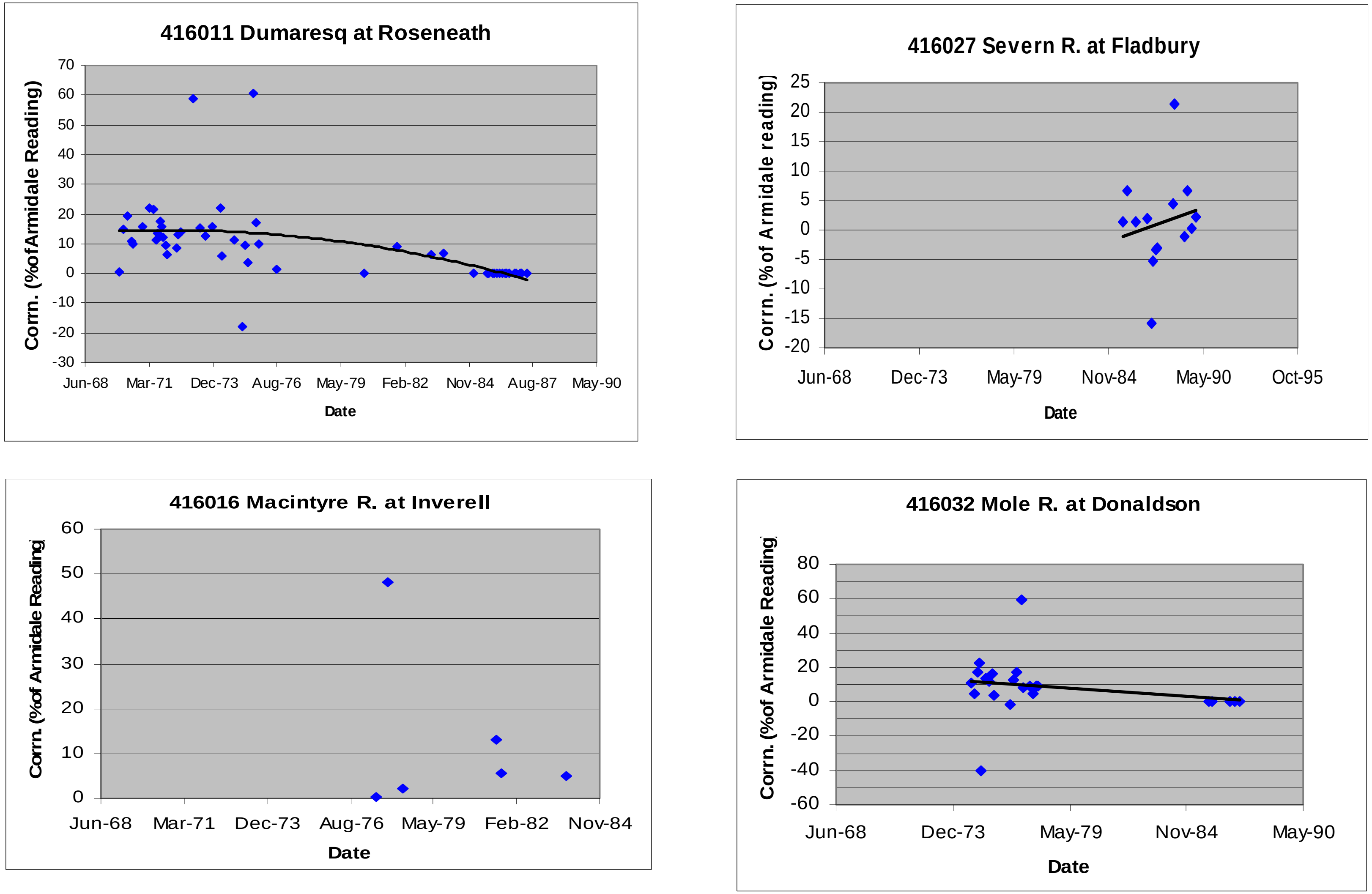


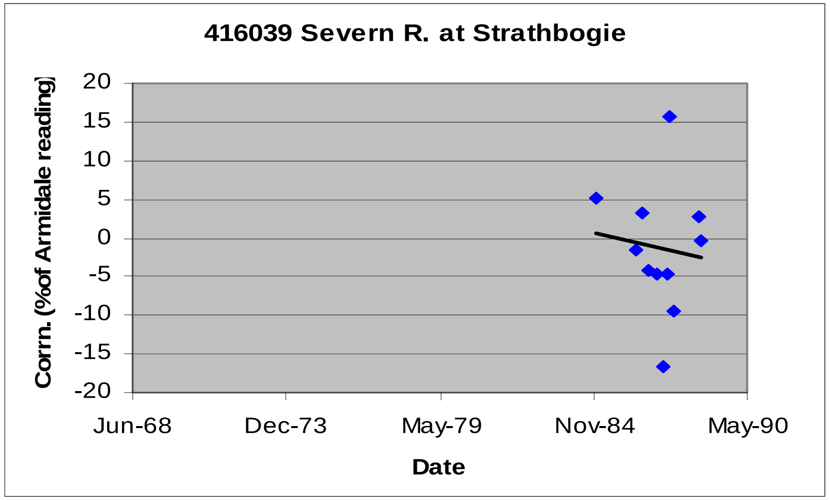
Figure 2b. Correction (percentage) to Armidale data using laboratory analyses as datum.

