THE BASIN PLAN

Water quality technical report for the Murrumbidgee surface water resource plan area (SW9)

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Summary

Good quality water protects public health, supports economic production and maintains a healthy river ecosystem. Water quality is mostly determined by land use, geology, climate, riparian vegetation and stream flow, and reflects the interactions of natural and man-made practices that occur in a drainage area and the riparian zone.

Degradation of water quality can put stress on a range of aquatic organisms, impinge on Aboriginal cultural and spiritual uses of water, increase the cost of drinking water treatment, contribute to public health risks and decreases the suitability of water for irrigation and agriculture.

Alteration of the Australian landscape since European settlement has resulted in marked changes in catchment conditions. Runoff from cropping areas, erosion of soil and nutrients from stream banks and discharge from saline areas have led to increased turbidity, salinity, sedimentation, nutrient loads and chemical residues. These in turn can degrade aquatic ecosystem health. The regulation of rivers through the construction of large storages and weirs lead to changes to flow regimes, thermal pollution, harmful algal blooms and disruption of longitudinal connectivity of river processes.

Water quality condition in the Murrumbidgee water resource planning area (WRPA) varies from poor to excellent. Water quality issues occurring within the catchment are the result of a combination of factors. These include alteration to natural flow regimes, in particular disruption by Burrinjuck and Blowering Dams, changes to catchment conditions and land use change. Table 1 summarises the major water quality issues in the Murrumbidgee WRPA.

Table 1: Summary of major issues and causes of water quality degradation

Issue	Location	Potential causes
Harmful algal blooms	uplands, midlands, lowlands	Reduced flow, stratification and warm water temperatures in Burrinjuck Dam, lowland weirs and recreational lakes. Nutrient inputs.
Dissolved oxygen outside of normal ranges	uplands, midlands, lowlands	Reduced flow, and increased low flow and cease to flow periods disrupting dissolved oxygen dynamics and increasing eutrophication. Hypoxic blackwater events following large scale flooding and inundation of floodplains.
Increased nutrients and turbidity	uplands, midlands, lowlands	Stream bank and riparian condition, grazing and cropping practices, carp and feral species. In the midlands, increased sediment and nutrient input associated with erosion.
Toxicants and pesticides	midlands, lowlands	Pesticide use in cropping areas.
Disruption to organic carbon cycling	midlands, lowlands	Reduced freshes and high flows, disruption of longitudinal connectivity by Blowering and Burrinjuck Dams.
Thermal pollution	midlands	Cold water released from Blowering and Burrinjuck Dams in summer. Warm water releases in winter.

Contents

List of Tables

List of Figures

1. Introduction

1.1. Purpose

The Murray Darling Basin Plan (2012) is an instrument of the Commonwealth *Water Act (2007).* It provides the framework for long term integrated management of water resources of the Murray Darling Basin. The Basin Plan requires water quality management plans (WQMP) are developed for all water resource areas in the Basin. Each WQMP will:

- Establish water quality objectives and targets for freshwater dependent ecosystems, irrigation water and recreational purposes;
- Identify key causes of water quality degradation;
- Assess risks arising from water quality degradation, and
- Identify measures that contribute to achieving water quality objectives.

This report provides an overview of the water quality condition of the Murrumbidgee water resource plan area (WRPA) by comparing data to the Basin Plan water quality targets (Basin Plan 2012, Schedule 11). The Basin Plan water quality targets set out the appropriate water quality required for environmental, social, cultural and economic benefits in the Murray Darling Basin. Monitoring progress towards achieving the targets will identify trends and inform actions that address the causes of water quality decline. These targets have been used to assess existing water quality data, and to identify areas of risk to aquatic ecosystems, and recreational and irrigation use.

The report also outlines the factors influencing water quality in the region, specifically the likely causes of water quality degradation issues, as required by Chapter 10, Section 10.30 of the Basin Plan.

> **BASIN PLAN 10.30 Water quality management plan to identify key causes of water quality degradation.** The water quality management plan must identify the causes or likely causes, of water quality degradation in the water resource plan area having regard to the key causes of water quality degradation identified in Part 2 of Chapter 9 and set out in Schedule 10.

The information in this report supports the development of the Murrumbidgee WQMP. It provides the background and technical information to develop water, land and vegetation management measures to maintain or improve water quality in the Murrumbidgee WRPA. Figure 1 is a flow diagram illustrating how this report supports other components of the surface water resource planning process.

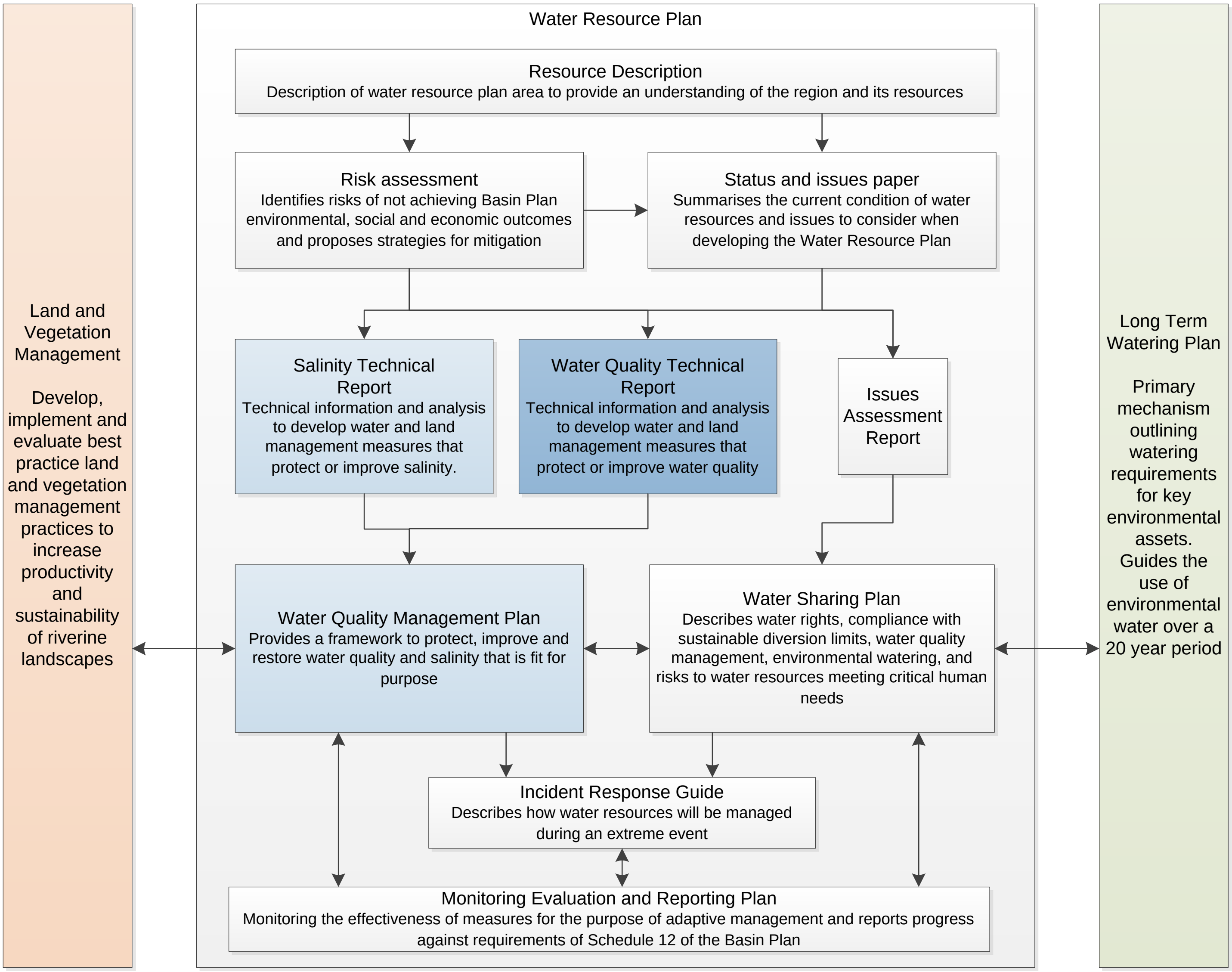


Figure 1: Flow diagram illustrating the components of the Murrumbidgee surface water resource plan

1.2. Context

Water quality can be defined in terms of the physical, chemical and biological content of water and in terms of purpose and use. Water quality may be fit for one purpose, but not another. For example, water may be of good quality to irrigate crops, but may not support a healthy population of fish.

This report refers to water quality degradation or poor water quality as:

- Elevated levels of nutrients, turbidity, blue-green algae, salinity, toxicants or pathogens, and
- Water temperature, pH and dissolved oxygen outside of certain ranges.

Water quality is dynamic. The physical, chemical and biological content of water varies with time and location. Table 2 shows how water quality can be defined in three related, but slightly different ways.

Table 2: Water quality processes

Long term water quality	Poor water quality event	Ecosystem processes
This describes long-term average trends over a period of months to years. In this report the water quality parameters used are from monthly measurements at a selection of locations. Major trends are reported in five year periods. Indicator targets are listed in Tables 3 to 6.	These refer to occurrences of water quality issues for set periods of time that are generally not ongoing. Examples may include a potentially toxic algal bloom or anoxic blackwater (low-oxygen) event. While the occurrence of these events may be short lived, their effects can be long-term.	Water quality parameters are bound up in fundamental ecological functions of rivers and catchments. These are less easy to define as 'good' or 'bad', and often involve complex interrelationships. Examples may include the movement of organic carbon from floodplains to rivers to support productivity, or the delivery of sediment from upstream to downstream.

1.3. Catchment description

The Murrumbidgee WRPA is bounded by Cooma in the east, Balranald in the west, Temora to the north and Henty to the south. The catchment covers an area of approximately 84 000 km^2. The Murrumbidgee River starts in the Kosciuszko National Park on the Long Plain, and flows 1 600 km westward to its confluence with the Murray River near Balranald. It has average annual flows of around 4.4 million megalitres and is the third largest river in the Murray–Darling Basin. Major streams in the Murrumbidgee Catchment include: the Bredbo River, Numeralla River, Goodradigbee River, Cotter River, Goobarragandra River, Tumut River and Yass River in the upper catchment; Tarcutta Creek and Jugiong Creek in the mid catchment; and Old Man Creek, Mirrool Creek, Billabong Creek, Yanco Creek and Colombo Creek in the lower catchment.

West of Gundagai, the Murrumbidgee River meanders across the floodplain where numerous floodplain wetlands rely on periodic connectivity to the river. The Murrumbidgee River encounters a number of regulatory structures in its headwaters and on the lowland floodplain. The process of river regulation has led to a major alteration of the natural flow regime of the Murrumbidgee River. Artificially high flow regimes and the historical removal of natural instream structures has resulted in stream bank instability and significantly changed instream habitat and associated floodplain.

The Murrumbidgee River is a heavily regulated system and has 14 dams and eight large weirs. The largest dams are Burrinjuck Dam near Yass, with a capacity of 1.026 million megalitres, and Blowering Dam near Tumut, holding 1.628 million megalitres. More than 10 000 km of irrigation channels supplied by the two storages provide water to the irrigation areas.

The Murrumbidgee Irrigation Area, located on the northern side of the Murrumbidgee River downstream of Narrandera, is privately owned and operated by Murrumbidgee Irrigation. The area is fed by two canals. The Main Canal receives water diverted at Berembed Weir to serve the Yanco, Leeton and Griffith areas and while the Sturt Canal receives water diverted at Gogeldrie Weir to supply the Whitton and Benerembah areas. Located to the south of the Murrumbidgee River, the Coleambally Irrigation area is privately owned and managed by Coleambally Irrigation Corporation. Water is diverted at Gogeldrie Weir into the Coleambally Canal. The Hay Private Irrigation District diverts water from Hay Weir and Maude Weir regulates flow into the Lower Murrumbidgee's Nimmie-Caira system.

The Murrumbidgee catchment contains many significant wetland habitats such as the extensive Lowbidgee wetlands, and Tuckerbill and Fivebough Swamps, listed under the Ramsar Convention for international ecological importance. Extensive areas of riparian river red gum forest along the middle and lower reaches of the river provide valuable riparian habitat for waterbirds and a variety of threatened fauna species.

A detailed description of climate, land and water usage and water regulation infrastructures can be found in the Murrumbidgee resource description report (DoIW 2018a).

1.4. Water quality targets

The Basin Plan water quality targets set out the appropriate water quality required for environmental, social, cultural and economic benefits in the Murray Darling Basin. Monitoring progress towards achieving the targets will identify trends and inform actions that address the causes of water quality decline. The Basin Plan identifies water quality “target application zones” approximating lowland, upland and montane areas of the major river valleys. Lowland areas have an altitude of less than 200 m, upland areas fall between 200 and 700 m and montane areas have an altitude greater than 700 m. The boundaries of these zones are shown in Figure 2.

Two water-dependent ecosystems are described in the Basin Plan; *Declared Ramsar wetlands (streams and rivers; lakes and wetlands)* and *Other water-dependent ecosystems (streams, rivers, lakes and wetlands)*. There are two Ramsar listed wetlands in the Murrumbidgee WRPA, namely Fivebough and Tuckerbil Swamps near Leeton. As there are no routine water quality monitoring sites in these wetlands, the assessment of water quality targets in this report has focused on *Other water-dependent ecosystems.* A revision of the current water quality monitoring program is to be undertaken to fill identified information gaps.

The Basin Plan water-dependent ecosystem targets for turbidity, total phosphorus, total nitrogen, dissolved oxygen and pH were developed following the methods outlined in the ANZECC Guidelines (2000). Water quality data for rivers and streams in ‘reference’ condition from each of the water quality zones were used to develop the target values for each zone (Tiller and Newall 2010). In zones where there were no reference sites, the appropriate default trigger value from the ANZECC Guidelines (2000) for *slightly to moderately disturbed* systems was used as the Basin Plan water quality target (Tiller and Newall 2010).

1.4.1. Assessment using Basin Plan water quality targets

The ANZECC Guidelines (2000) are currently under revision (Guideline Document 4: Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000) as part of the broader revision of the National Water Quality Management Strategy. It is anticipated that there will be no default trigger values in the revised guidelines for Basin States as it is expected that these states have developed regional water quality targets as part of other water planning processes. Basin States may choose to use the water quality targets of the Basin Plan *in lieu* of the default trigger values of the ANZECC Guidelines (2000) if local water quality guidelines are not available. Trigger values and management targets are conceptually different. A trigger value is a concentration below which there is a low risk of adverse effects and if exceeded indicates that some form of action should commence. Management targets are long term objectives used to assess whether an environmental value is being achieved or maintained.

An assessment of Basin Plan water quality targets in NSW (Mawhinney and Muschal 2015) identified targets in some zones and zone boundaries as being inappropriate. Perceived poor water quality at a monitoring site may be due to an inappropriate target, rather than excessive pollutants. In these cases, the Basin Plan targets should be revised in preference for location specific targets which consider local catchment conditions.

It is anticipated the revision of the National Water Quality Management Strategy will improve the advice about comparing results from individual monitoring sites against water quality targets, with more emphasis on catchment assessments and flow-dependant trigger values. The Basin Plan allows an alternate target to be specified in the WQMP under certain conditions. It is expected that the recommendation to develop specific targets will also be retained in the revised National Water Quality Management Strategy. There will be further discussion of water quality targets in the Murrumbidgee WQMP.

1.4.2. Water quality targets for water-dependent ecosystems

The targets for water dependent ecosystems are to ensure water quality is sufficient to:

- Protect and restore ecosystems;
- To protect and restore ecosystem functions;
- Ensure ecosystems are resilient to climate change, and
- Maintain the ecological character of wetlands.

Turbidity, total phosphorus and total nitrogen annual medians in the Murrumbidgee WRPA should be below the target values listed in Table 3. For dissolved oxygen and pH, the annual median should fall within the stated range. The toxicants targets are taken from the ANZECC water quality guidelines (2000) using the values for the protection of 95% of species. The 95% protection of species trigger values applies to typical, slightly to moderately disturbed systems.

Table 3: Water quality targets for water dependent ecosystems objective for all aquatic ecosystems

Water Quality Zone	Ecosystem Type	Turbidity (NTU)	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Dissolved oxygen (mg/L; or saturation (%))	pH	Salinity	Temperature	Toxicants (must not exceed values in 3.4.1 of the ANZECC guidelines)
Water dependent ecosystems (not including Ramsar sites)									
C3 (Murrumbidgee Valley Montane zone)	Streams, rivers, lakes and wetlands	10	20	250	>8.5 mg/L or 90-110%	6.5-7.5	End of valley targets for salinity in Appendix 1 of Schedule B to the agreement	Between the 20th and 80th percentile of natural monthly water temperature	The protection of 95% of species
B3 (Murrumbidgee valley, upland zone)	Streams, rivers, lakes and wetlands	20	35	600	>8.0 mg/L or 90-110%	7.0-8.0			
CMum (Billabong Creek, Upper and Middle Zone)	Streams, rivers, lakes and wetlands	15	40	500	>7.7 mg/L or 90-110%	6.5-7.5			
A3 (Murrumbidgee Valley Lowland zone)	Streams, rivers, lakes and wetlands	35	50	600	>7.0 mg/L; or 80-110%	6.5-8.0			
Ramsar listed water dependent ecosystems									
C3 (Murrumbidgee Valley Montane zone)	Streams and rivers	5	20	250	>8.5 mg/L or 90-110%	6.5-7.5	End of valley targets for salinity in Appendix 1 of Schedule B to the agreement	Between the 20th and 80th percentile of natural monthly water temperature	The protection of 99% of species
	Lakes and wetlands	20	10	350	90–110%	6.5-8.0			
B3 (Murrumbidgee valley, upland zone)	Streams and rivers	5	20	310	>8.0 mg/L or 90-110%	7.0-8.0			
	Lakes and wetlands	20	10	350	90–110%	6.5–8.0			
CMum (Billabong Creek, Upper and Middle Zone)	Streams and rivers	15	40	500	>7.7 mg/L or 90-110%	6.5-7.5			
	Lakes and wetlands	20	10	350	90-110%	6.5-8.0			
A3 (Murrumbidgee Valley Lowland zone)	Streams and rivers	20	30	320	>7.0 mg/L; or 80-110%	6.5–8.0			
	Lakes and wetlands	20	10	350	90-110%	6.5-8.0			

1.4.3. Water quality targets for raw water for treatment for human consumption

The human consumption target is to minimise the risk that raw water taken to be treated for human consumption results in adverse human health effects. The quality of raw water for treatment should also maintain palatability and odour ratings. The *Public Health Act 2010* and the Public Health Regulation (2012) require drinking water suppliers to develop and adhere to a Drinking Water Management System (DWMS). The DWMS addresses the elements of the Framework for Management of Drinking Water Quality (Australian

Drinking Water Guidelines (NHMRC and NRMMC, 2011)) and is a requirement of water suppliers operating licence (NSW Ministry of Health 2013). Water providers in the Murrumbidgee WRPA include:

Balranald Shire Council
Carrathool Shire Council
Coolamon Shire Council
Cootamundra-Gundagai Regional Council
Federation Council
Goldenfields Water
Goulburn Mulwarree Council
Greater Hume Shire Council
Griffith City Council
Hilltops Council
Junee Shire Council
Leeton Shire Council
Lockhart Shire Council
Murray River Council
Murrumbidgee Council
Narrandera Shire Council
Queanbeyan-Palerang Regional Council
Riverina Water County Council
Snowy-Monaro Shire Council
Snowy Valleys Council
Wagga Wagga City Council
Yass Valley Shire Council

1.4.4. Water quality targets for irrigation water

The aim of the agriculture and irrigation target is that the quality of surface water, when used in accordance with the best irrigation and crop management practices and principles of ecologically sustainable development, does not result in crop yield loss or soil degradation. The target is for the electrical conductivity 95th percentile of each 10 year period that ends at the end of the water accounting period, not exceed 833 µS/cm. The target in Table 4 applies at sites where water is extracted by an irrigation infrastructure operator for the purpose of irrigation. The development of the Sodium Adsorption Ratio (SAR) target is outside the scope of this document and will be determined in future reporting when data is available. The time series electrical conductivity data collected by the gauging station network was used to assess this target rather than monthly manual grab samples.

Table 4: Salinity targets for irrigation water

Water Quality Zones	Ecosystem Type	Electrical conductivity (µS/cm)	Sodium adsorption ratio
All	Streams, rivers, lakes and wetlands	833	undetermined

1.4.5. Water quality targets for recreational water

The primary aim of these targets is to protect the health of humans from threats posed by the recreational use of water. This includes a low level of risk to human health from water quality threats posed by exposure to blue-green algae (cyanobacteria) through ingestion, inhalation or contact during recreational use of water resources. The targets are based on Chapter 6 of the National Health and Medical Research Council Guidelines for Managing Risk in Recreational Water (NHMRC 2008). In addition, it is also a general target that cyanobacterial scums should not be consistently present. The recreational water targets are listed in Table 5.

Table 5: Blue-green algae targets for recreational water

Water Quality Zone	Ecosystem Type	Guidelines
All	Recreational water bodies suitable for primary contact.	• ≥ 10 µg/L total microcystins; or ≥ 50 000 cells/mL toxic *Microcystis aeruginosa;* or biovolume equivalent of ≥ 4 mm^3/L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or • ≥ 10 mm^3/L for total biovolume of all cyanobacterial material where known toxins are not present; or • Cyanobacterial scums consistently present

1.4.6. Salinity targets for long-term salinity planning and management

Electrical conductivity targets have not been described for each water quality zone of the Murray Darling Basin. Instead, the Murray Darling Basin End-of-Valley salinity targets, as described in Schedule B, Appendix 1 of the Commonwealth *Water Act (2007),* have been incorporated into the water quality targets. The End-of-Valley targets for the Murrumbidgee River downstream Balranald Weir are listed in Table 6. As for the irrigation water targets, the time series electrical conductivity data has been used to assess this target rather than monthly samples.

Table 6: Salinity targets for purposes of long term salinity planning in the Murrumbidgee WRPA

Water Quality Zones	Ecosystem Type	End of Valley Targets (as absolute values)		
		Salinity (EC µS/cm)		Salt Load (t/yr)
		Median (50%ile)	Peak (80%ile)	Mean
All	Streams, rivers, lakes and wetlands	162	258	169 600

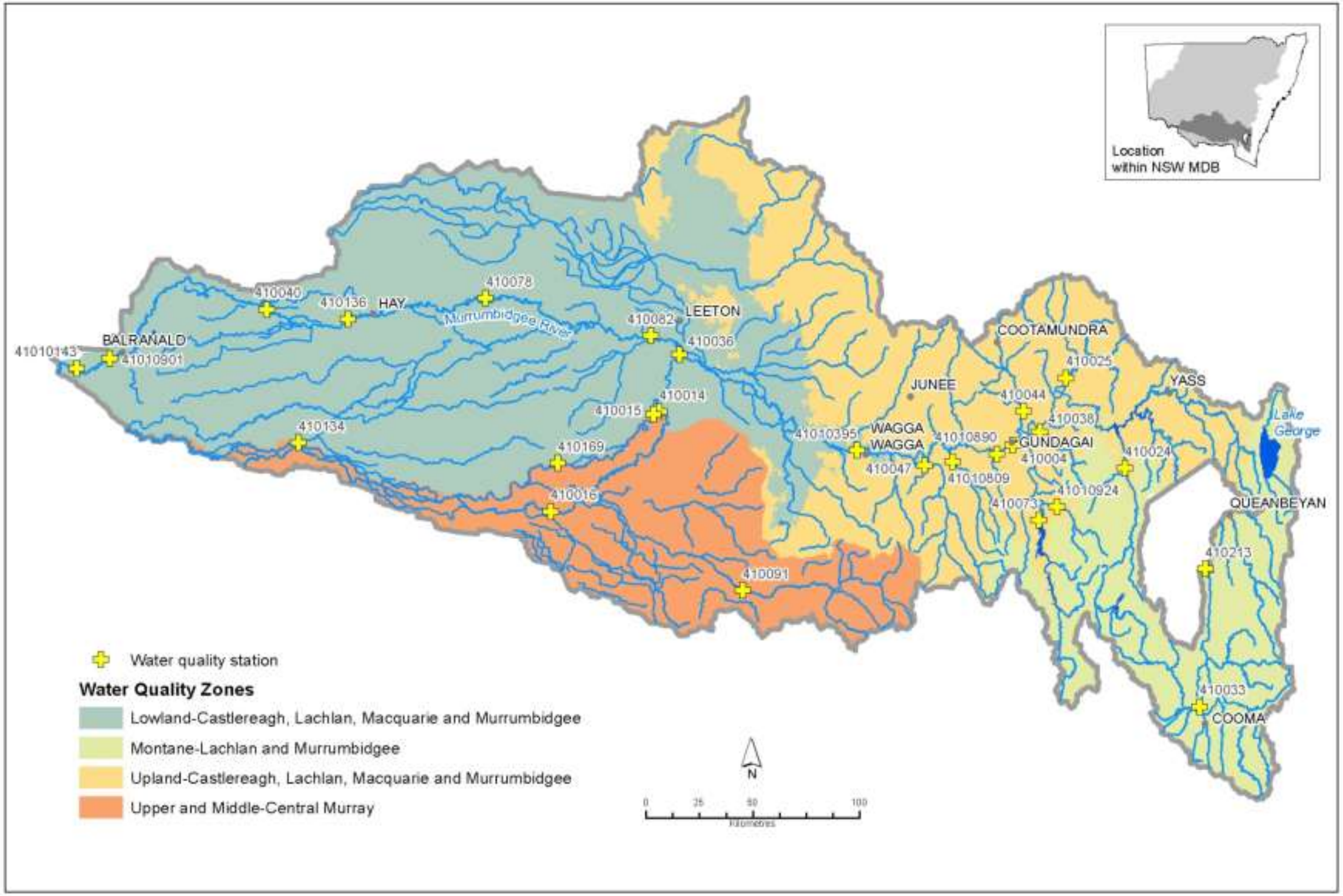


Figure 2: Water quality zones and monitoring sites for the Murrumbidgee WRPA

2. Water quality parameters

This report focuses on assessment of water quality parameters listed in the Basin Plan. These parameters represent general water quality condition and are most likely to demonstrate change over time from broad scale implementation of natural resource management.

