CSIRO WATER FOR A HEALTHY COUNTRY FLAGSHIP
www.csiro.au

Trends in physical and chemical aspects of water quality in the Murray-Darling Basin 1978-2012

Prepared for:

Murray Darling Basin Authority

GPO Box 1801

Canberra City 2601

September 2013

Water for a Healthy Country Flagship Report series ISSN: 1835-095X

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills.

CSIRO initiated the National Research Flagships to address Australia's major research challenges and opportunities. They apply large scale, long term, multidisciplinary science and aim for widespread adoption of solutions. The Flagship Collaboration Fund supports the best and brightest researchers to address these complex challenges through partnerships between CSIRO, universities, research agencies and industry.

The Water for a Healthy Country Flagship aims to provide Australia with solutions for water resource management, creating economic gains of $3 billion per annum by 2030, while protecting or restoring our major water ecosystems.

For more information about Water for a Healthy Country Flagship or the National Research Flagship Initiative visit www.csiro.au/org/HealthyCountry.html

CSIRO Contact details:

Dr Brent Henderson

Research Group Leader - Environmetrics, Biometrics and Bioinformatics

CSIRO Computational Informatics / Water for a Healthy Country Flagship

Phone: +61 2 6216 7095

Brent.Henderson@csiro.au

Postal Address: GPO Box 664 Canberra ACT 2601 Australia.

Citation

Henderson, B., Liu Y, and Baldwin D (2013) Trends in physical and chemical aspects of water quality in the Murray-Darling Basin 1978-2012. CSIRO Water for a Healthy Country Flagship, Australia.

Note: Appendices exist as separate report under the same name.

Acknowledgement:

This report into trends in physical and chemical aspects of water quality in the Murray-Darling Basin 1978-2012 was funded by the Murray-Darling Basin Authority. This report has been reviewed and approved by Tapas Biswas and Brian Lawrence of the MDBA.

Copyright and disclaimer

Important disclaimer

Contents

APPENDICES (Separate report)

List of Figures

List of Tables

EXECUTIVE SUMMARY

Monitoring data has been collected as part of the River Murray Water Quality Monitoring Program (and its forerunners) since 1978. This report examines trends in key physico-chemical water quality parameters over that time, focusing in particular on total phosphorus, filterable reactive phosphorus, total Kjeldahl nitrogen, oxidised nitrogen, Electrical Conductivity (EC), turbidity, dissolved organic carbon, and silica. 16 monitoring sites are considered, spanning the upper to lower Murray, and representing some key tributaries.

Generalized additive models, which use splines to describe non linear trends and dependence on flow, are the primary vehicle for assessing the trend. These analyses are performed on the log transformed water quality parameter and on a site basis for each water quality parameter. Trends are considered over the full 1978-2012 time period and over the most recent 10 years (2003-2012). The latter is important as interpretation is often clearer over medium time spans when the linearity is stronger and provides a stronger sense of the future trajectory. The analysis approach is consistent with previous trend analyses commission by the MDBA (AWT 1999, WATER Ecoscience 2002, Henderson 2006) which enables comparisons to be made.

The analysis of the monitoring data undertaken establishes that there have been important and statistically significant changes in key water quality parameters at monitoring sites within the Murray-Darling Basin. Changes over the 35 year period from 1978 to 2012 are hard to summarise simply as there are typically non-linear, with increases and decreases corresponding to different climate regimes, hydrological drivers and management practices. The estimated % change per annum trends for total phosphorus (TP), filterable reactive phosphorus (FRP), total Kjeldahl nitrogen (TKN), oxidised nitrogen (NOx), EC, turbidity, dissolved organic carbon (DOC), silica and flow for these sites over the period 1978-2012 are summarised in Table 1. Adjustments are made for flow in the estimated trends because flow has been found to generally have an important and positively related effect. The analogous summary table for 2003-2012 is presented in Table 2. Figure 1 presents these trends graphically for each water quality parameter in river profile plots which present the long term geometric mean and then change the plotting character, size and colour according to whether it is increasing or decreasing, the magnitude of that change, and whether the site is on the main stem of the Murray or on a tributary.

Across the entire period there have been general broad decreases in nutrients (TP, FRP, TKN, NOx), though NOx and TP show increases in the upper Murray (Jingellic to Bandiana). Capels Flume and Kerang however show stronger increases in these nutrients. Silica decreases across the period at all sites except Kerang. EC has been decreasing uniformly though Yarrawonga appears to buck that trend. Turbidity has been increasing in the upper-mid Murray sites, though is decreasing below Swan Hill, with the exception of Burtundy which represents the unique contribution of the Darling River. DOC is less consistent, though appears to decrease for all sites below Swan Hill. There is notably a large decrease in DOC at Yarrawonga and increase at Kerang and Capels Flume.

The 2010/11 floods have had a large impact on the water quality at that time, increasing nutrients fairly consistently with the exception of NOx that decreased at many sites, increasing EC (other than at Morgan), increasing turbidity at most sites, and increasing DOC. The effect on silica is a bit more mixed with increases in the upper Murray sites but decreases between Torrumbarry and Kyalite. Following the floods most of these parameters have returned to levels more typical of recent preceding years.

Table 1. Trend summary in percentage per annum for the water quality parameters and flow, 1978-2012. Increases are shown in black and decreases in red. Percentage changes in bold indicate significance at the 0.01 level.

Monitoring Site	Flow (ML/day)	TP	FRP (SRP)	TKN	NOX	EC	Turbidity	DOC (SOC)	Silica
Jingellic	-0.53	0.16	**-1.05**	-0.16	**2.57**	**-0.38**	**2.50**	-0.41	-0.44
Tallandoon	0.36	**-0.66**	**-1.50**	**-0.84**	0.47	**-0.67**	**1.21**	**-0.84**	**-0.50**
Heywoods	-0.44	0.02	**-1.30**	**1.02**	-1.74	**-0.62**	1.51	0.92	**-2.20**
Bandiana	0.02	0.33	-0.05	0.27	**1.91**	**-0.84**	**2.71**	0.63	**-1.44**
Peechelba	-0.87	**-1.30**	**-2.00**	**-0.82**	-0.59	**-0.93**	**3.02**	**-0.98**	-0.28
Yarrawonga	-0.67	**-1.48**	**-0.56**	**-1.46**	**-1.84**	**2.11**	**2.50**	**-5.19**	**-2.14**
Torrumbarry	-0.54	**-1.32**	**-1.13**	**-0.81**	-0.42	**-1.35**	0.11	0.00	-0.47
Kerang	**-4.75**	**1.24**	0.32	0.86	**2.06**	-0.62	**1.01**	**3.15**	1.27
Capels Flume	**-4.68**	**3.30**	**2.27**	**2.17**	**3.81**	**-1.90**	0.44	**1.49**	-0.55
Swan Hill	-0.55	**-0.95**	**-0.85**	**-0.83**	-0.40	**-3.80**	-0.18	-0.42	-0.22
Kyalite	-0.78	-0.77	-0.32	**-0.87**	-0.30	**-1.86**	**-2.03**	-0.80	**-1.64**
Euston Weir	-1.03	**-2.27**	**-0.88**	-0.40	**-2.96**	**-3.15**	**-1.06**	**-7.15**	**-0.94**
Merbein	-1.11	**-1.65**	**-0.90**	**-1.11**	**-3.25**	**-3.66**	-0.62	**-5.76**	-0.59
Burtundy	-3.29	**-1.42**	**-3.83**	0.29	0.66	-0.52	**2.63**	**-3.30**	**-2.88**
Lock 9	-2.01	**-1.27**	-1.26	-0.35	**-2.33**	**-3.64**	**-2.60**	**-1.31**	**-1.63**
Morgan	-1.45	**-1.03**	-1.02	**-0.85**	**-2.29**	**-2.29**	**-2.29**	-0.49	**-2.04**

Table 2. Trend summary in percentage per annum for the water quality parameters and flow, 2003-2012. Increases are shown in black and decreases in red. Percentage changes in bold indicate significance at the 0.01 level.

Monitoring Site	Flow (ML/day)	TP	FRP (SRP)	TKN	NOX	EC	Turbidity	DOC (SOC)	Silica
Jingellic	3.416	**4.28**	**1.28**	1.07	0.33	**2.18**	**6.02**	**7.42**	1.44
Tallandoon	-6.351	**3.98**	0.23	**1.93**	-1.63	**-0.62**	**4.21**	**6.02**	**-5.09**
Heywoods	4.449	1.87	-0.26	2.12	3.06	1.25	1.39	**11.7**	-6.08
Bandiana	**10.009**	**2.64**	**1.87**	-0.19	**-8.51**	0.39	**4.43**	**5.04**	-0.46
Peechelba	13.484	0.7	0.77	-1.3	**-6.13**	-1.3	-0.25	**4.3**	-1.15
Yarrawonga	3.924	1.56	**3.01**	-1.38	-6.62	1.41	**6.43**	0.66	-4.29
Torrumbarry	**8.228**	-0.07	-1.17	0.18	-6.87	-0.9	**7.94**	0.42	-3.94
Kerang	0.386	**9.48**	**2.29**	**8.7**	-3.79	-3.77	**14.69**	**12.72**	1.15
Capels Flume	10.015	**-16.51**	**-32.25**	4.37	6.92	**-8.1**	**15.63**	2.81	0.54
Swan Hill	**7.825**	0.2	**-3.38**	1.44	**-9.94**	-0.95	**5.66**	1.13	**-5.76**
Kyalite	9.087	4.17	-0.21	**3.82**	**-4.76**	0.35	**8.74**	4.65	-1.39
Euston Weir	**10.347**	-1.78	1.05	**11.27**	2.5	**-3.71**	**6.34**	-6.35	**-11.29**
Merbein	**10.109**	-1.13	**4.09**	-2.37	1.57	-2.16	**7.51**	0	**-28.29**
Burtundy	**69.171**	0.29	5.45	-3.17	7.86	-6.32	13.49	-3.61	7.22
Lock 9	**22.875**	**6.94**	**9.6**	4.23	7.03	2.43	1.82	6.44	4.22
Morgan	**20.204**	**6.63**	**9.02**	**3.5**	**11.5**	-1.15	**-17.01**	3.59	5.16

The trends presented in Table 1, and to a lesser extent Table 2, do however need to be treated cautiously. Strong and significant non-linearity has been found in many of the trends. This does not mean that the linear trend is invalid but it does highlight that other features of the trend are important and that the linear trend calculated over different subsets of the data could deliver different results (because the local linear trend is differs from the trend over the entire range). It is also important to bear in mind that the interpretation of the % change per annum trends is intimately tied to the mean level. A percentage change per annum trend has a different impact according to whether the base level is low or high. That is, a 2% p.a. trend starting from a very low level may be of less concern than a 2% p.a. trend from a higher base.

Figure 1: River profile plot summarising geometric mean and % change per annum: 2003-2012.

There are some strong gradients along the River with a confirmation of general increases in DOC, EC, FRP, TKN, TP, and turbidity as you travel towards the river mouth. With the exception of some of the more unusual sites Morgan has the largest values on average. NOx and Silica decrease in the same direction, though not as consistently. The individual analyses identify a clear coherence between trends observed at many of the monitoring sites, particularly amongst sites that are closer geographically, because they are often exhibiting similar peaks and troughs. While the focus in this report has been very much on changes in water quality at individual monitoring sites, this coherence indicates that the changes are occurring at a broader spatial scale.   The comparisons and multivariate analyses (cluster, PCA) confirm that there are few distinct groups of sites.

- Capels Flume stands out as having a fairly unique water quality profile. Kerang is often tracks similarly though is fairly less extreme.
- Jingellic, Tallandoon, Bandianna and Peechalba respond fairly similarly and are one group.
- The mid Murray sites of Torrumbarry, Swan Hill and possibly Kyalite, Euston Weir and Merbein act as group.
- Lock 9 and Morgan track similarly.
- Burtundy does group with Lock 9 and Morgan at times but it also comes across as unique with higher nutrients, silica, DOC and turbidity.

- Yarrawonga also differs from its adjacent sites at times (e.g. for changes in EC or DOC), and possibly reflects the influence of Lake Mulwala.
- There is also an interesting effect of Lake Hume on water quality from comparing Tallandoon and Jingellic with Heywoods Bridge. This is especially true for silica, as would be expected, but also some of the other water quality parameter.

With 35 years of water quality data the River Murray Water Quality Program provides a unique and invaluable record of changes in water quality in the Murray Darling Basin. In the context of a potential changes due to future climate and other changes driven by the Murray Darling Basin Plan, the importance of that monitoring data will persist.

Baldwin et al. (2013) through an analysis of annual load data for up to seven key constituents of water quality at 22 sites clearly showed that a reduction in the frequency of sampling from weekly to biweekly or 4-weekly will substantially affect the ability to accurately determine total annual loads at these sites – in some cases by up to 500%. Their recommendation was that if the sampling program is being reduced, the number of sites rather the frequency of sampling be reduced. The site groupings identified through the site trend comparisons and the multivariate analyses in this report may be useful if that is ever under consideration.

The trend analyses undertaken indicate that the tributaries are clearly playing an important role. Some stand out, but they often have their own unique characteristics and management needs that need to be tracked. Their contributions also impact on sites downstream of their confluence with the Murray. The analyses also identify the on-going importance of tracking above and below Lake Hume given the potential modifying effect of the dam on water quality.

1 INTRODUCTION

River Murray Water Quality Monitoring Program

The routine assessment of physico-chemical water quality in the Murray River and its major tributaries was initiated by the River Murray Commission in 1978, as part of its increased charter to take water quality into consideration in the operation of its works. It was continued by the Murray-Darling Basin Commission, and now by the Murray-Darling Basin Authority, and the data base it has generated is an extremely valuable environmental resource. To get the most out of the data collected and to ensure that its story is told, it is essential that the data is reviewed periodically and meaningful trends in the monitoring data be considered.

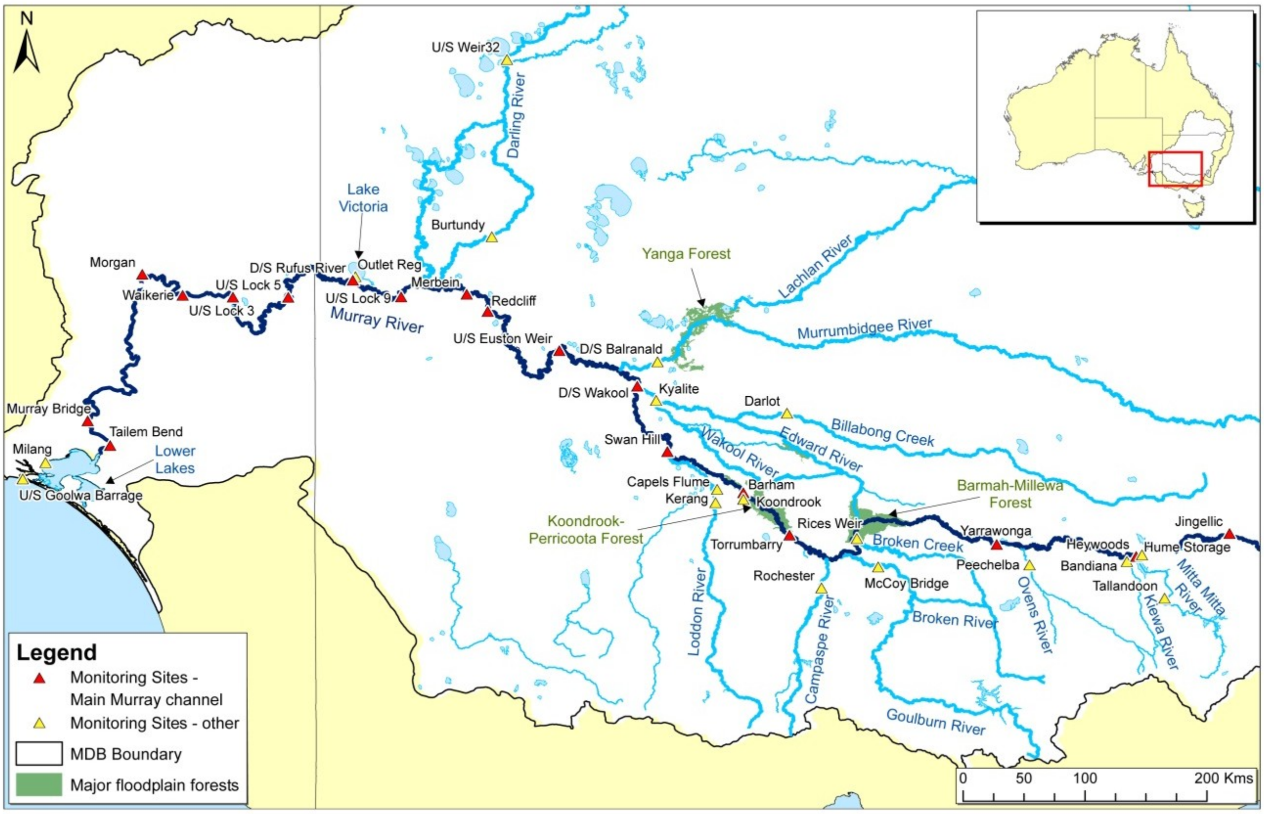

Figure 2. River Murray water quality monitoring locations. (Figure courtesy of Baldwin et al. 2013).

Water Quality Issues in the Murray River

While water quality in the Murray River is generally good, particularly with respect to industrial pollution, there are a number of water quality issues that the river has experienced in the last few decades.

Salinisation: High levels of salt can cause ecological damage in freshwater aquatic ecosystems (Nielsen et al 2003). Land clearing, irrigation and river regulation has resulted in raised saline groundwater tables which in turn has resulted in an increased salinity in the Murray River and its tributaries. In response the Murray-Darling Basin has invested substantial resources into the construction and operation of salt interception schemes. For example, in 2010/2011 financial year salt interception schemes funded by the MDBA removed about 325,000 tonnes of salt from creeks and shallow aquifers that otherwise would have reached the Murray River (MDBA, 2011).

Development of sulfidic sediments: The formation of sulfidic sediments has recently emerged as a serious environmental problem in parts of the Murray-Darling Basin (Murray Darling Basin Ministerial Council, 2011). Sulfidic sediments are sediments that contain large amounts of reduced inorganic sulfur, typically in the form of highly reactive sulfidic minerals and are often associated with salinised waterways. These develop in the absence of oxygen when certain bacteria use sulfate rather than oxygen for respiration resulting in the production of sulfide. In turn, sulfide reacts with metal ions to form metal sulfides. Sulfidic sediments, when disturbed/exposed to oxygen can cause considerable ecological damage and have the potential to significantly detract from aesthetic values and impact on human health. Left undisturbed and covered with water, these sulfidic sediments may cause relatively little harm but if disturbed or exposed to oxygen (e.g. when a water body dries), a range of biogeochemical processes can be triggered which may lead to large-scale fish kills, the death of riparian vegetation and the release of toxic heavy metals, metalloids such as arsenic and noxious odours. Acidification, deoxygenation of the water column and the mobilisation of toxic heavy metals and metalloids are the major processes of concern that can occur in response to the oxidation of sulfidic sediments.

Cyanobacterial blooms: Cyanobacteria (or blue-green algae) blooms form in warm, usually still, nutrient rich waters. Although naturally occurring, blooms along the Murray River were historically quite rare (e.g. Matveev and Matveeva, 2005). However a recent review of phytoplankton dynamics in the Murray River found that cyanobacterial numbers in the river are increasing (Croome et al, 2011). This increase in numbers was particularly evident during the drought years at the beginning of the new millennium including extensive algal blooms along large reaches of the river in 2007 (Baldwin et al, 2010) and 2009 (Al-Tebrineh et al, 2012)

Hypoxic blackwater: Blackwater refers to water high in dissolved organic carbon, often flushed into the river from the floodplain during floods. If the load of carbon is particularly high and the water temperature is high, microbial metabolism of the DOC can remove oxygen from the water column faster than it can be replenished from the air, resulting in low oxygen concentrations in the water column (hypoxia). Hypoxia can lead to the death of aquatic organisms. The drought breaking floods in 2010/2011 inundated substantial areas of Murray River floodplain, much of which hadn't been flooded in a decade. This created a plume of hypoxic blackwater that stretched along 200km of the Murray River and its tributaries and which persisted for up to 6 months (Whitworth et al, 2012)

Report objectives

The major objective for this project is to undertake a trend analysis of the physico-chemical dataset of the WQMP to provide information for enhanced management and monitoring, specifically seeking to:

- Understand the patterns of water quality trends along the river and over time;
- Understand links between water quality and other major factors such as flow and climate, including implications of the results for the management of water quality problems;
- Refine monitoring locations and frequency to assist management of the River Murray System water quality and its impacts upon river health and human uses, and
- Inform future monitoring and research directions.

Scope

Parameter Selection

The Murray–Darling Basin Authority (MDBA) has a statutory obligation to monitor and assess water quality in the Murray River, as well as in the Murray Catchment upstream of Hume and Dartmouth Dams. To meet these obligations the River Murray Water Quality Monitoring Program was established in 1978. The current program measures a suite of water quality parameters at 36 sites along the Murray River and its major tributaries. Basic water quality parameters (pH, turbidity, electrical conductivity (EC), temperature and colour) are measured at all sites on a weekly basis. A further six parameters (oxides of nitrogen (NOx), total Kjeldahl nitrogen (TKN), total phosphorus (TP), filterable reactive phosphorus (FRP), silica and dissolved organic carbon (DOC)) are measured weekly at 26 sites. At 6 sites, bicarbonate, chloride, sulfate potassium, sodium, calcium and magnesium are measured on a quarterly basis while metals (boron, cadmium, copper, chromium, iron, lead, manganese, mercury, nickel and zinc) are measured at one site on monthly basis. This report looks at long term trends for eight of these constituents: EC, turbidity, TP, FRP, TKN, silica and DOC. These parameters were chosen because there is relatively complete data set available for each of them at many sites and they are associated with key water quality issues along the Murray River, for example;

- EC is a surrogate measure of salt concentrations and is also highly correlated with chloride, sulfate, sodium, calcium, and magnesium (Baldwin et al, 2013);
- Turbidity is a surrogate measure of total suspended solids and hence gives an indication of erosion processes occurring in the catchment;
- Nutrients (TP, FRP, TKN, NOx and silica) are involved in controlling algal biomass; and
- DOC is associated with hypoxic blackwater.