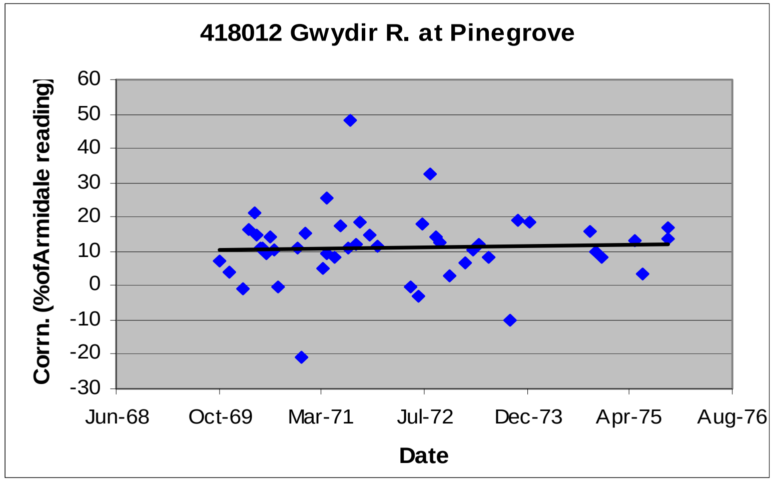


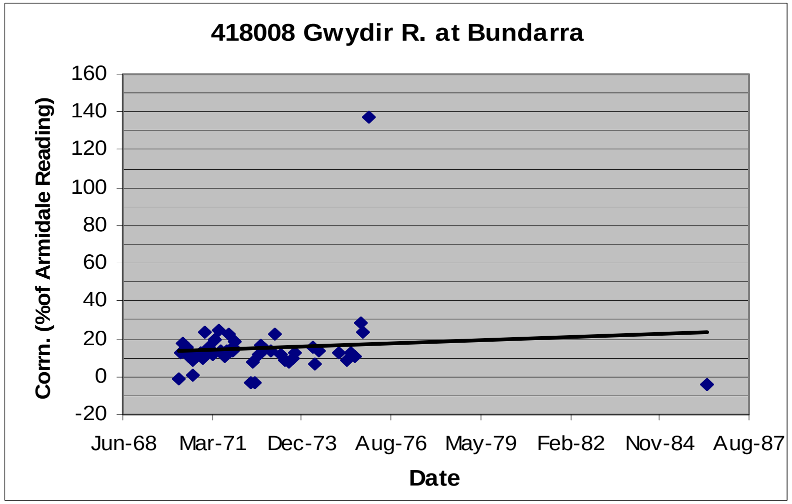
The sites were plotted in Figure 3 and examined individually to assess any relationship that might exist between the 2 sources.