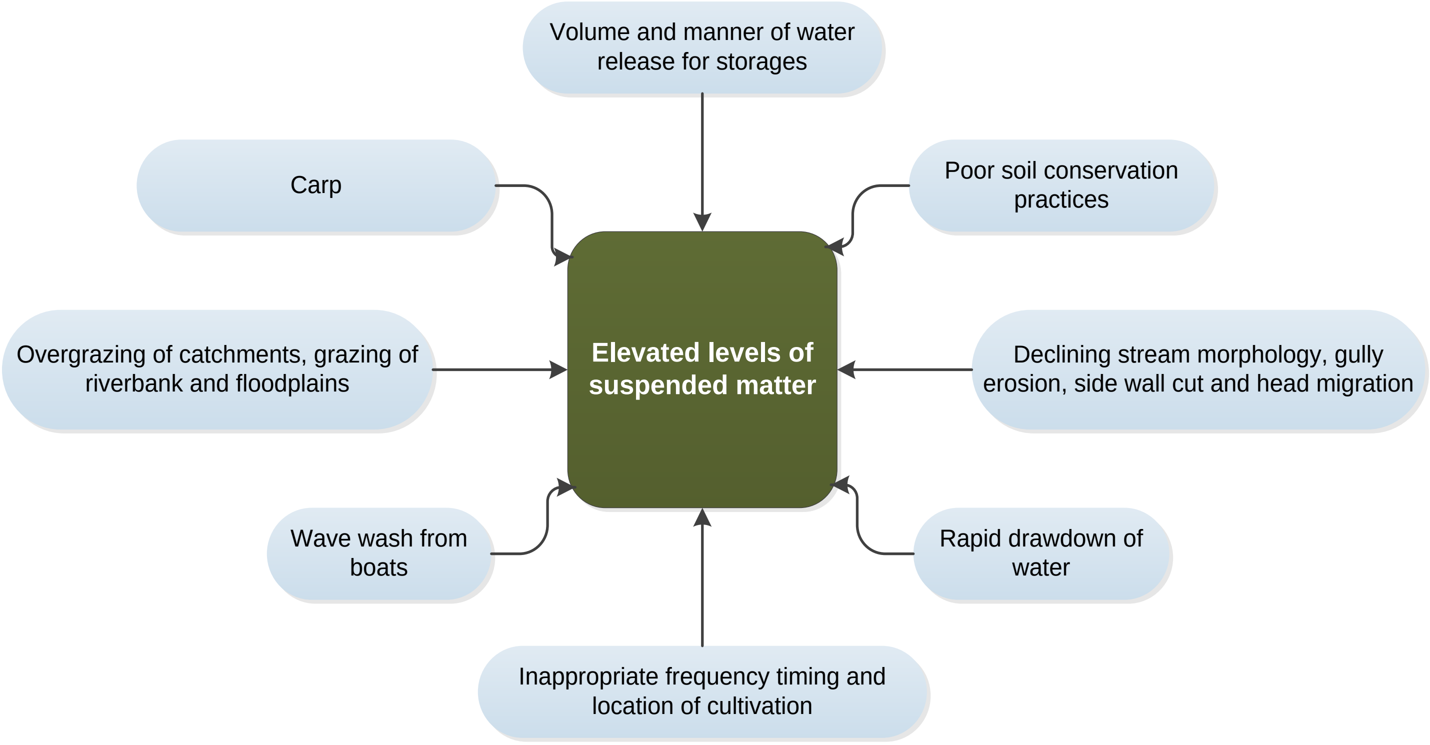
2.1. Turbidity and suspended sediment

Turbidity is a measure of water clarity. As light passes through water it is scattered by suspended material; the higher the scattering of light, the higher the turbidity. For example, after rain, water in rivers may appear brown due to scattering of light from high levels of suspended soils. Turbidity and the amount of total suspended solids are closely related in the Murrumbidgee catchment.

The amount of suspended sediment in water is generally related to the intensity of human activity in the catchment, such as land clearing, accelerated erosion from agricultural land, stream banks or channels and localised issues such as the dispersive nature of the soil and stock access. High turbidity is often associated with increased flow following storm events.

Increased turbidity can lead to reduction in light penetration and primary production. It can also lead to blooms of some harmful blue-green algae species as they are able to out compete other algal species for light in highly turbid conditions (Oliver et al. 2010). Increased suspended sediments can also have negative impacts on plants through smothering (Brookes 1986) and on fish, for example, by clogging gills (Bruton 1985). Suspended matter can also provide a mode of transport for pollutants, such as heavy metals, (Chapman et al. 1998), nutrients and pesticides (Mawhinney 1998) and bacteria (Wilkinson et al. 1995).

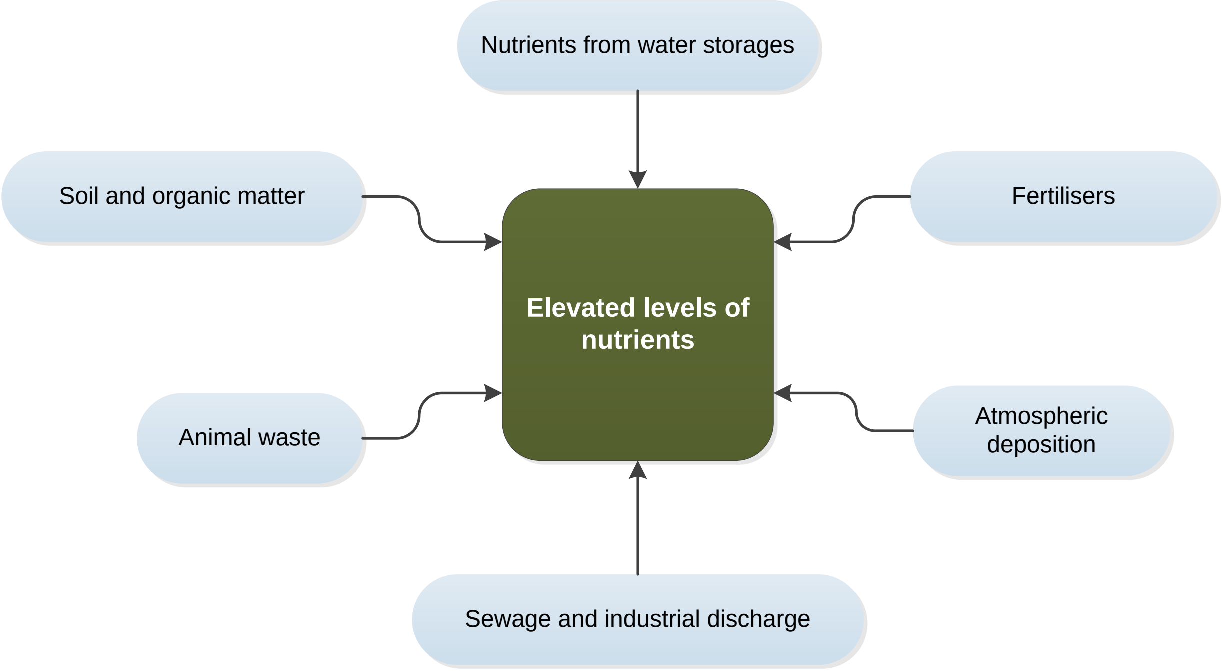
The turbidity of a water sample should be measured immediately without altering the original sample conditions such as temperature and pH (APHA 1995). Field turbidity is more representative of instream conditions and should be used in preference to a laboratory measurement (Buckland et al. 2008).



2.2. Nutrients

Nutrients such as nitrogen and phosphorus are important for sustaining growth and productivity within rivers, but at high concentrations can become an issue in freshwater ecosystems. In many circumstances the inputs of nutrients to rivers has increased due to human activities. This process is known as eutrophication (meaning well-nourished) (Smith et al. 1999).

Sources of nutrient contamination include discharge from sewage treatment works, farms and industry, runoff from agricultural land and urban storm water (Smith et al. 2006). Nutrients can be dissolved, bound within sediments, or adsorbed onto suspended material (i.e. soil or organic matter). Increased nutrient concentration can cause issues including nuisance algal blooms (Anderson et al. 2002), dissolved oxygen depletion (Dodds 2006) or inversely supersaturated and toxic effects to aquatic organisms (e.g. ammonia) (Davis and Koop 2006). This document generally refers to total nitrogen or total phosphorus as a basic measure of all forms of these two elements.



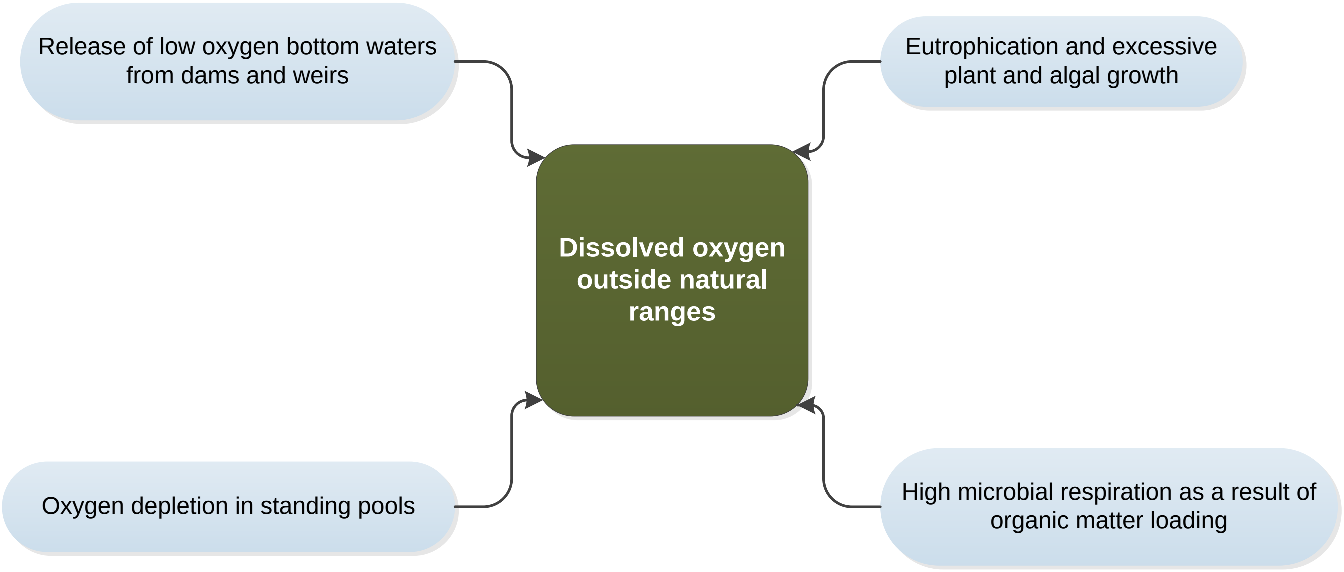
2.3. Dissolved oxygen

Dissolved oxygen in water is essential for supporting fish and aquatic animals. If oxygen levels rise too high or drop too low it places stress on animals and can be fatal (Boulton et al. 2014). Dissolved oxygen may be measured as either the concentration of oxygen in water (mg/L), or as a percentage of the maximum amount of oxygen that may dissolve in water (% saturation). Dissolved oxygen concentrations vary throughout the day and are generally lowest at night when plants and algae are not producing oxygen.

Dissolved oxygen levels drop when respiration (microbes and animals breathing oxygen) out paces oxygen replenishment by primary production (photosynthesis from aquatic plants and algae, and atmospheric adsorption). This process is called ecosystem metabolism. Factors that influence metabolism include the concentration of organic carbon and nutrient bioavailability, temperature, light penetration, turbidity and hydrology (Caffrey 2004; Young et al. 2008). The Basin Plan targets for dissolved oxygen include a lower and upper range. Maintaining dissolved oxygen levels within this range indicates that ecosystem metabolism is largely in equilibrium.

When there is a sudden input of bioavailable organic carbon and nutrients, for example when flood waters inundate an area with high levels of fresh leaf litter and flush this material back into the river, microbial respiration can increase rapidly causing oxygen levels to drop to very low concentrations. These are known as anoxic blackwater events (Whitworth et al. 2012). Alternatively, high nutrient inputs can lead to excessive aquatic plant growth resulting in very high oxygen levels or supersaturation.

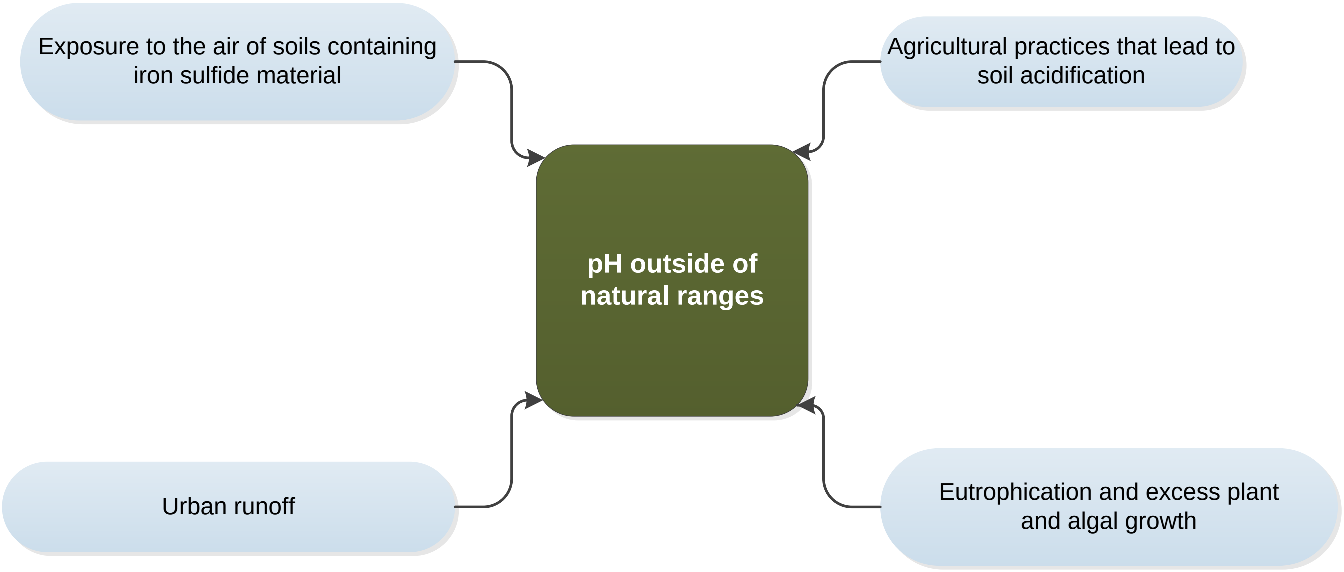
While anoxic blackwater events occurred naturally in the past, regulation of Australian lowland floodplain river systems has increased their intensity, while decreasing their frequency (Boulton and Lloyd 1992; Bunn et al. 2006). Blackwater events are now more likely to lead to lower levels of oxygen in rivers and more devastating fish kills and ecosystem collapse.



2.4. pH

The pH is a measure of how acidic or basic water is. The pH ranges between 0 (very acidic) to 14 (very basic) with 7 being neutral. pH outside of natural ranges can be harmful to plants and animals (Boulton et al. 2014). It influences the solubility and bioavailability of nutrients and carbon and the toxicity of pollutants (Closs et al. 2009). Very high or low pH can affect the taste of water, increase corrosion in pipes and pumps and reduce the effectiveness of drinking water treatment (WHO 2004).

The pH of water varies with soil type, geology and surface water and groundwater interactions. Human activities such as agricultural practices that expose acid sulphate soils and increase erosion may lead to decreased pH (Dent and Pons 1995). Eutrophication and excessive algal growth can lead to increases in pH (Boulton et al. 2014). Detrimental effects from pH on aquatic ecosystems are unlikely at the levels found across much of the Murray Darling Basin (Watson et al. 2009).

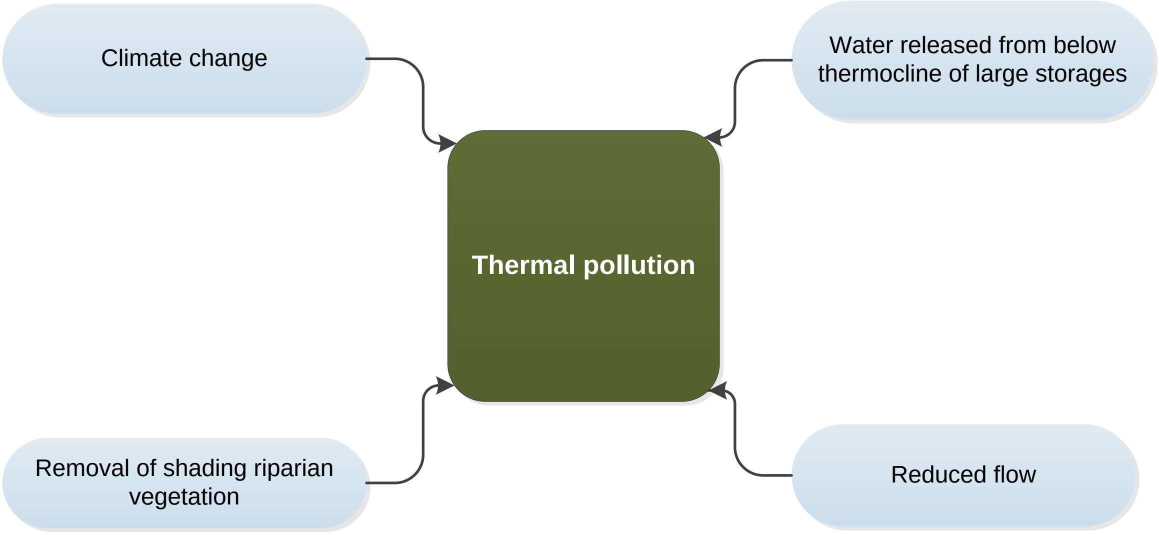


2.5. Water temperature and thermal pollution

Water temperature influences many biological and ecosystem processes. Warmer temperatures can increase growth rates and metabolism of microbes, animals, plants and algae (Boulton et al. 2014; Kaushal et al. 2010). Temperature is also linked to spawning, breeding and migration patterns of many aquatic animals (Astles et al. 2003; Lessard and Hayes 2003). Higher temperatures can result in increased solubility of salts and decreased solubility of oxygen (Boulton et al. 2014).

Temperature is highly dynamic and varies at different time scales (e.g. seasonally and day/night). Human activities can have large impacts on temperature. Cold water pollution can occur when dams stratify, creating a cold bottom layer. If water is released from this bottom layer, it can lead to considerably colder water temperature than normal (Preece 2004). Thermal water pollution has had significant negative impacts on fish recruitment and can potentially influence ecosystem productivity and carbon cycling downstream of dams (Lugg and Copeland 2014; Webb et al. 2008).

The removal of riparian vegetation reduces shading, leading to increased water temperatures (Marsh et al. 2005; Rutherford et al. 2004). Other human activities such as discharge from power plants or warmer groundwater can also lead to increased river temperature (Lardicci et al. 1999). Climate change is also affecting river temperatures in the Murray Darling Basin (Pittock and Finlayson 2011).

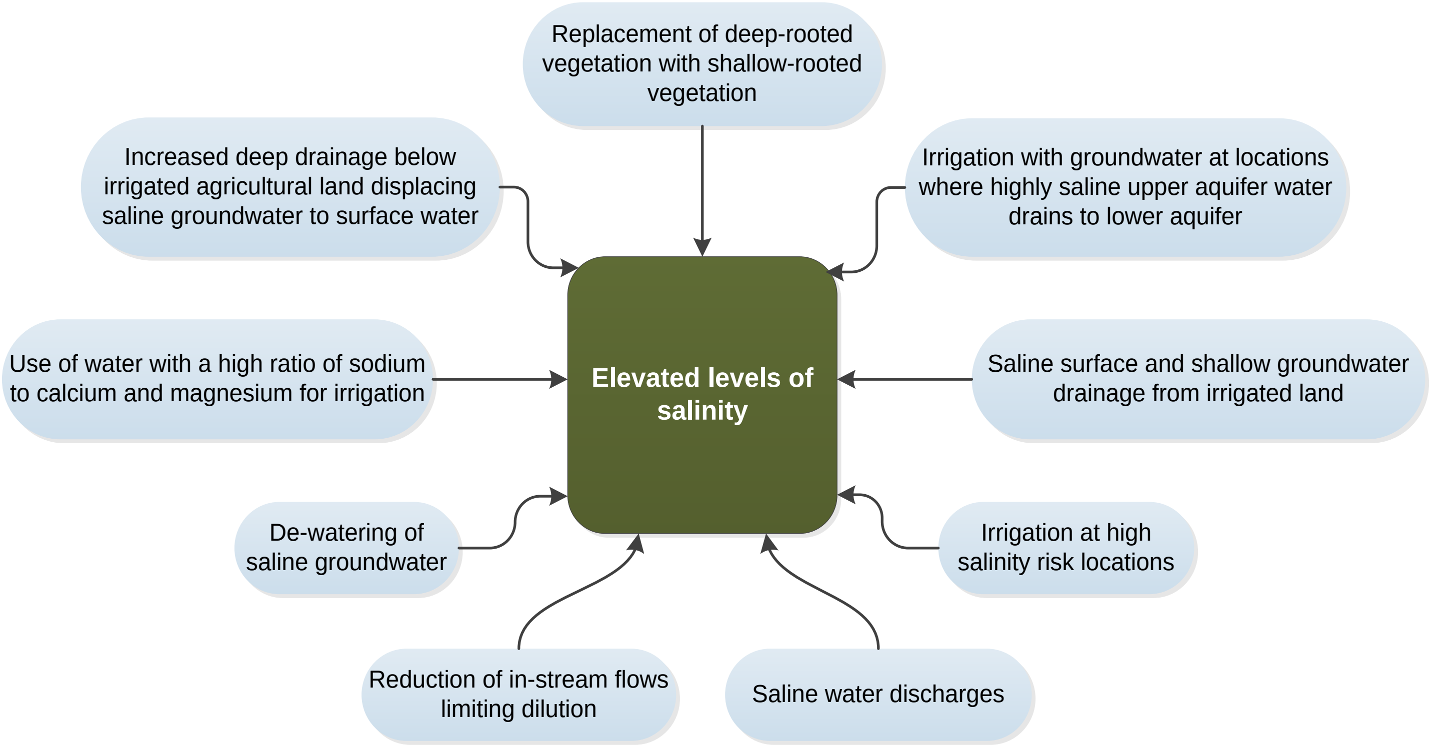


2.6. Salinity

Salinity is the presence of soluble salts in water. It is generally measured as electrical conductivity (the ability of dissolved salts to transmit an electric current). Increased salinity can have harmful effects on many plants and animals (James et al. 2003), effect drinking water supplies (WHO 2004) and cause damage and loss to cropping and horticulture sectors (Hillel 2000). The suitability of water for irrigation is often measured as a sodium adsorption ratio (SAR), which is a measure of the relative concentration of sodium, calcium and magnesium (Sposito and Mattigod 1977).

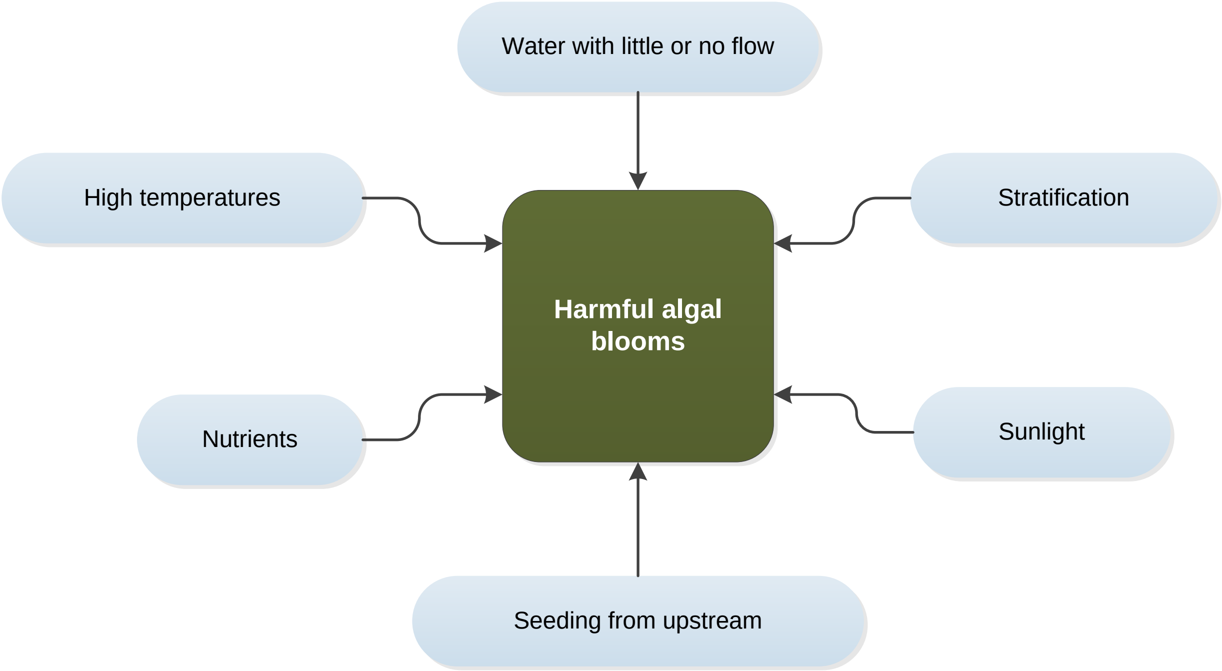
Increased electrical conductivity in rivers may be derived from the presence of salt in underlying soil, salt released from bedrock by weathering, from salt deposited during past marine inundation of an area, or salt particles being carried over the land surface from the ocean. Australia’s arid climate provides insufficient rainfall to dilute the high levels of salt in the landscape. This has been further exacerbated by the increased mobilisation of salts by the use or discharge of saline groundwater to surface water, removal of deep-rooted native vegetation to be replaced with shallow-rooted crops or pastures and discharge of saline water from mining or industrial processes.

The initial stage of a flood is characterised by high electrical conductivity, often called a ‘first flush’. These appear as sharp spikes in the data followed by a rapid decline. As rainfall first starts to run off the landscape, it mobilises salts concentrated on the soil surface and washes them into the waterways. As flow increases, salts concentrated in the bottom of pools are also flushed out. Following this peak, electrical conductivity drops rapidly due to the dilution of salts by rainwater. The irrigation industry is more likely to experience difficulties with these high salinity spikes before impacts of any long term accumulation are realised. It is advisable for irrigators to let this first flush pass downstream before commencing to pump.



2.7. Harmful algal blooms

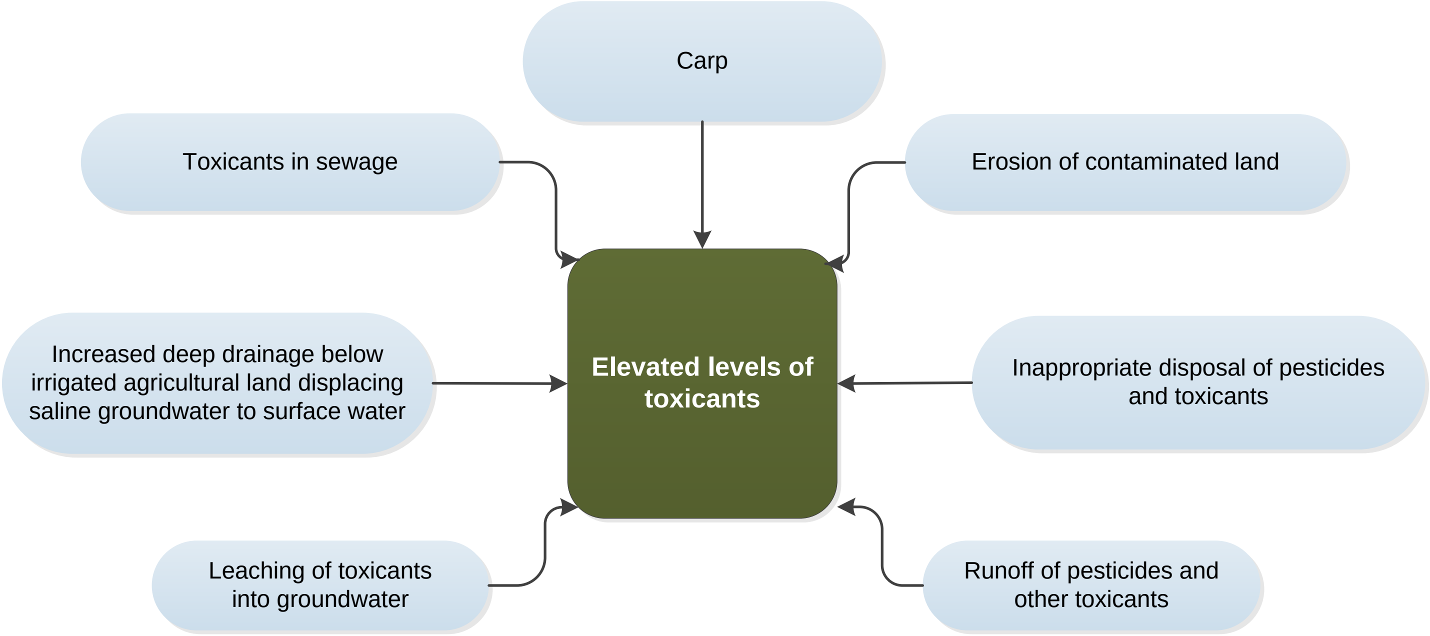
Most algae are safe and are a natural part of aquatic ecosystems. However, some types of blue-green algae (cyanobacteria) can produce hepatotoxins, neurotoxins and contact irritants. When these species occur in bloom proportions (harmful algal blooms) they pose a serious risk to human, animal and ecosystem health (Chorus and Bartram 1999). In addition to toxin production, algal blooms can produce taste and odour problems in water supplies and blockages in irrigation systems. Harmful algal blooms can occur when there are suitable conditions including high levels of nitrogen and phosphorus, warm water temperatures and sunny days, low turbidity and calm water conditions where water may stratify (Anderson et al. 2002; Hudnell 2008). Blue-green algal blooms are normally associated with lakes and reservoirs, but do occur in rivers when conditions are favourable.