In addition, flow was included as a separate parameter. A number of parameters were excluded from the current study because:

- They were highly correlated with a parameter we have included (chloride, sulfate, sodium, calcium, and magnesium are all highly correlated with EC);
- Their concentration changes markedly over very short time frames (less than a day – DO, temperature and pH);
- Their ecological significance is uncertain (colour); or
- The spatial and temporal extent of measurements was narrow (boron, cadmium, copper, chromium, iron, lead, manganese, mercury, nickel and zinc).

Table 3 summarises the past parameter selections in related trend analyses and those considered in this report.

Table 3. Water quality parameters considered in past trends analyses, and those considered in this report.

WQ parameters	Mackay et al	AWT (1999)	Henderson (2006)	Selection in this report	Comments (including data availability)
Streamflow	X	X	X	X	Morgan and Tailem Bridge in SA uses flow from Lock 1, Merbein NSW uses flow from Euston Weir or Colignan
Total Phosphorus		X		X	

Filterable Reactive Phosphorus	X			X	Prior data to 2000 less
Total Nitrogen		X			Reported as TKN
Total Kjeldahl Nitrogen (TKN)	X		X	X	
Oxidised nitrogen (NOx) (Nitrate + nitrite)	X			X	
salinity / Electrical Conductivity	X	X		X	Cond @25 degC(uS/cm)
Turbidity	X	X	X	X	"Corrected" is used
Dissolved organic carbon (soluble organic carbon)	X			X	
Silica	X	X		X	Limiting nutrient for diatoms
pH	X	X			Not considered
Colour	X	X	X		Not considered
Temperature	X				Not considered
Total dissolved solids	X				Not considered
Metals, pesticides	X				Not considered

Site Selection

Past trend analyses by Mackay et al. (1998); AWT (1999); Water Ecoscience (2002); Henderson (2006); Croome et al. (2011) and Baldwin et al. (2013), have considered different subsets of these and are summarised in Table 4. The sites considered in this report are driven by data availability and completeness, the desire to revisit sites considered in past analyses for purposes of comparison and the potential to capture changes in water quality (e.g. from the contribution of a key tributary).

Given the scope of the project it was not possible to determine constituent trends for all the sites in the Murray River Water Quality Monitoring Program. In choosing sites we took into account their geographical location and completeness of the available data sets. We also took into consideration whether or not the sites were included in other studies of water quality trends in the Murray River:

- McKay et al (1988) which looked at water quality changes in the period 1978 – 1986;
- Australian Water Technologies (1999) that analysed water quality trends along the Murray River for the period 1978 – 1997;
- Henderson (2006) examined Colour, Turbidity, TKN and flow changes over the period 1978-2005;
- Croome et al (2011) who ostensibly were concerned with changes in phytoplankton community composition (from 1980 – 2008) but also included an analysis of key water quality parameters associated with algal growth (e.g. P, TKN and silica);
- Baldwin et al (2013) which did not set out to detect trends in water quality, rather the purpose of that study was to determine if a reduction in the frequency of sampling, a reduction in the number of sites and/or a reduction in the number of constituents measured by the Murray–Darling Basin Authority under the River Murray Water Quality Monitoring Program would result in an erosion of the Authority's ability to assess trends in key water quality parameters.

There are 36 sites with monitoring data. A total of 16 sites were chosen for the current study (Table 4), 2 above Lake Hume and nine sites on the Murray River itself stretching from Heywoods Bridge immediately below Lake Hume (NSW) to Morgan in South Australia. Few additional sites were chosen from key tributaries that potentially would have substantially different water quality than that observed in the

Murray River, eg., - Wakool River at Kyalite, Loddon River at Kerang, Barr Creek at Capels Flume and the Darling River at Burtundy.

Table 4. Sites considered for trend analyses in previous analyses: Mackay et al. (1998); AWT (1999); Henderson (2006); Croome et al. (2011) and Baldwin et al. (2013), and the sites considered in this report. The tributary rivers are shaded in grey.

Site	State	Mackay et al (1988)	AWT (1999)	Henderson (2006)	Croome et al. (2011)	Baldwin et al. (2013	Data availability	Selection for these analyses
River Murray @Jingellic	VIC	X	X	X		X	Mix 1976-2012, 1981-2012	X
Lake Hume	VIC	X	X	X			Largely 1991-2005	
Mitta Mitta @Tallandoon	VIC	X	X			X	1978-2012, some missing	X
River Murray @ Heywoods	VIC	X	X	X	X	X	1978-2012, some missing	X
Kiewa River @ Bandiana	VIC	X	X	X		X	Mix 1986-2012, 1991-2012	X
Oven River @ Peechelba	VIC	X	X	X		X	Mix 1979-2012, 1981-2012, some gaps	X
River Murray @Yarrawonga	VIC	X	X	X	X	X	Flow 1977-2003 with gaps, the rest largely 1971-2013 with gaps	X
Broken Creek @ Rices Weir	VIC	X	X			X	Mix 1970s-2000, 1976-2008	
Goulburn River @ McCoy Bridge	VIC	X	X			X	1970s-2013 with gaps	
Campaspe River @ Rochester	VIC	X	X			X	Class 3 variables 1970s-2000, most others 1970s-2013 with gaps	
River Murray @ Torrumbarry	VIC	X	X	X	X	X	Mix 1976-2012, 1981-2012	X
Gunbower Creek @ Koondrook	VIC	X	X			X	Most 1970s-2013 with gaps	
River Murray @ Barham	VIC	X	X			X	Most 1970s-2013 with gaps	
Loddon River @ Kerang	VIC	X	X			X	Most 1970s-2013 with gaps	X
Barr Creek @Capels Flume	VIC	X	X		X	X	Mix 1976-2012, 1981-2012	X
River Murray @ Swan Hill	VIC	X	X	X	X	X	Mix 1976-2012, 1981-2012 with gaps	X
Wakool @ Kyalite	VIC	X	X			X	Most 1970s-2013 with gaps	
River Murray D/S Wakool	VIC	X				X		X
River Murray @ Red Cliffs	VIC	X					Most 1983-2013, HYDRO has earlier data 1978	
Billabong Creek @ Darlot	NSW	X				X	Most 1970s-2013 with gaps	
Murrumdidgee @ Balranald	NSW	X	X	X	X	X	Nothing post 2006	
River Murray U/S Euston Weir	NSW	X	X	X	X	X	EC, colour and Tem up to 2012, the rest up to 2009	X
River Murray @ Merbein	NSW	X	X	X	X		Largely 1987-2013	X
Darling River @ Burtundy	NSW	X		X	X	X	Largely 1977-2013	X

Darling River d/S Weir32	NSW	X				X	Most 1970s-2013 with gaps	
River Murray d/s Lock 9	SA	X	X	X	X	X	Most 1970s-2013 with gaps, DOC only 2005-2013	X
Lake Victoria outlet	SA	X	X				Most 1970s-2013 with gaps	
River Murray D/S Rufus River jnct	SA	X				X	Most 1970s-2013 with gaps, HYDRO has no data for this site	
River Murray d/S Lock 5	SA	X	X			X	Most 1970s-2013 with gaps especially for 2006	
River Murray d/s Lock 3	SA	X	X				Most 1970s-2013 with gaps especially for 2006, large Tem gap 1999-2005	
River Murray @ Waikerie	SA	X					Most 1970s-2013 with gaps especially for 2006	
River Murray @ Morgan	SA	X	X	X	X		Most 1970s-2013 with gaps, DOC only 2005-2013	X
River Murray @ Murray Bridge	SA	X	X				Most 1978-2013, colour from 1980, SOC from 1985	
River Murray @Tailem Bend	SA	X	X		X		Most 1970s-2013 with gaps, DOC only 2003-2013	
Lake Alexandrina @Milang	SA	X	X				Most no data 1999-2006, EC is good	
Goolwa	SA						No data 1996-2007, no class 2 data	

2 STATISTICAL METHODS

Data availability and pre-processing

Table 4 provides broad comments about the data available at a site level at the time of analysis. Subsequent follow up by others may have identified additional data and created a more complete picture at some sites but this was outside the scope of this project. The physico-chemical water quality data availability plots are presented in Appendix A. These provide a picture of data availability in a single image for the water quality parameters of interest for each site. While there is strong consistency, it is also clear that gaps and differing record lengths are an important feature of the data.

Time series plots over the full time record are presented as annual boxplots so as to summarise conditions compactly, capture the range of variability, and provide a sense of the changes that may be occurring. The data are presented on a log scale. Note that a constant of 1 is added to the flow measurements. The geometric mean for the full time record is included to provide a reference point for each annual distribution. The geometric mean is used throughout this report because it is less sensitive to outliers than the arithmetic mean. The geometric mean for data $x_1, \ldots, x_n$ is equivalent to the exponential of the mean on the log scale.

River profile plots for the time periods 1978-2012 and 2003-2012 are used to plot the geometric mean for each water quality variate and visualise the difference along the river and its tributaries in Appendix C. The strong differences along the river gradient and the importance of contributing rivers are evident.

The monitoring data was reduced to monthly means prior to analysis for trends in water quality. While this reduction represents some loss of information, the effect on trend estimation is negligible given the time scale over which trends are of interest. The use of monthly means also results in a time series that is more regular, readily amenable to analysis and less affected by the strong correlation between observations that are close together in time. This is consistent with previous analyses (Henderson 2006; AWT 1999).

Statistical trend analyses methodology

The primary vehicle for assessing changes or trends in key physico-chemical water quality variables is the generalized additive modelling (GAM) framework (Hastie and Tibshirani 1990; Wood 2006) and applied to water quality by Morton & Henderson (2008), Henderson & Morton (2008), Henderson et al. (2010). This approach uses a flexible regression framework that captures both linear and non-linear components of the trend, can incorporate seasonality and adjustments for other covariates such as flow, handles autocorrelation and non-Normal data, and is fairly robust to outliers. Water quality variables are analysed on the log-scale given positive skewness, covariate effects are often found to be additive on the log-scale, the variance is more constant and the linear trend translates naturally to a percentage change per annum.

The generalized additive modelling approach is widely recognised as a standard for water quality trend analysis. It is noted that analogous approaches have been used in many of the previous reviews in the Murray-Darling Basin provided, e.g. Croome et al. (2011), Henderson (2006), and Water Ecoscience (2002) review, and some other related trend analyses in Australia, including Nathan et al. (1999) and Jolly et al. (2001) and Henderson & Kuhnert (2005). Using a similar approach will ensure some consistency with past results.

Trend analyses using the GAM approach described are be considered with and without flow adjustment to assess how any changes in water quality observed relate to changes in flow or for other reasons. Trend analyses are considered for the full 1978-2012 period and the last 10 years (2003 to current).

The methods focus on individual site and water quality variables and the analysis of trends over time. The trend analyses in this report are primarily summarised as the estimated linear component of the trend (and its standard error) and are expressed as percentage per annum. It is the most important feature to tabulate as it indicates whether there has been an overall increase or decrease in the water quality over the period. It is not necessarily the only feature of interest. For any site where the P-value for the non-linear component of the trend is significantly small (say p-value < 0.01), the linear trend is an insufficient summary of the nature of the trend, and the supporting graphs for that site should be consulted. Note that, although the non-linear component is significant, it does not mean that the estimate of the linear trend is invalid; it means that other features could be as important too. The trend should be interpreted in conjunction with the mean value; a percent p.a. trend has a different impact according to whether the base level is low or high. That is, a 2% p.a. trend starting from a very low level may be of less concern than a 2% p.a. trend from a higher base.

River profile plots are used to present changes along the river. Trend analyses are also compared and contrasted across the range of water quality variables and sites using multivariate analysis methods.

Appendix D provides a more detailed account of the generalized additive model trend analysis approach.

The statistical code used to perform these trend analyses is written in the *R* statistical language (http://www.r-project.org/ ; Ihaka & Gentleman 1996).

Interpretation of trends

Summaries of trends and regression coefficients are obtained from the model with autocorrelated errors. In many sites, log-flow has a strong seasonal component. Since all terms are fitted simultaneously, the parameters represent the effects on the response (*y*) after allowing for all other terms in the model. Thus, the flow effect estimates changes in the response not attributable to time trends or to season. The parameters β_1 and β_2 represent the component of the seasonal effect not attributable to flow. This is not the net seasonal effect when the flow effects are added in, but it is put that the seasonal effect eliminating the component attributable to flow is more relevant here, and thus what is given.

The trend analyses in this report are primarily summarised estimated linear component of the trend (and its standard error) expressed as percentage per annum. It is the most important feature to tabulate as it indicates whether there has been an overall increase or decrease in the water quality over the period. It is not necessarily the only feature of interest. For any site where the P-value for the non-linear component of the trend is significantly small (say p-value < 0.01), the linear trend is an insufficient summary of the nature of the trend, and the supporting graphs for that site should be consulted. Note that, although the non-linear component is significant, it does not mean that the estimate of the linear trend is invalid; it means that other features could be as important too. The trend should be interpreted in conjunction with the mean value; a percent p.a. trend has a different impact according to whether the base level is low or high. That is, a 2% p.a. trend starting from a very low level may be of less concern than a 2% p.a. trend from a higher base.

The linear trend unadjusted for flow represents the change in quality to the user and may be important in enabling us to see how much the flow adjustment has changed the trend, particularly at those sites where there has been large change in flow over the period. For any sites where the adjustment has been obtained from a relationship to flow that could be considered unusual, a comparison with the raw trend should also be considered.

Seasonal effects are summarised in this report by the amplitude (on the log-scale) and phase as described in Appendix E to M The relationship between log flow and the water quality variates are simply presented in summary tables in these appendices by the sign of the relationship and a measure of statistical significance. In most case flow was found to have a strong positive effect. This can be evidenced from plots of the water quality variates against log flow that are provided in Appendices E through M.

A large number of potential significance tests are under of interest in this report. It follows that statistical significance at a nominal 0.05 level would have been achieved by chance in several cases. One may wish to protect against such false positives. If the significance is not at least $P < 0.01$ (t-statistic exceeds ±2.6), one should look for other features to support the tentative conclusion, such as agreement between sites. Quite simply, a combination of weakly significant results that are all pointing in the same direction yield a stronger conclusion. The strength of evidence required to determine whether an estimate is significantly non-zero depends on the relative seriousness of a false positive or a false negative conclusion, and this must be left to the user to judge.

The use of a spline smoother to estimate a trend is effective when the underlying trend is indeed smooth. It fails to pick up rapid changes in slope, and always underestimates the peak of a local maximum or the trough of a local minimum. At an extreme of the period, the spline takes time to respond and produces a sloping rise to meet the data. It would not be sensible to predict the future by extending a spline curve that has recently changed direction. Indeed, the degree of non-linearity of the curves illustrates that it is unreliable to predict the future without some hydrological insight as to why the peaks and troughs have occurred.

3 WATER QUALITY TREND ANALYSES

Streamflow

Trends in flow were examined for 16 sites in the Murray-Darling Basin for the period 1978-2012. The GAM trend model used is identical to that described for each water quality variable and in more detail Appendix D, though the term for covariate $s(x;df_x)$ was dropped.

Table 5 lists the monitoring sites considered and their estimated linear trends (in % p.a.). The trends for 2003-2012 are provided for comparison as they give a stronger representation of recent conditions and possible trajectories. Each trend is supplemented by an indication of the statistical significance of the linear trend and the non-linearity. It is recommended that the higher level of significance (i.e. 0.01) be used given the large number of significance tests and the need to protect against getting significance by chance alone.

Table 5. Flow: Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	5835.7558	-0.534		NL	3.416		NL
Tallandoon	1511.0522	0.363		NL	-6.351		NL
Heywoods	5400.9369	-0.444		NL	4.449		NL
Bandiana	996.2909	0.02			**10.009**	**	NL
Peechelba	1508.4015	-0.87			13.484	*	NL
Yarrawonga	9455.7220	-0.674		NL	3.924		NL
Torrumbarry	6772.0896	-0.541		NL	**8.228**	**	NL
Kerang	203.5751	**-4.752**	**	NL	0.386		NL
Capels Flume	67.5855	**-4.681**	**	NL	10.015	*	NL
Swan Hill	6204.9598	-0.549		NL	**7.825**	**	NL
Kyalite	2227.1253	-0.784		NL	9.087	*	NL
Euston Weir	9241.2578	-1.03		NL	**10.347**	**	NL
Merbein	9013.1076	-1.113		NL	**10.109**	**	NL
Burtundy	610.7838	-3.287		NL	**69.171**	**	NL
Lock 9	5327.2240	-2.005		NL	**22.875**	**	NL
Morgan	6802.4485	-1.448		NL	**20.204**	**	NL

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

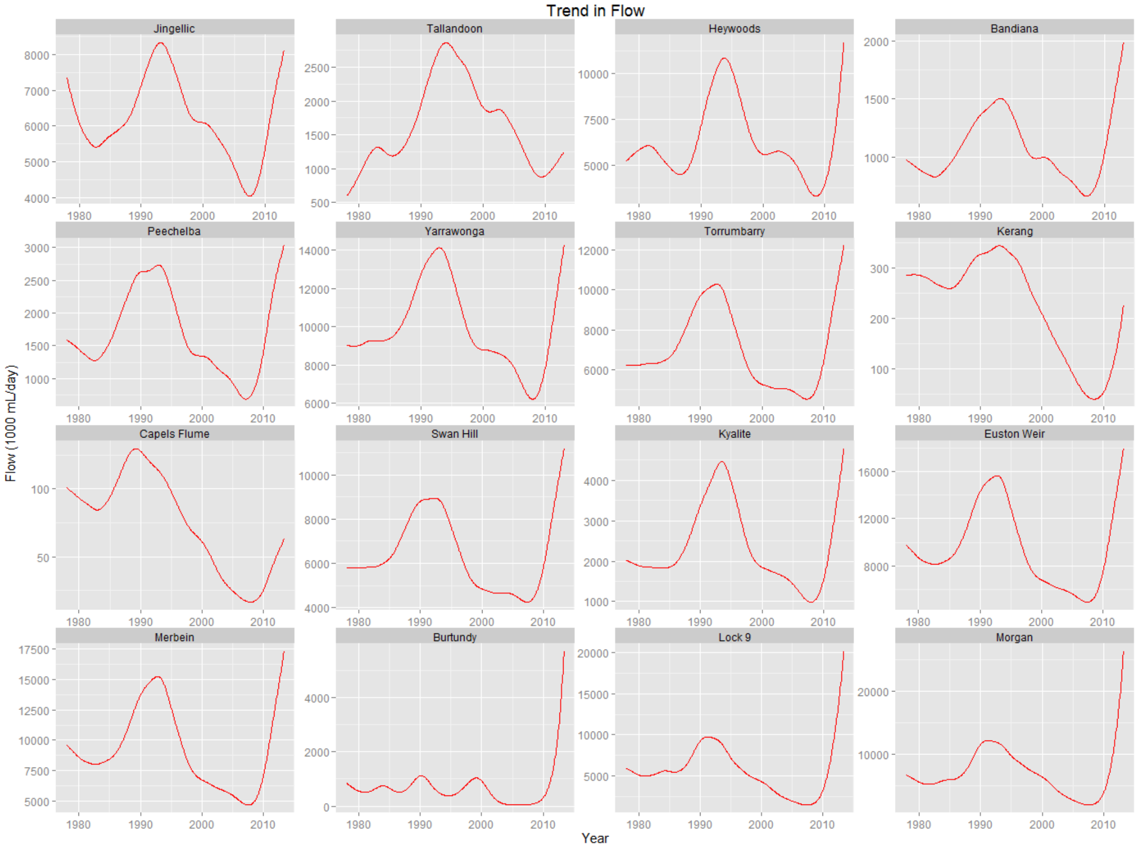

Figure 3. Trend in Flow (ML/day) 1978-2012.

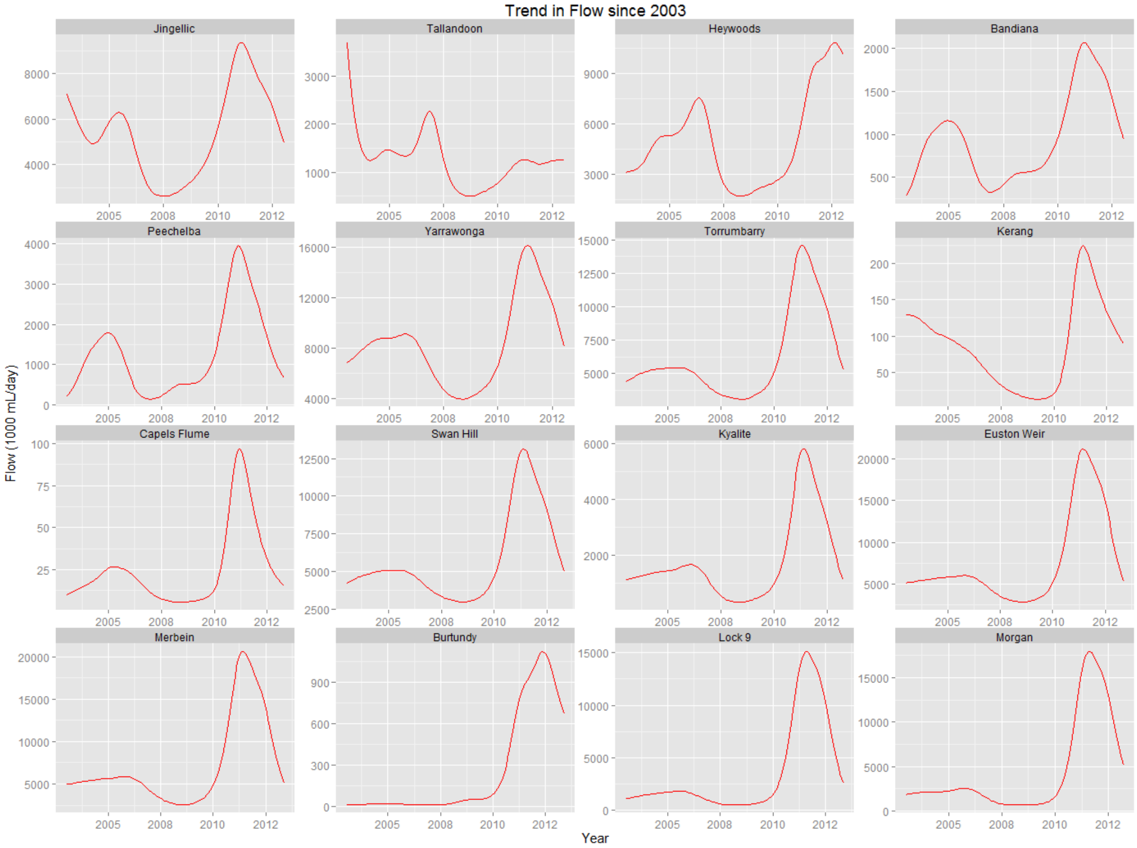

Figure 4. Trend in Flow (ML/day) 2003-2012.