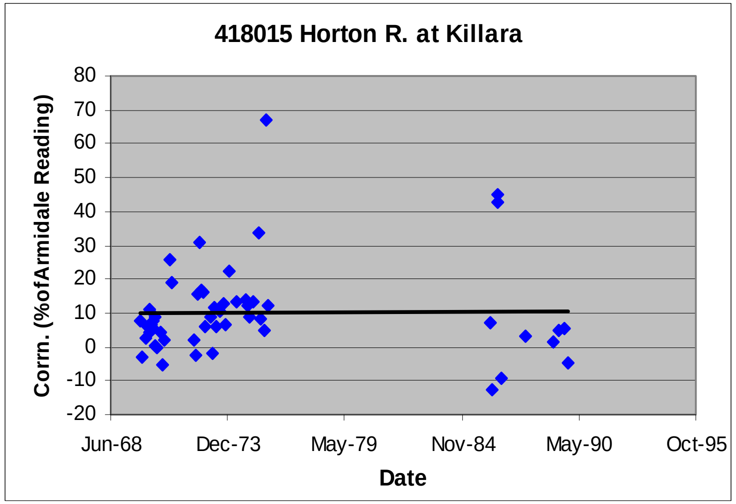
Figure 3. Correction (percentage) to Armidale data using laboratory analyses as datum.

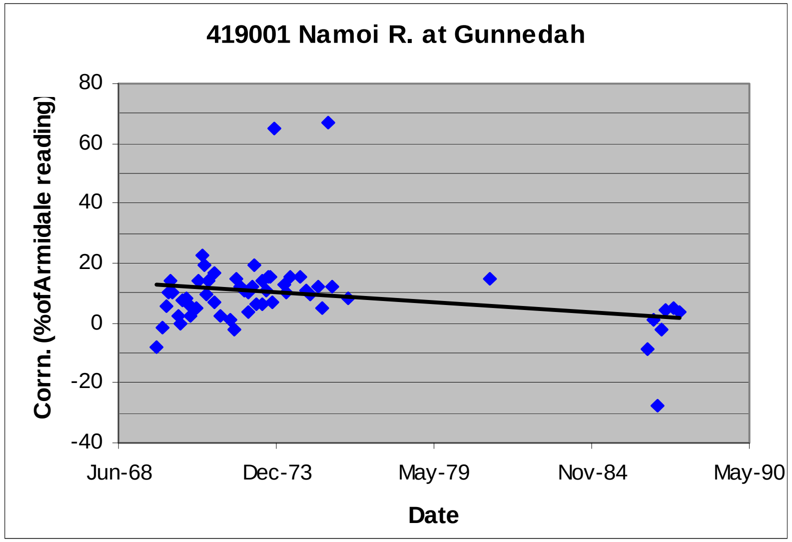


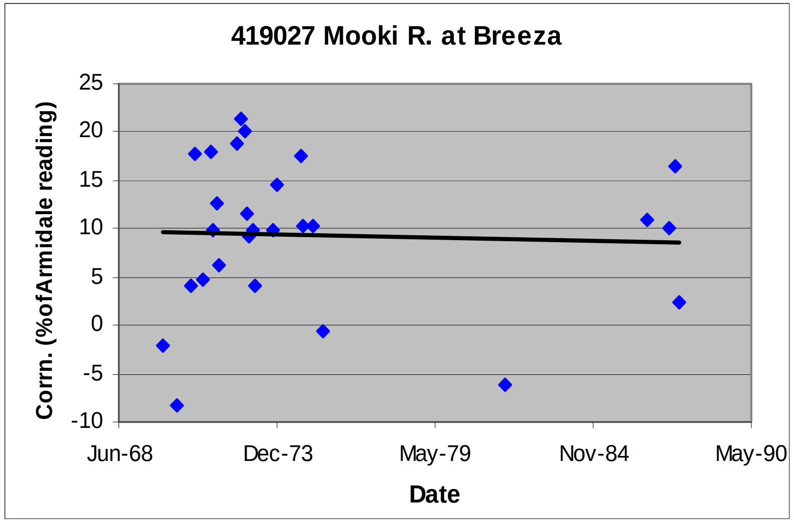

416039 Severn R. at Strathbogie
Corrn. (%of Armidale reading)
20
15
10
5
0
-5
-10
-15
-20
Jun-68
Dec-73
May-79
Nov-84
May-90
Date