2.8. Toxicants

Toxicants refer to chemical contaminants that have the potential to be toxic at certain concentrations. These include metals, inorganic and organic toxicants (Warne 2002; Warne et al. 2014). Toxicants can have public health impacts and induce stress and fatalities in plants and animals (Heugens et al. 2001; Newman 2009). Toxicants enter water from a range of human activities including agriculture, industry and mining, and can also enter surface waters naturally through groundwater connectivity.

Spray drift, vapour transport and runoff are the main pathways for pesticide transport into river systems (Mawhinney 1998, Raupach et al. 2001). Spray drift and vapour can both contribute low level but almost continuous inputs to the riverine ecosystem during the peak spraying season. The likelihood of pesticide drift is influenced by weather conditions, the method of application, equipment used and crop structure. Runoff tends to provide occasional high concentrations of pesticide contamination. Pesticides in runoff can be dissolved in the water, bound within sediments or adsorbed on to suspended particles.

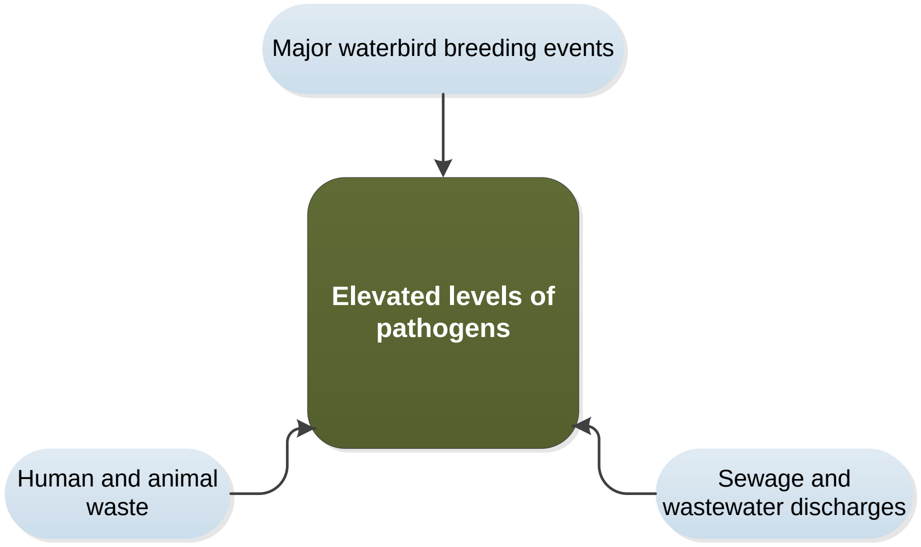


2.9. Pathogens

Bacteria and microorganisms occur naturally in rivers. Certain species have the potential to elicit disease symptoms; these are referred to as pathogens. In certain concentrations, pathogens can have negative impacts on public health (Prüss 1998; WHO 2004), aquatic animals (Gozlan et al. 2006), stock watering (LeJeune et al. 2001) and inhibit the use of water for irrigation (Steele and Odumeru 2004).

Human activities can increase the potential risk from pathogens including discharge of human and animal waste and sewage, and access of stock and animals to rivers and water supplies (Ferguson et al. 1996; Fong and Lipp 2005; Hubbard et al. 2004). Deal and Wood (1998) reported high levels of faecal coliforms were generally reported in spring and summer whilst autumn and winter had lower levels. The sources of the *E.Coli* in river samples were identified as both animal and human in origin. Current monitoring and knowledge of the presence of pathogen issues in the Murrumbidgee catchment is limited.

It is expected that increased runoff will result in increased faecal coliforms, as material such as soil and faecal matter is washed into waterways. Additionally, periods of low rainfall, low flow, and warm water temperatures provide appropriate conditions for faecal coliforms to multiply (Deal 1997). Large water bird breeding events in the Lower Murrumbidgee result in naturally high levels of faecal coliforms. The pathogens would largely be restricted to the rookery area and immediately downstream.



3. Water access rules and flow management in the Murrumbidgee WRPA

In parts of the catchment where flows are unregulated, there are very limited opportunities to manage water quality through flow management. Under the water sharing plan for the Murrumbidgee unregulated and alluvial water sources (2012), pumping is not permitted from natural pools when the water level in the pool is lower than its 'full capacity'. 'Full capacity' can be approximated by the pool water level at the point where there is no visible flow into and out of that pool. The Cease to Pump rule ensures that additional pressure is not placed on pools by extracting water when the waterway has stopped flowing. During low flows, as pools contract, water quality can deteriorate, algal blooms occur, dissolved oxygen levels decline and fauna compete for the reducing food supplies.

In the regulated system downstream of Burrinjuck and Blowering Dams there is more scope to utilise flow rules and environmental flows to benefit water quality. In the water sharing plan for the Murrumbidgee regulated water source (2016) there are numerous rules for consideration.

End of system flows – A minimum daily flow in the Murrumbidgee River at Balranald gauge must be maintained throughout the year. The Murrumbidgee regulated water sharing plan identifies how the volume required is determined. A minimum daily flow of 50 ML/day must also be maintained in Billabong Creek at Darlot throughout the year. Maintaining base flow is important to slow the decline in water quality by preventing pools from stratifying and stagnating.

Daily minimum flow release – Water released from Blowering and Burrinjuck Dams to deliver benefits downstream of the storages. The delivery is based on rules outlined in the water sharing plan.

Plan extraction limits - Sets a limit on the long term average volume of water that can be extracted. All water above the plan extraction limit (estimated 1 925 000 ML/year) is to be used for the environment. On a long-term average basis, the Murrumbidgee water sharing plan ensures that approximately 50% of long-term average annual flows (estimated 4 360 000 ML/year) in the river are preserved and will contribute to the maintenance of basic environmental health.

Protect low flows in upper reaches (Dam transparency) – Release up to 560 ML/day from Blowering Dam and between 300 and 615 ML/day from Burrinjuck Dam, depending upon the inflows into each storage. The aim is to ensure some degree of natural flow variability in the river reach immediately downstream of Burrinjuck and Blowering Dams.

Dam translucency – There are rules to ensure that some degree of natural flow variability is restored downstream of Burrinjuck Dam. The translucency rule aims to release a proportion of the inflows to Burrinjuck Dam, depending on the time of year and the catchment conditions. There are no translucent releases from Blowering Dam into the Tumut River.

Environmental contingency allowance - Under the Murrumbidgee regulated water sharing plan, there are three environmental water allowances maintained for environmental purposes:

- Environmental Water Allowance 1 (EWA1);
- Environmental Water Allowance 2 (EWA2), and
- Environmental Water Allowance 3 (EWA3).

The volume of water credited to each of these allowances depends on a variety of factors, which are detailed in the Murrumbidgee Regulated Water Sharing Plan. The release of an environmental allowance may be made to provide water for wetland inundation, fish passage or breeding, water bird breeding, water quality management or to support environmental assets or environmental functions within and downstream of this water source that have been identified as water-dependent Aboriginal cultural values. Detailed release rules are developed before the start of each year. The Plan provides for an Environmental Water Allowance Reference Group (including representation from conservation interests and water users) to give advice on the release rules.

Supplementary flow access rules - There are also restrictions on extractions under supplementary water access licences. Holders of these licences are able to extract water during announced periods when flows exceed those required to meet other obligations and environmental needs. This is typically during periods when Blowering or Burrinjuck Dams are spilling or as a result of high tributary inflows downstream of the dams. These restrictions are in place to:

- Preserve a significant proportion of natural tributary flows for river health and the wetlands;
- Protect important rises in water levels;
- Maintain wetland and floodplain inundation, and
- Maintain natural flow variability.

The Commonwealth Environmental Water Office (CEWO) has approximately 54 000 ML of environmental water that must be managed to protect or restore environmental assets, so as to give effect to relevant international agreements, such as the Ramsar Convention. The CEWO water must also be managed in accordance with the Basin Plan and the Basin Watering Strategy.

In addition to the environmental water allowance under the water sharing plan, the NSW Office of Environment and Heritage (OEH) holds approximately 8 000 ML of “discretionary” or “held” environmental water which was acquired under the Riverbank Program or Wetlands Recovery Program, either through water efficiency works or by purchase of entitlement. Current environmental watering is largely focused on supporting high flow, river and floodplain functions and improving the health of wetlands and floodplains.

It is not the intent of the Water Quality Management Plan to propose the use of environmental water to address water quality issues. However, the release of environmental water for its designated purpose, will provide water quality benefits for the Murrumbidgee WRPA, such as breaking up stratification in pools, diluting salts, mobilising dissolved organic carbon and making conditions less favourable for harmful algal bloom development. Holders of environmental water in their independent decision making, must 'have regard' to dissolved oxygen, salinity and recreational water quality when making decisions about the use of environmental water.

Environmental water is to be managed in accordance with the Long Term Watering Plan (LTWP), Basin Watering Strategy and Annual Basin Watering Priorities. In relation to water quality, the draft Murrumbidgee LTWP recognises water being of a quality unsuitable for use, as a risk to achieving environmental outcomes. Issues identified include poor water quality in terms of nutrients, dissolved oxygen and salinity, hypoxic blackwater, blue-green algae, chemical contaminants and cold water pollution.

There are opportunities to adjust the way water is delivered from Burrinjuck and Blowering Dams to provide additional water quality and environmental benefits to the aquatic ecosystem. Releasing large volumes water as a block, with very steep rising and falling limbs, has the potential to pose threats to the Tumut and Murrumbidgee Rivers through bank slumping and bank erosion. Mimicking a natural flood event by maintaining natural flow variability and natural rates of change in water levels, with more gradual rising and falling limbs, can help reduce bank slumping. Increased water levels can inundate lower benches, flushing carbon into the system providing fuel to stimulate riverine food webs. High flow velocities can also scour silt and biofilms from rocks and logs in the river, resetting biofilm development and improving habitat quality.

The trade of water entitlement is another potential rule to manage risks to water quality. Trading entitlement out of an over allocated water source or away from a potentially sensitive area, could have long term benefits by assisting in mitigating the impact on instream values via reduced levels of extraction. Similarly, the trade of held environmental water into a stressed water source could provide benefits to water quality. Water trade has not been identified in this report as an immediate mitigation measure, as there is no certainty of where, when or if it may occur.

4. Methods

4.1. Site selection and monitoring

The water quality data used in this report were compiled from 26 routine water quality monitoring stations located within the Murrumbidgee WRPA. The data were collected on a monthly basis for the State Water Quality Assessment and Monitoring Program (SWAMP). This water quality monitoring program is responsible for collecting, analysing and reporting the ambient water quality condition of rivers in NSW. The program in its current form commenced in November 2007 replacing numerous regionally based water quality monitoring programs.

A full station list is given in Table 7 and the location of these sites in relation to the Basin Plan water quality zones is shown in Figure 2. The coordinates for all monitoring sites are listed in Appendix A.

Table 7: List of routine water quality monitoring stations in the Murrumbidgee WRPA

Basin Plan WQ zone	Station Number	Station Name
C3	410033	Murrumbidgee River at Mittagang Crossing
B3	410213	Murrumbidgee River at Angle Crossing
B3	410024	Goodradigbee River at Wee Jasper
B3	410025	Jugiong Creek at Jugiong
B3	410044	Muttama Creek at Coolac
B3	410038	Adjungbilly Creek at Darbalara
B3	41010924	Goobarragandra River at Little River Road
B3	410073	Tumut River at Oddys Bridge

Basin Plan WQ zone	Station Number	Station Name
B3	410004	Murrumbidgee River at Gundagai
B3	41010809	Hillas Creek at Mundarlo Road Bridge
B3	41010890	Adelong Creek at Bereena
B3	410047	Tarcutta Creek at Old Borambola
A3	41010395	Murrumbidgee River downstream Wagga Wagga
A3	410014	Colombo Creek at Morundah
A3	410015	Yanco Creek at Morundah
A3	410169	Yanco Creek at Yanco Bridge
A3	410036	Murrumbidgee River downstream Yanco Weir
A3	410082	Murrumbidgee River at Gogeldrie Weir
A3	410078	Murrumbidgee River at Carathool
A3	410136	Murrumbidgee River downstream Hay Weir
A3	410040	Murrumbidgee River downstream Maude Weir
A3	41010901	Murrumbidgee River downstream Balranald Weir
A3	41010143	Murrumbidgee River at Waldaira
CMum	410091	Billabong Creek at Walbundrie
CMum	410016	Billabong Creek at Jerilderie
CMum	410134	Billabong Creek at Darlot

There are 37 continuous electrical conductivity monitoring sites in the Murrumbidgee WRPA. These are located at existing river gauging stations and take electrical conductivity readings every 15 minutes. All continuous electrical conductivity data is stored in the Hydstra database. The Murrumbidgee River downstream of Balranald Weir is the Murrumbidgee catchment End-of-Valley salinity target site.

Water temperature data is collected at all routine water quality monitoring sites, however as it is collected monthly, it does not give an indication of diurnal variation or detect cold water impacts. Continuous water temperature data is collected at 39 sites. Two of these sites have temporary Hobo loggers installed. The station list in Table 8 contains the electrical conductivity and water temperature monitoring sites. The locations of some of these sites in relation to Burrinjuck and Blowering Dams in the Upper Murrumbidgee catchment are shown in Figure 3. Site coordinates are listed in Appendix A.

Table 8: List of continuous water temperature and electrical conductivity monitoring stations in the Murrumbidgee WRPA

Station Number	Station Name	Sensor type
410090	Yass River at Gundaroo	Permanent
410176	Yass River Upstream Burrinjuck Dam	Permanent
410024	Goodradigbee River at Wee Jasper	Permanent
410777	Murrumbidgee River at Halls Crossing	Permanent
410008	Murrumbidgee River d/s Burrinjuck Dam	Permanent
410068	Murrumbidgee River at Glendale	Permanent
410025	Jugiong Creek at Jugiong	Permanent
410195	Murrumbidgee River u/s Gobarralong Bridge	Permanent
410057	Goobarragandra River at Lacmalac	Permanent
410073	Tumut River at Oddys Bridge	Permanent
410039	Tumut River at Brungle Bridge	Hobo
41010891	Tumut River at Murrumbidgee Junction	Hobo
410044	Muttama Creek at Coolac	Permanent
410004	Murrumbidgee River at Gundagai	Permanent
410061	Adelong Creek at Batlow Road	Permanent
410043	Hillas Creek at Mount Adrah	Permanent
410047	Tarcutta Creek at Old Borambola	Permanent
410156	Kyeamba Creek at Book Book	Permanent
410048	Kyeamba Creek at Ladysmith	Permanent
410001	Murrumbidgee River at Wagga Wagga	Permanent
410023	Murrumbidgee River d/s Berembed Weir	Permanent
410103	Houlaghans Creek at Downside	Permanent
410093	Old Man Creek at Kywong	Permanent
410005	Murrumbidgee River at Narrandera	Permanent
410108	Diversion Channel 800 at Outfall	Permanent
410169	Yanco River at Yanco Bridge	Permanent

Station Number	Station Name	Sensor type
410186	Billabong Creek d/s Ten Mile and Mountain Creeks	Permanent
410168	Billabong Creek at Hartwood	Permanent
410091	Billabong Creek at Walbundrie	Permanent
410148	Forest Creek at Warriston Weir	Permanent
410170	Billabong Creek u/s Innes Bridge	Permanent
410110	Diversion Channel 500 at Outfall	Permanent
410134	Billabong Creek at Darlot	Permanent
410040	Murrumbidgee River d/s Maude Weir	Permanent
410041	Murrumbidgee River d/s Redbank Weir	Permanent
410130	Murrumbidgee River d/s Balranald Weir	Permanent
41000271	Alum Creek at Jones Plain Road	Permanent
41000027	Bredbo River at Bredbo Station	Permanent
41000272	Murrumbidgee River u/s Michelago Creek	Permanent

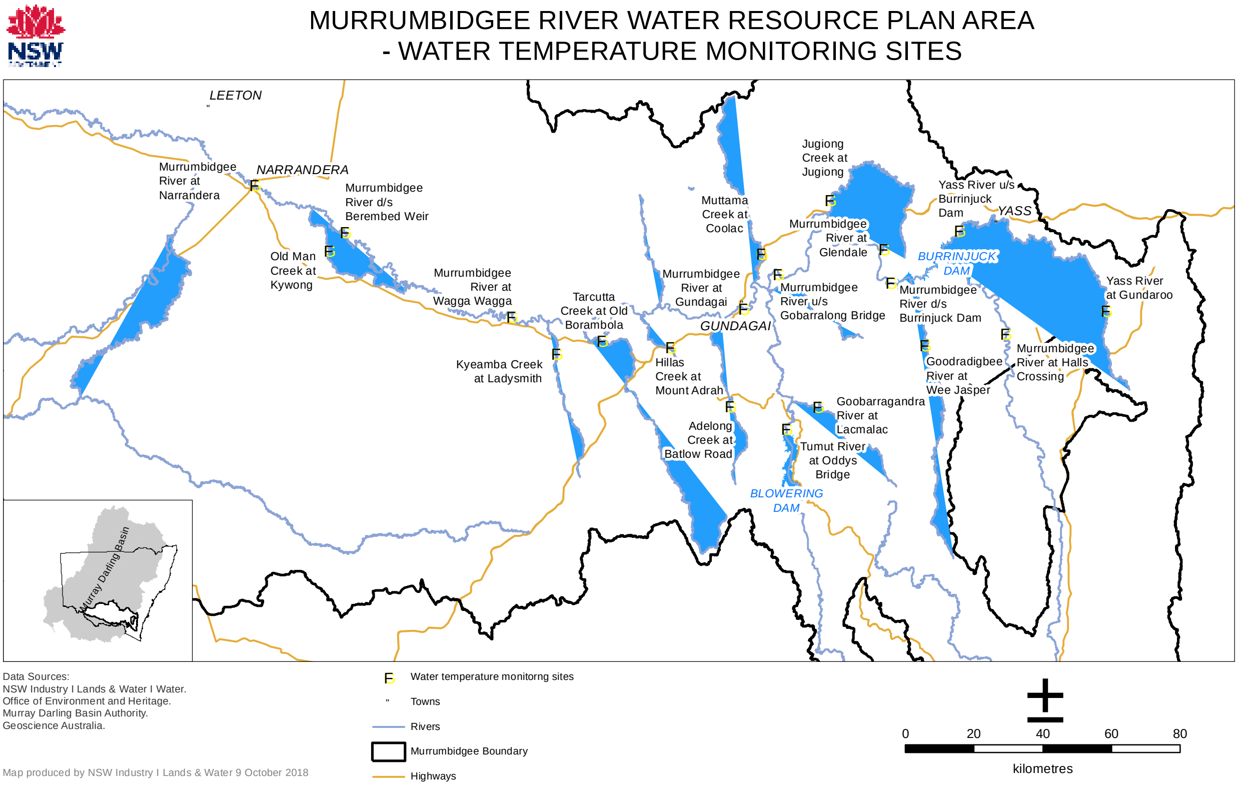


Figure 3: Continuous water temperature monitoring sites in the upper Murrumbidgee WRPA

Blue-green algae monitoring in Blowering and Burrinjuck Dams focuses on the main impoundment upstream of the wall. Samples are also collected downstream of Blowering and Burrinjuck Dams to determine if potentially toxic blue-green algae are being released. Routine monitoring is undertaken in the lowland weirs such as Redbank, Maude, Hay and Balranald and recreational lakes (Lake Albert, Lake Wyangan and Yanga Lake). Table 9 lists the blue-green algal monitoring sites in the Murrumbidgee WRPA.

Table 9: List of blue-green algae monitoring stations in the Murrumbidgee WRPA

Station Number	Station Name
410033	Murrumbidgee River at Mittagang Crossing
41010021	Burrinjuck Reservoir
410008	Murrumbidgee River downstream of Burrinjuck Dam
410004	Murrumbidgee River at Gundagai
41015431	Tantangara Reservoir
41010001	Blowering Reservoir

Station Number	Station Name
410073	Tumut River at Oddys Bridge
41010395	Murrumbidgee River downstream of Wagga Wagga
N/A	Lake Albert, Wagga Wagga
41010839	Lake Wyangan, Griffith
41010711	Barren Box swamp
41010888	Yanga Lake
410082	Murrumbidgee River at Gogeldrie Weir
410078	Murrumbidgee River at Carathool
410002	Murrumbidgee River at Hay
41010343	Murrumbidgee River at Hay Weir
41010362	Murrumbidgee River at Maude Weir
41010361	Murrumbidgee River at Redbank Weir
41010901	Murrumbidgee River at Balranald Weir
410091	Billabong Creek at Walbundrie
410016	Billabong Creek at Jerilderie
410134	Billabong Creek at Darlot

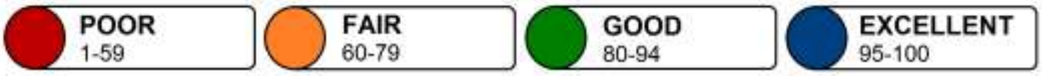
4.2. Water quality index (WaQI)

A water quality index (WaQI) is an important tool to communicate and report water quality condition. It conveys information that is complex and on different scales (e.g. 75% saturation dissolved oxygen, 0.05 mg/L total phosphorus) to a common score and rating.

A literature review was conducted in 2015 to understand the different approaches and techniques for calculating and using water quality indexes globally. A method based on a modified Canadian Council of Ministers of the Environment (CCME) water quality index (Lumb et al. 2006) was then defined, that incorporated both frequency and exceedance of water quality targets. The method scales five years of data into a single number between 1 and 100 which corresponds to four categories: poor, fair, good and excellent. It is applied to both individual parameters and parameters combined to provide an overall score (Appendix B).

For New South Wales WQMP, the WaQI is calculated for each water quality parameter individually and as an overall integrated index. It includes total nitrogen, total phosphorus, turbidity, dissolved oxygen and pH. There is no weighting of individual parameters. It is based on the exceedance of water quality targets as prescribed in Schedule 11 of The Basin Plan. Where data is available, temperature, salinity and blue-green algae have also been scored as individual parameters.

The outcome provides a number between 1 and 100, and is categorised according to the following water quality rating.



4.3. Catchment stressor identification

The Catchment Stressor Identification process (CSI) (Figure 4) helps describe the status, issues and potential causes of water quality degradation. The process uses an eco-epidemiological approach (Cormier 2006), and is broadly related to the approach developed by Cormier et al. (2003) for water quality planning in North America for the United States Environmental Protection Agency (USEPA). It identifies issues and causes based on the idea of abductive inference that is; considering possible causes of water quality degradation, weighing evidence and putting forward factors likely contributing to water quality degradation. Once the water quality degradation issues are defined, evidence is gathered and weighed before conclusions on probable causes synthesised.

The CSI process is intended to be iterative and involves conceptual mapping, data evaluation, literature reviews, GIS mapping and input of local and expert knowledge. The process consists of a standard set of procedures and outputs. The final output expresses what water quality degradation is present and the likely cause, using narrative, figures and maps.

Figure 4: Conceptual diagram of the CSI process

4.3.1. Conceptual mapping

Conceptual models are a useful step in mapping out possible causes of water quality degradation. They help define the scope of possible causes of water quality degradation and show interlinkages between both causes of degradation and between water quality parameters. A standard conceptual diagram for overall water quality and each parameter has been created based primarily on Schedule 10 of the Basin Plan.

4.3.2. Literature review

A review of both published and grey literature has been undertaken for the Murrumbidgee WRPA. Published literature was reviewed using a standardised approach through the Web of Science database. Grey literature was reviewed in an informal manner through web searches and Google Scholar.

4.3.3. Summary statistics

The data used for this and the following analysis is primarily from the State Water Quality Assessment and Monitoring Program (SWAMP). Summary statistics of available data for each parameter in a WRP area have been defined. These include basic statistics such as range (minimum, maximum), central tendency (mean, median) and variability (standard deviation, interquartile range, coefficient of variation). These statistics help define basic patterns of water quality degradation.

4.3.4. Data analysis

Analysing water quality data is a crucial step in diagnosing issues and their causes. Basic analysis involved examining relationships between parameters, temperature and season, location and hydrology. Data analysis is used to help understand the nature of ecological problems, their interdependencies, seasonal variances, relationship to flow regimes and spatial relationships. Data analysis was based on routine sampling conducted between 2010 and 2015.

4.3.5. Spatial and GIS

Existing spatial information relevant to the causes of water quality degradation for each parameter has been compiled into ArcGIS geodatabases. Initial maps have been produced with relevant spatial information and land use are determined through the CSI process for each WRP area boundary. The spatial information may be refined during the CSI process.

4.3.6. Local and expert knowledge

For each WRP area, meetings were held with the technical working group comprised of representatives from partner agencies and other invited experts. These meetings facilitated input of local knowledge and expert opinion to the WQMP. In general, these meetings occurred on a one-on-one or organisational basis. This approach was chosen to allow more freedom for people to speak and explore ideas. Information from these meetings was used to refine the scope of water quality degradation, conceptual diagrams, GIS mapping, and to guide further exploration. They also help define conclusions reached for the causes of water quality degradation and most relevant and fit-for-purpose information to include in this report and the Murrumbidgee WQMP.

4.4. Murrumbidgee WRPA Risk Assessment

Risk assessments are the first step in the development of a water resource plan for each surface water and groundwater planning area in the Murray Darling Basin. Risk assessments and associated water resource plans must be prepared having regard to current and future risks to the condition and continued availability of water resources in a water resource plan area, and outline strategies to address those risks.

The risk assessment approach compiles the best available information to highlight the range of potential risks that may be present. Where a risk is highlighted as medium or high, it does not necessarily imply that existing rules in the water sharing plan require change or are inadequate, but rather, that further detailed investigation may be required. The risk assessment also highlights where existing plan rules may already be mitigating the risk.

The risk to the health of water dependent ecosystems was assessed by identifying the risk, quantifying the impact based on instream values (consequence) and determining the probability of that consequence occurring (likelihood).

The consequence of poor water quality was determined using the HEVAE (High Ecological Value Aquatic Ecosystems) instream value. For each monitoring station, a reach was defined as 25 km upstream and downstream of the site. This was chosen as a conservative estimate of the spatial representativeness of water quality data and movement of instream biota within the river channel. The consequence decision support tree was then used to define the final consequence score using the HEVAE instream values within each reach area. For detailed description of the risk assessment process and outputs, refer to the Risk Assessment for the Murrumbidgee Water Resource Plan Area (SW9) (DoIW 2018b).

The calculation method for the likelihood scores varied between water quality attributes. The likelihood scores for total nitrogen, total phosphorus, dissolved oxygen, pH and turbidity were the frequency that the Basin Plan water quality target was exceeded, based on monthly sampling data for the five year period, 2010 to 2015.

Continuous electrical conductivity data, rather than discrete monthly data, was used to assess risks from poor salinity. The data was assessed against the Murrumbidgee End-of-Valley salinity target and the irrigation water target at sites where water is extracted by an irrigation infrastructure operator. The likelihood of water being unsuitable for irrigation was calculated using the frequency that the 95th percentile of the daily mean electrical conductivity exceeded the irrigation salinity target (833 µS/cm) for the 10 year period from 2005 to 2015.