Figure 3 plots the trends in the geometric mean of the daily flow for the 16 sites of interest. These trends are determined by taking the estimated smooth trend as a % change per annum from the flow trend analyses and using this to adjust the geometric mean. It is important to remember that the geometric mean will be less than the arithmetic mean, because it is less affected by extreme values, and that under positively skewed log-Normal data it will be close to the median. The most important feature to take from Figure 3 are the shapes of these trend curves. Changing from the geometric mean to the arithmetic mean will alter the level but not the shape. Note that each panel is allowed a different vertical axis to cope with the different flow magnitudes and make for easier comparison.

Figure 4 is a similar plot but for the most recent decade. The shorter time allows a greater identification of short range features, most notably the large increases stemming from the 2010/11 floods and the subsequent return to drier conditions. This return is not as evident over the longer time frame as smoothness of the curves is constrained to identify the most important features over the entire time frame.

There is strong non-linearity in the trend curves in Figure 3, Figure 4 and indicated through Table 5. This indicates that the linear trend must be treated cautiously as a summary measure because other non-linear effects are also present. There is considerable consistency in the flow trends with the floods in the 1990s carrying strongly through all the Murray sites but dampening further down the river. The increase observable in the upper sites around 2006-2007 appears to coincide with the changes to irrigation diversion limits. The subsequent reduction in flow through the mid to late 2000’s is consistent. The major rains in 2010/11 drive the strong increases in flow post 2010, though the delay at Heywoods from retention in Lake Hume is clear. By in large the patterns for the tributaries and those sites on the Murray are very similar reflecting a response to the same broad drivers (Figure 5).

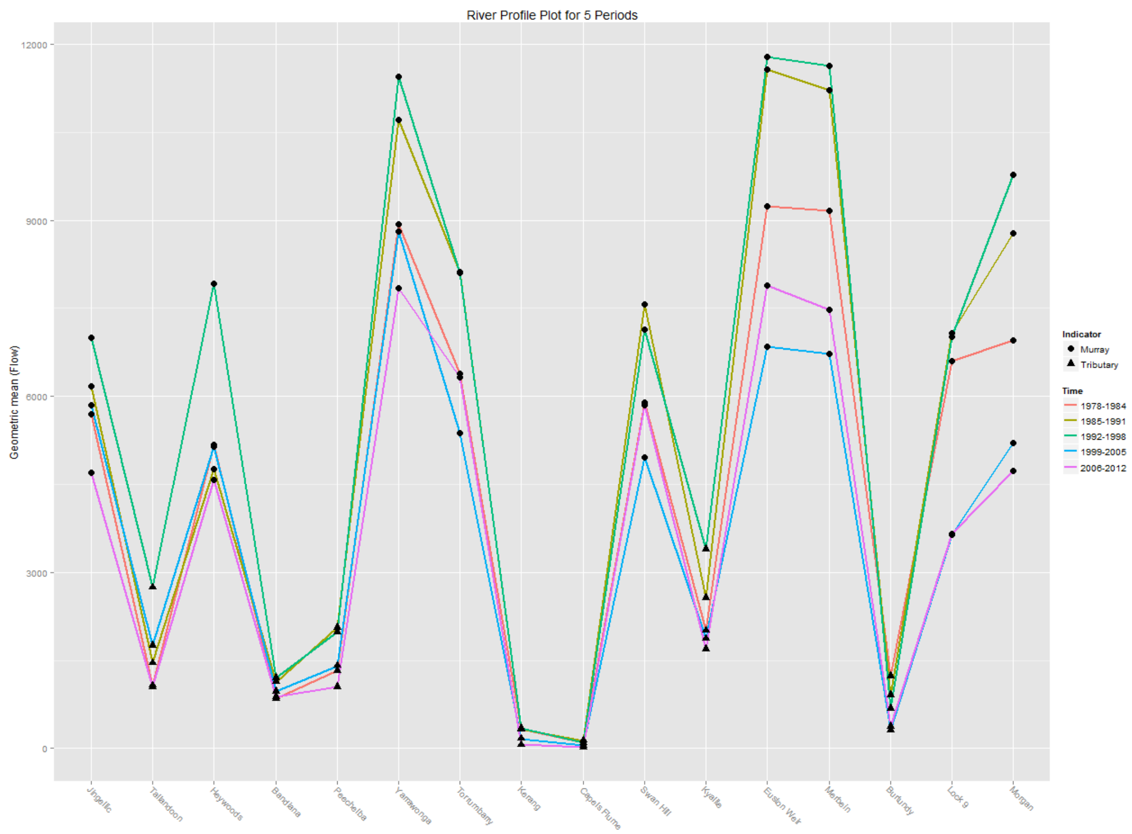

Figure 5. River profile plot of geometric mean for flow (ML/day) grouped by 6 yearly time periods

Total Phosphorus

Total phosphorus includes all forms of phosphorus, including phosphorus attached to particulate material and filterable reactive phosphorus. It is considered a fairly conservative parameter and is ecologically important, particularly for plant growth. In excess it can drive algal growth.

Total phosphorus is available weekly. Table 6 presents a summary of the trend for total phosphorous at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum total phosphorous over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012.

Figure 7 presents a graphical summary of the trends in total phosphorus across all sites of interest. These trends are derived from multiplying the geometric mean by the estimated smooth trend in terms of percentage change per annum. These trends thus represent the change in the geometric mean. This is used as it is less affected by extreme values. It is less than the arithmetic mean and can be interpreted as being close to the median value.

Additional plots and tables from the site specific analyses are provided in Appendix F. These are useful if there is a need to interrogate any of the summary trends in more detail as there is a greater representation of the observed data, the relationship between total phosphorus and flow, seasonal effects, and the data characteristics including outliers and autocorrelation.

Table 6. Total Phosphorus (mg/L): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (mg/L)	Min	Max	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	0.0223	0.005	0.92	0.16		NL	**4.28**	**	
Tallandoon	0.0172	0.005	0.24	**-0.66**	**	NL	**3.98**	**	nl
Heywoods	0.0231	0.002	0.15	0.02		NL	1.87		
Bandiana	0.0275	0.005	0.58	0.33		nl	**2.64**	**	
Peechelba	0.0404	0.005	1.84	**-1.30**	**	NL	0.70		NL
Yarrawonga	0.0374	0.000	6.00	**-1.48**	**	NL	1.56		NL
Torrumbarry	0.0547	0.005	0.84	**-1.32**	**	NL	-0.07		NL
Kerang	0.0919	0.005	0.98	**1.24**	**	NL	**9.48**	**	nl
Capels Flume	0.4799	0.016	3.60	**3.30**	**	NL	**-16.51**	**	NL
Swan Hill	0.0633	0.005	0.68	**-0.95**	**	NL	0.20		NL
Kyalite	0.0661	0.005	2.00	-0.77	*	NL	4.17	*	NL
Euston Weir	0.0548	0.000	0.76	**-2.27**	**	NL	-1.78		
Merbein	0.0542	0.000	9.00	**-1.65**	**	NL	-1.13		NL
Burtundy	0.2130	0.000	9.00	**-1.42**	**	NL	0.29		NL
Lock 9	0.0916	0.000	0.77	**-1.27**	**	NL	**6.94**	**	nl
Morgan	0.1083	0.000	1.50	**-1.03**	**	NL	**6.63**	**	NL

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

There is considerable non-linearity in the shape of these trend curves in Figure 7 and Figure 8. As such the estimated linear trend % per annum may depend greatly on the interval of time over which it is calculated. This is highlighted in the difference between the trends over the 1978-2012 and 2003-2012 time periods.

Note that it is difficult to visualise the trends for 2003-2012 by simply truncating the plots in Figure 7 to a reduced the range. The curve is refitted and all covariate effects, including seasonality, and flow effects based on the shorter sequence of data. The variability in the shape of the site trends is also evident. The increase in response to the recent 2010/11 wet years is not uniform across all sites, though note the shorter record for Euston. The mid Murray and lower Murray all have maxima about 2000. In the southern MDB. Burtundy on the Darling River, Lock 9 and Morgan are all showing a similar response. From Figure 6 total phosphorus shows broad increases from Jingellic to Morgan. Capels Flume continues to have much higher total phosphorus. Burtundy is also higher but has been reducing over time.

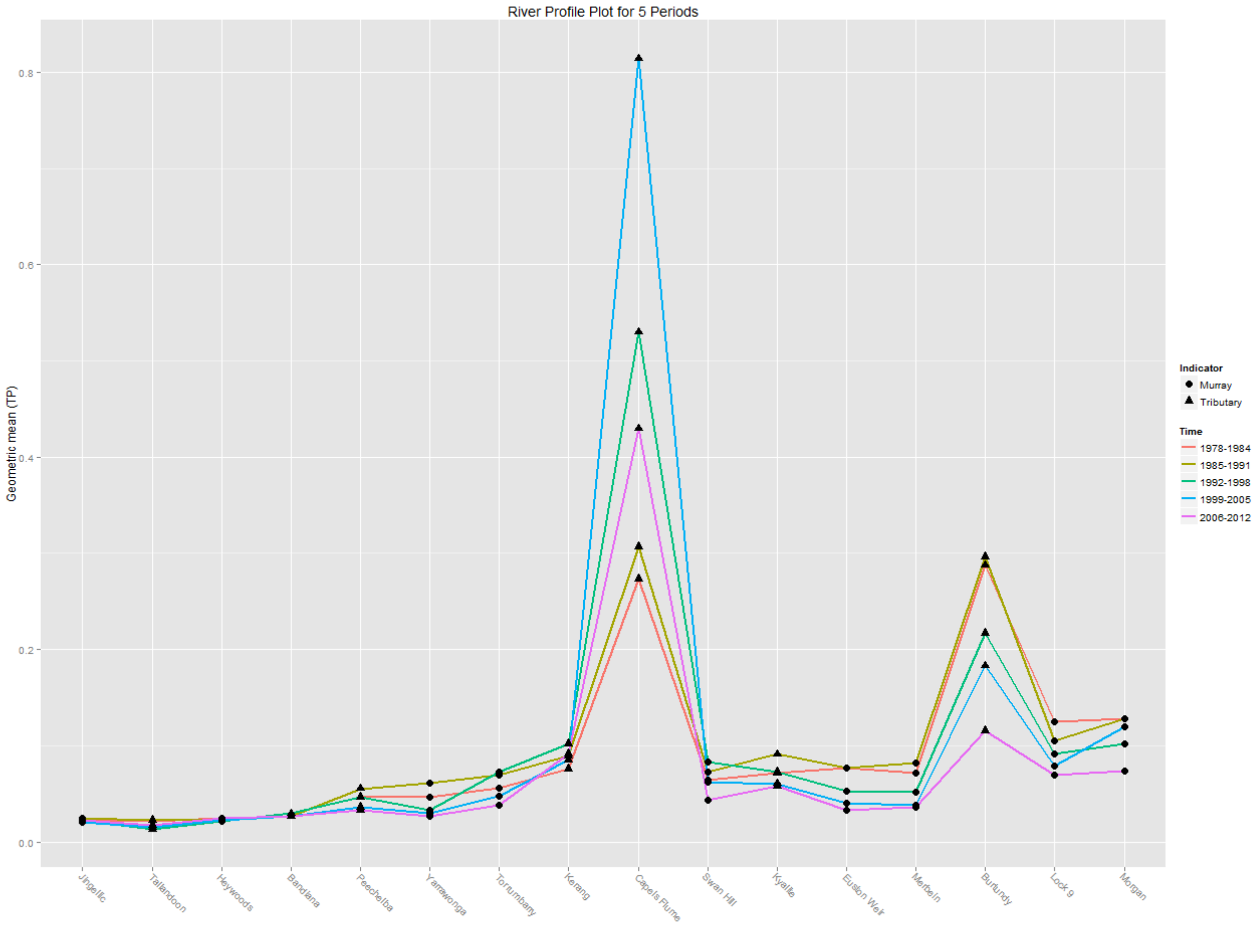

Figure 6. River profile plot of geometric mean for total phosphorus (mg/L) grouped by 6 yearly time periods.

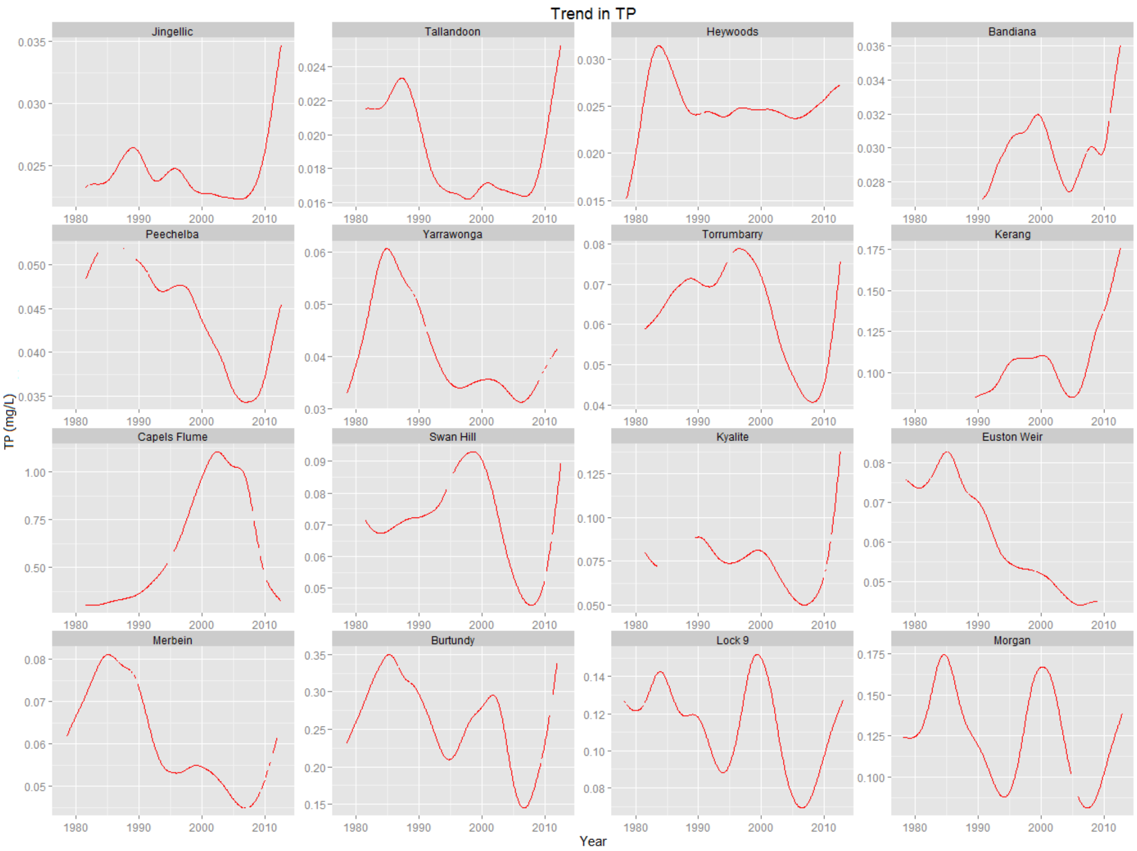

Figure 7. Trend in Total Phosphorus (mg/L) 1978-2012.

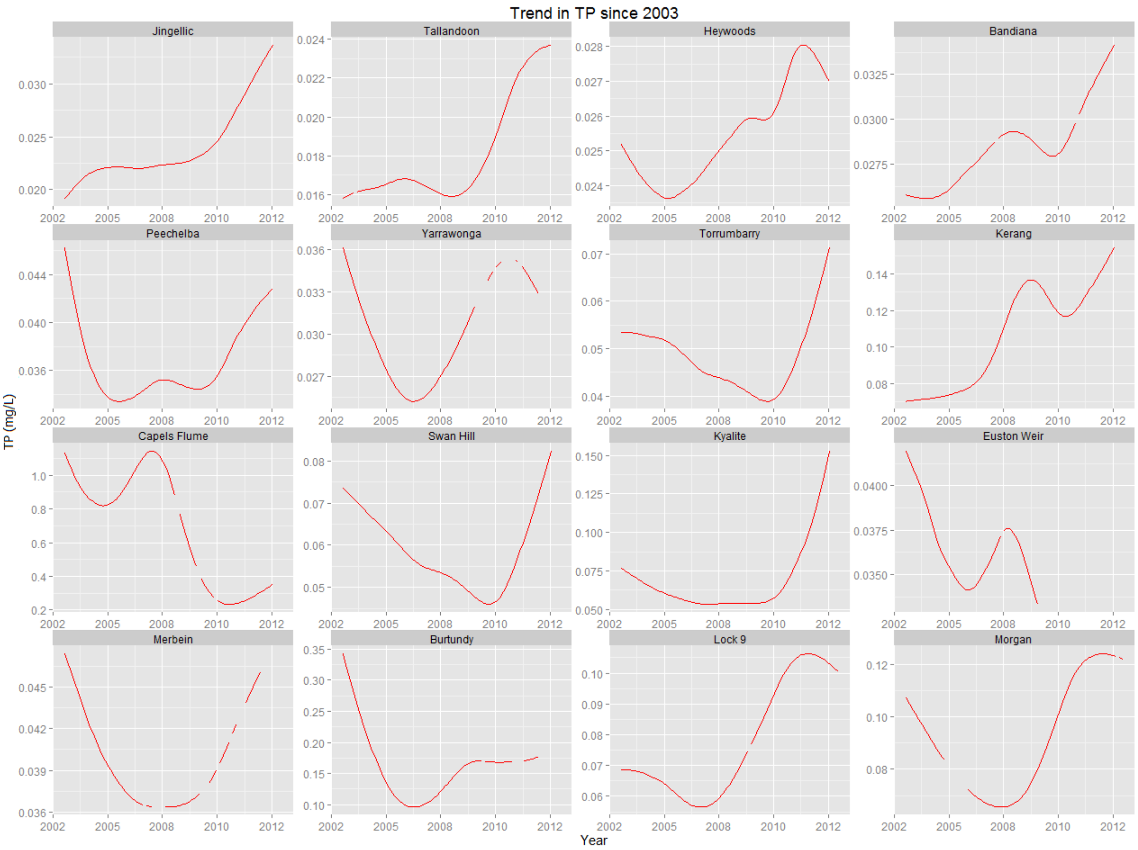

Figure 8. Trend in Total Phosphorus (mg/L) 2003-2012.

Filterable Reactive Phosphorus

Filterable reactive phosphorus (FRP) or soluble reactive phosphorus is the dissolved component of total phosphorus and is important because it is in a form that is readily available to plants, algae and bacteria. FRP is measured weekly at most sites. Table 7 presents a summary of the trend for filterable (soluble) reactive phosphorus at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum FRP over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012.

Figure 9 and Figure 10 present graphical summaries of FRP across all sites of interest for the periods 1978-2012 and 2003-2012 respectively, and confirms why the non-linearity in the tables is important. Additional plots and tables from the site specific analyses are provided in Appendix G.

The upper sites of Jingellic, Tallandoon, Heywoods, Bandiana, and Peechalba all exhibit a similar peak in the late 1980's followed by steady decline until an upsurge in 2010. The decline may be a function of the efforts to decrease nutrients entering river following the 1992 algal bloom on the Darling. The strong upsurge in 2010 is a response to the flooding and overbank flow in 2010/11. Sites in the middle part of the Murray do not show the same FRP response to the flooding with steady decrease through the last decade (Swan Hill, Torrumbarry, and Capels). FRP at Lock 9 and Morgan appear to track similarly. From Figure 11 FRP generally increases as move towards the river mouth. The levels are markedly higher on Barr Creek at Capel's Flume, Burtundy is higher but has been reducing over time.