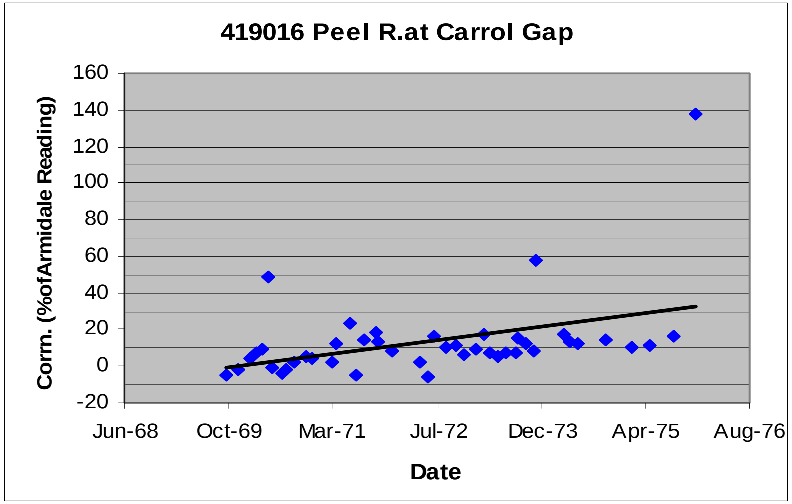

418012 Gwydir R. at Pinegrove
Corrn. (%ofArmidale reading)
60
50
40
30
20
10
0
-10
-20
-30
Jun-68
Oct-69
Mar-71
Jul-72
Dec-73
Apr-75
Aug-76
Date


418008 Gwydir R. at Bundarra
Corrn. (%of Armidale Reading)
160
140
120
100
80
60
40
20
0
-20
Jun-68
Mar-71
Dec-73
Aug-76
May-79
Feb-82
Nov-84
Aug-87
Date


418015 Horton R. at Killara
Corrn. (%ofArmidale Reading)
80
70
60
50
40
30
20
10
0
-10
-20
Jun-68
Dec-73
May-79
Nov-84
May-90
Oct-95
Date


419001 Namoi R. at Gunnedah
Corrn. (%ofArmidale reading)
80
60
40
20
0
-20
-40
Jun-68
Dec-73
May-79
Nov-84
May-90
Date


419027 Mooki R. at Breeza
Corrn. (%ofArmidale reading)
25
20
15
10
5
0
-5
-10
Jun-68
Dec-73
May-79
Nov-84
May-90
Date


419016 Peel R.at Carrol Gap
Corrn. (%ofArmidale Reading)
160
140
120
100
80
60
40
20
0
-20
Jun-68
Oct-69
Mar-71
Jul-72
Dec-73
Apr-75
Aug-76
Date

The information in Figure 3 was assessed by eye, and the ramifications of this approach are discussed in Section 4.

It was concluded that the Armidale EC meter was reading approximately 10% lower than the Sydney laboratory results from 1969. The gap in the Armidale hardcopy records made it difficult to finalise how long the situation continued. The 10% discrepancy could be definitely tracked to the end of 1977, and possibly extended to October 1980. The available information suggests that the data from the 2 measuring systems had achieved reasonable agreement by late 1986, and possibly as early as December 1984.

We concluded that a discrepancy of the order of 10% exists in Triton for the Armidale data until at least the end of 1977. The datasets used to draw this conclusion came from the sites used in the stream EC trend analysis study. They represent about half of the data sets that should have been prepared and analysed for an accurate calculation of the adjustment, but time constraints prevented a thorough analysis. The 10% value was considered a reasonable approximation.