Water temperature risk was based on the presence of a dam classified as having a severe, moderate or low cold water pollution status, according to Preece (2004).

The objective for recreational water quality is to achieve a low risk to human health from water quality threats posed by exposure through ingestion, inhalation or contact during recreational use. Blue-green algae were chosen as the indicator for risk to recreational water quality because of the potential for some species to impact on human health. The risk of water being unsuitable for recreational use considered the frequency of high concentrations of potentially toxic algal blooms (likelihood), compared to the degree of recreational usage of the water body where the sample was taken (consequence).

New South Wales currently manages the risk of human exposure to blue-green algal blooms through a coordinated regional approach with the Regional Algal Coordination Committees (RACC). State-wide and regional contingency plans and guidelines have been developed to provide methodologies on the management of algal blooms (NSW Office of Water 2014). The objective of the guidelines is to provide a risk assessment framework to assist with the effective management response to freshwater, estuarine and marine algal blooms. They aim to minimise the impact of algal blooms, by providing adequate warning to the public ensuring their health and safety in recreational situations and for stock and domestic use.

Under the current management of algal blooms, the level of human exposure to a bloom can be reduced by management practices such as issuing algal alerts. Alert levels have been developed and are used to determine the actions that need to be undertaken with respect to an algal incident. These alerts have been adopted from the National Health and Medical Research Council algal bloom response guidelines (NHMRC 2008). The risk to a site with a high recreational usage may be reduced by the management strategy of placing algal warning signs at the site and informing users of the risks and dangers. Therefore, where these warning arrangements are in place, a low consequence value was used.

Pathogens, pesticides, heavy metals and other toxic contaminants are not monitored regularly in the Murrumbidgee WRPA, so were not included in the risk assessment.

5. Results

5.1. Water quality index (WaQI)

5.1.1. Water-dependent ecosystems

The WaQI score for each parameter and the overall score for each site was calculated for the 2010 to 2015 water quality data set. The results from the WaQI are shown in Table 10 and summarised in Figure 5.

Table 10: Water quality index scores for the Murrumbidgee WRPA 2010-2015 water quality data

Station Name	Rating	WaQI	Total N	Total P	Turbidity	pH	DO
Murrumbidgee River at Mittagang Crossing	Fair	68	66	38	54	66	91
Murrumbidgee River at Angle Crossing	Good	87	93	78	81	93	97
Goodradigbee River at Wee Jasper	Excellent	98	98	96	100	98	100
Jugiong Creek at Jugiong	Fair	74	70	67	88	67	75
Muttama Creek at Coolac	Poor	43	29	15	50	83	54
Adjungbilly Creek at Darbalara	Fair	73	69	48	66	88	94
Goobarragandra River at Little River Road	Excellent	97	100	98	96	89	100
Tumut River at Oddys Bridge	Fair	78	100	90	100	39	61
Murrumbidgee River at Gundagai	Good	81	80	78	71	84	93
Hillas Creek at Mundarlo Road Bridge	Fair	61	58	20	51	93	92
Adelong Creek at Bereena	Poor	58	75	29	37	96	54
Tarcutta Creek at Old Borambola	Fair	69	69	46	39	100	96
Murrumbidgee River d/s Wagga Wagga	Good	80	66	74	68	99	96
Colombo Creek at Morundah	Fair	67	75	51	31	98	85
Yanco Creek at Morundah	Fair	63	71	42	26	98	86
Yanco Creek at Yanco Bridge	Poor	52	65	29	20	95	59
Murrumbidgee River d/s Yanco Weir	Fair	78	73	68	58	99	95
Murrumbidgee River at Gogeldrie Weir	Fair	78	72	70	60	99	93
Murrumbidgee River at Carrathool	Fair	74	76	58	55	95	90
Murrumbidgee River d/s Hay Weir	Fair	79	82	68	64	97	81
Murrumbidgee River d/s Maude Weir	Fair	77	80	65	63	99	79
Murrumbidgee River d/s Balranald Weir	Fair	66	75	48	51	98	59
Murrumbidgee River at Waldaira	Fair	70	75	50	48	99	85
Billabong Creek at Walbundrie	Poor	36	19	25	10	95	65
Billabong Creek at Jerilderie	Poor	32	32	20	7	99	49
Billabong Creek at Darlot	Poor	27	21	14	4	97	50

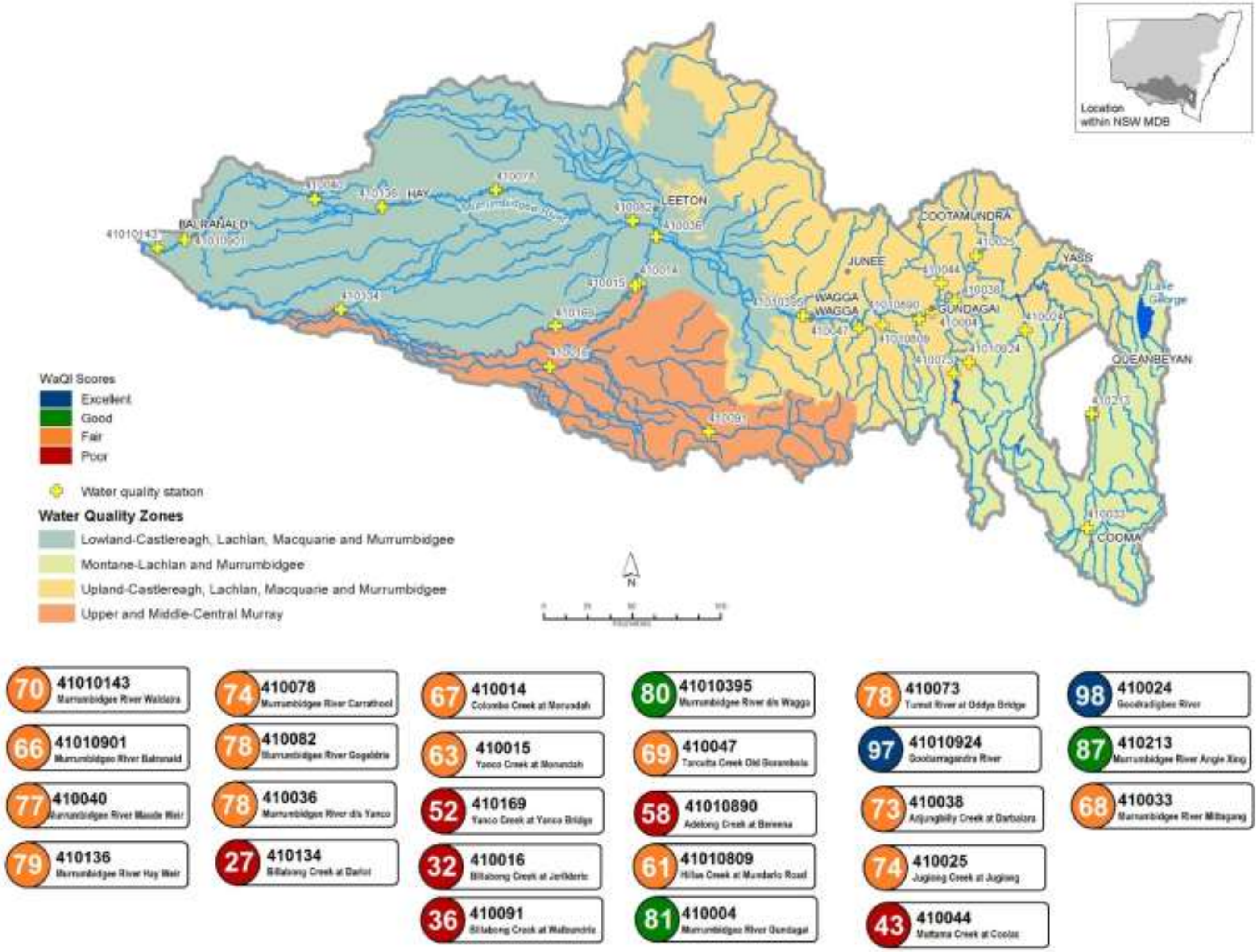


Figure 5: Murrumbidgee WRPA water quality index scores

5.1.2. Water temperature

The monthly 20th and 80th percentiles for Blowering Dam were calculated using the hourly water temperature data from the Goobarragandra River at Lacmalac. As there are no temperature monitoring sites upstream of Blowering Dam, data from the Goobarragandra River was used as a surrogate, due to similar altitude and catchment characteristics. The monthly median temperature downstream of Blowering Dam was calculated using the hourly water temperature data from the Tumut River at Oddys Bridge.

Blowering Dam is located immediately downstream of Jounama and Talbingo Dams. Due to their close proximity to Blowering Dam, their impacts on the temperature regime of the Tumut River has not been assessed.

Figure 6 compares the monthly median temperature at the downstream Blowering Dam site to the percentiles of the reference site. The thermal pollution WaQI score, using the difference between the reference site and downstream data, was 36, which is a poor rating.

There are three monitoring sites downstream of Blowering Dam. The first is 1.3 km below the dam outlet at Oddys Bridge (410073). The Tumut River at Brungle Bridge (410039) is 62 km downstream of Blowering Dam and the Tumut River at Murrumbidgee Junction is 79 km downstream. The Murrumbidgee Junction site is 1 km upstream of the Tumut-Murrumbidgee Junction. The water temperature data for these sites has been compared to flow in Figure 7.

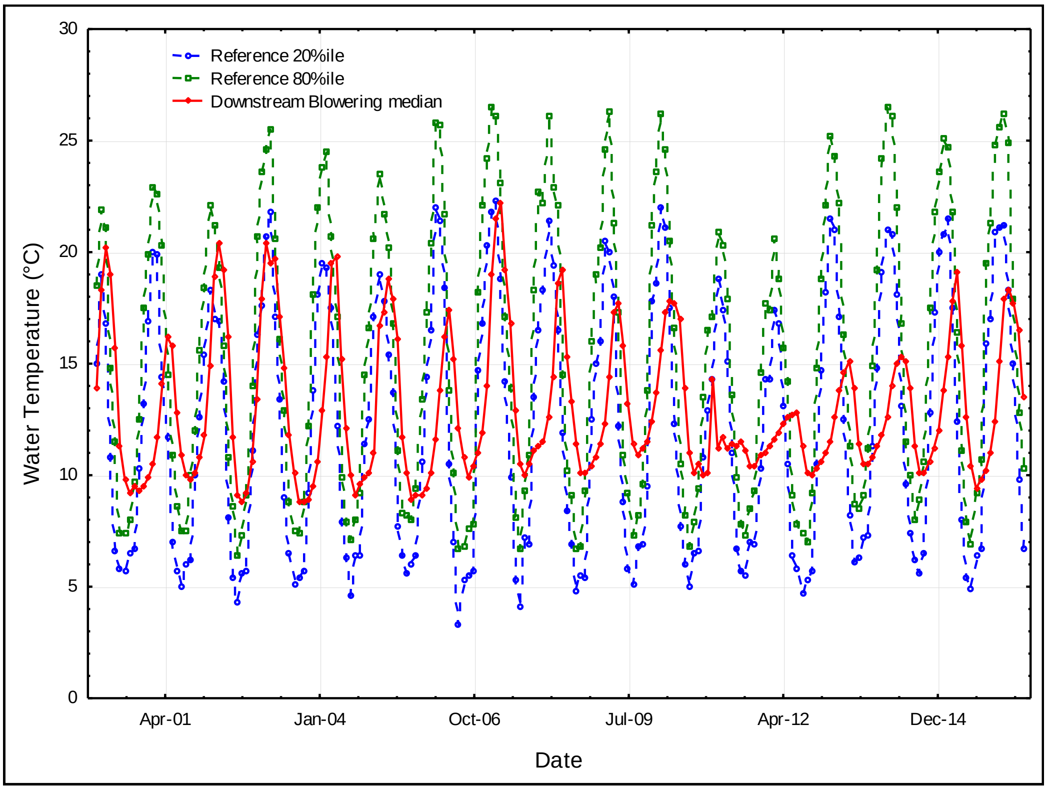


Figure 6: Assessment of the Tumut River at Oddys Bridge (downstream of Blowering Dam) median water temperature against MDBA target “reference site” (Goobarragandra River at Lacmalac) data from 2000 to 2016

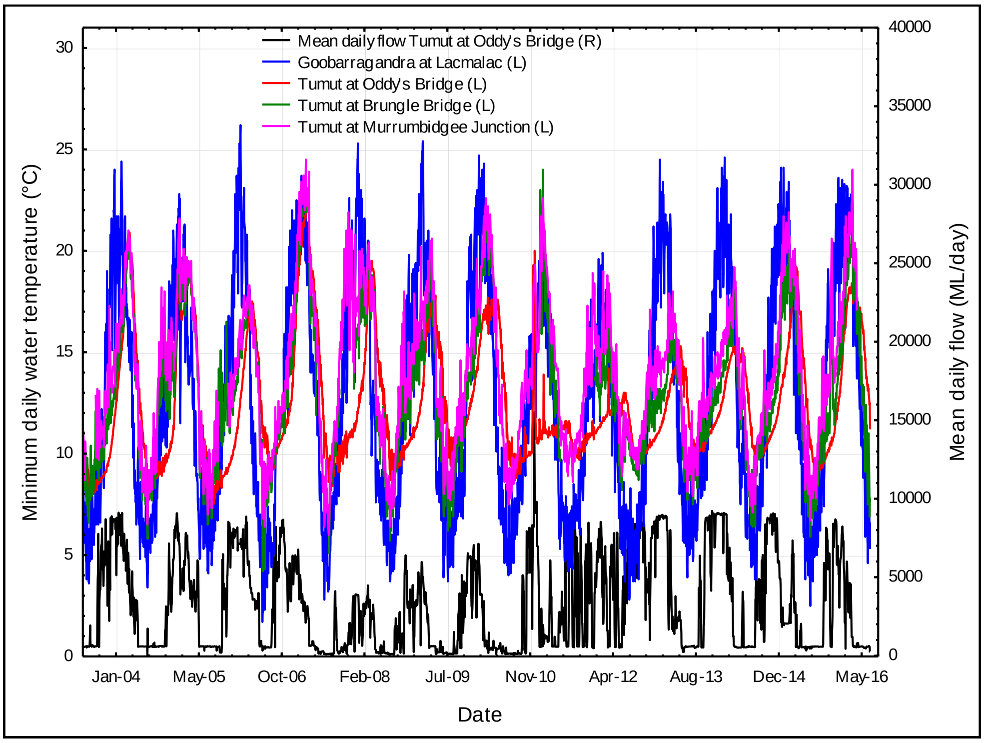


Figure 7: Minimum daily water temperature in the Tumut River against mean daily flow downstream of Blowering Dam from 2003 to 2016

The monthly 20th and 80th percentiles for Burrinjuck Dam was calculated using the hourly water temperature data from the Murrumbidgee River at Halls Crossing. As the majority of flow is sourced from the Murrumbidgee River rather than the Yass or Goodradigbee Rivers, the water temperature data from Murrumbidgee at Halls Crossing has been used in the assessment between upstream and downstream sites. The monthly median temperature downstream of Burrinjuck Dam was calculated using the hourly water temperature data from the downstream Burrinjuck gauging station.

Figure 8 compares the monthly median temperature at the downstream Burrinjuck Dam site to the percentiles of the reference site. The thermal pollution WaQI score, using the difference between the reference site and downstream data, was 45, which is a poor rating.

The Murrumbidgee River downstream of Burrinjuck Dam is 850 m below the outlet of the dam. There are an additional two sites on the Murrumbidgee River before the junction with the Tumut River. Murrumbidgee River at Glendale (410068) is 17 km downstream and Murrumbidgee River upstream Gobarralong Bridge (410195) is 82 km downstream. The Gobarralong site is approximately 14 km above the Tumut-Murrumbidgee confluence. The water temperature data for these sites has been compared to flow in Figure 9.

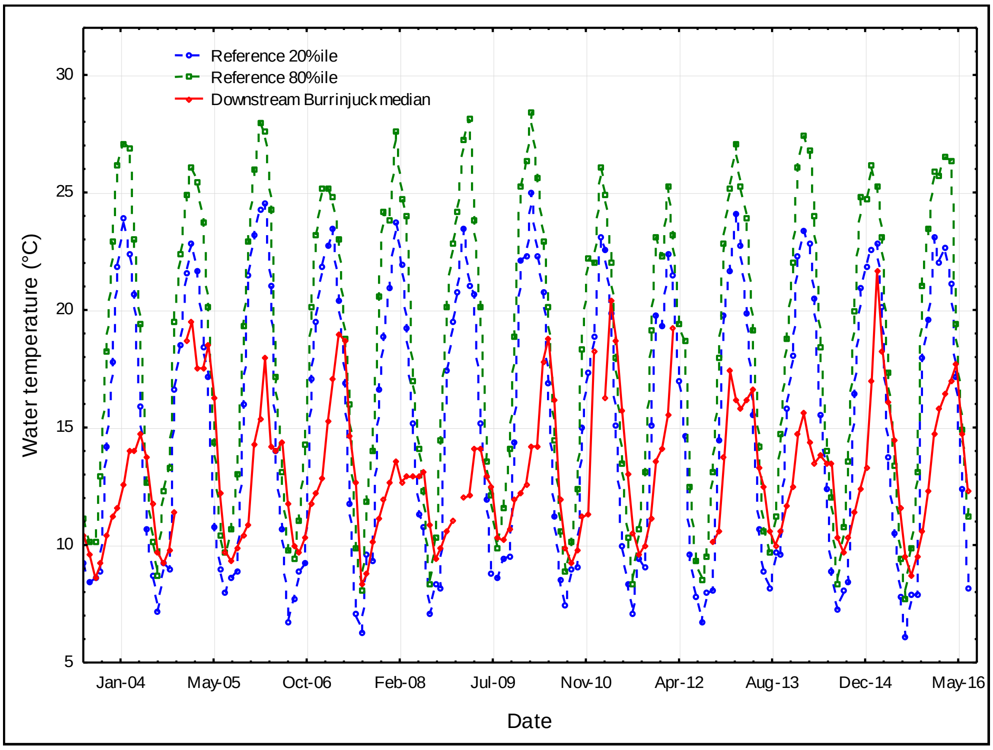


Figure 8: Assessment of the Murrumbidgee River downstream of Burrinjuck Dam median water temperature against MDBA target "reference site" (Murrumbidgee River at Halls Crossing) data from 2004 to 2016

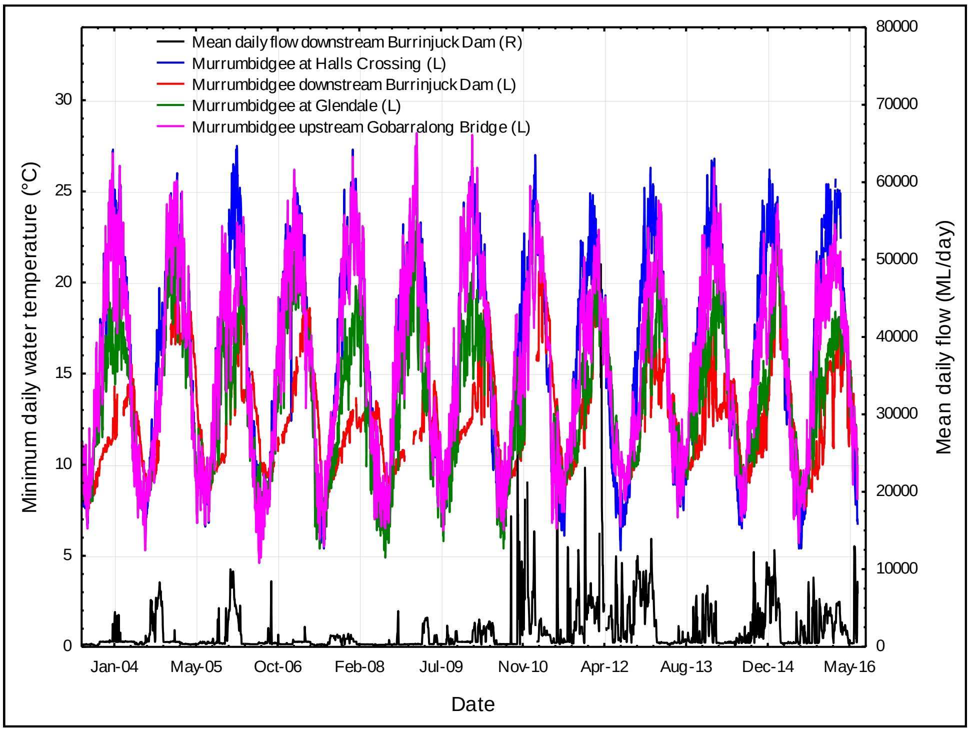


Figure 9: Minimum daily water temperature in the Murrumbidgee River against mean daily flow downstream of Burrinjuck Dam from 2003 to 2016

There are a further four sites downstream of the Tumut-Murrumbidgee confluence at Gundagai (410004), Wagga Wagga (410001), downstream of Berembed Weir (410023) and Narrandera 410005). The distance of these sites from the outlet of Burrinjuck Dam are 115 km, 240 km, 382 km and 435 km respectively. Figure 10 illustrates the changes in water temperature with distance down the Murrumbidgee River.

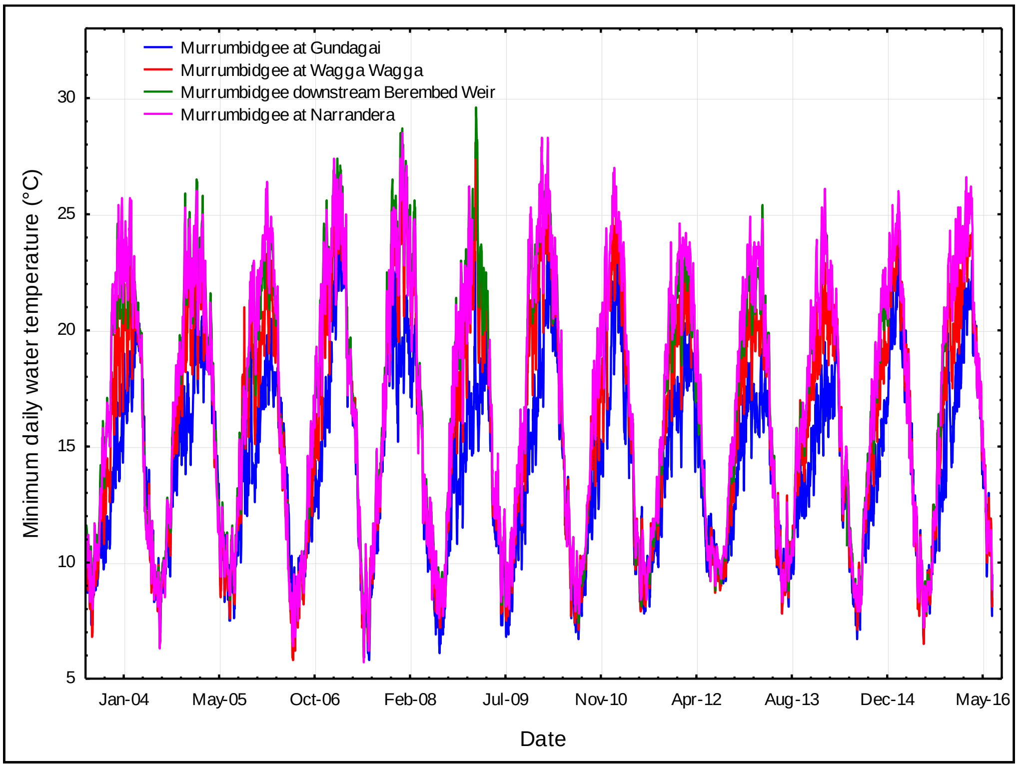


Figure 10: Minimum daily water temperature in the Murrumbidgee River downstream of the Tumut – Murrumbidgee Junction from 2003 to 2016

5.1.3. Irrigation

The agriculture and irrigation salinity target is for the 95th percentile of the daily mean electrical conductivity, over a 10 year period, not to exceed 833 µS/cm. This target applies at sites where water is extracted by an irrigation infrastructure operator for the purpose of irrigation. Water is diverted to the Murrumbidgee Irrigation Area at Berembed Weir (Main Canal) and Gogeldrie Weir (Sturt Canal). There is continuous electrical conductivity data collected at the Murrumbidgee River downstream of Berembed Weir, but not at Gogeldrie Weir. The Coleambally Irrigation Area also receives water from Gogeldrie Weir which is located approximately 100 km downstream of Berembed Weir. The Hay Irrigation District is fed from Hay Weir. The closest continuous electrical conductivity gauging station is at Balranald Weir which is situated on the Murrumbidgee River downstream of Hay.

The 95th percentile of the 2005 to 2015 electrical conductivity data set for the Murrumbidgee River downstream of Berembed and Balranald Weirs, and results of the WaQI are shown in Table 11. The mean daily electrical conductivity in the Murrumbidgee River downstream Balranald Weir fluctuates throughout the year, though no results exceed the agriculture and irrigation salinity target (Figure 11).