Table 7. FRP (mg/L): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (mg/L)	Min	Max	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	0.0064	0.001	0.230	**-1.05**	**	NL	**1.28**	**	NL
Tallandoon	0.0058	0.001	0.210	**-1.50**	**	NL	0.23		
Heywoods	0.0047	0.001	0.280	**-1.30**	**	NL	-0.26		NL
Bandiana	0.0053	0.001	0.100	-0.05		NL	**1.87**	**	
Peechelba	0.0078	0.001	0.230	**-2.00**	**	NL	0.77		
Yarrawonga	0.0102	0.000	1.000	**-0.56**	**	NL	**3.01**	**	
Torrumbarry	0.0074	0.001	0.180	**-1.13**	**	NL	-1.17		
Kerang	0.0072	0.001	0.350	0.32		NL	**2.29**	**	
Capels Flume	0.1825	0.001	2.700	**2.27**	**	NL	**-32.25**	**	NL
Swan Hill	0.0086	0.001	0.460	**-0.85**	**	NL	**-3.38**	**	
Kyalite	0.0064	0.001	0.150	-0.32	*	NL	-0.21		
Euston Weir	0.0134	0.001	0.190	**-0.88**	**	NL	1.05		NL
Merbein	0.0113	0.000	3.000	**-0.90**	**	NL	**4.09**	**	NL
Burtundy	0.0704	0.000	6.000	**-3.83**	**	NL	5.45		nl
Lock 9	0.0202	0.000	0.282	-1.26	*	NL	**9.60**	**	
Morgan	0.0180	0.000	0.257	-1.02		NL	**9.02**	**	

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

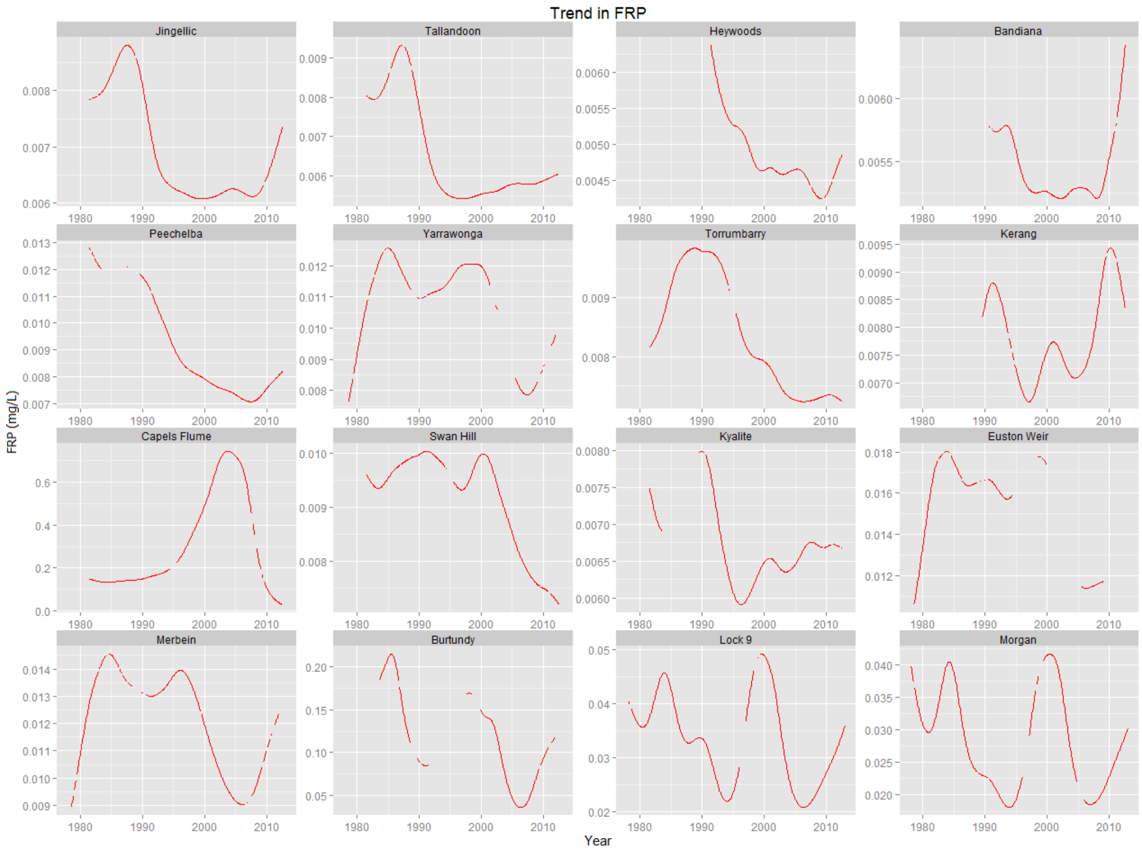

Figure 9. Trend in FRP (mg/L) 1978-2012.

Figure 10. Trend in FRP (mg/L) 2003-2012.

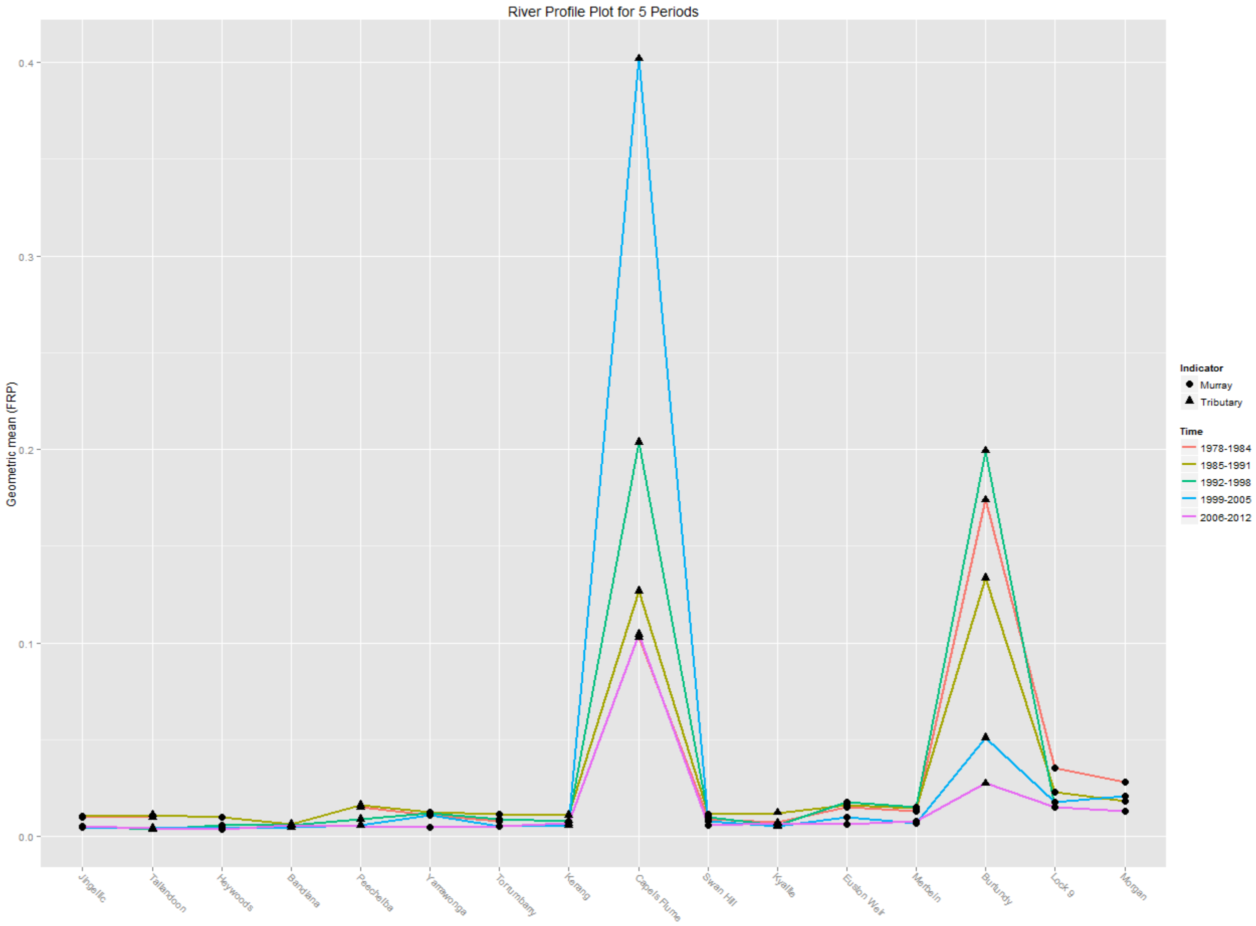

Figure 11. River profile plot of geometric mean for filterable reactive phosphorus (mg/L) grouped by 6 yearly time periods.

Total Kjeldahl Nitrogen (TKN)

Nitrogen is not a conservative element, and may be transformed between ionic and gaseous forms, primarily through the action of microorganisms. Nitrogen is represented in the River Murray Water Quality Program as dissolved inorganic nitrogen (NOx; nitrate+nitrite) and Kjeldahl nitrogen (TKN) which represents the total organic nitrogen.

TKN is available weekly. Table 8 presents a summary of the trend for Total Kjeldahl Nitrogen at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum TKN over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012.

Figure 12 and Figure 13 present graphical summaries of TKN across all sites of interest for the periods 1978-2012 and 2003-2012 respectively. Additional plots and tables from the site specific analyses are provided in Appendix H.

Jingellic and Tallandoon are tracking similarly. Torrumbarry, Yarrawonga, Swan Hill, Kyalite, and Euston all show the pattern of the a consistent decline through the 1980's to the mid 1990's, a subsequent hump around 2000, and then spike in 2010 in response to the floods. The levels of TKN are markedly higher on Barr Creek at Capel's Flume, and show consistent increase with the distance along the River Murray (Figure 14).

Table 8. TKN (mg/L): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (mg/L)	Min	Max	1978-2003 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	0.2148	0.01	2.40	-0.16		NL	1.07		
Tallandoon	0.1983	0.01	2.50	**-0.84**	**	NL	**1.93**	**	
Heywoods	0.2811	0.01	2.81	**1.02**	**	NL	2.12		
Bandiana	0.2131	0.01	1.60	0.27			-0.19		
Peechelba	0.2776	0.03	1.90	**-0.82**	**		-1.30		nl
Yarrawonga	0.3810	0.00	9.00	**-1.46**	**	NL	-1.38		NL
Torrumbarry	0.4823	0.10	2.20	**-0.81**	**	NL	0.18		NL
Kerang	0.7371	0.11	4.30	0.86	*	nl	**8.70**	**	
Capels Flume	1.7131	0.19	8.80	**2.17**	**	NL	4.37		NL
Swan Hill	0.5294	0.06	6.50	**-0.83**	**	NL	1.44		NL
Kyalite	0.5657	0.01	3.80	**-0.87**	**	NL	**3.82**	**	NL
Euston Weir	0.4639	0.05	2.20	-0.40		NL	**11.27**	**	NL
Merbein	0.4612	0.00	9.00	**-1.11**	**	NL	-2.37		nl
Burtundy	0.8833	0.00	23.00	0.29		NL	-3.17		NL
Lock 9	0.6230	0.00	3.94	-0.35	*	NL	4.23	*	NL
Morgan	0.7267	0.00	2.37	**-0.85**	**	NL	**3.50**	**	NL

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

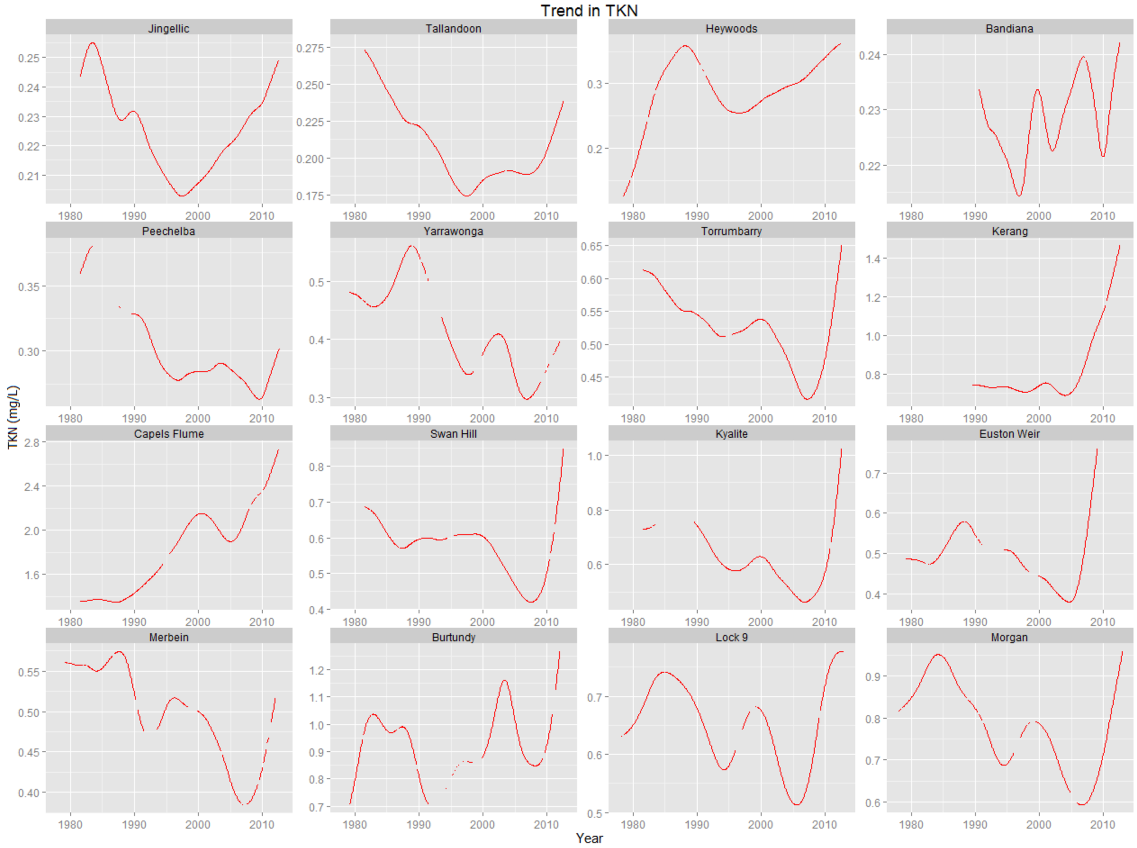

Figure 12. Trend in TKN (mg/L) 1978-2012.

Figure 13. Trend in TKN (mg/L) 2003-2012.

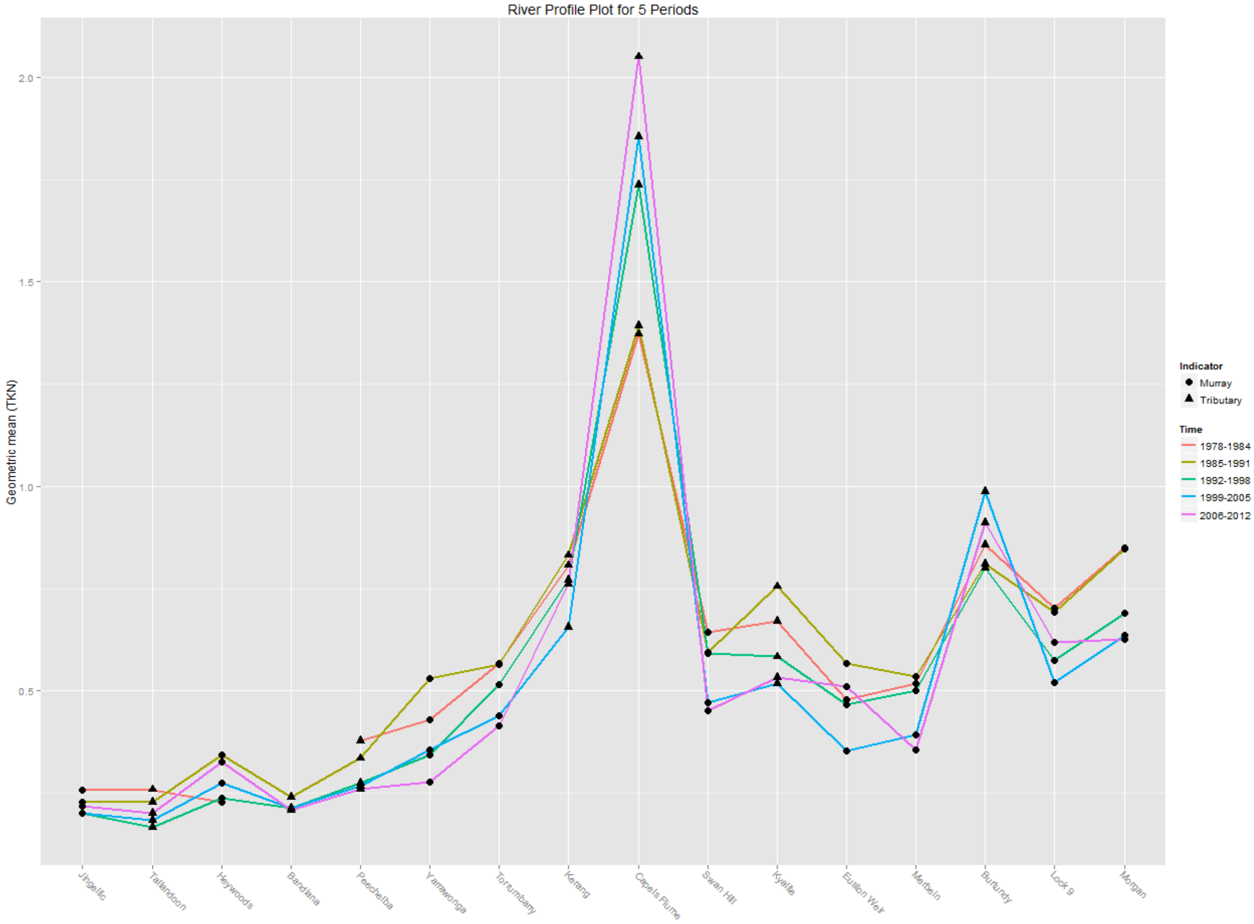

Figure 14. River profile plot of geometric mean for total Kjeldahl nitrogen (mg/L) grouped by 6 yearly time periods.

Oxides of nitrogen (NOx)

The oxides of nitrogen (NOx) consist of nitrate and nitrite and represent the dissolved inorganic nitrogen. Table 9 presents a summary of the trend for NOx at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum total NOx over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012.

Oxidised nitrogen is available weekly. Figure 15 and Figure 16 present a graphical summary of NOx across all sites of interest for the periods 1978-2012 and 2003-2012 respectively. Additional plots and tables from the site specific analyses are provided in Appendix I.

There is less consistency in the trends in NOx in the upper Murray sites than for some of the other parameters, though there is a fairly consistent peak in the early 1990s across many sites (Tallandoon, Peechelba, Yarrawonga, Euston, Merbein). The response to the floods of 2010/11 is inconsistent with increases at Jingellic, Tallandoon, Heywoods, Merbein and Burtundy but fairly steady decreases elsewhere. Merbein and Euston are tracking similarly over the period, as are Lock 9 and Morgan. Figure 17 emphasizes the higher NOx values in the upper Murray and tributaries and the decreases in the middle and lower Murray sites that have occurred since the 1990s.

Table 9. NOx (mg/L): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (mg/L)	Min	Max	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	0.0435	0.003	0.77	**2.57**	**	NL	0.33		NL
Tallandoon	0.0972	0.003	1.10	0.47		nl	-1.63		nl
Heywoods	0.0577	0.002	0.71	-1.74			3.06		nl
Bandiana	0.0893	0.002	1.20	**1.91**	**	NL	**-8.51**	**	nl
Peechelba	0.1055	0.003	1.00	-0.59		nl	**-6.13**	**	NL
Yarrawonga	0.0344	0.003	2.56	**-1.84**	**	NL	-6.62		nl
Torrumbarry	0.0266	0.002	1.00	-0.42			-6.87	*	
Kerang	0.0166	0.002	0.60	**2.06**	**	NL	-3.79		NL
Capels Flume	0.0305	0.002	1.34	**3.81**	**	NL	6.92		NL
Swan Hill	0.0216	0.002	0.79	-0.40		NL	**-9.94**	**	
Kyalite	0.0106	0.002	0.57	-0.30		NL	**-4.76**	**	
Euston Weir	0.0276	0.005	1.75	**-2.96**	**	NL	2.50		nl
Merbein	0.0261	0.003	0.92	**-3.25**	**	NL	1.57		nl
Burtundy	0.0469	0.002	1.13	0.66		NL	7.86	*	NL
Lock 9	0.0303	0.000	3.00	**-2.33**	**	NL	7.03		NL
Morgan	0.0223	0.000	0.72	**-2.29**	**	NL	**11.50**	**	NL

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

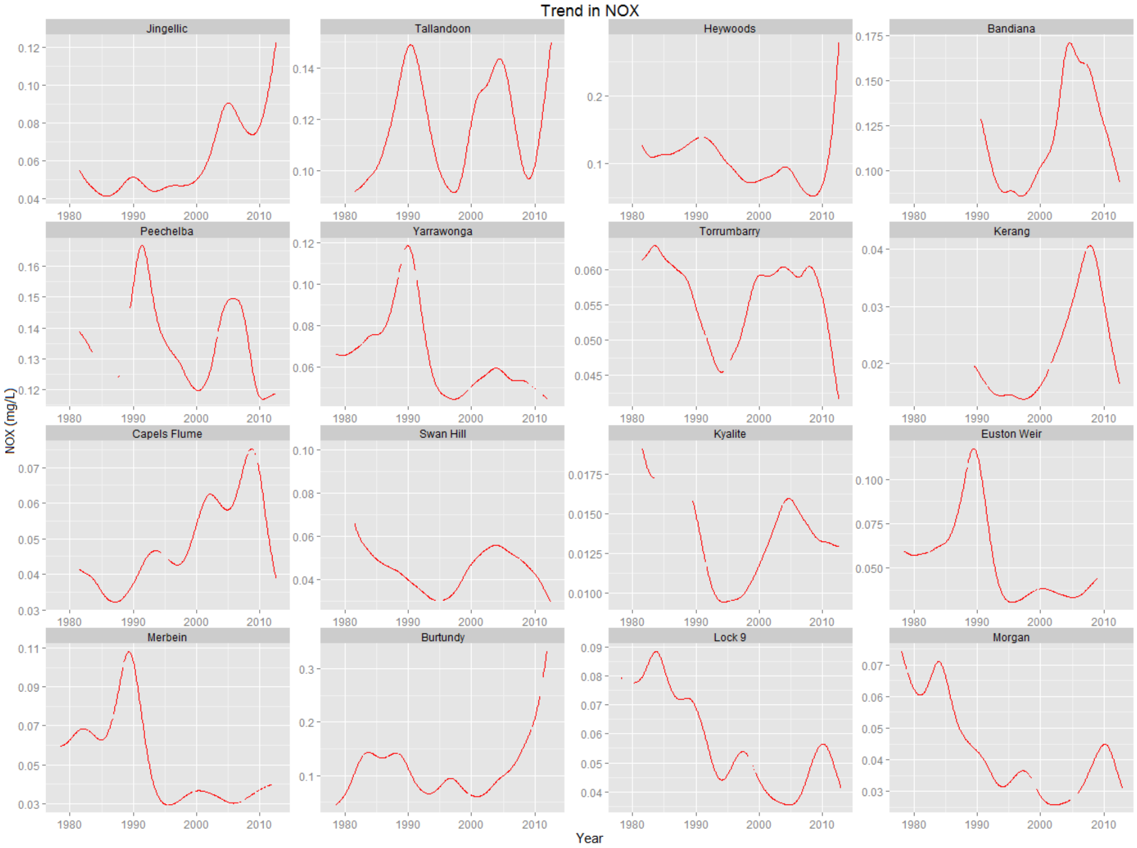

Figure 15. Trend in oxides of nitrogen (NOx) (mg/L) 1978-2012.