3 TRITON Archive after 1992

From 1992, the hydrographic staff ceased to be the main data collectors, and a number of different programs evolved for data collection. During the preparation of the TRITON data sets for this study, several issues became apparent:

- Laboratory staff apply code ‘NEWVER’ in TRITON after analysis but before final clearance. The code flags that the data point has not been validated. There seems to be some confusion as to who is responsible for the final approval.
- At a few sites, good-quality EC data were being collected but without instantaneous flow data. These sites could not be used in the stream EC trend study, because the analysis methods rely on flow-weighting of the EC data. Accurate temperature data are also necessary in EC field sampling.
- If there is more than 1 reading during a site visit, the additional information should add to our knowledge of EC behaviour. In the stream EC trend study, variations in the data need to be explained in the context of the flow variations across the stream. Perhaps TRITON requires an EC cross-section archiving procedure similar to Step 2 of DWE Hydrometric Procedure 73044.
- If portable meters are used to measure field data, then instrument performance must be tracked over long periods. In TRITON, the portable meters measurements often differ from the laboratory analyses. The portable meter data in TRITON should be flagged as unedited.
- Any procedure which condones the frequent undocumented adjustment of a portable EC meter in the field is flawed, because the adjustment masks other sources of failures in the process.
- EC data from the Murrumbidgee Valley are stored under 2 variables in TRITON: ‘EC @ 25’ and ‘EC’. Both variables should be downloaded in order to recover all the data.

4 Historical Data Discussion

Discrepancies between Tumut data / Armidale data and laboratory data need evaluation. At many sites (particularly in southern NSW), the Tumut meter readings are the only available data. If it is concluded that the local procedures were flawed in the early years, then the trend analyses for many sites across the State contain a bias.

4.1 Origins of the discrepancy

Intuitively, we might expect that the local meters are the source of the error. However, it is quite possible that the laboratory results are the source, because the differences are of the same order in Armidale and Tumut. The laboratory analyses have been assessed visually in Microsoft Excel and are generally around 10% to 15% higher than the 2 local meter readings. It is possible that the differences could be explained by either the sample handling or the laboratory analysis.

Handling. It is not clear what time elapsed between sampling and analysis. It is possible that up to a week passed between sampling and return to Tumut or Armidale. R. Boyton (DIPNR, pers. comm. 2004) indicated that:

- not many samples were sent from Tumut to Sydney for analysis
- most of those sent from Tumut were chilled—e.g. 401009 Maragle Creek at Maragle
- if samples were no longer chilled on arrival, they were not used for laboratory analysis.

Various informal discussions at the Armidale and Tumut offices implied some concern about the delays in samples sent to Sydney by rail. It is unlikely that the delays had any effect on the samples because of the static nature of salt.

Laboratory procedures. If the discrepancies were a result of laboratory procedures or equipment, then they should be similar between Tumut and Armidale. Indeed, there was a 15% variation in Tumut data and 10% in Armidale data. However, the hypothesis is weakened by the fact that the Tumut discrepancy alters drastically in 1977 and then disappears shortly thereafter. In comparison, the Armidale discrepancy remains unaltered throughout 1977, and appears to continue throughout 1978.

Quality assurance. Informal enquiries suggest that the Sydney laboratory may not have had QA in the early record.

4.2 Options for EC trend analyses

To progress, we need to identify the source of the error. There are 3 possibilities:

- The laboratory readings are correct, and the EC meters are out by 10% in Armidale and 15% in Tumut.
- The EC meter results are more or less correct, and the laboratory procedures, instrumentation or sample delivery created an error of >10%.
- All the sources contribute to the error in roughly equal proportions.

A solution might have been to average the 2 data sets, but as most of the southern sites didn't have laboratory check readings, this was not an option. It was concluded that there was no way of apportioning the discrepancy without local knowledge. Informal inquiries indicated that a definitive answer might be elusive at this late date, and would probably require extensive investigations.

As a short-term solution, it was decided to undertake a sensitivity analysis, using the local and laboratory data to generate 2 EC trends at each site. This would reveal whether the data differences had a major impact on the trend results and could explain the trends ascribed to certain sites in previous studies.