Table 11: Water quality index scores for selected sites the Murrumbidgee WRPA for 2005-2015 continuous electrical conductivity data

Station Name	95th percentile	WaQI	Rating
Murrumbidgee River downstream Berembed Weir	243	100	Excellent
Murrumbidgee River downstream Balranald Weir	278	100	Excellent

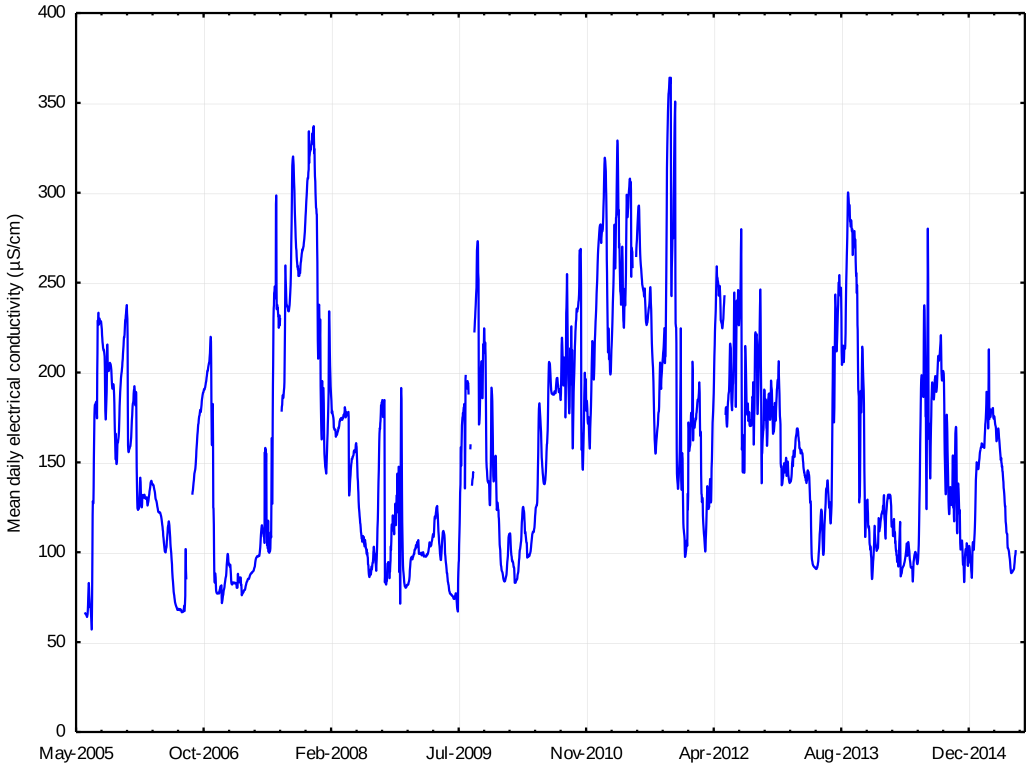


Figure 11: Mean daily electrical conductivity (µS/cm) in the Murrumbidgee River downstream Balranald Weir from 2005 to 2015

5.1.4. Recreation

The algal monitoring in the Murrumbidgee valley indicates that potentially toxic algal blooms occur occasionally in Burrinjuck Dam during the warmer months. The data are used to assign recreational alerts based on the National Health and Medical Research Council guidelines for recreational use. At the red alert level, waters are not suitable for recreational use and exceed the Basin Plan target. Burrinjuck Dam was placed on red alert for recreational use in January 2011. Lake Albert, Lake Wyangan and Yanga Lake were placed on red alert for recreational use on numerous occasions. Algal blooms occasionally occur in weirs on the Murrumbidgee River, such as at Hay (Figure 12)

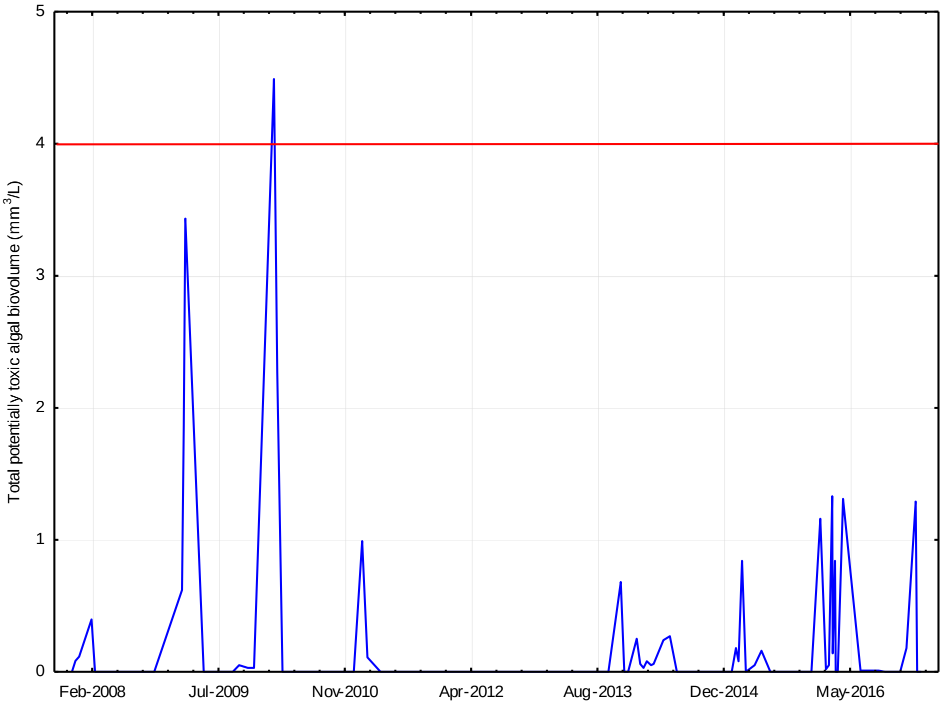


Figure 12: Harmful algal blooms in the Murrumbidgee River at Hay Weir from 2007 to 2017

5.1.5. Dissolved oxygen

There is one continuous dissolved oxygen sensor installed in the Murrumbidgee River downstream of Balranald Weir as an early warning for possible hypoxic events. Figure 13 illustrates that dissolved oxygen is generally suitable to maintain ecological process and support aquatic life. In 2012 and 2016, major flooding resulted in hypoxic blackwater events, with dissolved oxygen concentrations in the Murrumbidgee River dropping to critical levels.

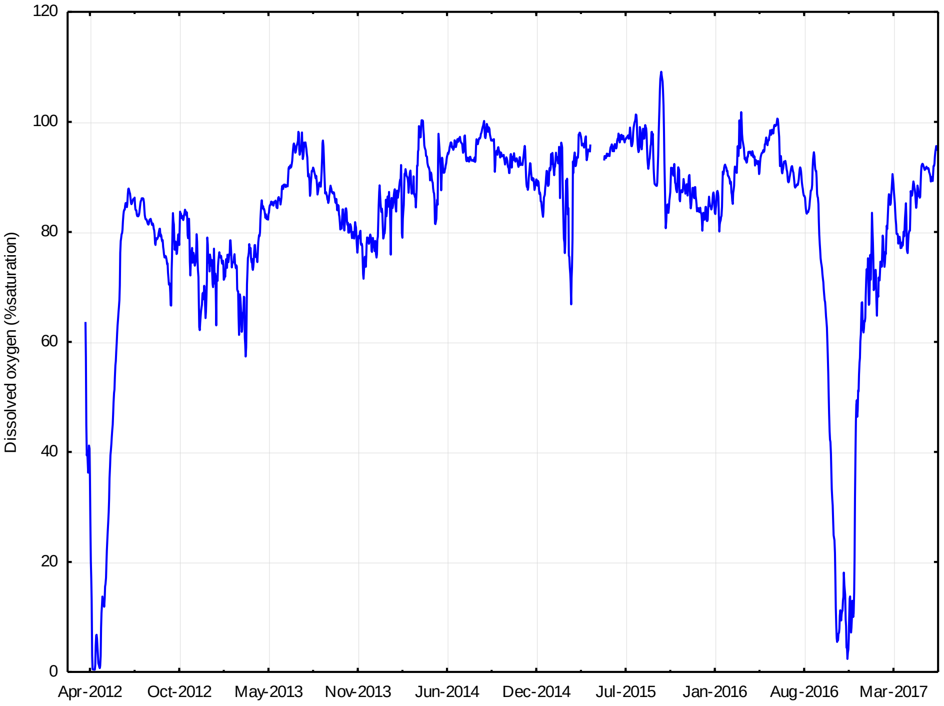


Figure 13: Dissolved oxygen in Murrumbidgee River downstream Balranald Weir from 2012 to 2017

5.2. Literature review

A literature search was undertaken to gather information from the published literature relevant to water quality in the Murrumbidgee WRPA. Following is a summary of relevant information with more detailed information listed in Appendix C.

Parts of the Murrumbidgee River are extremely impaired and may have lost more than 80% of species likely to have occurred there (Norris et al. 2001). Approximately 37% of the river length has been substantially modified from natural condition. The most impacted areas are the tributary catchments upstream of Wagga Wagga, with some long reaches of less than 20% native woody riparian vegetation. Inversely, the Tumut, Goobarragandra and Goodradigbee River catchments there are long reaches with greater than 80% cover (DoIW 2018b). Riparian vegetation is important as a carbon source, its shading reduces solar radiation, limiting in-channel autotrophic production (Kelleway et al. 2010) and as a source of large woody debris to protect against erosion and restore river health (Erskine et al. 2012).

Estimates are that climate change my reduce water yield in the Murrumbidgee River by up to 21% by 2030 and 48% by 2070 (Austin et al. 2010). Dyer et al. (2014) suggests that river regulation has resulted in greater changes to ecologically relevant streamflow characteristics than climate change scenarios involving a 1 to 2°C temperature rise.

The pre European settlement sediment flux from the Upper Murrumbidgee catchment (above Burrinjuck Dam) was estimated at approx. 2 400 t/year (Olley and Wasson 2003). The introduction of livestock triggered widespread gully erosion in the catchment, increasing the sediment flux to approx. 480 000 t/year. As the gully networks reached maximum extension, sediment yield from headwater areas has declined.

Using radioactive fallout traces, Wallbrink et al. (1998) demonstrated the dominant source of material (>80%) to suspended sediments in channels of the mid-Murrumbidgee is erosion of channel banks and gully walls. Spatial analysis of hillslope derived suspended sediment delivery indicated that most of the sediment in the mid Murrumbidgee originates from a few tributaries adjacent to the Murrumbidgee River downstream of Burrinjuck Reservoir (Verstraeten et al. 2007). It was suggested that the mean residence time of the fine grained sediment within the mid-Murrumbidgee system was 10 ± 5 years (Wallbrink et al. 1998).

Based on the differences in discharge between the two major storages, Blowering was identified by Preece (2004) as likely to be the main contributor to thermal pollution in the Murrumbidgee River, due to the higher discharge. Indications are that cold water impacts, persists in the Murrumbidgee River (irrespective of the contributing source) for between 200 and 300 km below the Tumut-Murrumbidgee confluence (Keenan and Buchan unpub; Astles 2001).

The ionic composition of the water in the Murrumbidgee River is predominantly controlled by the major flow volumes released from Burrinjuck and Blowering Dams (Conyers et al. 2008). Investigations into the ionic composition found that sodium chloride was not always dominant, as might be expected if cyclic marine salt dominated. The presence of calcium and magnesium bicarbonate in all streams, indicates that mineral weathering is a major contributor to the salt load. Calcium and magnesium bicarbonates have limited solubility, so their concentrations will not become a cause of osmotic stress when the water is used for drinking or irrigation. Prioritising catchments for changed land management requires examination of the salts they discharge, not just the electrical conductivity (Conyers et al. 2007).

Studies in the Murrumbidgee River have indicated that flow is the dominant factor controlling the degree of thermal stratification in weir pools (Sherman and Webster, 1997; Sherman et al. 1998). Stratification in turn is a necessary condition for the growth and development of potentially toxic cyanobacterial blooms (Sherman et al. 1998). Under stratified conditions, turbulent mixing is reduced and positively buoyant cells of *Anabaena* can accumulate and grow in the surface layers where there is more light available. Stratification in weirs can be prevented or eliminated through turbulence generated by increased flow. It is possible to propose a range of flow control strategies and options for destroying thermal stratification in weir pools, thereby limiting cyanobacterial growth (Sherman and Webster, 1997). The Maude Weir pool remained persistently stratified during periods when discharge was less than 1000 ML/day. Flows of 1000 to 3000 ML/day generally allowed diurnal stratification, while flows greater than 4000 ML/day kept Maude Weir pool well mixed at all times (Sherman et al. 1998).

Assessing environmental water releases from Burrinjuck Dam found the water quality in the regulated rivers differed substantially from unregulated rivers, and the water released from Burrinjuck Dam in particular, was affected by upstream catchment development (elevated nutrients) as well as the influence of the dam itself (water temperature, deoxygenated, nutrients) (Hardwick et al. 2012). These affects are likely to mitigate any environmental improvement expected to result from flow restoration in the Murrumbidgee River downstream of Burrinjuck Dam. Thermal pollution mitigation forms a necessary long term objective to aid rehabilitation of the Murrumbidgee River downstream of Burrinjuck Dam (Hardwick et al. 2012).

Water temperature, flows, habitat and food resource (prey size and availability) all impair fish recruitment. Flow magnitude and water temperature appear to have the largest effect in determining larval fish composition (Rolls et al. 2013). It is suggested that a lack of prey and food resources may be one reason why there is not a strong response to managed flow events (Rolls et al. 2013). In addition, where river channels have already been impacted by regulated flows, complex surfaces, such as benches, may have already been lost. Restoring more natural flows at these levels of channel, may have little immediate impact on nutrient processing (Woodward et al. 2015). Low level benches will need to be ‘rebuilt’ before environmental flows can increase connectivity.

The annual compliance reports for Murrumbidgee Irrigation Limited (2017) and Coleambally Irrigation Limited (2017) identify the detection of agricultural chemical residues at some outfall monitoring sites. High rainfall can result in the release of drainage water that would normally be recycled on farm. Chemicals detected include metolachlor, atrazine, diuron and simazine.

5.3. Summary statistics

Summary statistics for the key water quality parameters at each monitoring site in the Murrumbidgee WRPA have been displayed as tables (Appendix D) and represented using box plots (Appendix E). The box plots in Figures 14 (upper catchment) and 15 (lower catchment) show the annual 25th, 50th and 75th percentile values, with error bars indicating the 10th and 90th percentile values for each site. The data set extends from 2007 to 2015 and displays monitoring site variability within the Murrumbidgee WRPA. There are numerous plots within Figures 14 and 15; A) total nitrogen, B) total phosphorus, C) turbidity, D) total suspended solids, E) dissolved oxygen, F) pH, G) electrical conductivity measured during monthly sampling.

Upper Murrumbidgee

The Muttama Creek catchment had the highest concentrations of both nitrogen and phosphorus in the upper Murrumbidgee, followed by numerous unregulated catchments that flow into the Murrumbidgee River downstream of Burrinjuck Dam. The Goodradigbee and Goobarragandra Rivers had the lowest nutrient concentrations. Trends in nutrient concentration and turbidity are usually similar. The highest turbidity was in the Tarcutta Creek catchment, again followed by the numerous unregulated catchments downstream of Burrinjuck Dam. The Tumut River at Oddys Bridge site did not follow this trend. This site is located approximately 1.3 km downstream of Blowering Dam. Nutrients dissolved in the water column are able to be transferred downstream through the outlet works. The turbidity and total suspended solids results at Oddys Bridge are low, as sediment and organic matter settles to the bottom of Blowering Dam and are only released downstream during major flooding when the dam is spilling.

The median dissolved oxygen at most sites was between 90 and 100% saturation, which is suitable for maintaining aquatic ecosystems. Muttama Creek had a wide range of results. The high nutrient concentrations at this site provide ideal conditions for algal and aquatic plant growth, resulting in increased oxygen production. In contrast, during low/zero flow oxygen can be depleted, resulting in low dissolved oxygen. There was also a range of results in the Tumut River. The dissolved oxygen levels in the Tumut River downstream of Blowering Dam is more likely impacted by the depth of the offtake below the water surface rather than flow or local environmental factors.

Muttama Creek had the highest median electrical conductivity followed by Jugiong Creek. These two catchments are adjacent to each other, with similar geology and sources of salt. There is limited opportunity for irrigation from both Muttama and Jugiong Creeks, making the risk to agriculture production and soil structure, low. Electrical conductivity is low and stable across other monitoring sites in the upper catchment, and would not pose a threat to water uses.

Lower Murrumbidgee

In most rivers, nutrient concentrations and turbidity tend to increase with distance down the catchment, reflecting the cumulative impacts of land use, soil disturbance and human activity on water quality. Yanco Creek followed this trend with higher total nitrogen, total phosphorus and turbidity at Yanco Bridge than at Morundah. Billabong Creek had higher turbidity and total phosphorus at the downstream site (Darlot), but total nitrogen was highest at the upstream site (Walbundrie). In the regulated Murrumbidgee River downstream of Yanco Weir, there is very little change in turbidity and nutrient concentration with progression down the catchment.

Dissolved oxygen levels fluctuate between sites in response to local drivers. Increased aquatic macrophyte and algal growth can result in increased photosynthesis and subsequent elevated oxygen levels. The lowest dissolved oxygen readings are usually in the lower catchment where high turbidity reduces light penetration, reducing aquatic plant growth and higher water temperature reduces the solubility of oxygen in the water column. Median dissolved oxygen in the lower Murrumbidgee is generally suitable to maintain aquatic ecosystems, though dissolved oxygen levels did drop in response to major flooding in 2010/2011. This was particularly evident in Billabong Creek at Jerilderie and Darlot, Yanco Creek at Yanco Bridge and Murrumbidgee River downstream of Balranald Weir.

The pH was relatively consistent throughout the lower Murrumbidgee WRPA and would not impact on the health of aquatic ecosystems or agricultural enterprises.

The release of water from Burrinjuck and Blowering Dams maintains a low electrical conductivity in the Murrumbidgee River. As electrical conductivity does not increase with distance down the catchment, suggests limited contributions to surface water from shallow saline groundwater. This agrees with surface-groundwater connectivity studies in the lower Murrumbidgee (Parsons et al. 2008). The annual salt load in the Murrumbidgee River downstream of Balranald Weir exceeded the End-of Valley salt load target (169 600 t/year) during the high flow years from 2010 through to 2012. Annual median salt loads are summarised in Tables 21 and 22 in Appendix D.

Draftsman plots for all sites have been developed to assess the relationships between water quality parameters. These figures are shown in Appendix E. Sites generally showed a positive correlation between total nitrogen, total phosphorus and turbidity, indicating the bulk of nutrients are transported in the river system bound to particulate matter. The highest total nitrogen and total phosphorus concentrations coincide with increased flow, indicating that the majority of the nutrients are derived from diffuse sources, rather than point sources. There were occasional high nutrient readings during low flow, indicating there can be a mixture of nutrient sources at a local level, such as livestock access. In contrast to nutrients and turbidity, electrical conductivity was often negatively correlated to flow. This was predominantly the case in the unregulated catchments where salts are diluted by high flow events.

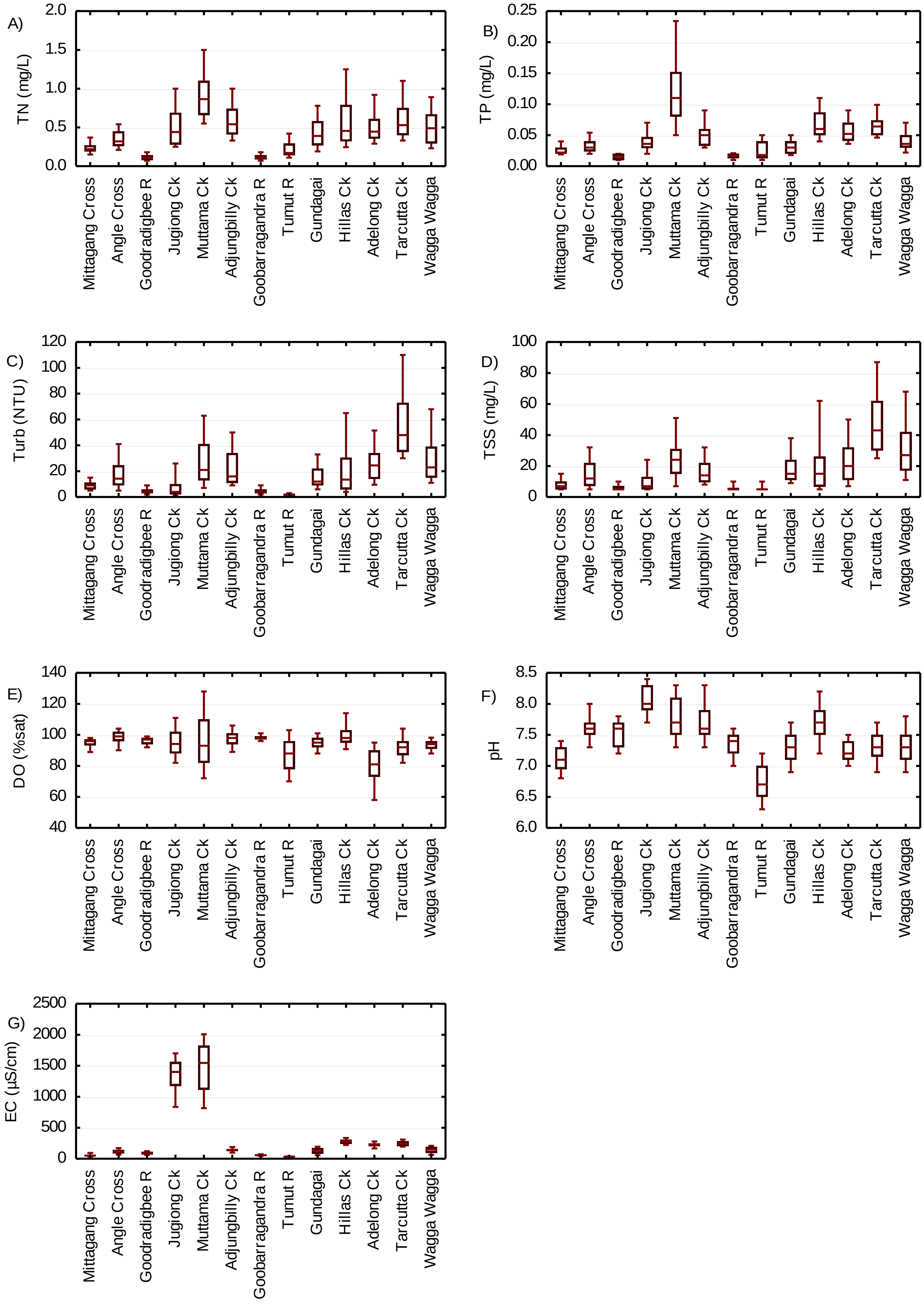


Figure 14: Water quality data for water quality parameters by site in the Upper Murrumbidgee valley

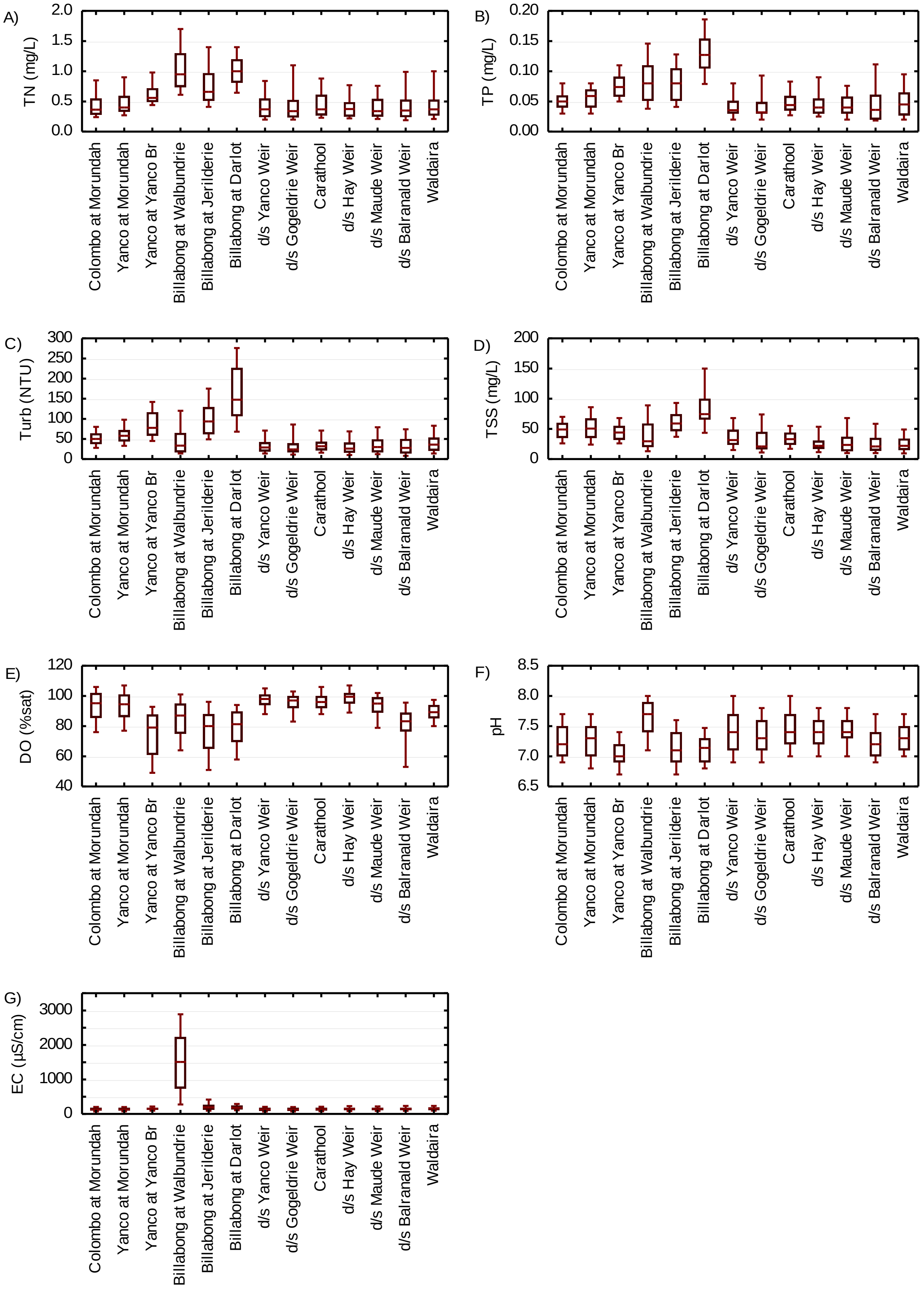


Figure 15: Water quality data for water quality parameters by site in the Lower Murrumbidgee valley

5.3.1. Total annual flow

Many water quality attributes are strongly correlated to river flow conditions. Flow during the 2010 to 2015 data period was characterised by high flows from 2010 to 2012, and lower flow from 2013 to 2015. Figure 16 illustrates the total annual flow at selected gauging stations from the upland, midland and lowland areas. The use of total annual flow gives a general indication of river flow conditions. No attempt has been made to assess individual results against flow at the time of sampling, or the timing of sampling in relation to high or low flow events. The general trend at most sites were higher nutrient and turbidity results during the wetter years and lower results during dryer years.

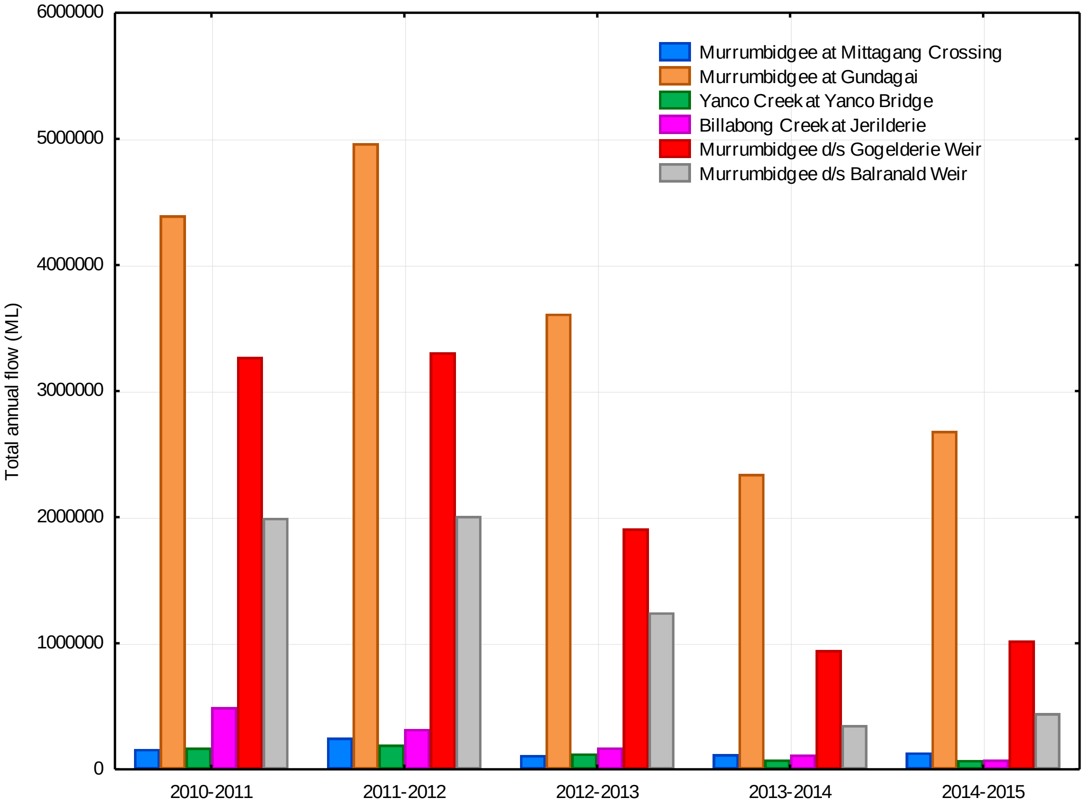


Figure 16: Annual flow (ML/year) at selected gauging stations

5.4. Local and expert knowledge

Meetings were held with relevant stakeholders and technical experts to gather information and identify water quality issues relevant for the development of the Murrumbidgee WRPA water quality technical report.

Cold water pollution from Blowering and Burrinjuck Dams - Cold water pollution extends downstream of both storages with little influence from the tributaries downstream. There is also evidence of warming during winter.