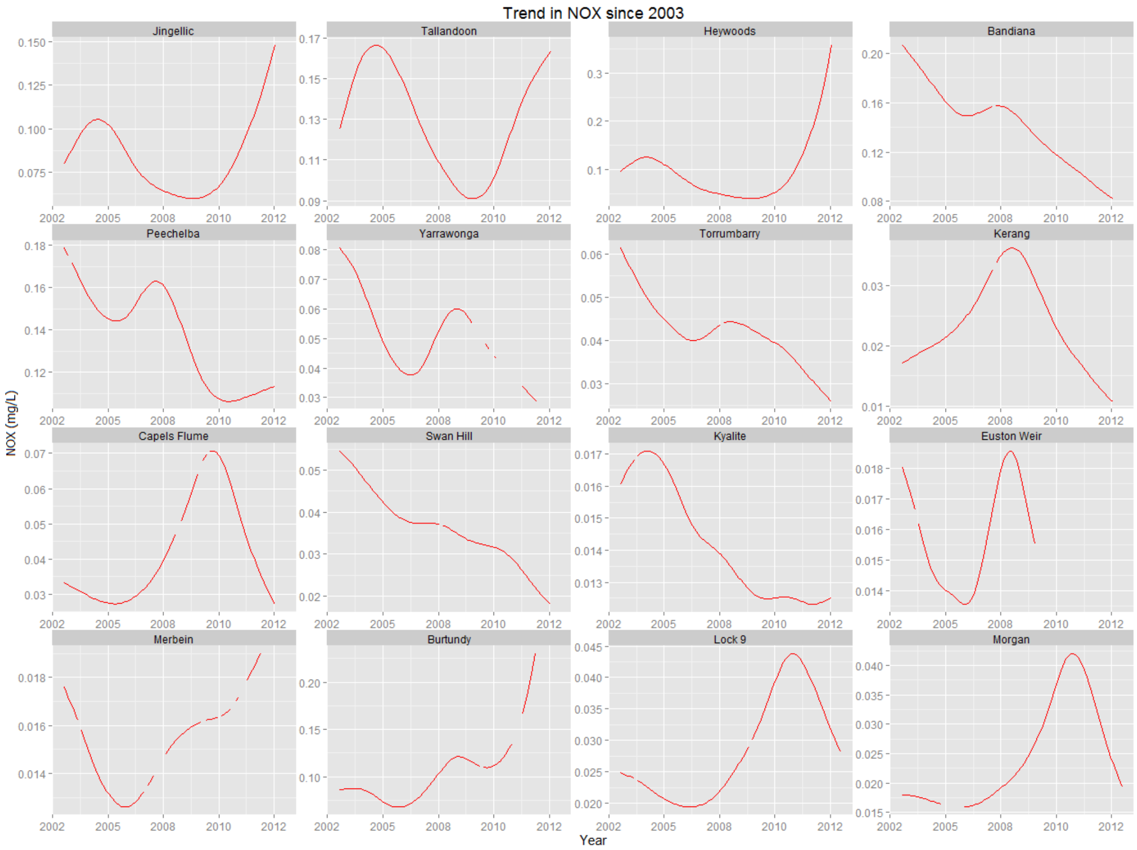

Figure 16. Trend in Oxides of nitrogen (NOx) (mg/L) 2003-2012.

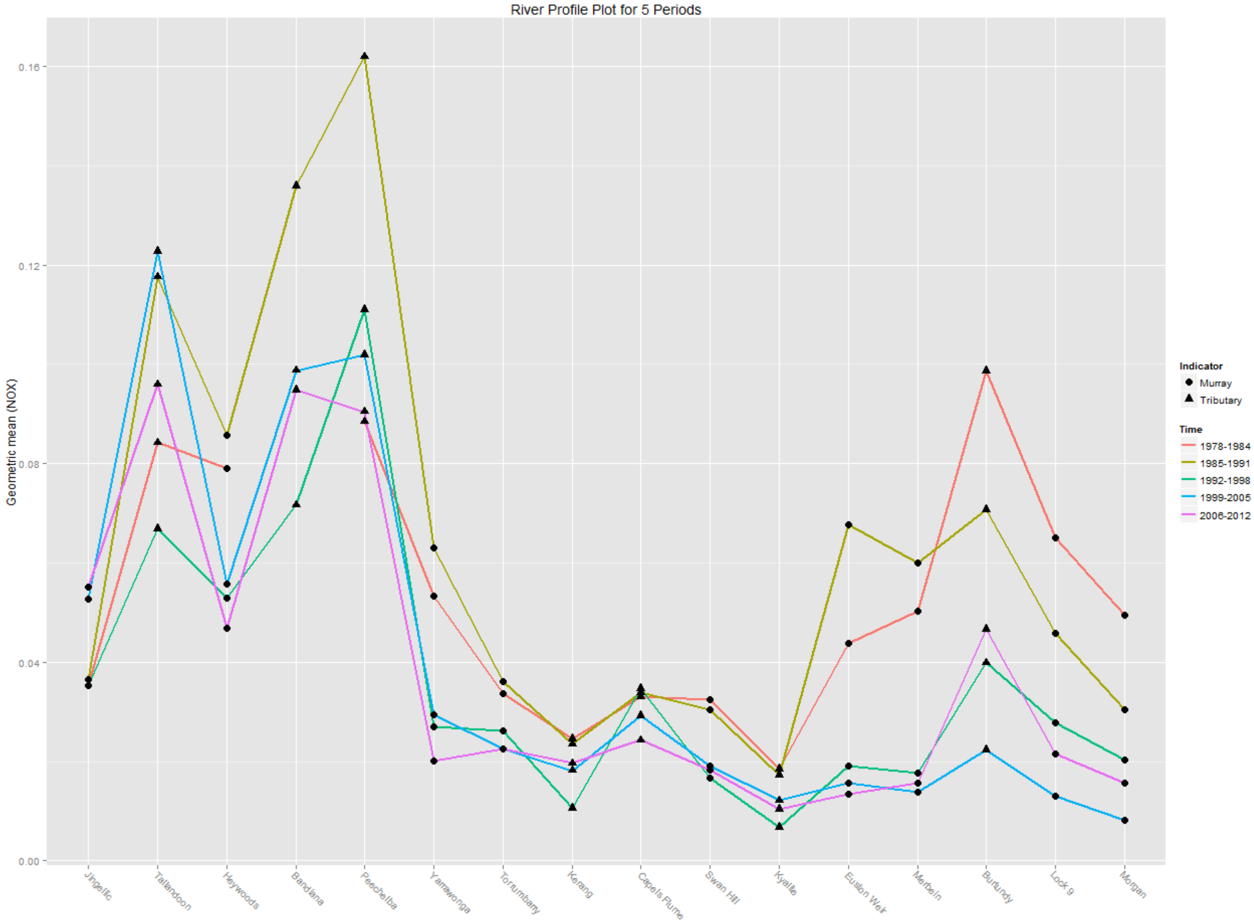

Figure 17. River profile plot of geometric mean for oxides of nitrogen (mg/L) grouped by 6 yearly time period.

Salinity / Electrical Conductivity

Electrical conductivity (EC) is typically used as a measure of salinity or the concentration of salts in the water. EC corrected to a standard temperature of 25 degrees is used in these analyses.

Table 10 presents a summary of the trend for EC at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum EC over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012.

Figure 18 and Figure 19 present graphical summaries of EC across all sites of interest for the periods 1978-2012 and 2003-2012 respectively. Additional plots and tables from the site specific analyses are provided in Appendix J.

The majority of sites show a similar pattern, with a decline from the early 1980's to mid 1990's then an increase (hump) around about 2000, followed by a decline over the period 2000 – 2010, before a subsequent increase from 2010. The declines are likely to represent a combination of operation of salt interception schemes and lack of overbank flows. The hump around 2000 is harder to explain but the late upswing clearly related to the floods and increased flows. Tallandoon is interesting in that it does not exhibit the upswing in EC following the 2010/11 floods. Lock 9 and Morgan receive most of their water from the Murray and do show not the same upswing from the floods either.

Yarrawonga stands out as an outlier with a consistent increase. Figure 20 highlight that there is markedly higher salinity at Barr Creek on Capels Flume, and the strong east-west gradient with lower salinity in the upper sites and higher salinity towards Merbein, Burtundy, Lock 9 and Morgan.

Table 10. EC (µS/cm): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (µS/cm)	Min	Max	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	39.74	0	140	**-0.38**	**	NL	**2.18**	**	NL
Tallandoon	49.93	26	240	**-0.67**	**	NL	**-0.62**	**	
Heywoods	50.88	0	33200	**-0.62**	**	NL	1.25		NL
Bandiana	42.92	0	415	**-0.84**	**	NL	0.39		NL
Peechelba	70.77	0	610	**-0.93**	**	NL	-1.30		NL
Yarrawonga	40.88	0	619	**2.11**	**	NL	1.41		NL
Torrumbarry	98.02	0	3600	**-1.35**	**	NL	-0.90		NL
Kerang	478.45	0	4300	-0.62		nl	-3.77		nl
Capels Flume	6959.21	0	64608	**-1.90**	**	NL	**-8.10**	**	NL
Swan Hill	187.75	0	2300	**-3.80**	**	NL	-0.95		NL
Kyalite	192.43	0	1160	**-1.86**	**	NL	0.35		
Euston Weir	205.39	28	945	**-3.15**	**	NL	**-3.71**	**	
Merbein	241.09	23	1500	**-3.66**	**	NL	-2.16		nl
Burtundy	483.97	73	635000	-0.52		NL	-6.32	*	nl
Lock 9	303.06	0	2750	**-3.64**	**	NL	2.43		
Morgan	522.18	166	32100	**-2.29**	**	NL	-1.15		

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

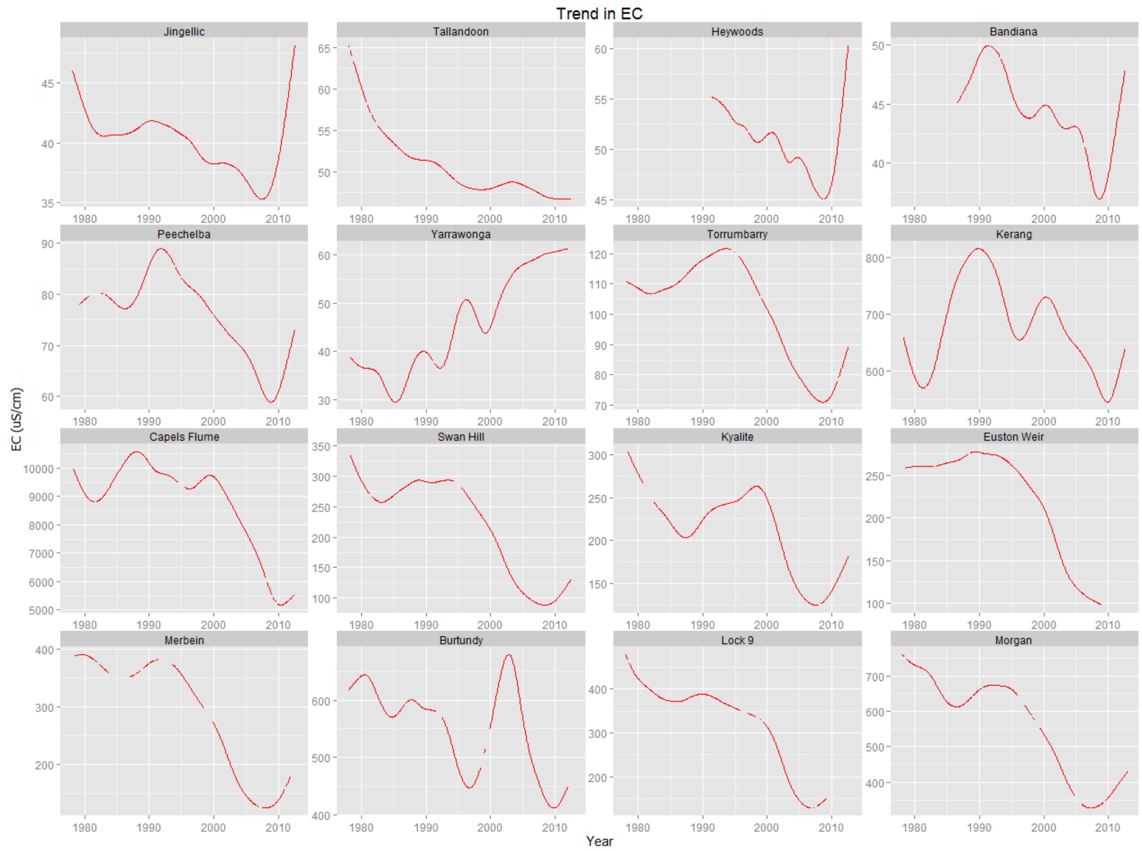

Figure 18. Trend in EC (µS/cm) 1978-2012.

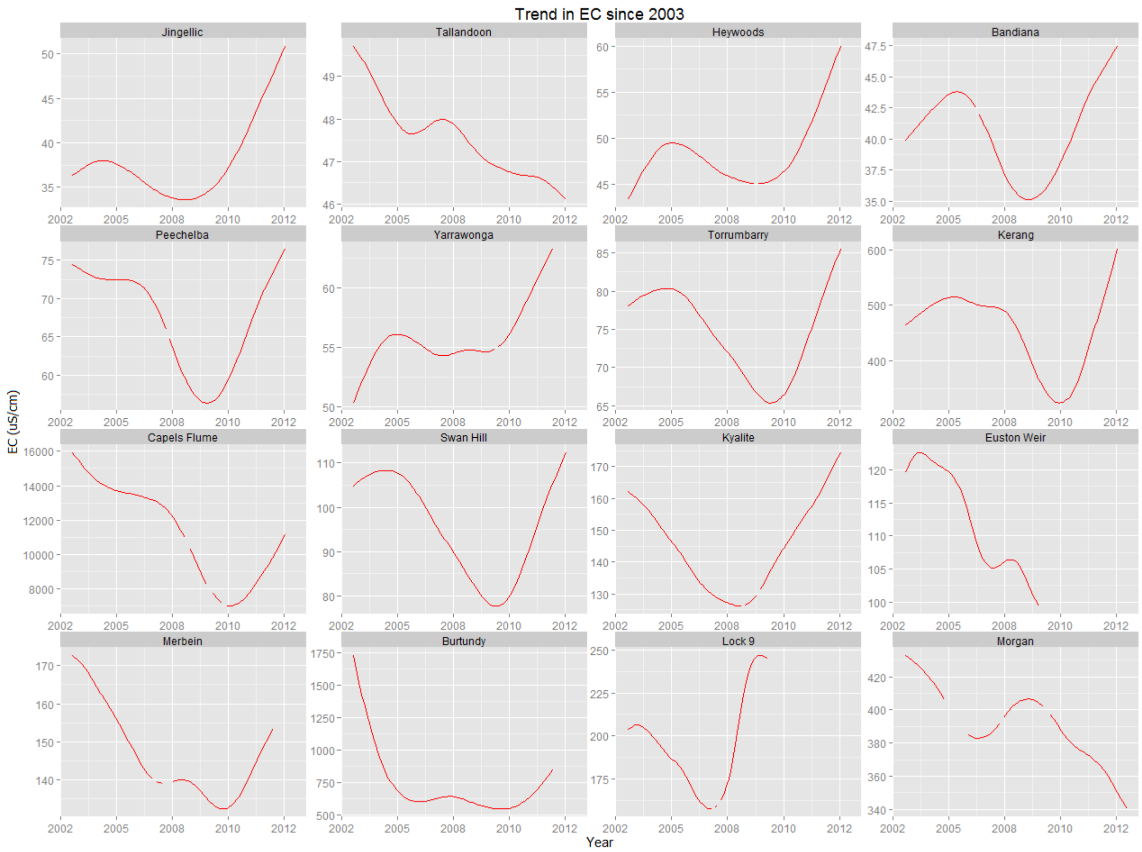

Figure 19. Trend in EC (µS/cm) 2003-2012.

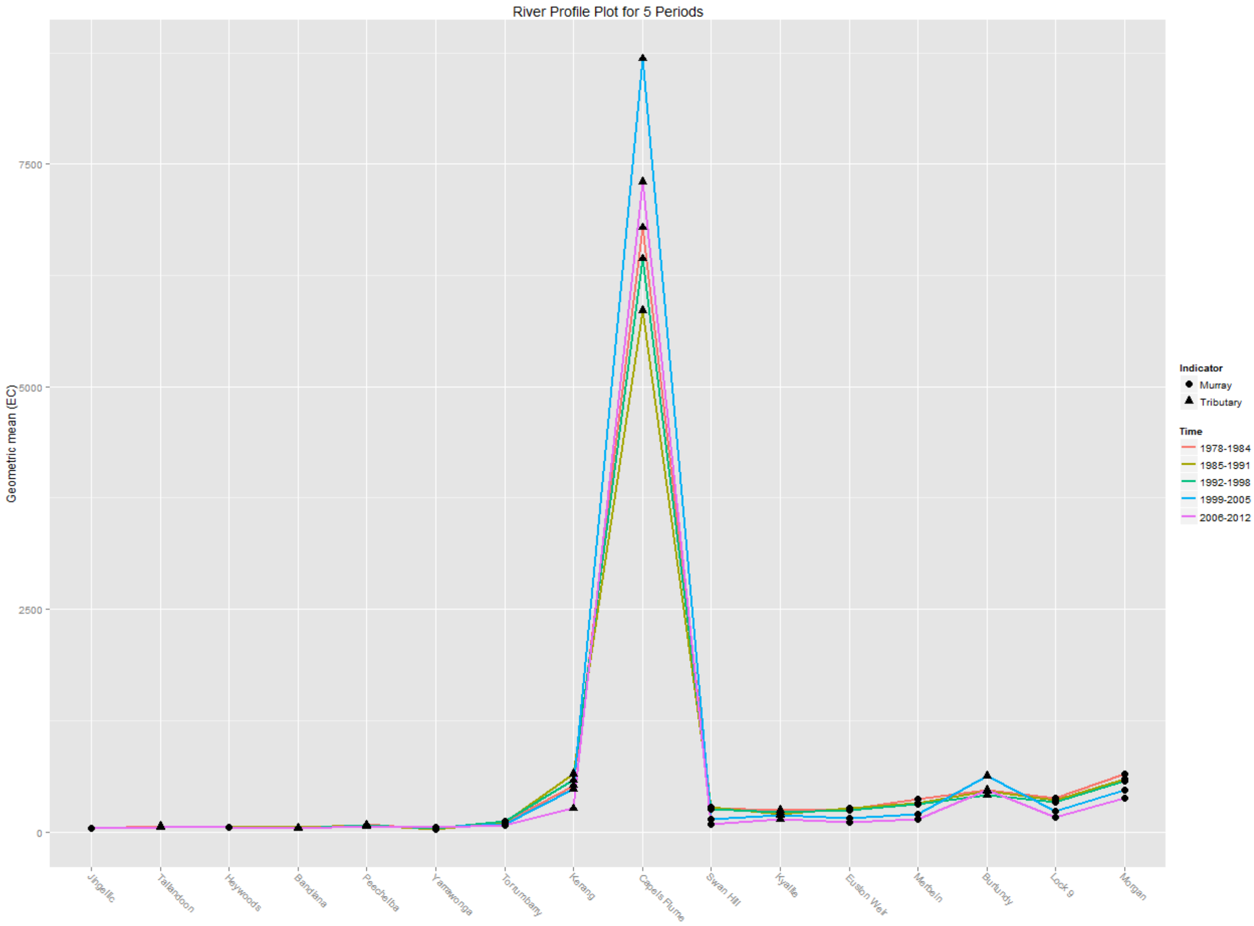

Figure 20. River profile plot of the geometric mean for electrical conductivity (μS/cm) grouped by 6 yearly time periods.

Turbidity

Turbidity is a measure of the cloudiness or muddiness of the water, and is caused by the presence of suspended particles, including clays, silts, and organic matter. Turbidity is available weekly and is measured optically through light scattering instrumentation. The units are nephelometric turbidity units (NTU). It is often used as an indirect measure of suspended solids.

Turbidity is measured weekly. Table 11 presents a summary of the trend for turbidity at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum turbidity over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012.

Figure 21 and Figure 22 present graphical summaries of turbidity across all sites of interest for the periods 1978-2012 and 2003-2012 respectively. Note that the last few years missing at some sites. Additional plots and tables from the site specific analyses are provided in Appendix G.

Turbidity is increasing at Jingellic, Tallandoon, Heywoods and Bandiana, though notably from a low base. Peechalba and Yarrawonga are also increasing across the period. Kyalite decreases in turbidity through the 1980s and 1990s before increasing again over the last decade. Swan Hill, Euston and Merbein track fairly similarly. Turbidity is consistently higher at Kerang, Kyalite and Burtundy from Figure 23. This plot also highlights the increasing turbidity with proximity to the river mouth.