The data sets were generated in the following way for each gauging station. Where duplicates were found, the local readings were identified first, and the remainder were attributed laboratory status. Where there was only the local source, the early records were adjusted: by +15% for Tumut data before 1976 (the overestimates during 1977 were ignored) and by +10% for Armidale data before 1978.

4.3 Ramifications of data adjustment—sensitivity tests

How the bias is corrected may determine whether the EC trend at any particular site is rising or not. The early data bias had far-reaching implications. It was decided to run a sensitivity test, analysing adjusted and unadjusted data using the methods described in Harvey et al. (2009).

4.3.1 Southern NSW

A sensitivity analysis was undertaken to see the effect of the adjustment on the (log_e) linear component of the EC trend in the Lachlan, Murrumbidgee and Murray valleys. At the 23 sites where a comparison could be made, the slope always decreased (i.e. became more negative), but the outcomes were not always statistically significant. It was decided to use the existing archive data, although it was suspected that the EC in the earlier years should be increased by approximately 15%.

At 18 of the southern sites, there was no change in the sign of the slope (Table 1). Of these:

- 7 slopes were already negative and became statistically significant
- 8 remained positive and statistically significant
- 3 remained positive but became statistically non-significant.

Table 1. Southern sites exhibiting no change in sign of trend.

StationNo.	Name	Linear Trend Sign	Statistical Significance
401013	Jingellic Ck. at Jingellic	Negative	Becomes Significant
410091	Billabong Ck. at Walbundrie	Positive	Significant
410097	Billabong Ck. at Aberfeldy	Positive	Significant
410025	Jugiong Ck. at Jugiong	Positive	Significant
410038	Adjungbilly Ck. at Darbalara	Negative	Becomes Significant
410044	Muttama Ck. at Coolac	Positive	Significant
410045	Billabung Ck. at Sunnyside	Positive	Not Significant
410047	Tarcutta Ck. at Old Borambola	Positive	Significant
410048	Kyeamba Ck. at Ladysmith	Positive	Significant
410061	Adelong Ck. at Batlow Rd.	Negative	Becomes Significant
410103	Houlaghans Ck. at Downside	Positive	Significant
412028	Abercrombie R. at Abercrombie	Negative	Becomes Significant
412030	Mandagery Ck.at U/S Eugowra	Positive	Significant
412050	Crookwell R. at Narrawa North	Negative	Becomes Significant
412065	Lachlan R. at Narrawa	Positive	Becomes Not Significant
412072	Back Ck at Koorawatha	Positive	Becomes Not Significant
412083	Tuena Ck. at Tuena	Negative	Becomes Significant
412086	Goobang Ck. at Parkes	Negative	Becomes Significant

At the 5 remaining southern sites (Table 2), the adjustment would have changed the slope of the trend from positive to negative, but the slopes were statistically non-significant.

Table 2. Southern sites exhibiting change in sign of trend.

StationNo.	Name	Linear Trend Sign	Statistical Significance
401009	Maragle at Maragle	Becomes Negative	Not Significant
410057	Goobragandra at Lacmalac	Becomes Negative	Not Significant
412009	Belubula at Canowindra	Becomes Negative	Becomes Not Signific
412043	Goobang at DarbysDam	Becomes Negative	Becomes Not Signific
412055	Belubula at Bangaroo Bge	Becomes Negative	Not Significant

4.3.2 Northern NSW

In the Macintyre, Gwydir and Namoi, the existing archive data was adjusted by +10% in the earlier record. It was suspected that the real difference might be several percentage points higher. A sensitivity analysis was undertaken to see the effect of the adjustment on the slope of the EC trend. At the 30 sites where a comparison could be made, the slope always reduced in magnitude, becoming relatively more negative, but the outcomes were not always statistically significant.

The sign of the trend slope did not change at 18 sites (Table 3):

- 4 slopes remained negative and significant
- 3 remained negative and non-significant
- 4 remained negative but became statistically significant
- 1 remained positive and significant
- 3 remained positive and non-significant

- 3 remained positive but became non-significant.