Turbidity - It was also acknowledged that even though turbid, the lower Murrumbidgee can still support macroinvertebrate and fish communities. There is increased turbidity in the upper catchment from grazing and livestock access to waterways. Bank erosion and sedimentation in Yanco Creek was also raised as an emerging issue.

River salinity - River salinity is largely isolated to a few tributaries located to the north of the Murrumbidgee River upstream of Gundagai, the upper Billabong catchment and Houlaghans Creek. The electrical conductivity in these tributaries is high, but it is diluted by regulated flows upon entering the Murrumbidgee River.

Anoxic blackwater - Anoxic blackwater was identified as a major issue during overbank flooding, following major events in 2012 and 2016. Government agencies are trying to reduce the impact when these events occur by reinstating/protecting flows to regularly inundate high benches and banks and reconnecting the river with the floodplain. Issues were raised in regard to the accessibility to dissolved oxygen data in a timely manner to assist in the delivery and regulation of water to help manage the impacts of anoxic blackwater events.

Programs to benefit native fish such as improving fish passage, managing cold water pollution and habitat restoration to provide conditions conducive to fish breeding and population growth are ongoing in the Murrumbidgee Catchment. These works are vital and provide an environment where fish populations can bounce back from blackwater events.

Toxicants – Due to the lack of data, the risk from toxicants is largely unknown in the Murrumbidgee WRPA.

Blue-green algae - Blue-green algae can be an issue for recreational use in Burrinjuck Dam. Algal blooms are regularly detected in Lake Albert, Lake Wyangan and Yanga Lake. High flow from irrigation releases over summer help regulate algal blooms in the Murrumbidgee River and weir pools.

Pathogens - There is an unknown risk from the high prevalence of septic systems across the catchment.

Other issues raised included major barriers to fish passage, supporting refugia, protecting flow events, releasing water to mimic natural flow events, discretionary or more effective use of supplementary/environmental water and addressing water quality data gaps.

There have been numerous projects undertaken that will help to address water quality issues in the Murrumbidgee WRPA. These include, but not limited to:

- Riparian rehabilitation partnership program including the Yass Rivers of Carbon project, the Yass River willow control project undertaken by Crown Lands and Yass River fish habitat rehabilitation project funded under the small habitat action grants;
- Adelong Creek fish habitat enhancement, and
- Queanbeyan River Restoration – resnagging and rehabilitation of the riparian zone, extending the Queanbeyan Traditional Owner river restoration project.

5.5. Risk assessment

The impact of the quality of the water in Murrumbidgee waterways on the health of water dependent ecosystems was assessed by identifying the risk (DoIW 2018b). This was achieved by quantifying the impact based on instream values (consequence) and determining the probability of that consequence occurring (likelihood).

Tables 12 to 16 list the sites scoring a medium or high risk in the Murrumbidgee Risk Assessment for each parameter. There were no high risks sites identified for pH. Of the 26 routine monitoring sites, 11 had a high risk for both turbidity and total phosphorus. Five of these sites (Colombo Creek at Morundah, Murrumbidgee River downstream of Balranald Weir and Billabong Creek at Walbundrie, Jerilderie and Darlot) also had a high risk for total nitrogen. Colombo Creek at Morundah, Murrumbidgee River downstream of Balranald Weir and Billabong Creek at Jerilderie and Darlot had a high risk for dissolved oxygen.

The risk to the health of water dependent ecosystems in the Murrumbidgee River downstream Balranald Weir (End-of-Valley site) from salinity was low and the risk to the suitability of water for irrigation was also low. The risk to the health of water dependent ecosystems from the release of cold water from both Burrinjuck and Blowering Dams was high.

Table 12: Sites with high and medium risk to the health of water dependent ecosystems from turbidity

Station Name	Consequence	Likelihood	Level of Risk
Muttama Creek at Coolac	Low	High	Medium
Adelong Creek at Bereena	Low	High	Medium
Hillas Creek at Mundarlo Road	Medium	Medium	Medium
Tarcutta Creek at Old Boambola	Medium	High	High
Murrumbidgee River downstream Yanco Weir	Very high	Medium	High
Colombo Creek at Morundah	Very high	High	High
Yanco Creek at Morundah	Very high	High	High
Yanco Creek at Yanco Bridge	Medium	High	High

Station Name	Consequence	Likelihood	Level of Risk
Murrumbidgee River downstream Gogeldrie Weir	Very high	Low	Medium
Murrumbidgee River at Carrathool	Very High	Medium	High
Murrumbidgee River downstream Maude Weir	High	Medium	Medium
Murrumbidgee River downstream Balranald Weir	Very high	High	High
Murrumbidgee River at Waldaira	High	High	High
Billabong Creek at Walbundrie	Medium	High	High
Billabong Creek at Jerilderie	Medium	High	High
Billabong Creek at Darlot	Medium	High	High

Table 13: Sites with high and medium risk to the health of water dependent ecosystems from total phosphorus

Station Name	Consequence	Likelihood	Level of Risk
Murrumbidgee River at Mittagang Crossing	Low	High	Medium
Muttama Creek at Coolac	Low	High	Medium
Adjungbilly Creek at Darbalara	Medium	High	High
Hillas Creek at Mundarlo Road	Medium	High	High
Tarcutta Creek at Old Boambola	Medium	High	High
Murrumbidgee River downstream Yanco Weir	Very high	Medium	High
Colombo Creek at Morundah	Very high	Medium	High
Yanco Creek at Morundah	Very high	High	High
Yanco Creek at Yanco Bridge	Medium	High	High
Murrumbidgee River downstream Gogeldrie Weir	Very high	Low	Medium
Murrumbidgee River at Carrathool	Very high	Medium	High
Murrumbidgee River downstream Hay Weir	High	Medium	Medium
Murrumbidgee River downstream Maude Weir	High	Medium	Medium
Murrumbidgee River downstream Balranald Weir	Very high	High	High
Murrumbidgee River at Waldaira	High	High	High
Billabong Creek at Walbundrie	Medium	High	High
Billabong Creek at Jerilderie	Medium	High	High
Billabong Creek at Darlot	Medium	High	High

Table 14: Sites with high and medium risk to the health of water dependent ecosystems from total nitrogen

Station Name	Consequence	Likelihood	Level of Risk
Muttama Creek at Coolac	Low	High	Medium
Hillas Creek at Mundarlo Road	Medium	Medium	Medium
Murrumbidgee River downstream Yanco Weir	Very high	Low	Medium
Colombo Creek at Morundah	Very high	Medium	High
Yanco Creek at Morundah	Very high	Low	Medium
Yanco Creek at Yanco Bridge	Medium	Medium	Medium
Murrumbidgee River downstream Gogeldrie Weir	Very high	Medium	High
Murrumbidgee River at Carrathool	Very high	Low	Medium
Murrumbidgee River downstream Balranald Weir	Very high	Medium	High
Murrumbidgee River at Waldaira	High	Medium	Medium
Billabong Creek at Walbundrie	Medium	High	High
Billabong Creek at Jerilderie	Medium	High	High
Billabong Creek at Darlot	Medium	High	High

Table 15: Sites with high and medium risk to the health of water dependent ecosystems from pH

Station Name	Consequence	Likelihood	Level of Risk
Tumut River at Oddys Bridge	Low	High	Medium
Murrumbidgee River downstream Yanco Weir	Very high	Low	Medium
Colombo Creek at Morundah	Very high	Low	Medium
Yanco Creek at Morundah	Very high	Low	Medium
Murrumbidgee River downstream Gogeldrie Weir	Very high	Low	Medium
Murrumbidgee River at Carrathool	Very high	Low	Medium
Murrumbidgee River downstream Balranald Weir	Very high	Low	Medium
Billabong Creek at Walbundrie	Medium	Medium	Medium

Table 16: Sites with high and medium risk to the health of water dependent ecosystems from dissolved oxygen

Station Name	Consequence	Likelihood	Level of Risk
Adelong Creek at Bereena	Low	High	Medium
Murrumbidgee River downstream Yanco Weir	Very high	Low	Medium

Colombo Creek at Morundah	High	High	High
Yanco Creek at Morundah	Very high	Low	Medium
Yanco Creek at Yanco Bridge	Medium	Medium	Medium
Murrumbidgee River downstream Gogeldrie Weir	Very high	Low	Medium
Murrumbidgee River at Carrathool	Very high	Low	Medium
Murrumbidgee River downstream Balranald Weir	Very high	Medium	High
Billabong Creek at Walbundrie	Medium	Medium	Medium
Billabong Creek at Jerilderie	Medium	High	High
Billabong Creek at Darlot	Medium	High	High

Twenty sites were routinely monitored for blue-green algae between 2006 and 2015. Lake Wyangan, Barren Box Swamp and Yanga Lake were all rated as having a high likelihood of algal blooms. Burrinjuck Dam, Lake Albert at Griffith and the Murrumbidgee River at Hay had a medium likelihood. When algal blooms occur, the level of human exposure can be reduced by implementing management practices. The risk at a site with a high recreational usage can be reduced by the management strategies of issuing algal alerts, placing algal warning signs at the site and informing users of the risks and dangers. The consequence values reflect these arrangements and were calculated as being low for all sites in the Murrumbidgee WRPA. The risk rating from blue-green algae to recreational water use for Lake Wyangan, Barren Box Swamp and Yanga Lake was medium and all other sites. The consequence and likelihood scores for high recreational use sites are shown in Table 17.

Table 17: Sites with high and medium risk to recreational water quality from blue-green algae and reviewed level of risk

Station Name	Consequence	Likelihood	Level of Risk
Burrinjuck Reservoir	Low	Medium	Low
Murrumbidgee River at Gundagai	Low	Low	Low
Murrumbidgee River downstream Wagga Wagga	Low	Low	Low
Lake Albert, Wagga Wagga	Low	Medium	Low
Lake Wyangan, Griffith	Low	High	Medium
Barren Box Swamp	Low	High	Medium
Murrumbidgee River at Gogeldrie Weir	Low	Low	Low
Murrumbidgee River at Carathool	Low	Low	Low
Murrumbidgee River at Hay Weir	Low	Medium	Low
Murrumbidgee River at Maude Weir	Low	Low	Low
Murrumbidgee River at Redbank Weir	Low	Low	Low
Murrumbidgee River at Balranald	Low	Low	Low
Yanga Lake	Low	High	Medium
Billabong Creek at Walbundrie	Low	Low	Low
Billabong Creek at Jerilderie	Low	Low	Low
Billabong Creek at Darlot	Low	Low	Low

6. Discussion

Water quality attributes in the Murrumbidgee WRPA are strongly correlated to flow. High flow from rainfall and runoff can result in higher turbidity, nutrients and possibly pesticides and pathogens, but lower electrical conductivity. The Basin Plan water quality targets were developed using data collected from 1991 through to 2009 to try and incorporate a spread of climatic and flow conditions (Tiller and Newall 2010). It was noted that although the time period covered a range of conditions, the data used was primarily collected at base or low flow and generally missed high flow and flood events. River flow between 2007 and 2015 was characterised by low flow from 2007 to 2010, with substantially higher flows from 2010 to 2012. Low flows minimise erosion processes, assisting in lowering turbidity and nutrient levels. There was a general trend of turbidity, total phosphorus and total nitrogen exceeding respective targets more frequently in the higher flow years of 2010 to 2012 than in the drier years. Water quality targets that are flow partitioned or flow modelled may need to be derived for future assessment. Until then, assessment of flow dependent attributes against the Basin Plan targets must note that they are likely to be exceeded in wetter years.

All three monitoring sites on Billabong Creek (Walbundrie, Jerilderie and Darlot) were rated by the WaQI as poor. Mawhinney and Muschal (2015) identified the poor water quality in Billabong Creek may be as a consequence of an inappropriate zone boundary, rather than an indication of the quality of the water at the sites. Billabong Creek is more like the central Murrumbidgee River in nature than the central Murray River. As such, the water quality targets for the Murrumbidgee River would be more appropriate. For this reason, it was recommended that Billabong Creek be included in the Murrumbidgee lowland zone (A3), rather than the Central Murray (Upper, Middle) zone (CMum).

Longer term, Billabong Creek is a priority area to develop local water quality targets. The National Water Quality Management Strategy recommends, and provides guidance, for the development of regional and local targets. NSW has not developed targets beyond the default trigger values of the *ANZECC Guidelines* (2000). In this instance Basin Plan water quality targets are used for reporting and a commit to the development of regional or location specific guidelines made. This issue will be addressed further in the WQMP.

6.1. Elevated levels of salinity

Assessment of the discrete electrical conductivity data has shown the salinity in the upland region is mostly low. High surface water flow dilutes salinity. The highest salinity concentrations occur during low flow and cease to flow periods when there is a higher contribution to base flow from groundwater and salts are concentrated in pools by evaporation. Progressing down the catchment, electrical conductivity levels are low for the majority of the midlands area, though there are localised areas such as Jugiong and Muttama Creeks and the upper reaches of Billabong Creek at Walbundrie with naturally occurring higher salinities. Irrigation is limited in these catchments, due to low and unreliable flows, reducing the risk of crop damage and increased soil salinity.

The median data from the unregulated catchments showed a gradual increase in electrical conductivity following the heavy rainfall across the catchment in 2010/2011. This is contrary to the idea of rainfall diluting salinity. McGeoch et al. (2017) hypothesised that an episodic decline in salinity in NSW rivers during the 2000’s may have been due to extended drought conditions. Long periods of low rainfall can result in a disconnection between shallow saline groundwater and fresher surface water. The outcome of this being the observed lower salinity levels in streams. The return of wetter conditions in 2010 would have recharged shallow water tables, increasing the contribution of groundwater to surface flows again, raising the electrical conductivity in surface water samples.

In the Murrumbidgee River at Mittagang Crossing and Angle Crossing, Goobarragandra and Goodradigbee Rivers and Adjungbilly Creek, the electrical conductivity was continuing to rise at the end of 2015. At the Jugiong and Muttama Creek sites, the median electrical conductivity had started to decline in 2015 following the return of dryer conditions. Future monitoring will show whether recent salinity observations in unregulated catchments will persist at current levels or decrease across all sites as shallow saline groundwater levels again loose surface water connection.

Surface water in the lowlands area is generally considered excellent for irrigation purposes. The mean daily electrical conductivity fluctuates throughout the year, but never exceeds the agriculture and irrigation salinity target. The risk of any impacts of salinity on soil and crop health is minimal.

The Murrumbidgee End-of-Valley site (Murrumbidgee River downstream Balranald Weir) was identified as having a low salinity risk to aquatic ecosystems. Brock et al. (2005) showed that aquatic plant germination and species richness decreases when salinities increase above 300 mg/L (500 µS/cm). The electrical conductivity in the lower Murrumbidgee is rarely above these levels, even during low flow.

Maintaining low flow in unregulated catchments and ensuring that freshes are available to the environment, helps to break up stratification, provide dilution flows and prevent saline water from sitting on the bottom of pools. This will maintain the health of the river and the continued use of the water for productive purposes. River salinity is not a major water quality issue in the lower Murrumbidgee. All water released from Blowering and Burrinjuck Dams has a low electrical conductivity and dilutes saline inflows from downstream saline tributaries. This ensures that water is suitable for irrigation and the protection of water dependent ecosystems.

A salinity assessment needs to consider land salinity, salt load and stream electrical conductivity in an integrated framework to determine the hazard of a landscape. The Murrumbidgee valley salinity technical report (DoIW 2018c) uses the Hydrogeological Landscapes (HGL) framework to undertake an assessment, determine the likely cause and identify solutions to salinity. In addition, salinity modelling was used to assess catchment behaviour, define problem areas and quantify impacts. The use of discrete and continuous long term salinity data in these modelling frameworks increased both the accuracy and utility of the salinity models. The salinity assessment in the Murrumbidgee valley salinity technical report (2018c) will inform and give support to the WQMP and identify water, land and vegetation measures to increase productivity and environmental sustainability.

6.2. Elevated levels of suspended matter

The draftsman plots show there is generally a linear relationship between turbidity and total suspended solids in the Murrumbidgee WRPA, except for the upper catchment where the relationship was masked by the 5 mg/L lower detection limit of total suspended solids. Turbidity and suspended sediments were closely related to discharge, with most sites displaying a positive correlation to flow. The Tumut River at Oddys Bridge does not follow this trend. Turbidity and total suspended solids in the Tumut River, downstream of Blowering Dam, are low and stable as sediment and organic matter settles to the bottom of the dam and is only released downstream when the dam is spilling. Inversely, rapid and large volume irrigation releases can be responsible for channel erosion downstream of Burrinjuck and Blowering Dams.

Tarcutta Creek had the highest median turbidity in the upper Murrumbidgee catchment. This is consistent with research suggesting that most of the suspended sediment delivery in the mid Murrumbidgee originates from tributaries adjacent to the Murrumbidgee River, downstream of Burrinjuck Reservoir. This suggests bank and riparian condition in the Tarcutta Creek catchment is poor. Turbidity issues are also influenced by grazing practices. Stock trampling causes removal of groundcover, pugging which is stock damaging the soil structure and pasture, destabilising soils and erosion of stream banks which can all lead to increased turbidity. Historically, the streams in this area were also the focus of significant mining and fossicking activities. Carp can contribute to increased turbidity by stirring up sediments when feeding, uprooting aquatic vegetation and increasing bank destabilisation (Koehn 2004). Carp are common throughout most of the WRPA.

High turbidity is an issue in Yanco, Colombo and Billabong Creeks. Yanco, Colombo and Billabong Creeks were identified as a high risk to water dependent ecosystems. High levels of turbidity are likely influenced by a number of factors including the widespread conversion of land for cropping and irrigation, bank and riparian condition, river regulation and the presence of carp. In addition, very fine clay particles are able to remain in suspension during low flows resulting in high turbidity results under all flow conditions.

Billabong Creek at Darlot had the highest median turbidity of all routine monitoring sites. This site is located at the bottom of the Billabong Creek catchment where it receives the cumulative impacts from landuse upstream. There were very few turbidity results from this site and the two upstream sites (Walbundrie and Jerilderie) that did not exceed the Basin Plan target. This suggests the current Basin Plan target is not appropriate for Billabong Creek.

River Styles® recovery potential (Figure 17) is synonymous with geomorphic condition. Recovery potential represents geomorphic stability and can indicate the capacity of a stream to return to good condition or to a realistic rehabilitated condition (Brierley and Fryirs 2005). Streams rated as having conservation, or rapid recovery potential, are likely to be the most stable and in a good condition. Whereas streams with low recovery potential may never recover to a natural condition or may continue to decline quickly without intervention (Cook and Schneider 2006).

The highest priority for intervention action is the strategic recovery potential reaches. These are reaches of river that may be sensitive to disturbance, triggering impacts that can have off-site effects. Particular emphasis should be placed on reaches or point-impacts (nick-points), where disturbances may threaten the integrity of remnant or refuge reaches. Figure 17 identifies strategic recovery potential reaches throughout the Murrumbidgee catchment. Proactive management strategies in these areas are the most effective means of river conservation, leading to improvements in water quality.

There are large areas of low recovery potential in the tributaries upstream of Wagga Wagga suggesting sparse riparian vegetation, erosion of the stream bed and stream bank and low instream geomorphic diversity. These reaches are likely sources of suspended sediment, which has been confirmed by the routine water quality monitoring.

There are extensive conservation reaches in the Tumut, Goobarragandra and Goodradigbee River catchments. This is reflected in the good quality water in these three catchments. The majority of the regulated

Murrumbidgee River has a moderate recovery potential. The long section downstream of Yanco Weir to Hay has high recovery potential.

There is a long reach of moderate recovery potential downstream of both Blowering and Burrinjuck Dams. A threat to the recovery potential of the Murrumbidgee and Tumut Rivers is the lack of sediment delivered from the upper catchment. Dams act as a barrier and as large sediment traps, restricting the movement of sediment down the catchment. The reduced sediment load released restricts the development of low level benches and bars in the rivers downstream, reducing the river complexity and the recovery potential.

In the unregulated catchments, land and vegetation management are the key drivers for sediment entering waterways. The principal factor generating high sediment loads (and associated nutrients) is loss of vegetation in the catchment and/or the riparian zone, leading to increased hillslope, gully and bank erosion and suspended sediment loads in the river. The main sources of sediment are gully erosion in degraded areas and hillslope erosion where cover is seasonally low through grazing or tillage of cropped lands (National Land and Water Resources Audit 2001). The implementation of flow rules in these catchments will have little impact on reducing sediment inputs. In the regulated system, reducing the extent of bank erosion and slumping is possible through ensuring a more natural, gradual rising and falling limb of water releases from Blowering and Burrinjuck Dams and the reregulation of flows in the lower catchment.

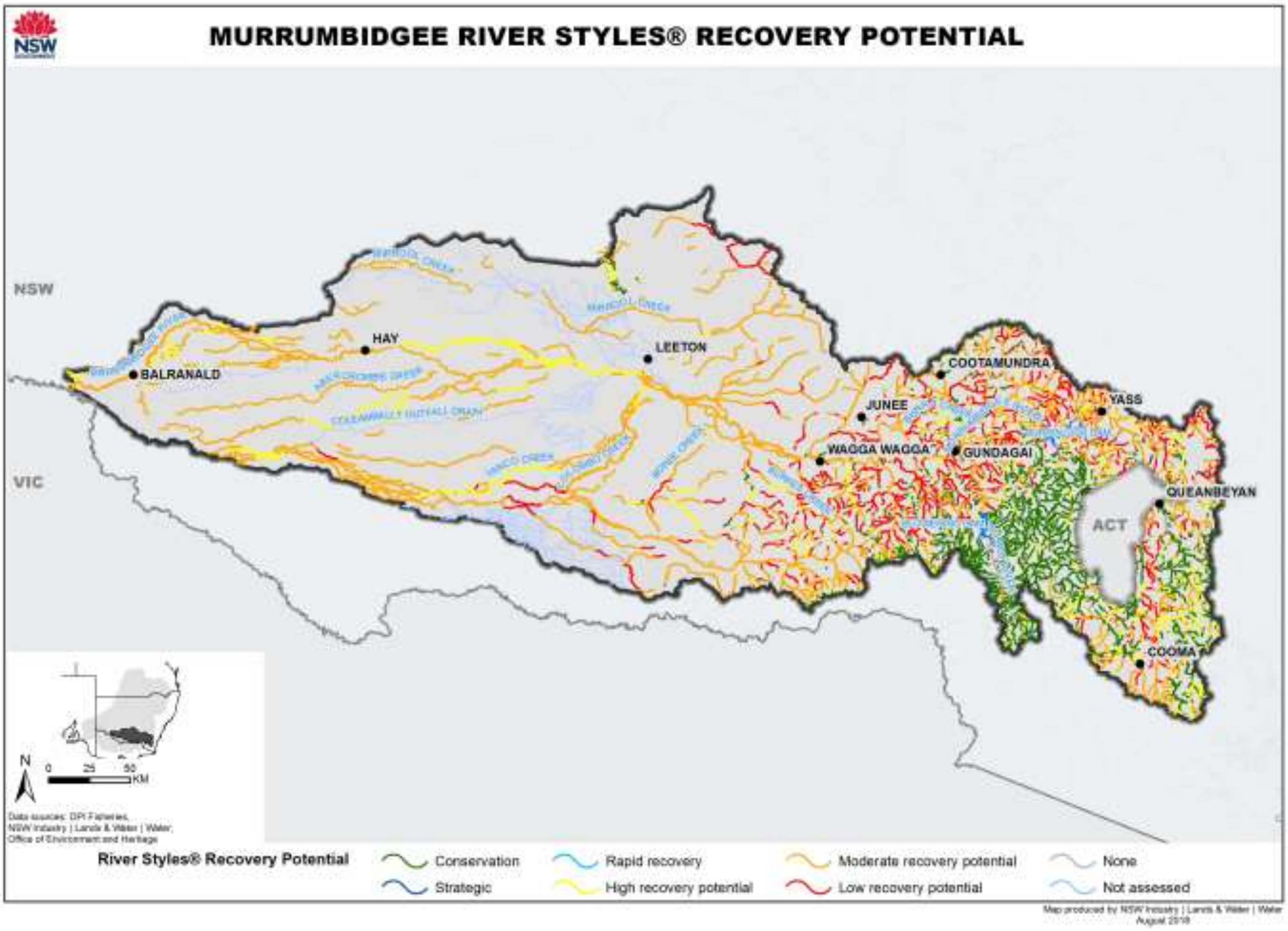


Figure 17: River styles recovery potential in the Murrumbidgee catchment

6.3. Elevated levels of nutrients

The highest nitrogen and phosphorus concentrations in the Murrumbidgee WRPA were in the tributaries downstream of Burrinjuck Dam (particularly Muttama Creek), Yanco Creek and Billabong Creek. The lowest results were in the Goodradigbee and Goobarragandra Rivers. In the unregulated catchments, the total phosphorus annual median exceeded the Basin Plan target more frequently than total nitrogen. In the lower

Murrumbidgee River nutrient targets were exceeded most frequently in the high flow years between 2010 and 2012. There were no sites with a high risk to water dependent ecosystems from total nitrogen. Sites with high risk from total phosphorus were Yanco Creek at Yanco Bridge and the Murrumbidgee River downstream of Yanco and Balranald weirs.

Nitrogen and phosphorus concentrations generally followed similar trends, indicating similar transport processes are driving both parameters. Nutrient concentrations are generally driven by runoff and erosion during rainfall events with higher concentrations at high flow. As for turbidity, many sites exceeded the Basin Plan nitrogen and phosphorus targets in the wetter years of 2010 to 2012. In addition, some of the higher nutrient concentrations at some sites occurred during low or cease to flow periods. This suggests the sources of nutrients can be mixed on some occasions.

Nutrient concentrations generally increase with distance down the catchment. This was not the case in the Lower Murrumbidgee River, with only minor changes between sites. Nutrient impacts can be ameliorated with distance downstream, possibly through a process of assimilation by the river, through phytoplankton uptake and deposition, uptake by benthic organisms or by adsorption onto the sediment of the river bed (Caitcheon et al. 1999).

Most of the uplands area has high soil nitrogen and phosphorus (Figures 18 and 19), which may be contributing to the high nutrient concentrations found in these rivers. Soil erosivity may be exacerbated by the historical conversion of forested land to grazing, particularly clearing in the riparian zone. Access of livestock to the river may be a source of nutrients and turbidity. Discharge from sewage treatment plants and septic tanks are other sources of nutrient input.

The land use in the region is dominated by grazing, with cropping of the more fertile soils. The fertile soils associated with cropping and irrigation, are a potential source of excess nutrients. It is also possible that the pre watering release, following periods of low flow over winter, may be re-suspending nutrients bound up in sediments on the river bed, and bank erosion on the rising limb of the hydrograph.

Similar to turbidity, there were very few total nitrogen and total phosphorus results from the three sites on Billabong Creek that did not exceed the Basin Plan targets, suggesting the current Basin Plan target is not appropriate.

Total nitrogen and total phosphorus concentrations in the Tumut River at Oddys Bridge followed a different pattern to other sites in the catchment. Nutrient concentrations were high in the dry years between 2007 and 2010. During this period, Blowering Dam was less than 50% capacity. The intake structure of the dam comprises an open intake tower with trashrack covered inlets from 33 to 74 m below full supply level. The low storage level would have meant that the bulk of the water released would have been nutrient rich water from the bottom of the storage. The flooding and subsequent filling of Blowering Dam in later 2010, would have allowed the release of water from higher in the water column, avoiding the nutrient rich water at depth.

Land and vegetation management are the key drivers for nutrients entering waterways in unregulated rivers. The implementation of flow rules upstream of Blowering and Burrinjuck Dams will have little impact on nutrient management. In the regulated system, reducing the extent of eutrophication caused by bank slumping is possible through a more natural, gradual rising and falling limb of water releases.