Table 11. Turbidity (NTU): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (NTU)	Min	Max	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	4.05	0.00	107.0	**2.50**	**	NL	**6.02**	**	nl
Tallandoon	3.12	0.00	73.0	**1.21**	**	NL	**4.21**	**	
Heywoods	4.79	0.00	51.5	1.51	*		1.39		NL
Bandiana	6.78	0.00	190.0	**2.71**	**	NL	**4.43**	**	NL
Peechelba	12.23	0.00	460.0	**3.02**	**	NL	-0.25		NL
Yarrawonga	8.70	0.50	130.0	**2.50**	**	NL	**6.43**	**	NL
Torrumbarry	18.38	0.00	195.0	0.11		NL	**7.94**	**	
Kerang	51.84	0.00	565.0	**1.01**	**	NL	**14.69**	**	NL
Capels Flume	19.09	0.00	1000.0	0.44		NL	**15.63**	**	NL
Swan Hill	26.74	0.00	155.0	-0.18		nl	**5.66**	**	
Kyalite	40.58	0.00	160.0	**-2.03**	**	NL	**8.74**	**	
Euston Weir	25.70	2.00	210.0	**-1.06**	**	NL	**6.34**	**	
Merbein	22.05	0.85	280.0	-0.62	*	NL	**7.51**	**	
Burtundy	89.46	1.00	1781.0	**2.63**	**	NL	13.49		nl
Lock 9	36.25	0.00	470.0	**-2.60**	**	NL	1.82		
Morgan	46.07	0.00	410.0	**-2.29**	**	NL	**-17.01**	**	NL

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

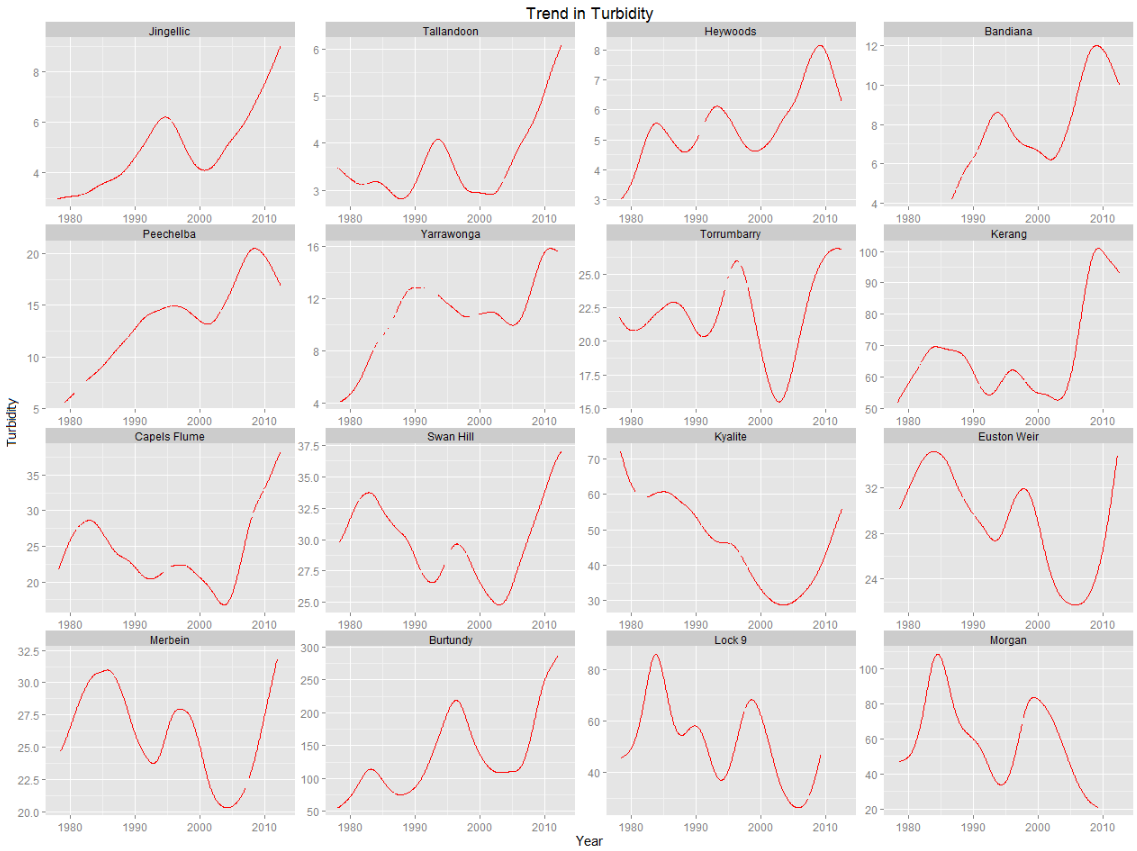

Figure 21. Trend in Turbidity (NTU) 1978-2012.

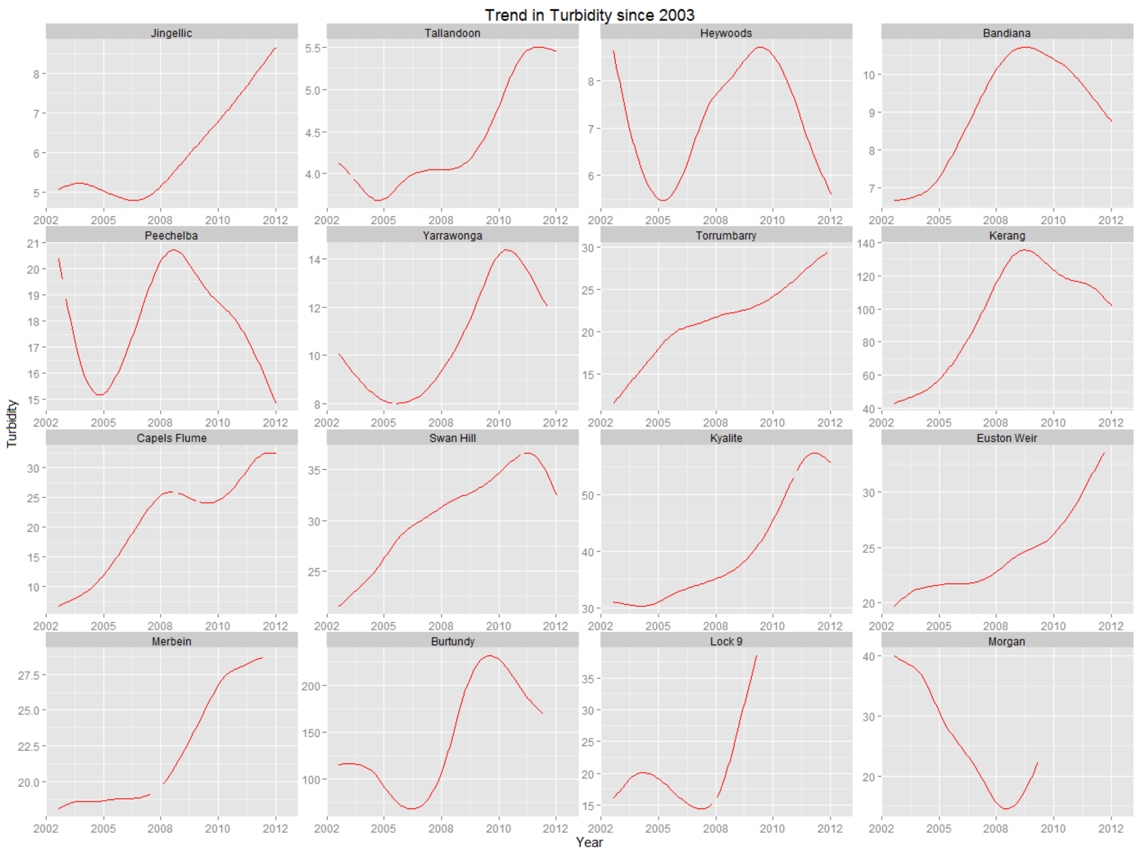

Figure 22. Trend in Turbidity (NTU) 1978-2012.

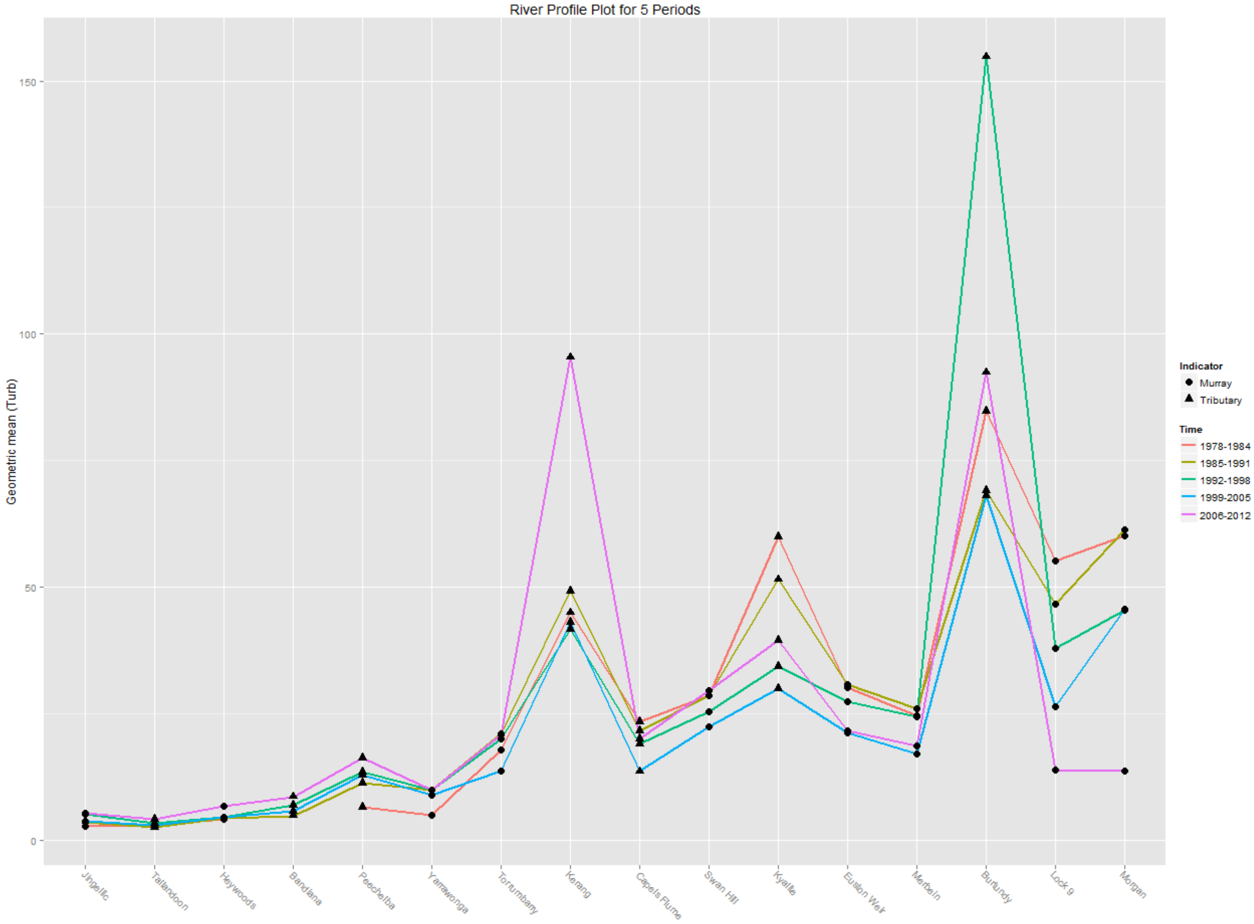

Figure 23. River profile plot of geometric mean for turbidity (NTU) grouped by 6 yearly time periods.

Dissolved organic carbon (soluble organic carbon)

Dissolved organic carbon (DOC) derives from the decomposition of dead organic matter such as plants. It is an important food source for microorganisms and can undergo rapid transformation as it can be lost as CO_2 or gained from carbon fixation. DOC is measured weekly. Past records tend to be measured more discretely than more frequently measured DOC, i.e. for past records it appears to be recorded at a more limited set of values.

Table 12 presents a summary of the trend for DOC at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum total phosphorous over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012. Figure 24 and Figure 25 present graphical summaries of DOC across all sites of interest for the periods 1978-2012 and 2003-2012 respectively. Additional plots and tables from the site specific analyses are provided in Appendix G.

Jingellic, Tallandoon, Heywoods, Bandianna, Peechlba, Torrumbarry, Swan Hill, and Kyalite all show a similar trend pattern, with maxima in the late 1980's early 1990's, declines from the mid 1990's until early 2000's then an increase over the mid 2000's to maximum for the 2010/2011 flood. Declines could be a factor of loss of connectivity. Increases at end undoubtedly follow from the 2010/11 flood. The reason for the rise in mid 2000s is less clear, though possibly reflects the increased importance of autochthonous production. Lock 9 and Morgan are tracking similarly over the last 10 years. Yarrawonga stands out as an is an outlier with little change from the 1990s, though some of the earlier higher values need to be tempered by recognising that records of DOC through the 1980s there are sparse. Barr Creek at Capels Flume and the Darling River at Burtundy are also unusual in the higher DOC that they carry (Figure 26).

Table 12. DOC (mg/L): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (mg/L)	Min	Max	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	2.7892	1.0	16.0	-0.41		NL	**7.42**	**	NL
Tallandoon	2.5734	1.0	14.0	**-0.84**	**	NL	**6.02**	**	NL
Heywoods	3.0143	1.0	200.0	0.92	*	NL	**11.70**	**	NL
Bandiana	2.3090	1.0	16.0	0.63		NL	**5.04**	**	NL
Peechelba	2.8291	0.6	14.0	**-0.98**	**	NL	**4.30**	**	NL
Yarrawonga	2.8345	0.7	100.0	**-5.19**	**	NL	0.66		NL
Torrumbarry	4.3122	1.0	30.0	0.00			0.42		nl
Kerang	5.9550	1.0	45.0	**3.15**	**	NL	**12.72**	**	
Capels Flume	14.0358	1.0	51.0	**1.49**	**	NL	2.81		nl
Swan Hill	4.5825	1.0	68.0	-0.42			1.13		nl
Kyalite	5.3299	1.0	28.0	-0.80	*	NL	4.65	*	
Euston Weir	3.8471	1.0	98.0	**-7.15**	**	NL	-6.35		nl
Merbein	3.9884	1.0	58.0	**-5.76**	**	NL	0.00		
Burtundy	11.0262	2.3	89.0	**-3.30**	**	NL	-3.61		NL
Lock 9	4.4944	0.0	19.5	**-1.31**	**	NL	6.44		
Morgan	4.7832	2.0	19.3	-0.49		NL	3.59		

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

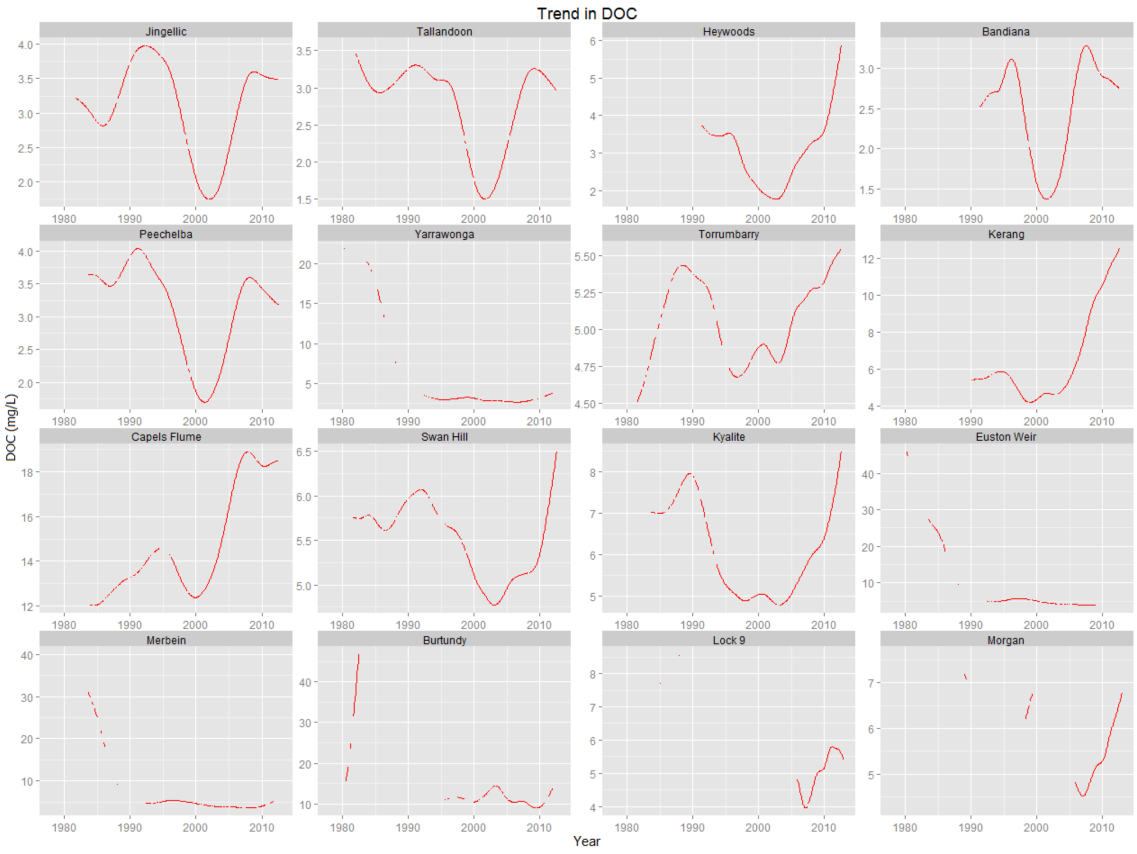

Figure 24. Trend in DOC (mg/L) 1978-2012.

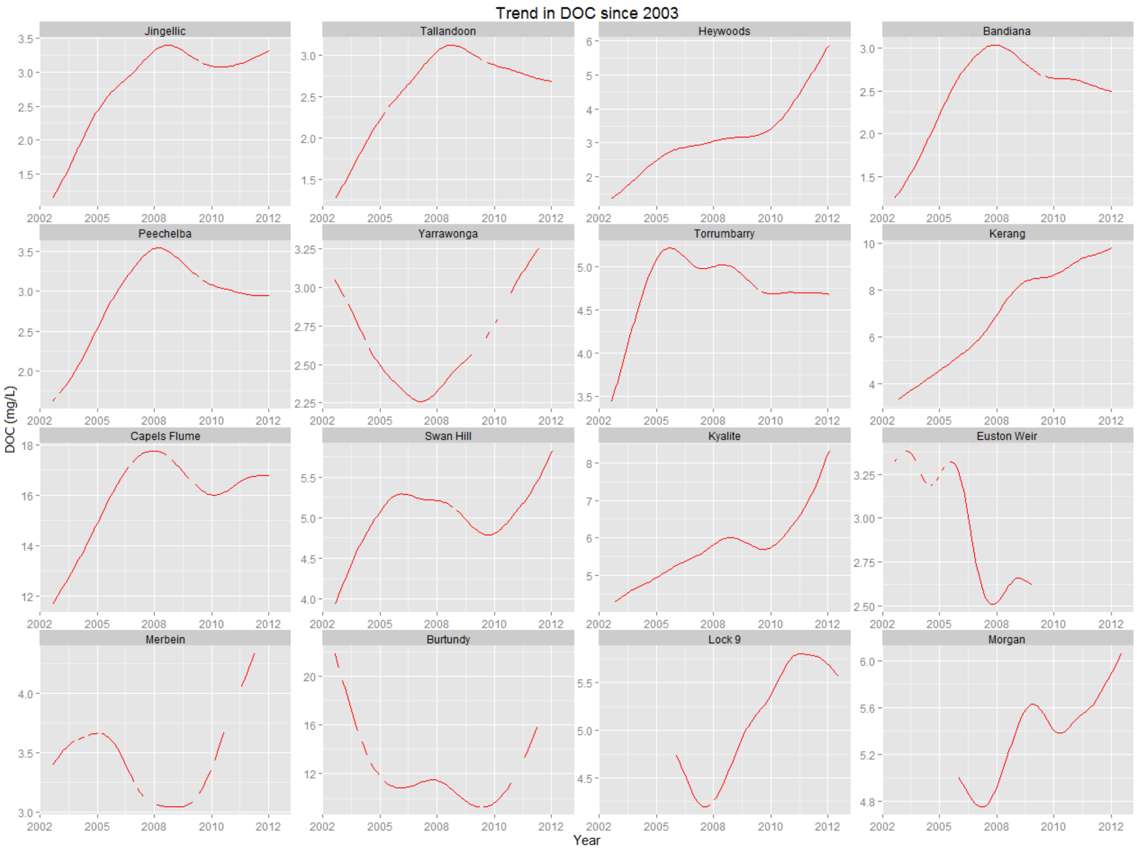

Figure 25. Trend in DOC (mg/L) 2003-2012.

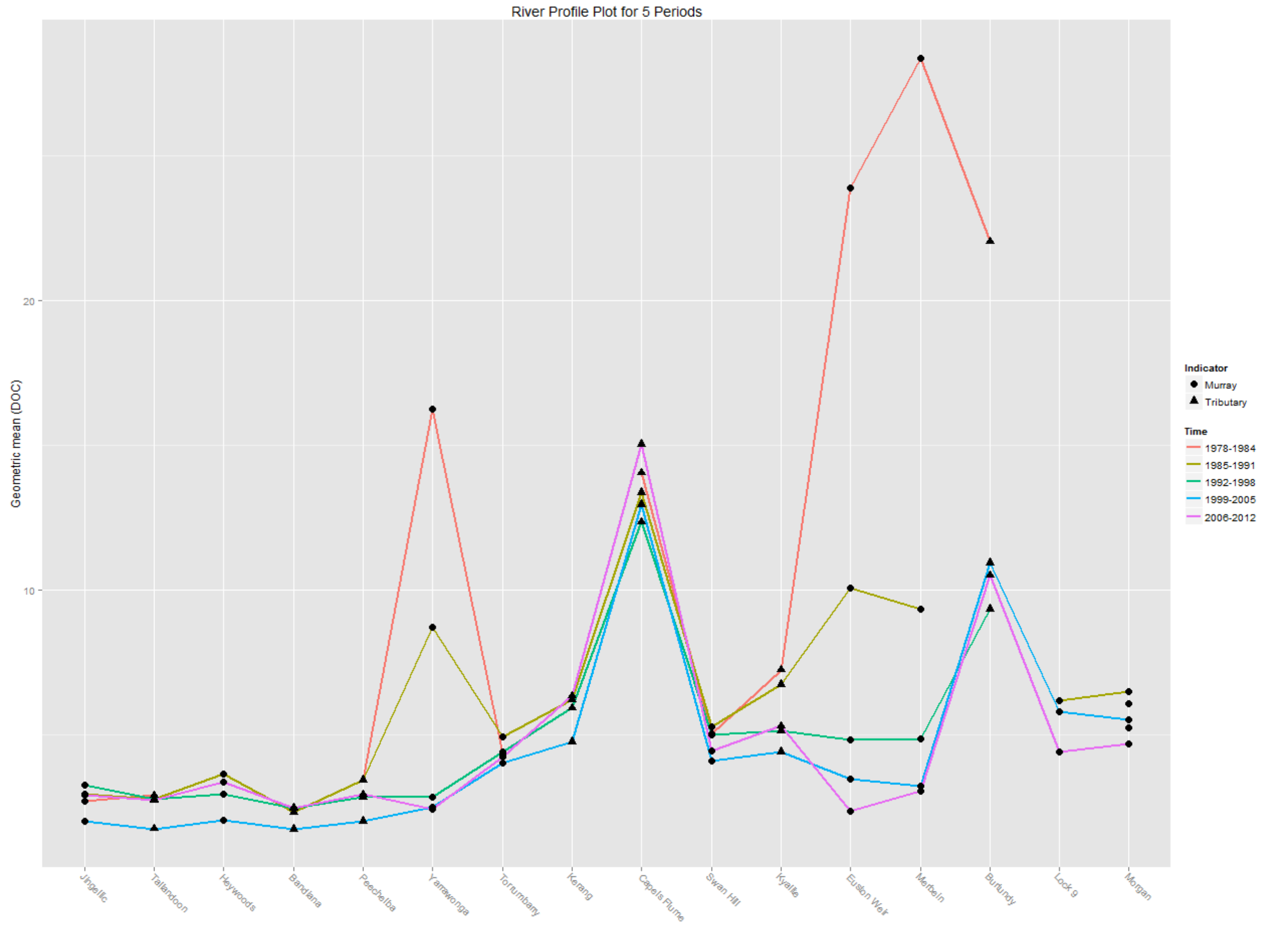

Figure 26. River profile plot of geometric mean for dissolved organic carbon (mg/L) grouped by 6 yearly time periods.