Table 3. Northern sites exhibiting no change in sign of trend.

StationNo.	Name	Linear Trend Sign	Statistical Significance
416008	Beardy at Haystack	Negative	Significant
416010	Macintyre at Wallangra	Negative	Not Significant
416020	Ottleys at Coolatai	Positive	Not Significant
416027	GilGil at Weemelah	Positive	Not Significant
417001	Moonie at Gundablouie	Positive	Not Significant
418005	CopesCk. At Kimberley	Negative	Becomes Significant
418014	Gwydir at Yarrowych	Negative	Becomes Significant
418021	Laura at Laura	Positive	Becomes Not Signific.
418023	Moredun at Bundarra	Positive	Becomes Not Signific.
418025	Halls at Bingara	Negative	Significant
418027	Horton at DamSite	Negative	Significant
418029	Gwydir at StoneyBatter	Positive	Becomes Not Signific.
419005	Namoi at NthCuerindi	Negative	Becomes Significant
419016	Cockburn at Mulla Xing	Negative	Significant
419027	Mooki at Breeza	Positive	Significant
419029	Halls Ck. At Ukalon	Negative	Becomes Significant
419032	Coxs at Boggabri	Negative	Not Significant
419054	Swamp Ck. At Limbri	Negative	Not Significant

In northern NSW, the adjustment resulted in 12 sites changing slope from positive to negative (Table 4). None of the slopes, either before or after the adjustment, was statistically significant.

As can be seen, the impact of the data adjustments is not dramatic in the statistical sense. However, the linear trend changed sign (from positive negative) at 17 of the study sites (Tables 2 and 4). Such a change would influence an observer's perception of the processes. It also adds a layer of uncertainty in forecasting EC levels.

Table 4. Northern sites exhibiting change in sign of trend.

StationNo.	Name	Linear Trend Sign	Statistical Significance
416003	Tenterfield at Clifton	Becomes Negative	Not Significant
416016	Macintyre at Inverell	Becomes Negative	Not Significant
416023	Deepwater at Bolivia	Becomes Negative	Not Significant
418015	Horton at Rider	Becomes Negative	Not Significant
418016	Warialda at Warialda	Becomes Negative	Not Significant
418017	Myall at Molroy with 4/1980	Becomes Negative	Not Significant
418018	Keera at Keera	Becomes Negative	Not Significant
418032	Tycannah at Horseshoe	Becomes Negative	Not Significant
419033	Coxs at Tambar springs	Becomes Negative	Not Significant
419035	Goonoo@Timbumburi	Becomes Negative	Not Significant
419051	Avoca at Maules	Becomes Negative	Not Significant
419053	Manilla at Black Springs	Becomes Negative	Not Significant

4.4 Resolving the bias

As seen from Tables 1 to 4, the data anomaly has implications. With the discovery that the data from the laboratory and the local meters were contradictory, it was decided to assess the correction by eye from the graphs (Figures 1–3). Considering the timeframe of the stream EC trend study, this approach was acceptable as a 'quick fix'.

It is outside the scope of the trend study to rectify a perceived systematic error in the database.

This data set is routinely used in salinity studies. The anomalies may have profound implications for any salinity strategy. Resolving the problem is a standalone major project. Time is not a major issue (although the work will take time), but the concentration of the appropriate expertise is important.

The steering committee in this future work should consist of biometricians, archivists, individuals with a laboratory background, and individuals familiar with the local EC meter protocols. A precise statistical evaluation of the problem would require all paired data values from all dual program sites before 1992. (The work undertaken in the stream EC trend study has gone part of the way to collating such a data set.) The statistics would require some form of least-squares adjustment with a time component and possibly other variables.

5 Conclusion

As part of an analysis of EC stream trends in NSW, a number of data issues arose. There is need for a review of TRITON management practices, as per Section 3. There should be a detailed statistical analysis of the early TRITON EC record, as described in Section 4.4.

6 References

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