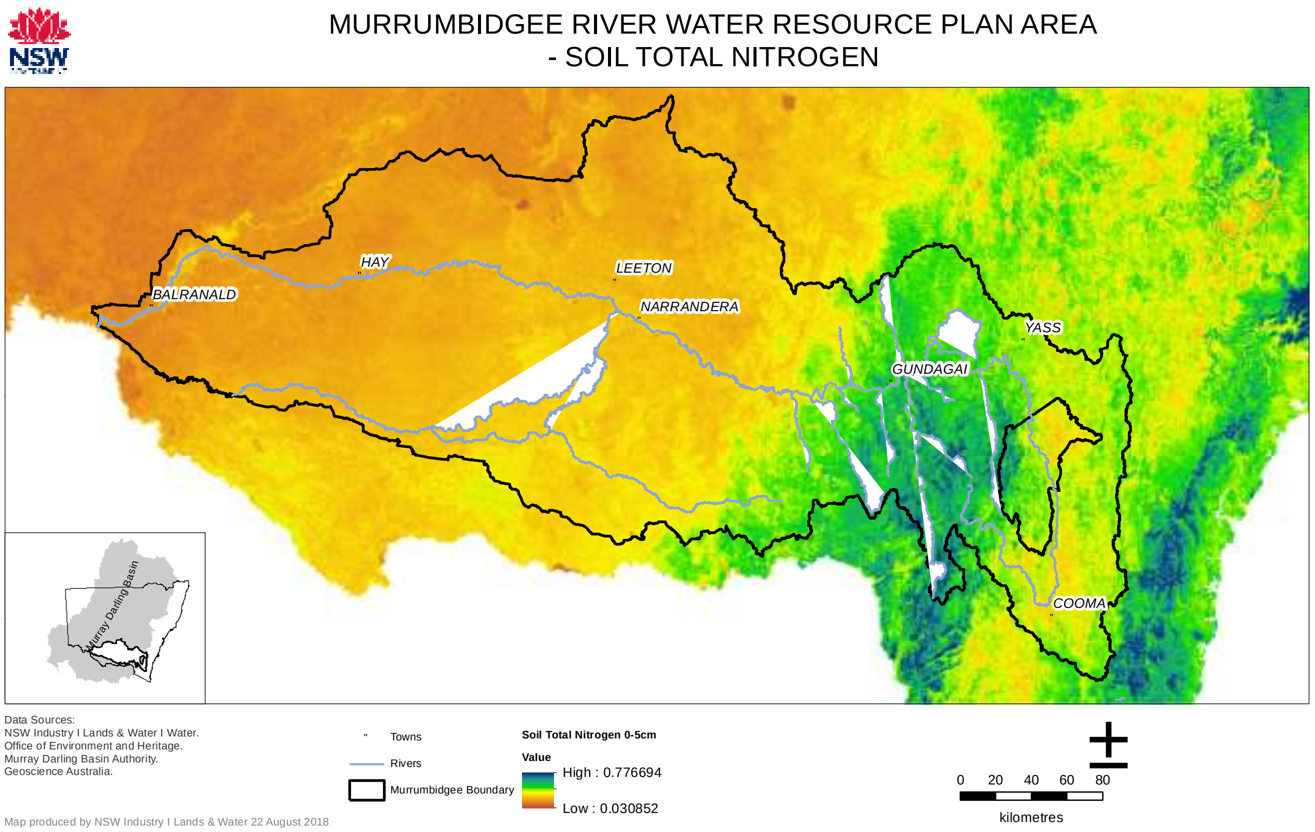


Figure 18: Soil total nitrogen for the Murrumbidgee catchment

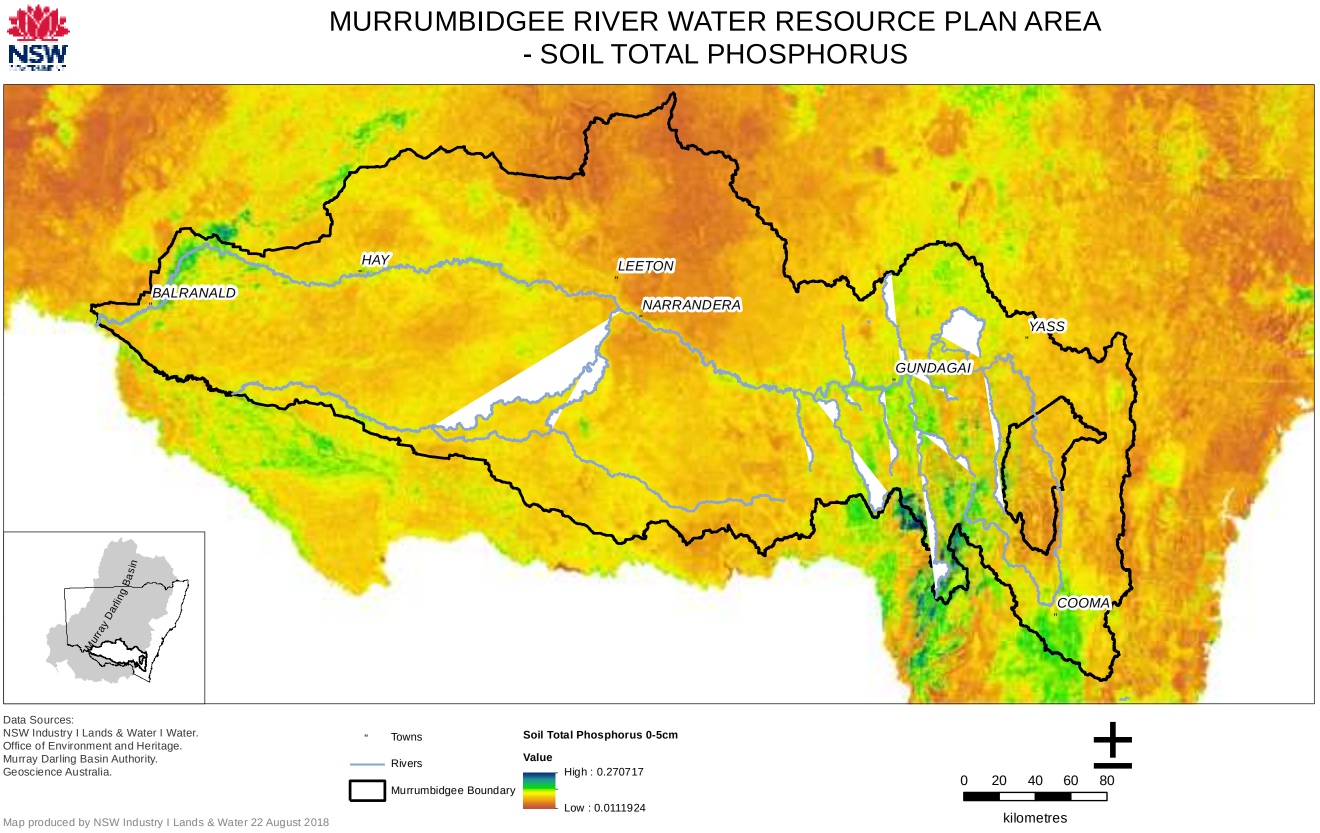


Figure 19: Soil total phosphorus for the Murrumbidgee catchment

6.4. Elevated levels of cyanobacteria

Harmful algal blooms in Blowering Dam are rare. Burrinjuck Dam experiences algal growth, but not on a regular basis. Blooms are more common in the recreational lakes lower in the catchment, such as Lake Albert (Wagga Wagga), Lake Wyangan (Griffith) and Yanga Lake near Balranald. Numbers of potentially toxic blue-green algae reach the red alert level for recreational use most summers, and remain on red alert for months. Nutrient rich inflows from local runoff combined with warm, shallow and still water during summer provide ideal conditions for algal growth.

Phosphorus and nitrogen concentrations are generally not limiting to algal growth in the Murrumbidgee WRPA. Despite this, algal blooms are rare in the Murrumbidgee River and weir pools indicating that other factors such as flow, turbidity and light availability are the limiting factors. The release of large volumes of water for irrigation over summer means the turbulent, high velocity water is not suitable for algal growth. Flows of 1,000 to 3,000 ML/day generally allow diurnal stratification, while flows greater than 4,000 ML/day keep Maude Weir pool well mixed at all times. As the water is usually released from depth from Blowering and Burrinjuck Dams, the rivers downstream are not seeded by the release of algae from within the storage, nor is warm water temperature aiding algal growth.

Nutrient management in the catchment area is essential to maintain a low risk of algal blooms within Blowering and Burrinjuck Dams. When algal blooms do occur, the level of human exposure can be reduced by implementing the established algal management framework of limiting access. The risk at a site with a high recreational usage can be reduced by erecting algal warning signs and informing users of the health risks, dangers and symptoms of ingesting or coming into contact with blue-green algae.

6.5. Water temperature outside natural ranges

Preece (2004) characterised storages across NSW according to their level of impact due to thermal (cold water) pollution. Both Blowering Dam on the Tumut River and Burrinjuck on the Murrumbidgee River have been identified as causing severe thermal disturbance (Preece 2004).

Releases from Blowering Dam are provided by a single, fixed level offtake. The intake structure comprises a 41 m high open intake tower with trashrack covered inlets from 33 to 74 m below full supply level. Blowering Dam thermally stratifies over summer with large temperature differences between the surface (28°C) and the bottom (11°C) waters (Bowling et al. 1994). The intake draws water from below the thermocline leading to marked cold water pollution in the Tumut River downstream of the dam. Keenan and Buchan (unpub.) reported 13 to 16°C reductions in natural summer water temperature immediately below the dam.

The storage volume in Blowering Dam fluctuates as water is released over summer and then replenishes following winter rainfall and snow melt. Stored water was mostly less than 50% capacity between 2002 and 2010 until heavy rain saw the dam fill in 2010. Irrigation releases from Blowering Dam into the Tumut River are regularly at a rate of 7 000 to 9 000 ML/day over most summers. Generally there is a larger temperature differential at the start of the irrigation season than at the end. Storage volume is drawn down resulting in the reducing of the height of water above the intakes. The exception is in 2010 to 2013 when the storage remained at full capacity across the seasons. In these years, the downstream water temperature only increased marginally over the summer. There is some fluctuation in the volume of the releases, but this is not reflected in the water temperature downstream at Oddys Bridge. The water temperature downstream is regularly 10°C colder than the Goobarragandra River during summer, up to almost 14°C on some occasions. The water temperature in the Tumut River does not recover to a more normal level before it joins the Murrumbidgee River.

Comparing the monthly median temperature downstream of Blowering Dam to the percentiles of the upstream “reference site”, the median water temperature downstream is less than the 20th percentile reference every summer indicating that the water temperature in the Tumut River downstream of Blowering Dam is ecologically harmful. This is especially evident in 2010 to 2013 when the storage was at 100% capacity, and there was a greater height of water above the intakes. Water temperature is also warmer than the 80th percentile in winter as large bodies of water are temperature-conservative.

Burrinjuck Dam stratifies through summer with temperature differences exceeding 10°C between surface and bottom waters (25 and 13°C respectively; Bowling et al. 1994). The storage is equipped with fixed level intakes at three different depths; a low level intake at 50 m, two mid-level intakes at 42 m and two upper level intakes at 14 m below full storage. The magnitude and extent of cold water pollution depends on which intake is in use. Keenan and Buchan (unpub.) reported 7 to 8°C temperature depression immediately downstream of the dam due to discharge.

Similar to Blowering Dam, the storage volume in Burrinjuck Dam fluctuates as water is released over summer and then the storage starts to fill again over winter. Stored water was mostly less than 50% capacity between 2002 and 2010. As with many other large storages across NSW, heavy rain resulted in the dam filling in 2010. However, the downstream water temperature does not appear to be as affected by storage capacity as other dams. The magnitude of cold water impacts downstream of Burrinjuck Dam in summer varies from year to year, most likely as a consequence of which intake was in use at the time of the release. The temperature difference at times can be up to 10°C, while at others only a few degrees. Instream thermal depression is evident at the Glendale site, but not as obvious every year at Gobarralong Bridge, which is 14 km upstream of the junction with the Tumut River.

The median monthly water temperature downstream of Burrinjuck Dam is regularly up to 10°C colder than the 20th percentile of the temperature at the upstream site on the Murrumbidgee River at Halls Crossing. The downstream water temperature is influenced by the depth of the outlet used at the time of the release. During some summers, there is a sudden drop in median water temperature (e.g. 2005, 2008, 2013 and 2014) possibly due to a change to a deeper outlet as the water level in the storage falls.

As suggested by Preece (2004), it appears that Blowering Dam on the Tumut River is the main contributor to cold water pollution in the Murrumbidgee River downstream of the Murrumbidgee-Tumut confluence, rather than Burrinjuck. The water temperature regime at Gundagai, and to a lesser extent Wagga Wagga, appears to be depressed over the summer months. By the time the flows have passed through Berembed Weir, water temperature has returned to a more natural regime. Berembed Weir is approximately 286 km downstream of the Murrumbidgee-Tumut confluence.

Cold water pollution can hinder ecological responses in the Murrumbidgee and Tumut Rivers. The issue of cold water pollution cannot be mitigated in the Murrumbidgee WRPA using flow rules, environmental flows or adjustments to release patterns. Environmental outcomes are currently able to be achieved through the management of the depth in the storage that water is released from the dams.

6.6. Dissolved oxygen outside natural ranges

The dissolved oxygen levels at most sites was within the target range for the majority of the data period. During low and cease to flow periods dissolved oxygen levels become unpredictable and fluctuate from very high to very low. These variations are primarily driven by the response of instream biota in these rivers. High organic carbon, nutrients and water temperatures result in increased microbial respiration. In Muttama Creek, the dissolved oxygen was mostly within the desired upper and lower limits. High nutrients combined with low turbidity and low flow, increased the photosynthesis from aquatic plant growth, resulting in a super saturated dissolved oxygen reading of 220% saturation.

In contrast to these factors, high turbidity and suspended sediment reduces light availability. The solubility of oxygen decreases as water temperature increases, reducing primary production and resulting in reduced dissolved oxygen levels. Murrumbidgee River downstream of Balranald Weir and Billabong Creek at Darlot are located at the bottom of the catchment where a combination of low flow and warm, turbid water can result in dissolved oxygen levels below the lower target. Colombo Creek at Morundah was the only site identified as having a high dissolved oxygen risk for water dependent ecosystems.

The dissolved oxygen in the Tumut River at Oddys Bridge fluctuated around the 90% saturation target. The dissolved oxygen at this site is more likely impacted by the depth of the offtake in Blowering Dam than flow or catchment management factors.

The Murrumbidgee River experienced drought conditions between 2000 and 2010, with flows well below long term averages. Floodplain inundation was minimal during these years, with any available water being diverted for essential human services and agriculture. During spring 2010, there were several large flow events that led to the end of the drought in the Murrumbidgee valley. During December 2010, the largest of these spilled substantially onto the Murrumbidgee floodplain with widespread inundation. Widespread flooding of the floodplain, which had experienced little recent inundation combined with extensive litter accumulation, led to large amounts of blackwater being generated on the floodplain and then entering the river.

Anoxic blackwater is a natural feature of lowland river systems and occurs during flooding when organic material (sticks, leaves, bark and grass) is washed off the floodplain and into the river. The breakdown of this material by bacteria can lead to a sudden decrease in the oxygen available to fish and other organisms. The black appearance of the water is due to the release of dissolved carbon compounds, including tannins, as the organic matter decays. Large blackwater events can lead to fish kills and ecosystem collapse (Whitworth et al. 2012).

The dilution of blackwater returning to the Murrumbidgee River from the floodplain using better quality water from upstream, has proven a successful management approach, as long as implementation occurs before hypoxia falls below lethal levels. However, during the 2010 and early 2011 flood events, anoxic events occurred several times, resulting in fish kills before dilution flows could be initiated.

Anoxic blackwater events on this scale have occurred in the past and will continue to occur in the future. It is distressing that these events occur, resulting in the loss of fish and other aquatic life. The impacts of these events on the environment are harmful, but are usually short-term, as the river water re-oxygenates again as the flooding subsides. Naturally occurring events such as these underpin the broad health of rivers. They provide nutrients to drive the overall production of our river and wetland systems. In the longer term, native fish, water birds and other organisms will benefit from the increased production in the river, boosting food supplies and supporting breeding cycles.

Recommendations to improve prediction and management of anoxic events in the lower Murrumbidgee River (DPIW 2013) include:

- Development of a monitoring plan ahead of expected hypoxic events;
- Better hydrological knowledge of lower Murrumbidgee floodplain returns, with a combination of time series flow data at points along the river, better ratings data from escapes and adequate gaugings at major floodplain escapes during events;
- More comprehensive dissolved oxygen time series monitoring;
- Comprehensive dissolved organic carbon monitoring before, during and following events, and
- Increased use of existing blackwater models to enable better validation and enhance prediction.

The Basin Plan dissolved oxygen target ranges were designed specifically to be applied to monthly data, and provide an indication of any issues and long term trends. Monitoring of dissolved oxygen is currently conducted monthly, however it does not capture the full diurnal variation. To fully capture dissolved oxygen dynamics, continuous monitoring during a range of hydrologic and seasonal conditions is required. Dissolved oxygen sensors have been installed at key gauging stations in the lower Murrumbidgee catchment as a tool to better monitor blackwater events. The use of continuous data may prove more beneficial for assessing dissolved oxygen concentrations than single monthly readings. Watson et al. (2009) suggests that when dissolved oxygen concentrations drop below 5 mg/L (or 50% saturation) in lowland rivers, there is a substantial increased risk to fish health. This target has been applied in the Basin Plan for managing water flows. It was proposed by Tiller and Newall (2010) that the assessment of continuous data against this proposed trigger level may prove more beneficial for dissolved oxygen data analysis and give a better assessment of the oxygen regime.

There is continuous dissolved oxygen data available for the Murrumbidgee River downstream of Balranald Weir, however being at the end of the catchment, this provides minor assistance for environmental water managers to coordinate the release of water prior to and during blackwater events. Additional sites have recently been added to the Murrumbidgee River downstream of Redbank and Maude weirs to monitor dissolved oxygen and aid in delivering environmental flows.

Maintaining low and base flows through cease and commence to pump rules and protection of small freshes in unregulated catchments assist to flush or turn over stratified pools. This flow physically breaks down the stratification and prevents water on the bottom of pools becoming anoxic and unsuitable for aquatic fauna. In addition, low flows help prevent excessive algal and aquatic macrophyte growth which can result in supersaturated oxygen conditions.

There are no flow rules available, nor is the volume of environmental water sufficient to flush organic material from the entire Murrumbidgee floodplain in an attempt to prevent anoxic blackwater events from occurring. Flows can be used to produce the small floods to flush material from high benches and lower floodplain areas. Delivering environmental flows to forest areas in winter or early spring, when water temperatures are lower, reduces the risk of triggering a blackwater event.

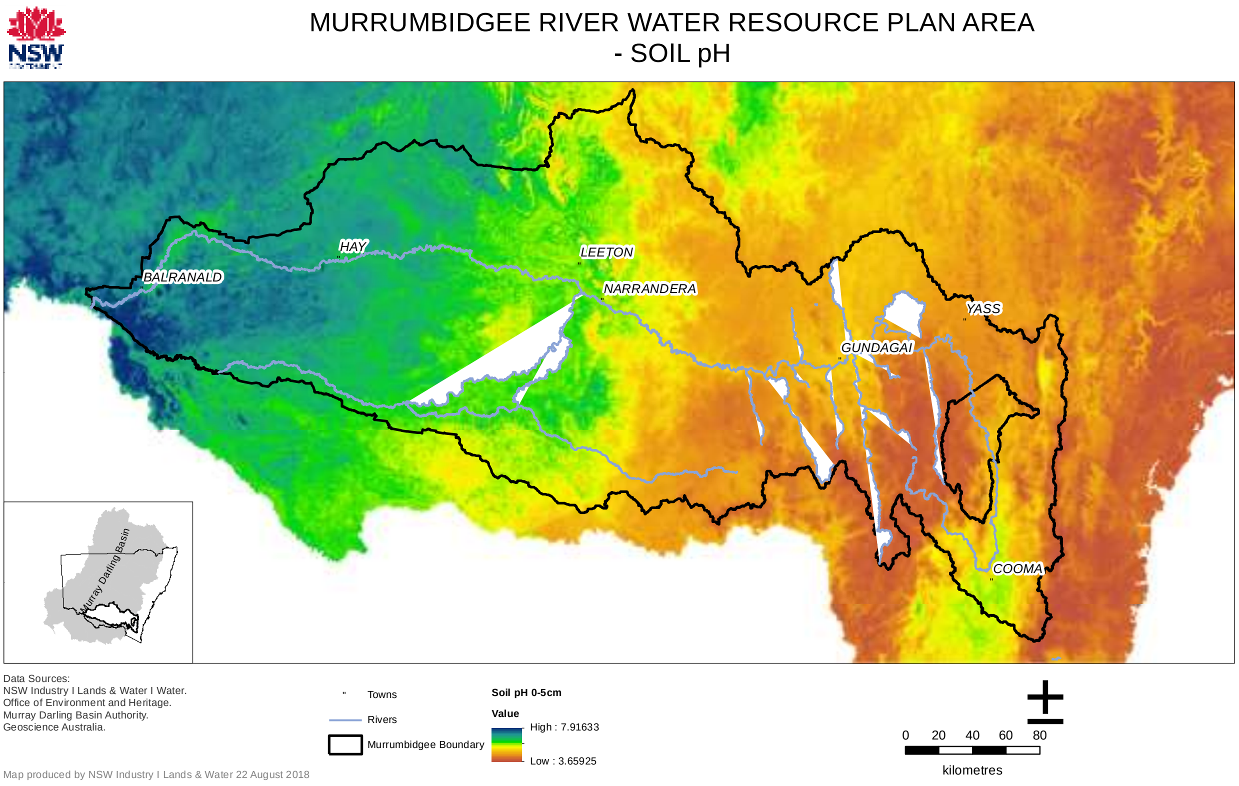
6.7. Elevated levels of pesticides and other contaminants

Historically, pesticide residues in rivers have not been monitored in the Murrumbidgee valley. With the agriculture industry becoming increasingly reliant on chemical use for weed and pest control, it is expected that the residues of some chemicals may be present in waterways. The detection of residues of herbicides used in dryland agriculture in other valleys has shown a need for natural filters such as grassed waterways, natural grasslands or vegetated buffer strips to reduce chemical concentrations in runoff and aerial drift.

There are no current monitoring data on the presence of toxicants in this area. Pollution from current mining and industrial activities is controlled through environmental protection licences under the *Protection of the Environmental Operations Act 1997* (*POEO Act*).

6.8. pH outside natural ranges

Soil pH increases with distance down the Murrumbidgee catchment (Figure 20), however this is not reflected in the water quality results. Most routine monitoring sites had pH results within the Basin Plan upper and lower limits. The highly saline sites (Jugiong Creek, Muttama Creek and Billabong Creek at Walbundrie) had elevated pH. This suggests increased concentrations of calcium and magnesium bicarbonates at these sites. Inversely, the pH in the Tumut River is low. This is consistent with other studies of water quality in Blowering Dam (Bowling et al. 1995).



Data Sources:
NSW Industry I Lands & Water I Water.
Office of Environment and Heritage.
Murray Darling Basin Authority.
Geoscience Australia.

Map produced by NSW Industry I Lands & Water 22 August 2018

Figure 20: Soil pH for the Murrumbidgee catchment

6.9. Elevated pathogen counts

There are no current data on the extent of pathogens in the Murrumbidgee WRPA. It is expected that with ongoing inputs of human and animal waste, and access of stock and animals to rivers and streams, that pathogens would be present in waterways. Higher counts would be expected following rainfall and runoff flushing contaminants into the rivers. Similarly, high counts may be common during low flows in areas with point source pollution. There is an unknown risk from the high prevalence of septic systems across the catchment. As for other pollutants, pathogens cannot be managed through water planning.

6.10. Knowledge gaps

Dissolved oxygen

Dissolved oxygen data in the Murrumbidgee WRPA is collected monthly, which does not cover the full diurnal variation in the water column. Efforts are made to collect samples at approximately the same time each month to allow comparison at a site through time. However, this can result in some sites having a low median, because the data is routinely collected earlier in the morning, or inversely, high readings because the samples are collected later in the afternoon. The Basin Plan dissolved oxygen targets were developed to accommodate monthly data. However, continuous real time data would provide a complete picture of dissolved oxygen variability and could be used as an early warning for catastrophic events (anoxic blackwater) and aid the delivery of water to provide refuge areas.

Water temperature

Water temperature in the Murrumbidgee River and tributaries is monitored continuously at numerous locations across the catchment. To date, investigations have focused on the extent of cold water pollution. Clearing of vegetation in the riparian zone and poor geomorphic condition can lead to increased sunlight reaching the water surface, resulting in increased water temperatures. The extent and scale of this form of increased thermal pollution is unknown.

Event based monitoring

The current water quality monitoring program targets low and base flow conditions with limited, high flow event based monitoring. High velocity water is generally required to transport large concentrations, and therefore loads, of suspended sediment and associated nutrients, pesticides and pathogens. Suspended solids and nutrients tend to increase during high river flow, when particulate matter is washed from the catchment, bank erosion contributes material and/or bed sediments are resuspended in the water column. The high velocity water in the upper catchment is capable of carrying greater quantities of sediment and nutrients. As the stream bed flattens out across the floodplain, these nutrient rich suspended particles fall out of suspension and are deposited on the floodplain and into river sediments. For streams upstream of Blowering and Burrinjuck Dams, this material is deposited in the dam, settling out of the water column and providing a source of nutrients to sustain algal blooms. The deposition of sediment in the dam results in less material for instream bar and bench formation downstream.

Hazard mapping

Spatial modelling to develop hazard mapping, utilising the range of data sets available such as riparian vegetation cover and geomorphic condition, and overlaying soil erosion risk areas and soil fertility could identify key areas most likely to contribute to poor water quality and guide the implementation of management decisions. In addition, the mapping and identification of high priority refuge pools would assist in the monitoring and delivery of water to maintain water quality suitable for water dependent ecosystems during extended dry periods.

Additional water quality monitoring sites

There is only one water quality monitoring site located in the Montane water quality zone (C3). Additional sites would provide a more accurate assessment of the quality of the surface water in this zone.

There are currently no routine water quality monitoring sites located between the Australian Capital Territory and Burrinjuck Dam to assess possible water quality impacts of discharges from the sewage treatment plant and urban runoff from Canberra.

The current New South Wales surface water quality monitoring program has been in operation since 2007. It was established and designed to meet the objectives and data requirements at the time. There are numerous routine water quality monitoring sites in the Murrumbidgee WRPA. A revision of the state wide water quality monitoring program is required to better meet the requirements of all WRPAs in the Murray-Darling Basin, and to fill identified information gaps.

Agricultural chemical, toxicants and pathogen data

There are no current data on the concentrations of agricultural chemicals in the creeks and rivers of the Murrumbidgee WRPA. As agriculture has become increasingly reliant on agricultural chemicals, large quantities of insecticides and herbicides are used in the catchment. As the main transport mechanisms for their movement in the environment still exist, it is assumed that there is a risk that chemical residues are present in waterways. Without monitoring data, we cannot determine which chemicals are present, when, or the concentration. Similarly, it is only assumed that there are pathogens present in the waterways.

Development of local water quality targets

It has been identified that some of the Basin Plan water quality targets may not be appropriate for some parameters, in some zones. It is recommended that Billabong Creek should be included in the Murrumbidgee lowland zone (A3), rather than the Central Murray (Upper, Middle) zone (CMum). Time frames do not allow for the development of local targets before the completion of the WQMP, but they will be incorporated as a long-term strategy in the plan.