Silica

Silica is an important, and often limiting, nutrient for diatoms. If silica concentrations are too low other algal species can out-compete diatoms, and hence the algal community structure can change.

Table 13 presents a summary of the trend for silica at the 16 monitoring sites of interest for the period 1978-2012. For each site, the geometric mean, the minimum and maximum silica over that period, the linear trend (as a % change per annum) with annotations denoting its statistical significance and the strength of non-linearity in the trend curve for two periods of time; 1978-2012 and 2003-2012.

Figure 27 and Figure 28 present a graphical summaries of silica across all sites of interest for the periods 1978-2012 and 2003-2012 respectively. Additional plots and tables from the site specific analyses are provided in Appendix G.

Figure 29 presents the geometric means for silica along the river profile. With the exception of Burtundy, the highest average silica values are recorded in the upper Murray (Jingellic, Tallandoon, Bandiana and Peechelba). Heywoods is an exception to this and shows a clear impact of the Hume dam as it is lower. The pattern of trend is quite variable. Most sites have a maxima in the mid 1980's and have shown consistent decreases. The response to the 2010/11 floods does however vary with the upper sites showing increasing silica and sites in the middle Murray (Torrumbarry, Capels Flume, Kerang, Kyalite, and Swan Hill) all decreasing. Lock 9 and Morgan track fairly similarly over time.

Table 13. Silica (mg/L): Summary of the temporal trend over the period 1978-2012.

Monitoring Site	Geometric Mean (mg/L)	Min	Max	1978-2012 Linear trend % p.a			2003-2012 Linear trend % p.a		
Jingellic	8.1016	0.000	13.00	-0.44	*	NL	1.44		NL
Tallandoon	9.6894	1.700	14.00	**-0.50**	**	NL	**-5.09**	**	NL
Heywoods	3.1974	0.005	16.71	**-2.20**	**	NL	-6.08		nl
Bandiana	7.8088	0.050	13.00	**-1.44**	**	NL	-0.46		NL
Peechelba	7.8566	0.000	18.00	-0.28		NL	-1.15		NL
Yarrawonga	3.0135	0.000	890.00	**-2.14**	**	NL	-4.29		
Torrumbarry	1.4484	0.000	11.00	-0.47		NL	-3.94		
Kerang	2.6612	0.000	26.00	1.27	*		1.15		NL
Capels Flume	3.1467	0.000	38.20	-0.55		NL	0.54		nl
Swan Hill	1.1480	0.000	13.00	-0.22		NL	**-5.76**	**	
Kyalite	1.1491	0.000	12.00	**-1.64**	**	NL	-1.39		
Euston Weir	2.1828	0.050	44.50	**-0.94**	**	NL	**-11.29**	**	NL
Merbein	2.0807	0.000	930.00	-0.59		NL	**-28.29**	**	NL
Burtundy	8.8229	0.000	860.00	**-2.88**	**	NL	7.22		NL
Lock 9	3.1654	0.000	37.00	**-1.63**	**	NL	4.22		
Morgan	3.4032	0.000	17.00	**-2.04**	**	NL	5.16		nl

** Indicates linear trend % p.a. significant at 0.01 level

*Indicates linear trend % p.a. significant at 0.05 level

NL Denotes non-linearity in trend that is significant at the 0.01 level

nl Denotes non-linearity in trend that is significant at the 0.05 level

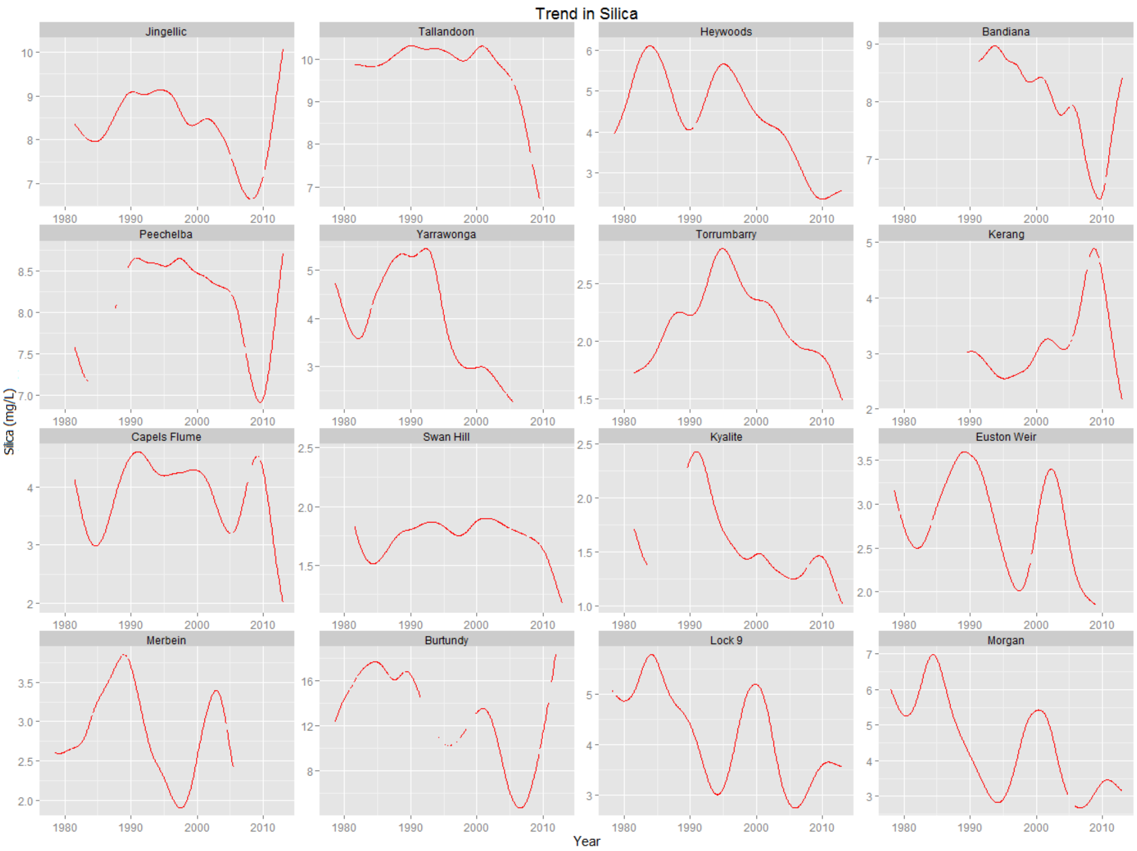

Figure 27. Trend in Silica (mg/L) 1978-2012.

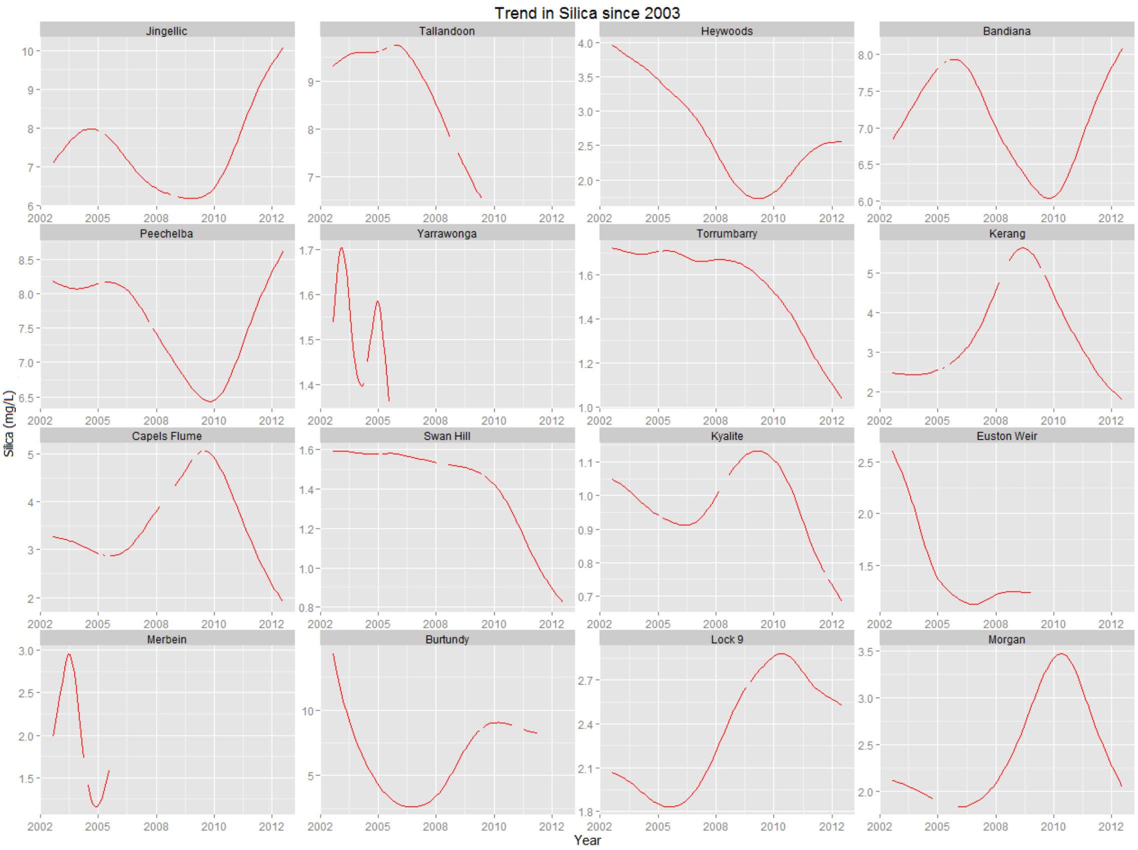

Figure 28. Trend in Silica (mg/L) 2003-2012.

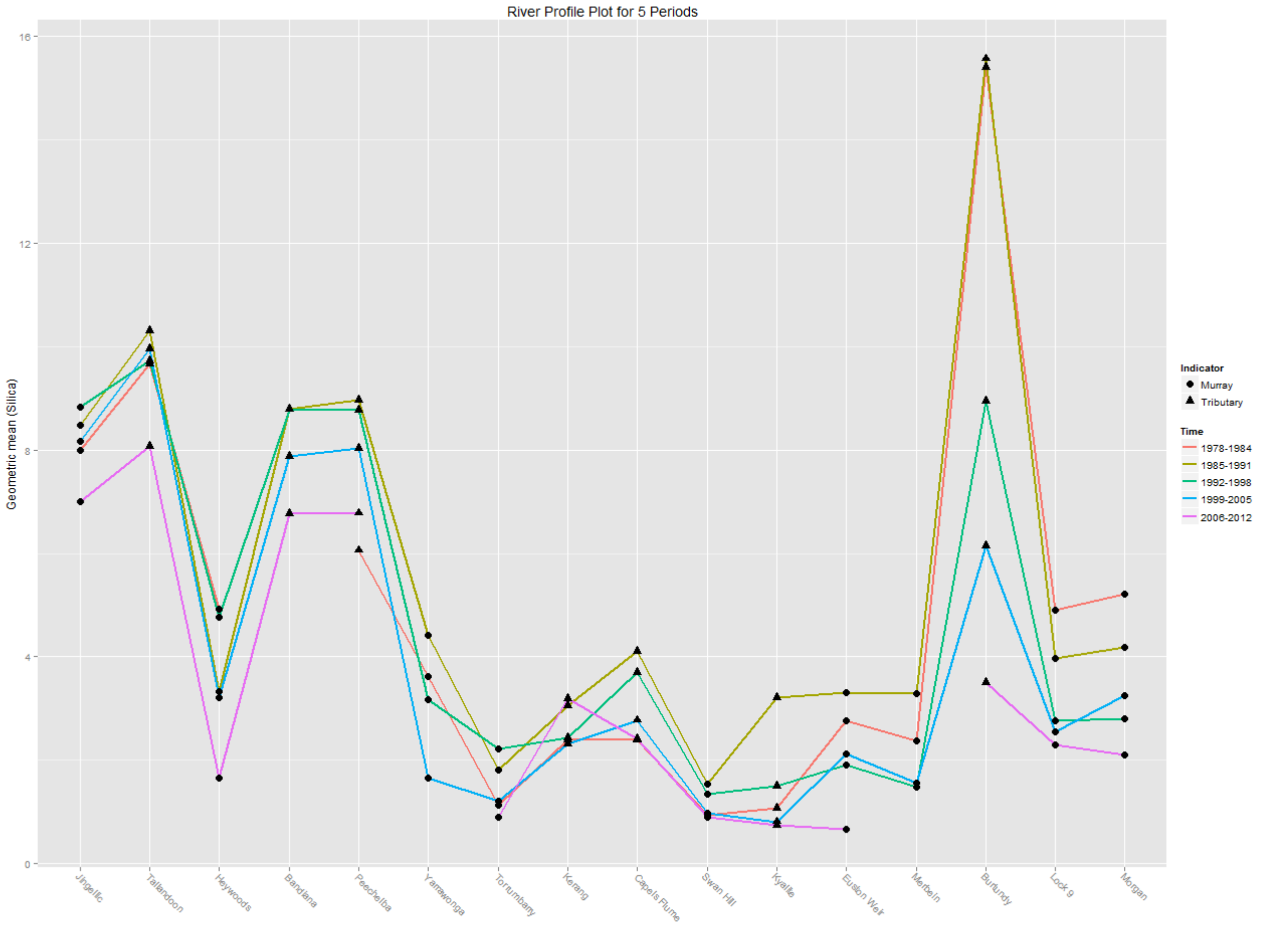

Figure 29 . River profile plot of geometric mean for silica (mg/L) grouped by 6 yearly time periods.

Comparisons between sites and water quality variables

The analyses described so far focus very much on individual water quality parameters. Comparisons between sites can be made from the interpreting the trend Figures or the River profile plots for individual parameters. This however does not consider site similarity across the different water quality parameters simultaneously.

The trends (% change p.a.) are summarised tables in Table 14 and Table 15 for the full 1978-2012 and the 2003-2012 time periods respectively. Figure 30 and Figure 31 present the all water quality variables for the 2003-2012 period as river profile plots with plotting characters designed to show the direction and magnitude of the change to enable the similarities and differences to be investigated in more detail. The Barr Creek at Capels Flume stands out as having considerably higher DOC, EC, FRP, TKN, and TP than other sites. The strong east-west gradient is clear with general increases in DOC, EC, FRP, TKN, TP, and turbidity as you travel westward. NOx and Silica decrease in the same direction, though not as consistently.

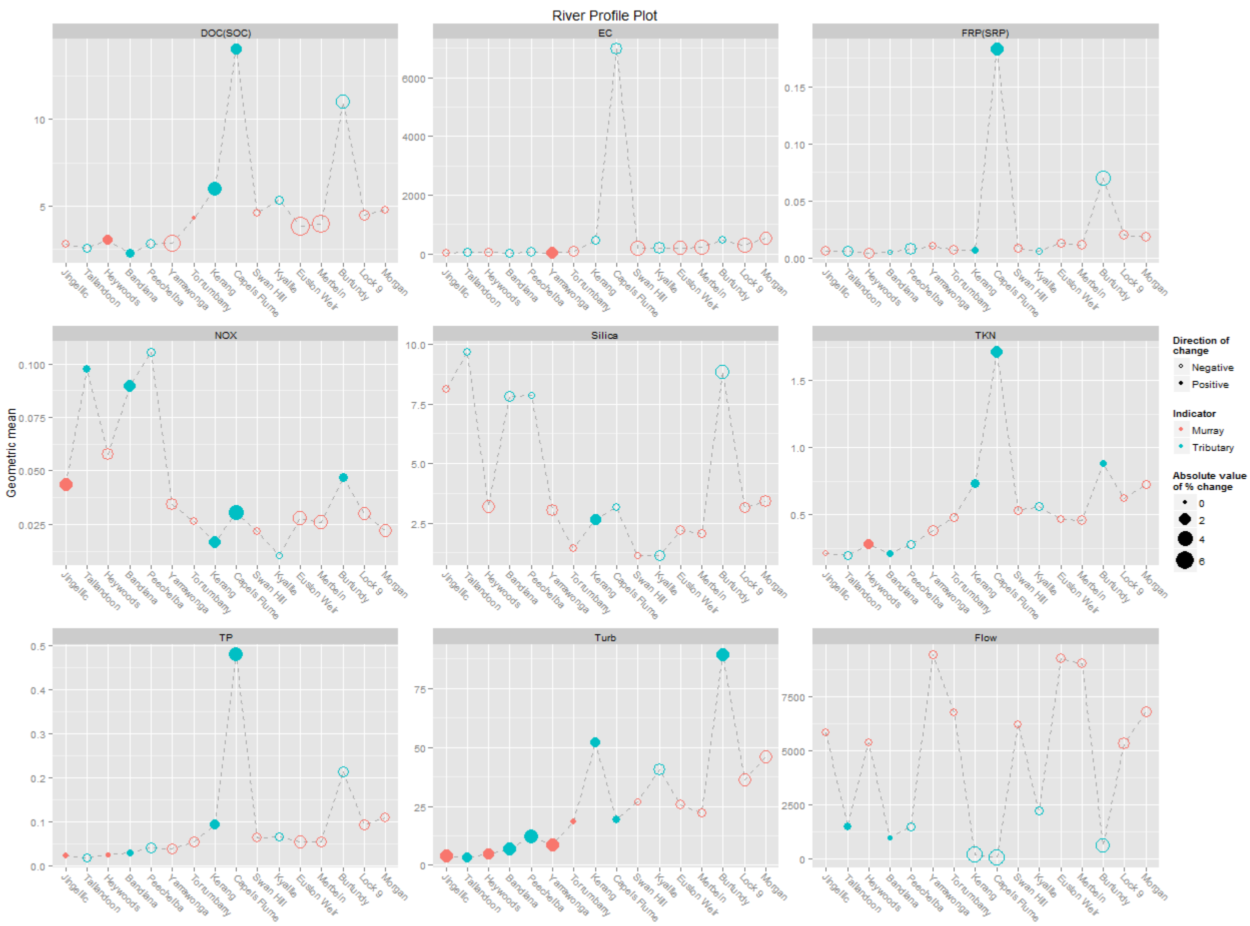

Figure 30. River profile plot of 2003-2012 geometric mean for each water quality parameter of interest. The plotting characters for each geometric mean are scaled according to the size of the change and whether it is decreasing or increasing.

Table 14. Trend summary in percentage per annum for the water quality parameters and flow, 1978-2012. Increases are shown in black and decreases in red. Percentage changes in bold indicate significance at the 0.01 level.

Monitoring Site	Flow (ML/day)	TP	FRP (SRP)	TKN	NOX	EC	Turbidity	DOC (SOC)	Silica
Jingellic	-0.53	0.16	**-1.05**	-0.16	**2.57**	**-0.38**	**2.50**	-0.41	-0.44
Tallandoon	0.36	**-0.66**	**-1.50**	**-0.84**	0.47	**-0.67**	**1.21**	**-0.84**	**-0.50**
Heywoods	-0.44	0.02	**-1.30**	**1.02**	-1.74	**-0.62**	1.51	0.92	**-2.20**
Bandiana	0.02	0.33	-0.05	0.27	**1.91**	**-0.84**	**2.71**	0.63	**-1.44**
Peechelba	-0.87	**-1.30**	**-2.00**	**-0.82**	-0.59	**-0.93**	**3.02**	**-0.98**	-0.28
Yarrawonga	-0.67	**-1.48**	**-0.56**	**-1.46**	**-1.84**	**2.11**	**2.50**	**-5.19**	**-2.14**
Torrumbarry	-0.54	**-1.32**	**-1.13**	**-0.81**	-0.42	**-1.35**	0.11	0.00	-0.47
Kerang	**-4.75**	**1.24**	0.32	0.86	**2.06**	-0.62	**1.01**	**3.15**	1.27
Capels Flume	**-4.68**	**3.30**	**2.27**	**2.17**	**3.81**	**-1.90**	0.44	**1.49**	-0.55
Swan Hill	-0.55	**-0.95**	**-0.85**	**-0.83**	-0.40	**-3.80**	-0.18	-0.42	-0.22
Kyalite	-0.78	-0.77	-0.32	**-0.87**	-0.30	**-1.86**	**-2.03**	-0.80	**-1.64**
Euston Weir	-1.03	**-2.27**	**-0.88**	-0.40	**-2.96**	**-3.15**	**-1.06**	**-7.15**	**-0.94**
Merbein	-1.11	**-1.65**	**-0.90**	**-1.11**	**-3.25**	**-3.66**	-0.62	**-5.76**	-0.59
Burtundy	-3.29	**-1.42**	**-3.83**	0.29	0.66	-0.52	**2.63**	**-3.30**	**-2.88**
Lock 9	-2.01	**-1.27**	-1.26	-0.35	**-2.33**	**-3.64**	**-2.60**	**-1.31**	**-1.63**
Morgan	-1.45	**-1.03**	-1.02	**-0.85**	**-2.29**	**-2.29**	**-2.29**	-0.49	**-2.04**

Table 15. Trend summary in percentage per annum for the water quality parameters and flow, 2003-2012. Increases are shown in black and decreases in red. Percentage changes in bold indicate significance at the 0.01 level.

Monitoring Site	Flow (ML/day)	TP	FRP (SRP)	TKN	NOX	EC	Turbidity	DOC (SOC)	Silica
Jingellic	3.416	**4.28**	**1.28**	1.07	0.33	**2.18**	**6.02**	**7.42**	1.44
Tallandoon	-6.351	**3.98**	0.23	**1.93**	-1.63	**-0.62**	**4.21**	**6.02**	**-5.09**
Heywoods	4.449	1.87	-0.26	2.12	3.06	1.25	1.39	**11.70**	-6.08
Bandiana	**10.009**	**2.64**	**1.87**	-0.19	**-8.51**	0.39	**4.43**	**5.04**	-0.46
Peechelba	13.484	0.70	0.77	-1.30	**-6.13**	-1.30	-0.25	**4.30**	-1.15
Yarrawonga	3.924	1.56	**3.01**	-1.38	-6.62	1.41	**6.43**	0.66	-4.29
Torrumbarry	**8.228**	-0.07	-1.17	0.18	-6.87	-0.9	**7.94**	0.42	-3.94
Kerang	0.386	**9.48**	**2.29**	**8.7**	-3.79	-3.77	**14.69**	**12.72**	1.15
Capels Flume	10.015	**-16.51**	**-32.25**	4.37	6.92	**-8.10**	**15.63**	2.81	0.54
Swan Hill	**7.825**	0.20	**-3.38**	1.44	**-9.94**	-0.95	**5.66**	1.13	**-5.76**
Kyalite	9.087	4.17	-0.21	**3.82**	**-4.76**	0.35	**8.74**	4.65	-1.39
Euston Weir	**10.347**	-1.78	1.05	**11.27**	2.50	**-3.71**	**6.34**	-6.35	**-11.29**
Merbein	**10.109**	-1.13	**4.09**	-2.37	1.57	-2.16	**7.51**	0.00	**-28.29**
Burtundy	**69.171**	0.29	5.45	-3.17	7.86	-6.32	13.49	-3.61	7.22
Lock 9	**22.875**	**6.94**	**9.6**	4.23	7.03	2.43	1.82	6.44	4.22
Morgan	**20.204**	**6.63**	**9.02**	**3.50**	**11.50**	-1.15	**-17.01**	3.59	5.16

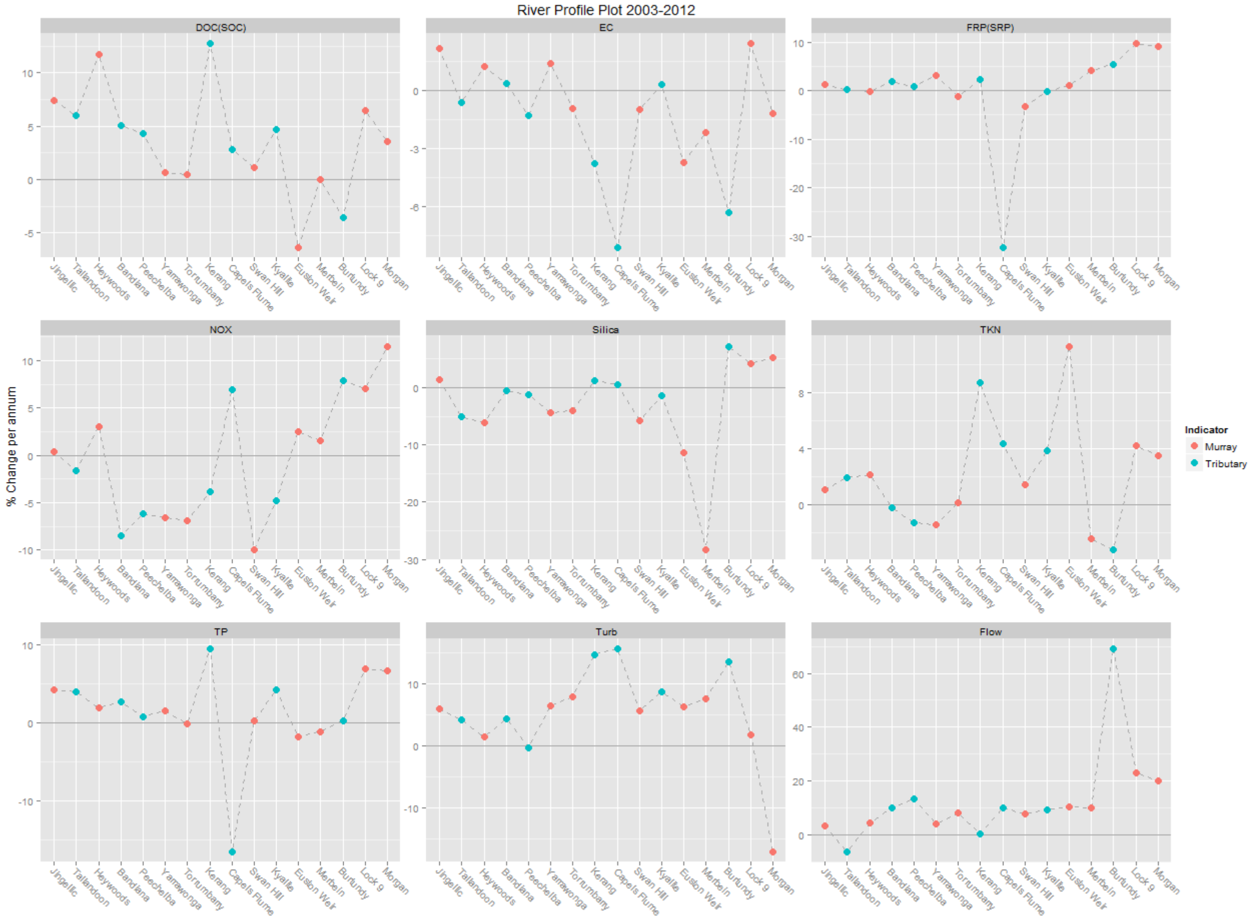

Figure 31. River profile plot: % change p.a. 2003-2012.

An alternative to investigating site similarities and differences, and the water quality parameters that are driving them, is to use multivariate analysis methods. There are a range of possible multivariate approaches that may be useful. The site specific data use in these multivariate analyses here are the summary data for the entire 1978-2012 time period, and specifically the linear % change per annum and the geometric mean for each parameter so that change is considered in the context of the whether the level is low or high. The data are scaled so that each variable (% change or mean) is standardized.

A site distance matrix is calculated based on the Euclidean distance and a divisive hierarchical cluster analysis is used to identify site similarities. Figure 32 presents the dendogram from that analysis. There are probably no strong surprises. Barr Creek at Capels Flume is the first site separate and stands out on its own given some of the water quality issues already mentioned. Kerang and Burtundy are also fairly individual, reflecting contributions from the Loddon and the Darling Rivers respectively. The sites in the upper Murray group together, with Heywoods the most different and reflecting the role of Hume dam. The sites in the mid Murray also cluster based on the water quality variables analysed, with stronger groupings between Torrumbarry and Swan Hill and between Euston and Merbein. Amongst those mid Murray sites, Yarrawonga has some uniqueness, possibly stemming from the increases in turbidity and EC that have been observed. In the Southern Murray, Lock9 and Morgan group strongly together.

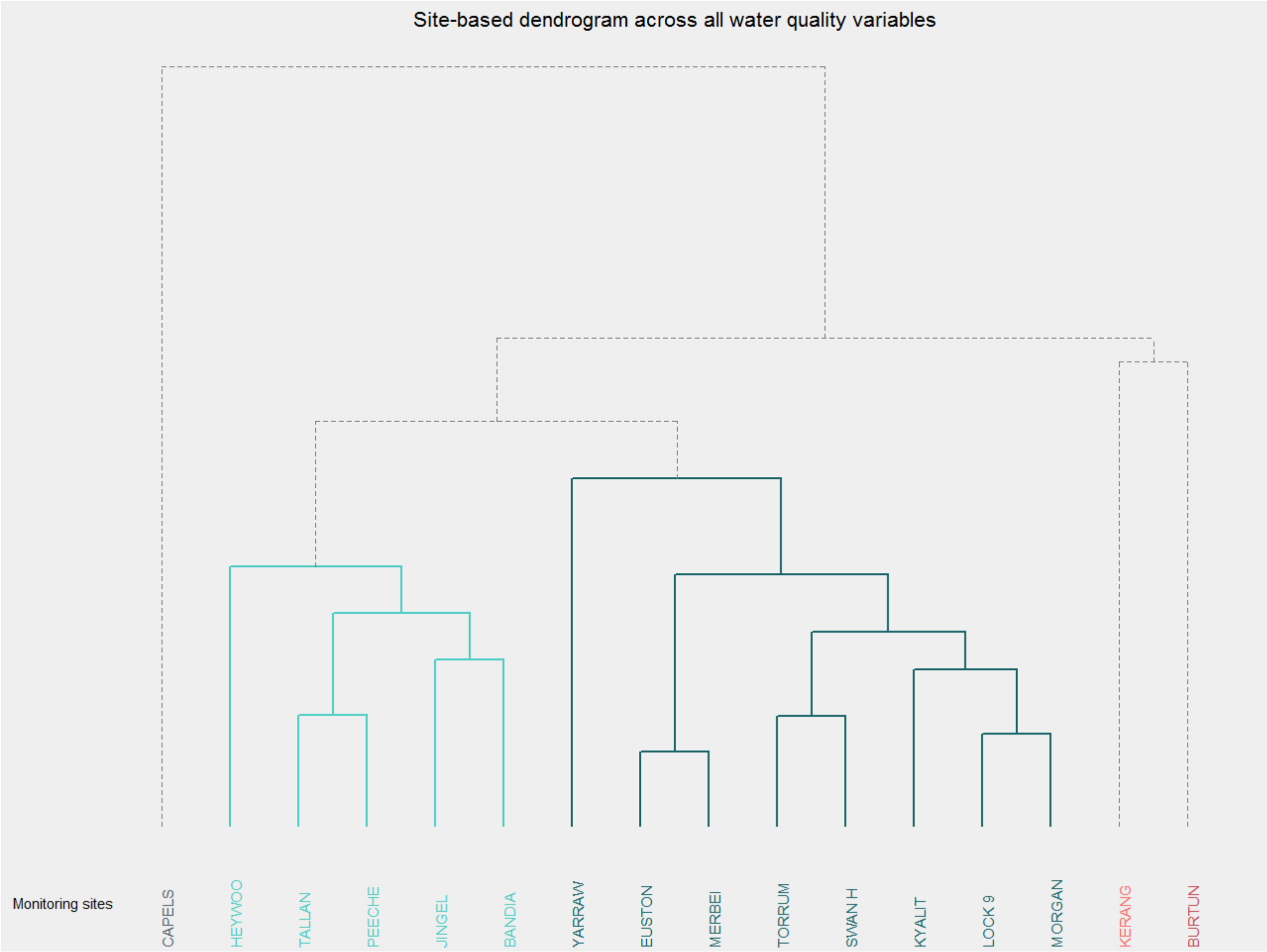

Figure 32. Site-based dendrogram across all water quality variables.

An alternative approach is to use principal components for the same summary data. This does not seek to separate the sites in anyway but identifies those linear combinations of the variables that explain the largest amount of variation subject to being orthogonal. The first two components explain 61% of the variation and are presented in Figure 33. Capels Flume is left out of this analysis given its uniqueness will otherwise dominate the first dimension. Biplots for the summary variables (% change per annum and geometric mean) are plotted. The first dimension appears to pick up the river gradient (increasing salinity, nutrients, turbidity as you get closer to the river mouth). The second dimension picks up more of the changes and show that changes in DOC, EC, turbidity, NOx and TKN are generally in the same direction. Sites largely group according to proximity, and show similar groupings to the cluster analysis in Figure 32, but with Burtundy standing out to some extent.

Figure 33. Principal components analysis of the 1978-2012 summary water quality variables (% change per annum and geometric mean). The sites are presented in grey and the variables as biplots in red.

4 DISCUSSION AND CONCLUSIONS

This report has sought to investigate changes in physico-chemical water quality across a set of key water quality parameters (total phosphorus, filterable reactive phosphorus, total Kjeldahl nitrogen, oxides of nitrogen, EC, turbidity, dissolved organic carbon, and silica) for 16 sites that are part of the River Murray Water Quality Monitoring Program.

Generalized additive models, which use splines to describe non linear trends and dependence on flow, are the primary vehicle for assessing the trend. These analyses are performed on the log transformed water quality parameter and on a site basis for each water quality parameter. Trends are considered over the full 1978-2012 time period and over the most recent 10 years (2003-2012). The latter is important as interpretation is often clearer over medium time spans when the linearity is stronger. The decadal window also provides a stronger sense of the future trajectory. The analysis approach is consistent with previous trend analyses commissioned by the MDBA (AWT 1999; WATER Ecoscience 2002; Henderson 2006) which enables comparisons to be made.

The analysis of the monitoring data undertaken establishes that there have been important and statistically significant changes in key water quality parameters at monitoring sites within the Murray-Darling Basin. Changes over the 35 year period from 1978 to 2012 are hard to summarise simply because they are typically non-linear, with increases and decreases corresponding to different climate regimes, hydrological drivers and management practices.

Across the entire period there have been general broad decreases in nutrients (TP, FRP, TKN, NOx), though NOx and TP show increases in the upper Murray (Jingellic to Bandiana). Capels Flume and Kerang however show stronger increases in these nutrients. Silica decreases across the period at all sites except Kerang. EC has been decreasing uniformly though Yarrawonga appears to buck that trend. Turbidity has been increasing in the upper-mid Murray sites, though is decreasing below Swan Hill, with the exception of Burtundy which represents the unique contribution of the Darling River. DOC is less consistent, though appears to decrease for all sites below Swan Hill. There is notably a large decrease in DOC at Yarrawonga and increase at Kerang and Capels Flume.

The 2010/11 floods have had a large impact on the water quality at that time, increasing nutrients fairly consistently with the exception of NOx that decreased at many sites, increasing EC (other than at Morgan), increasing turbidity at most sites, and increasing DOC. The effect on silica is a bit more mixed with increases in the upper Murray sites but decreases between Torrumbarry and Kyalite. Following the floods most of these parameters have returned to levels more typical of recent preceding years.

There are some strong gradients along the River with a confirmation of general increases in DOC, EC, FRP, TKN, TP, and turbidity as you travel towards the river mouth. NOx and Silica decrease in the same direction, though not as consistently. The individual analyses identify a clear coherence between trends observed at many of the monitoring sites, particularly amongst sites that are closer geographically, because they are often exhibiting similar peaks and troughs. The comparisons and multivariate analyses (cluster, PCA) confirm that there are few distinct geographical groupings of sites:

- Capels Flume stands out as having a fairly unique water quality profile. Kerang is often tracks similarly, and while clearly less extreme could be considered a group.
- Jingellic, Tallandoon, Bandianna and Peechalba respond fairly similarly and are one group.
- The mid Murray sites of Torrumbarry, Swan Hill and possibly Kyalite, Euston Weir and Merbein act as one group.
- Lock 9 and Morgan track similarly.

There are also some notable differences between some individual sites and other sites that are geographically close:

- Burtundy does group with Lock 9 and Morgan at times but it also comes across as unique with higher nutrients, silica, DOC and turbidity.
- Yarrawonga also differs from its adjacent sites at times (e.g. for changes in EC or DOC), and possibly reflects the influence of Lake Mulwala.
- There is also an interesting effect of Lake Hume on water quality from comparing Tallandoon and Jingellic with Heywoods Bridge. This is especially true for silica, as would be expected, but also some of the other water quality parameters.

Conclusions

With 35 years of water quality data the River Murray Water Quality Program provides a unique and invaluable record of changes in water quality in the Murray Darling Basin. In the context of a potential changes due to future climate and other changes driven by the Murray Darling Basin Plan, the importance of that monitoring data will persist.

Baldwin et al. (2013) through an analysis of annual load data for up to seven key constituents of water quality at 22 sites clearly showed that a reduction in the frequency of sampling from weekly to biweekly or 4-weekly will substantially affect the ability to accurately determine total annual loads at these sites – in some cases by up to 500%. Their recommendation was that if the sampling program is being reduced, the number of sites rather the frequency of sampling be reduced. The site groupings identified through the site trend comparisons and the multivariate analyses in this report may be useful if that is ever under consideration.

The trend analyses undertaken indicate that the tributaries are clearly playing an important role. Some stand out, but they often have their own unique characteristics and management needs that need to be tracked. Their contributions also impact on sites downstream of their confluence with the Murray.

The analyses also identify the on-going importance of tracking above and below Lake Hume given the potential modifying effect of the dam on water quality.

Future work

This review has provided an important overview of changes in physico-chemical water quality within the Murray-Darling Basin since 1978. The collated monitoring data is a valuable, long term and comprehensive data set that warrants detailed investigation to extract additional meaningful insight. Extensions to the current analyses that would provide additional value include the following:

i. There is an opportunity for a more complete picture across all sites as only 16 of the 36 sites are considered here. Other periods of record may also be more appropriate for some questions. For instance, it might be more meaningful in some cases to consider water quality to 2009, and before the floods on 2010/11 given the strong local impact on water quality those floods have had. Revisiting in the next few years to establish whether water quality has returned to levels preceding those floods may also be worth considering.

ii. This analysis has described and documented the changes that have occurred. While there has been description of some of the possible drivers of the changes observed this has not been pursued within a quantitative or statistical framework. This is something that might be pursued for particular water quality issues in specific parts of the basin. For instance, understanding some of the drivers of the changes in EC or DOC at Yarrawonga may be of interest.

iii. The primary analysis has been a site-based trend analysis for each water quality parameter. There are opportunities to consider the analyses for all sites together in some way. The multivariate analyses do this to some extent but could be more targeted and taken further. An alternative would be to extend the largely temporal analysis to a spatio-temporal analysis. This might provide additional insight to similarities and differences between sites. Comparisons between sites may also be improved by using approaches like functional data analysis that enable entire curves to be compared rather than compare features of those curves such as the % change per annum or the geometric mean.

REFERENCES

Al-Tebrineh, J. , C. Merrick, D. Ryan, A. Humpage, L. Bowling and B.A. Neilan (2012). Community composition, toxigenicity and environmental conditions during a cyanobacterial bloom occuring along 1100 kilometers of the Murray River. Applied and Environmental Microbiology 78(1) 263-272.

AWT (1999) Water Quality Monitoring Program Review – Part 1 Data Summary and Recommendations. Report no. 98/169 AWT Melbourne.

Baldwin DS, Whitworth KL and Pengelly J (2013) Investigating the influences of changes in the River Murray Water Quality Monitoring Program on future capacity to detect trends in water quality. Final Report prepared for the Murray-Darling Basin Authority by The Murray-Darling Freshwater Research Centre, May 2013.

D.S Baldwin, J. Wilson, H. Gigney and A. Boulding (2010) Influence of extreme drawdown on water quality downstream of a large water storage reservoir. Rivers Research and Applications. 26, 194-206.

Croome R, Wheaton L, Henderson B, Oliver R, Vilizzi L, Paul W and McInerney P. (2011). River Murray Water Quality Monitoring Program: Phytoplankton Data Trend Analysis 1980-2008. Final Report prepared for the Murray-Darling Basin Authority. MDFRC Publication 06/2011, June, 81pp.

Darnell R, Henderson B, Kuhnert P, & Kroon F (2012). Statistical power of detecting trends in total suspended sediment loads to the Great Barrier Reef. Marine Pollution Bulletin http://dx.doi.org/10.1016/j.marpolbul.2012.04.002

Hastie T and Tibshirani R, (1990), Generalized Additive Models, Chapman and Hall.

Henderson B, and Morton R.,(2008) Strategies for the estimation and detection of trends in water quality, Tech. report, CSIRO Mathematical and Information Sciences Technical Report 07/70, Canberra, 2008.

Henderson B & Kuhnert P (2005) Water quality trend analyses for the Swan-Canning Rivers: A report for the Department of Environment, Western Australia, CSIRO Mathematical and Information Sciences Technical Report, Number 05/197.

Henderson, B. (2006). Updated water quality trend analyses for key sites monitored as part of the MDBC's River Murray Water Quality Monitoring Program, 1978-2005. A report for the Murray-Darling Basin Commission. CMIS Report Number 06/78, June 2006.

Henderson B, Rustomji, P, Fitch, P, Mills K, Bai, Q. (2010). Water quality statistical analysis and reporting tool: Final report. CSIRO: Water for a Healthy Country National Research Flagship. Report delivered to Department of Agriculture, Forestry and Fisheries and the Bureau of Meteorology.

Jolly, I. D., et al. (2001), Historical stream salinity trends and catchment salt balances in the Murray-Darling Basin, Australia, Mar. Freshwater Res., 52, 53– 63.

Mackay, N., Hillman, T. and Rolls, J. (1988) Water Quality of the River Murray – Review of Monitoring 1978 to 1986. Water Quality. Report No.1, Murray-Darling Basin Commission, Canberra. 62pp.

Matveev, V. F. and Matveeva, L. K. (2005) Seasonal succession and long-term stability of the pelagic community in a productive reservoir. Marine and Freshwater Research 56(8), 1137-1149.

Morton, R., and B. L. Henderson (2008), Estimation of nonlinear trends in water quality: An improved approach using generalized additive models, Water Resour. Res., 44, W07420, doi:10.1029/2007WR006191.

Murray-Darling Basin Authority (2011) Murray-Darling Basin Authority Annual Report 2010-2011 http://www.mdba.gov.au/annualreports/2010-11/chapter_03_6.html

Murray Darling Basin Ministerial Council (2011) Acid Sulfate Soils in the Murray-Darling Basin. 81 pp. Murray-Darling Basin Commission http://www.mdba.gov.au/files/publications/Acid-sulfate-soils-in-the-MDB.pdf

Nathan, R. J., N. Nandekumar, and W. E. Smith (1999), On the application of Generalised Additive Models to the detection of trends in hydrologic time series data, in Water 99 Joint Congress; 25th Hydrology and Water Resources Symposium, 2nd International Conference on Water Resources and Environment Research, pp. 165– 172, Inst. of Eng., Barton, ACT.

Nielsen D. L., M. Brock, G. N. Rees and D. S. Baldwin (2003) The effect of increasing salinity on freshwater ecosystems in Australia. Australian Journal of Botany 51, 655-665

Water Ecoscience (2002) MDBC Water Quality Review Stage 2 – Data Analysis. Report No. 653. Water Ecoscience Melbourne.

Whitworth K, D.S. Baldwin and J. Kerr (2012) Drought, floods and water quality: drivers of a severe hypoxic blackwater event in a major river system (the southern Murray-Darling Basin, Australia). Journal of Hydrology 450-1, 190-198.

Wood, S. N. (2006). *Generalized Additive Models*: An Introduction with R. Chapman & Hall.

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

YOUR CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

FOR FURTHER INFORMATION

CSIRO Computational Informatics / CSIRO Water for a Healthy Country Flagship
Brent Henderson
t +61 2 6216 7095
e Brent.Henderson@csiro.au
w www.csiro.au/cci