Ramsar wetlands

Principle threats to the ecological character of the Ramsar sites in the Lower Murrumbidgee (Fivebough and Tuckerbil Swamps) include agricultural production (including livestock grazing and cultivation) flood mitigation, weeds and introduced vegetation, urban and industrial development and disposal of treated effluent. A plan of management is currently being updated. As there are no routine water quality monitoring sites in the Ramsar listed wetlands, no assessment of water quality targets has been made in this report and cannot be undertaken in future reports. Ramsar wetlands will be included in the revision of the water quality monitoring program.

7. Conclusion

The quality of the water in a river or stream is a reflection of underlying climate and geology and the multiple activities occurring in a catchment area. There are numerous factors contributing to the observed results, many of which are outside the influence of flow management and therefore cannot be addressed through water planning alone.

In unregulated catchments, greater emphasis must be focused on preventing pollutants such as sediment and nutrients from entering waterways through land, soil and vegetation management. As sediment is a major transport mechanism for many pollutants, practices such as maintaining groundcover, vegetated buffer strips and good agronomic practices together with management of riparian vegetation to reduce stream bank erosion, provide simple and effective means to improve water quality. Land and vegetation management does not only address water quality issues in the rivers, but also harmful algal blooms.

In the regulated system, issues of dissolved oxygen, contribution of sediment and nutrients through bank slumping, dissolved organic carbon and to a lesser degree, cold water pollution can be addressed through the implementation of flow rules.

There are opportunities for government agencies, including NSW Local Land Services (LLS), Office of Environment and Heritage (OEH), DPI Fisheries and DPI Agriculture to work closely with DoI Water in managing external constraints through complementary measures. Collaboration between natural resource management groups to examine alignment of priorities has been a continued focus of NSW Government (NRC 2010). Alignment of natural resource management continues to be identified as a priority for LLS (Local Land

Services 2016) and for the management of environmental water and water quality in New South Wales (OEH 2014). Alignment of priorities for river management will assist in strengthening the outcomes of mitigation measures.

The information and data analysis from this report will support the development of the Murrumbidgee Water Quality Management Plan (WQMP). Based on the water quality data and information available, water quality objectives for the Murrumbidgee WRPA will be formulated where there are flow ‘levers’ available to water managers. The WQMP will consider the impacts of wider natural resource and land management on water quality within the Murrumbidgee water resource plan area. It will provide a framework to protect and maintain water quality that is ‘fit for purpose’ for a range of outcomes. These uses and activities may include irrigation of crops, maintaining a healthy environment, recreational fishing or cultural and spiritual links to Country for Aboriginal communities.

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Appendix A. Water quality monitoring site locations

Table 18: Location of water quality monitoring stations in the Murrumbidgee WRPA

Station Number	Station Name	Latitude	Longitude
Routine water quality			
410033	Murrumbidgee River at Mittagang Crossing	-36.164444	149.094722
410213	Murrumbidgee River at Angle Crossing	-35.583039	149.109085
410024	Goodradigbee River at Wee Jasper	-35.165000	148.687222
410025	Jugiong Creek at Jugiong	-34.787928	148.377392
410044	Muttama Creek at Coolac	-34.930688	148.162661
410038	Adjungbilly Creek at Darbalara	-35.017613	148.247047
41010924	Goobarragandra River at Little River Road	-35.332088	148.340090
410073	Tumut River at Oddys Bridge	-35.388899	148.247912
410004	Murrumbidgee River at Gundagai	-35.074930	148.107160
41010809	Hillas Creek at Mundarlo Road Bridge	-35.146060	147.800900
41010890	Adelong Creek at Bereena	-35.112428	148.027352
410047	Tarcutta Creek at Old Borambola	-35.161915	147.656380
41010395	Murrumbidgee River downstream Wagga Wagga	-35.100740	147.310665
410014	Colombo Creek at Morundah	-34.936800	146.295400
410015	Yanco Creek at Morundah	-34.946500	146.267700
410169	Yanco Creek at Yanco Bridge	-35.148550	145.772500
410036	Murrumbidgee River downstream Yanco Weir	-34.695760	146.401250
410082	Murrumbidgee River at Gogeldrie Weir	-34.615190	146.255700
410078	Murrumbidgee River at Carathool	-34.449591	145.417238
410136	Murrumbidgee River downstream Hay Weir	-34.525961	144.711764
410040	Murrumbidgee River downstream Maude Weir	-34.477623	144.301000
41010901	Murrumbidgee River downstream Balranald Weir	-34.665194	143.492947
41010143	Murrumbidgee River at Waldaira	-34.701886	143.322347
410091	Billabong Creek at Walbundrie	-35.691715	146.721210
410016	Billabong Creek at Jerilderie	-35.353366	145.735270
410134	Billabong Creek at Darlot	-35.044000	144.447000
Blue-green algae			
410033	Murrumbidgee River at Mittagang Crossing	-36.164444	149.094722
41010889	Burrinjuck Reservoir	-35.002222	148.588611
410008	Murrumbidgee River d/s Burrinjuck Dam	-35.001225	148.574820
410004	Murrumbidgee River at Gundagai	-35.074930	148.107160
41015431	Tantangara Reservoir	-35.796226	148.662610
41010001	Blowering Reservoir	-35.401505	148.244000
410073	Tumut River at Oddys Bridge	-35.388899	148.247912
41010395	Murrumbidgee River downstream of Wagga Wagga	-35.100740	147.310665
	Lake Albert, Wagga Wagga	-35.166544	147.373584
41010839	Lake Wyangan, Griffith	-34.203738	146.032353
41010711	Barren Box Swamp	-34.153739	145.829579
41010888	Yanga Lake	-34.724042	143.583511
410082	Murrumbidgee River downstream Gogeldrie Weir	-34.615190	146.255700
410078	Murrumbidgee River at Carathool	-34.449591	145.417238
410002	Murrumbidgee River at Hay	-34.515418	144.843212
41010343	Murrumbidgee River at Hay Weir	-34.524308	144.712936
41010362	Murrumbidgee River at Maude Weir	-34.476111	144.306389
41010361	Murrumbidgee River at Redbank Weir	-34.375000	143.784444
41010901	Murrumbidgee River at Balranald Weir	-34.665194	143.492947
410091	Billabong Creek at Walbundrie	-35.691715	146.721210
410016	Billabong Creek at Jerilderie	-35.353366	145.735270
410134	Billabong Creek at Darlot	-35.044000	144.447000
Continuous electrical conductivity and water temperature			
410090	Yass River at Gundaroo	-35.065107	149.264533
410176	Yass River Upstream Burrinjuck Dam	-34.863444	148.792037
410024	Goodradigbee River at Wee Jasper	-35.165000	148.687222

Station Number	Station Name	Latitude	Longitude
410777	Murrumbidgee River at Halls Crossing	-35.131223	148.943984
410008	Murrumbidgee River d/s Burrinjuck Dam	-35.001225	148.574820
410068	Murrumbidgee River at Glendale	-34.915112	148.551208
410025	Jugiong Creek at Jugiong	-34.787928	148.377392
410195	Murrumbidgee River u/s Gobarralong Bridge	-34.984280	148.216492
410057	Goobarragandra River at Lacmalac	-35.329558	148.348997
410073	Tumut River at Oddys Bridge	-35.388899	148.247912
410044	Muttama Creek at Coolac	-34.930688	148.162661
410004	Murrumbidgee River at Gundagai	-35.074930	148.107160
410061	Adelong Creek at Batlow Road	-35.331667	148.067778
410043	Hillas Creek at Mount Adrah	-35.178171	147.874281
410047	Tarcutta Creek at Old Borambola	-35.161915	147.656380
410156	Kyeamba Creek at Book Book	-35.351230	147.552623
410048	Kyeamba Creek at Ladysmith	-35.196229	147.509843
410001	Murrumbidgee River at Wagga Wagga	-35.100556	147.367500
410023	Murrumbidgee River d/s Berembed Weir	-34.879167	146.835278
410103	Houlaghans Creek at Downside	-35.004007	147.355398
410093	Old Man Creek at Kywong	-34.927623	146.784572
410005	Murrumbidgee River at Narrandera	-34.755401	146.549019
410108	Diversion Channel 800 at Outfall	-35.103745	145.783204
410169	Yanco River at Yanco Bridge	-35.148550	145.772500
410186	Billabong Creek d/s Ten Mile and Mountain Creeks	-35.685500	147.185000
410168	Billabong Creek at Hartwood	-35.310000	145.288056
410091	Billabong Creek at Walbundrie	-35.691715	146.721210
410148	Forest Creek at Warriston Weir	-35.340975	145.120719
410170	Billabong Creek u/s Innes Bridge	-35.322356	145.975427
410110	Diversion Channel 500 at Outfall	-34.878745	145.574315
410134	Billabong Creek at Darlot	-35.044000	144.447000
410040	Murrumbidgee River d/s Maude Weir	-34.477623	144.301000
410041	Murrumbidgee River d/s Redbank Weir	-34.380000	143.781667
410130	Murrumbidgee River d/s Balranald Weir	-34.665194	143.492947
41000271	Alum Creek at Jones Plain Road	-35.993406	148.963600
41000027	Bredbo River at Bredbo Station	-35.990722	149.179593
41000272	Murrumbidgee River u/s Michelago Creek	-35.703758	149.138825

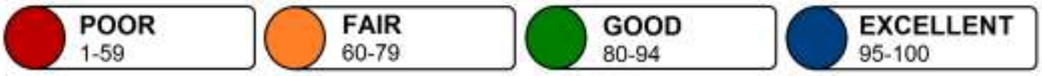
Appendix B. Water quality index (WaQI) method

A water quality index is a tool to communicate complex and technical water quality data in a simple and consistent way. It is useful for presenting information with different units (e.g. mg/L and % saturation) or characteristics (e.g. turbidity in a montane vs lowland river) on a common scale. It can also be used as a reporting tool for evaluation of changes in water quality over the life of a water quality management or water sharing plan.

For water quality management plans (WQMP) the WaQI is calculated as an overall integrated index (for five to eight parameters) and for each water quality parameter individually. These calculations are performed independently.

The overall WaQI for the WQMP includes total nitrogen, total phosphorus, turbidity, dissolved oxygen and pH. It is based on the exceedance of water quality targets as prescribed in Schedule 11 of The Basin Plan. Blue-green algae, salinity and temperature are calculated as individual parameters. To calculate the index a minimum of 30 samples is required across a five year period with a minimum of four samples in any one year.

The outcome provides a number between 1 and 100 that is categorised according to the following:



The index for both the overall score or, for an individual parameter is calculated as:

$$WaQI = \left(\frac{\sqrt{F1^2 + F2^2}}{1.41421}\right)$$

Where F1 (*frequency*), the frequency of the number of failed tests per total tests, is:

$$F1 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right) \times 100$$

And where F2 (*amplitude*), the amplitude is the amount a value exceeded he target, is:

$$F2 = (nse \div [0.01nse + 0.01])$$

Where *nse* (the normalised sum of excursions) is:

$$nse = \left(\frac{\sum_{i=1}^{n} excursion\ i}{number\ of\ tests}\right)$$

And where the excursion is:

$$Excursion = \left(\frac{Failed\ test\ value\ i}{Test\ objective}\right)$$

or

$$Excursion = \left(\frac{Test\ objective}{Failed\ test\ value\ i}\right)$$

How was the method determined?

A literature review of existing water quality index methods, purposes and reviews was conducted in 2015. There is extensive literature (over 500 papers), and a wide range of existing methods (more than 100) of calculating water quality indices. A number of individual index methods as well as key text and review papers (e.g Abbasi and Abbasi 2012; Achterberg 2014; Bauer et al. 2013; Brown et al. 1970; Cude 2001; Dinius 1987; Hurley et al. 2012; Lumb et al. 2011; Srebotnjak et al. 2012; Terrado et al. 2010; Van Oost et al. 2007) were reviewed to determine an appropriate index for NSW that is robust and meets our requirements.

The Canadian Council of Ministers of the Environment (CCME) water quality index (Roulet and Moore 2006) was chosen as method on which to base the WaQI. The key questions that were considered when making this decision were:

- Has it been tested and accepted in peer review literature?
- How widely is it used?
- Can it be used without requiring calibration to biogeographically distinct regions?
- Is it flexible, and can it be used with continuous data or toxicants if required?
- Has it been tested against ecological indices (e.g. macroinvertebrates)?
- Can it be easily presented and understood for reporting?

The method has been modified to remove a subindex that included the number of failed parameters. The subindex was excluded as only five to seven parameters will be used to calculate the NSW WaQI. In comparison, the CCME WQI is designed for up to +30 parameters.

Appendix C. Literature Review

A Web of Science search was undertaken that always included ‘NSW’ and then one of the following ‘Murrumbidgee River’, ‘Jugiong Creek’, ‘Billabong Creek’, ‘Yass Creek’, ‘Burrinjuck Dam’, or ‘Blowering Dam’. This search was supplemented with a search using the Google Scholar database and the terms ‘Murrumbidgee’, ‘river’ and ‘NSW’. The output is summarised in Table 19.

Table 19: Review of published literature

References	Subcatchment	Description
Macdonald et al. 2012	Lowlands	Flooding supports recruitment for weeds. Recruitment reduced by presence of other vegetation. Hotter constant temperatures reduced germination. Fluctuation and colder temperatures increases germination.
Kingsford 2000	Wetlands	Water quality has had an effect on river red gum survival. Also studied the Macquarie, Barmah, Millewa and Moira Marshes and Chowilla floodplain.
Brock et al. 2005	Narran Lakes, Gwydir wetlands, Macquarie Marshes, Billybung Lagoon, Lake Cowal, Great Cumbung Swamp, Darling anabranch	Tested response to zooplankton hatching and seed germination to different salinities in a range of wetlands. Salinity increases in soils when damp but not when flooded. Aquatic plant germination and species richness decreased significantly with increasing salinity. These decreases started immediately between the lowest treatments of <300 to 1000mg/L. Similar for zooplankton hatching, Macquarie Marshes had significant declines above <300mg/L, Narran Lakes and Gwydir had declines above 1000mg/L. Community structure changed above 1000mg/L Increased salinity however had no effects on Lake Cowal, Darling anabranch and Great Cumbung Swamp (ie up to 5000mg/L treatment). There was no change in community structure.
Kelleway et al. 2010	Wetlands	Carbon sources supporting consumers are varied and appear related to spatial distribution of primary producers. Highlights the importance of riparian vegetation as a carbon source, its influence on shading and decreases in in-channel solar radiation limiting in-channel autotrophic production.
Norris et al. 2001	Murrumbidgee and all of basin	Parts of the Murrumbidgee valley are extremely impaired. Some sections of the Murrumbidgee may have lost between 80-100 percent of species likely to have occurred there. Approximately 37% of river length has been substantially modified from natural condition.
Rolls et al. 2013	Lowlands and midlands	Temperature, flows, habitat and food resource (prey size and availability) all impair fish recruitment. Flow magnitude and water temperature appeared to have the largest effect in determining larval fish composition. Hypothesised that a lack of prey and resources may be one of the reasons why there is not a strong response to managed flow events.
Austin et al. 2010	Murrumbidgee (and all of Murray)	Estimates that climate change my reduce water yield in the Murrumbidgee by up to 21% by 2030 and 48% by 2070. These numbers are based on the higher resolution model of two scenarios tested. This scenario however is overly optimistic and assumes wide spread change

References	Subcatchment	Description
		in energy production industry towards less emissions intensive. The actual impacts may be much worse.
Woodward et al. 2015	Midlands	Examined carbon and nutrient inputs from banks under different flow heights. Where river channels have already been impacted by regulated flows, complex surfaces may have been lost, so restoring more natural flows at these levels of channel, may have little immediate impact on nutrient processing. Low level benches will need to be ‘rebuilt’ before environmental flows can increase connectivity.
Gilfedder et al 2009	Murrumbidgee	Developing a model to predict impacts of land use on stream flow and salt export to guide catchment managers towards areas requiring more detailed investigation.
Lawrence et al. 2000	Burrinjuck Reservoir	Investigation into factors determining algal growth in Burrinjuck Reservoir. There is a strong pattern of vertical thermal gradients and longitudinal partitioning of water over summer months. Nutrient availability determines algal biomass rather than light attenuation or grazing. Identified a significant reduction in phosphorus concentration and a change in nutrient forms post 1983 following the commissioning of a new sewage treatment plant for the ACT.
Olley and Wasson 2003	Upper Murrumbidgee (upstream of Burrinjuck)	Sediment flux in the upper Murrumbidgee has changed as result of grazing, historical climate change and dam closures. Pre settlement sediment flux from the entire catchment was estimated at approx. 2400 t/year. Grazing triggered widespread gully erosion, increasing sediment flux by a factor of about 200 to approx. 480 000 t/year. As gully networks reached maximum extension, sediment yield from headwater areas declined.
Dyer et al. 2014	Upper Murrumbidgee (upstream of Burrinjuck)	River regulation has resulted in greater changes to ecologically relevant streamflow characteristics than climate change scenarios involving a 1 to 2°C temperature rise.
Verstraeten et al. 2007	Murrumbidgee	Spatial pattern of hillslope derived suspended sediment delivery indicated that most of the sediment originates from a few small tributaries adjacent to the Murrumbidgee River downstream of Burrunjuck Reservoir.
Zierholz et al. 2001	Jugiong Creek	Recent and extensive infilling of the incised channel network of the Jugiong Creek catchment. The further spread of in-stream wetlands is likely to increase the sediment trapping capacity and further reduce the discharge of sediments and nutrients into the Murrumbidgee River. The in-stream wetlands may provide a significant capacity to buffer erosion from gullied catchments of considerable size (up to 300 km^2) as an adjunct to current riparian management options
Conyers et al. 2008	Mid Murrumbidgee	NaCl was not always dominant as might be expected if cyclic marine salt dominated. The presence of Ca and Mg bicarbonate in all streams, and their dominance in two streams, indicates that mineral weathering is also a major contributor to the salt load of water in the catchment. Ca and Mg bicarbonates have limited solubility, so their concentrations will not become a cause of osmotic stress when the water is used for drinking or

References	Subcatchment	Description
		irrigation. The ionic composition of the water in the Murrumbidgee River is predominantly controlled by the major flow volumes from Burrinjuck and Blowering Dams. Prioritising catchments for changed land management requires examination of the salts they discharge not just electrical conductivity.
Sherman and Webster 1997	Murrumbidgee	Studies in the Murrumbidgee River have indicated that persistent thermal stratification is a requirement for *Anabaena circinalis* blooms to occur. It is possible to propose a range of flow control strategies and options for destroying thermal stratification in weir pools to limit cyanobacterial growth.
Sherman et al. 1998	Murrumbidgee	Under stratified conditions in weirs, turbulent mixing is reduced and the positively buoyant cells of *Anabaena* can accumulate and grow in the surface layers in favourable light conditions. Weir pool remained persistently stratified during periods when discharge was less than 1000 ML/day. Flows of 1000-3000 ML/day generally allowed diurnal stratification, while flows greater than 4000 ML/day kept Maude Weir pol well mixed at all times.
Wallbrink et al. 1998	Murrumbidgee	Using fall out traces to demonstrate the dominant source of material (>80%) to suspended sediments in channels of the mid-Murrumbidgee is channel banks and gully walls. Suggested that the mean residence time of fine grained sediment within the mid-Murrumbidgee system was 10 ± 5 years. Residence time of some fine grained material could be in the order of weeks-months rather than years-decades.
Webster et al. 2000	Murrumbidgee	Based on the relationship between discharge, stratification, and bloom formation, four strategies that might be implemented to minimise the occurrence or impacts of cyanobacterial blooms in weir pools were suggested. These strategies include setting a minimum discharge, pulsing the discharge, changing the discharge height, and altering the depth of water withdrawal.
Hardwick et al. 2012	Burrinjuck Dam	Water quality in the regulated rivers differed substantially from unregulated rivers and water released from Burrinjuck Dam was affected by upstream catchment development as well as the influence of the dam itself. These affects are likely to mitigate any environmental improvement expected to result from flow restoration in the Murrumbidgee River downstream of Burrinjuck Dam. Thermal pollution mitigation forms a necessary long term objective to aid rehabilitation downstream of Burrinjuck Dam

Appendix D. Water quality summary statistics

Table 20: Water quality summary statistics for the Murrumbidgee WRPA 2007-2015 water quality data

Total Nitrogen (mg/L)											
Station Name	N	Mean	Std Dev	Std Error	Min	Q10	Q25	Median	Q75	Q90	Max
Murrumbidgee River at Mittagang Xing	90	0.247	0.115	0.012	0.080	0.150	0.190	0.220	0.270	0.370	0.960
Murrumbidgee River at Angle Xing	88	0.363	0.141	0.015	0.130	0.220	0.260	0.320	0.450	0.540	0.820
Goodradigbee River at Wee Jasper	93	0.134	0.154	0.016	0.050	0.070	0.080	0.110	0.140	0.180	1.500
Jugiong Creek at Jugiong	77	0.554	0.361	0.041	0.160	0.250	0.280	0.440	0.690	1.000	1.700
Muttama Creek at Coolac	74	0.940	0.439	0.051	0.280	0.550	0.660	0.865	1.100	1.500	2.500
Adjungbilly Creek at Darbalara	94	0.615	0.309	0.032	0.230	0.330	0.410	0.540	0.740	1.000	2.100
Goobarragandra River at Little River Rd	94	0.124	0.062	0.006	0.050	0.070	0.090	0.110	0.140	0.180	0.470
Tumut River at Oddys Bridge	94	0.219	0.121	0.012	0.075	0.110	0.140	0.170	0.290	0.420	0.560
Murrumbidgee River at Gundagai	93	0.458	0.266	0.028	0.110	0.190	0.270	0.390	0.580	0.780	1.600
Hillas Creek at Mundarlo Road Bridge	90	0.614	0.411	0.043	0.160	0.245	0.320	0.455	0.790	1.250	2.200
Adelong Creek at Bereena	88	0.519	0.247	0.026	0.190	0.290	0.355	0.445	0.610	0.920	1.400
Tarcutta Creek at Old Borambola	87	0.614	0.301	0.032	0.200	0.330	0.400	0.530	0.750	1.100	1.600
Murrumbidgee River DS Wagga Wagga	92	0.545	0.316	0.033	0.160	0.230	0.295	0.490	0.670	0.890	1.800
Colombo Creek at Morundah	94	0.472	0.281	0.029	0.180	0.240	0.280	0.365	0.550	0.850	1.500
Yanco Creek at Morundah	93	0.504	0.275	0.029	0.200	0.270	0.330	0.400	0.590	0.900	1.500
Yanco Creek at Yanco Bridge	65	0.645	0.271	0.034	0.350	0.440	0.490	0.560	0.720	0.980	2.000
Billabong Creek at Walbundrie	85	1.081	0.482	0.052	0.350	0.610	0.740	0.950	1.300	1.700	2.700
Billabong Creek at Jerilderie	87	0.787	0.375	0.040	0.350	0.410	0.510	0.660	0.970	1.400	2.400
Billabong Creek at Darlot	40	1.010	0.323	0.051	0.540	0.645	0.810	1.000	1.200	1.400	2.100
Murrumbidgee River DS Yanco Weir	93	0.476	0.343	0.036	0.050	0.200	0.240	0.370	0.550	0.840	1.600
Murrumbidgee River at Gogeldrie Weir	92	0.476	0.361	0.038	0.150	0.200	0.235	0.340	0.525	1.100	1.600
Murrumbidgee River at Carrathool	81	0.476	0.296	0.033	0.180	0.230	0.270	0.370	0.610	0.880	1.500
Murrumbidgee River DS Hay Weir	78	0.430	0.239	0.027	0.170	0.220	0.250	0.375	0.490	0.770	1.200
Murrumbidgee River DS Maude Weir	79	0.424	0.232	0.026	0.160	0.210	0.250	0.340	0.540	0.760	1.300
Murrumbidgee River DS Balranald Weir	83	0.481	0.368	0.040	0.150	0.190	0.240	0.350	0.530	0.990	1.700
Murrumbidgee River at Waldaira	84	0.488	0.358	0.039	0.180	0.210	0.265	0.370	0.530	1.000	1.900

Total Phosphorus (mg/L)											
Station Name	N	Mean	Std Dev	Std Error	Min	Q10	Q25	Median	Q75	Q90	Max
Murrumbidgee River at Mittagang Xing	91	0.030	0.032	0.003	0.010	0.019	0.020	0.022	0.030	0.040	0.289
Murrumbidgee River at Angle Xing	88	0.034	0.016	0.002	0.010	0.020	0.024	0.030	0.040	0.054	0.110
Goodradigbee River at Wee Jasper	94	0.017	0.012	0.001	0.009	0.010	0.010	0.015	0.020	0.020	0.119
Jugiong Creek at Jugiong	78	0.042	0.027	0.003	0.010	0.020	0.029	0.036	0.047	0.070	0.180
Muttama Creek at Coolac	75	0.127	0.070	0.008	0.030	0.050	0.080	0.110	0.152	0.234	0.360
Adjungbilly Creek at Darbalara	95	0.054	0.030	0.003	0.020	0.030	0.033	0.050	0.060	0.090	0.190
Goobarragandra River at Little River Rd	95	0.017	0.006	0.001	0.010	0.010	0.013	0.017	0.020	0.021	0.045
Tumut River at Oddys Bridge	95	0.025	0.018	0.002	0.009	0.010	0.013	0.018	0.040	0.050	0.070
Murrumbidgee River at Gundagai	93	0.032	0.020	0.002	0.010	0.018	0.020	0.030	0.040	0.050	0.140

Hillas Creek at Mundarlo Road Bridge	91	0.072	0.036	0.004	0.030	0.040	0.050	0.060	0.087	0.110	0.240
Adelong Creek at Bereena	89	0.059	0.023	0.002	0.018	0.036	0.041	0.052	0.070	0.090	0.140
Tarcutta Creek at Old Borambola	88	0.067	0.023	0.002	0.020	0.046	0.050	0.064	0.074	0.099	0.160
Murrumbidgee River DS Wagga Wagga	93	0.044	0.028	0.003	0.010	0.022	0.030	0.036	0.050	0.070	0.190
Colombo Creek at Morundah	95	0.056	0.031	0.003	0.020	0.030	0.040	0.050	0.060	0.080	0.262
Yanco Creek at Morundah	94	0.062	0.034	0.003	0.020	0.030	0.040	0.059	0.070	0.080	0.246
Yanco Creek at Yanco Bridge	65	0.082	0.049	0.006	0.028	0.050	0.058	0.074	0.091	0.110	0.380
Billabong Creek at Walbundrie	85	0.087	0.049	0.005	0.030	0.038	0.051	0.080	0.110	0.146	0.310
Billabong Creek at Jerilderie	87	0.086	0.041	0.004	0.028	0.041	0.051	0.080	0.105	0.128	0.300
Billabong Creek at Darlot	40	0.135	0.056	0.009	0.061	0.079	0.105	0.127	0.154	0.186	0.403
Murrumbidgee River DS Yanco Weir	94	0.047	0.032	0.003	0.010	0.020	0.030	0.036	0.051	0.080	0.190
Murrumbidgee River at Gogeldrie Weir	93	0.047	0.035	0.004	0.010	0.020	0.030	0.032	0.049	0.093	0.170
Murrumbidgee River at Carrathool	82	0.055	0.043	0.005	0.020	0.027	0.035	0.044	0.059	0.083	0.320
Murrumbidgee River DS Hay Weir	78	0.049	0.033	0.004	0.020	0.025	0.030	0.040	0.055	0.090	0.261
Murrumbidgee River DS Maude Weir	79	0.048	0.036	0.004	0.020	0.020	0.030	0.040	0.058	0.076	0.289
Murrumbidgee River DS Balranald Weir	90	0.053	0.053	0.006	0.010	0.019	0.020	0.036	0.061	0.112	0.314
Murrumbidgee River at Waldaira	85	0.060	0.069	0.008	0.010	0.020	0.027	0.045	0.065	0.095	0.430

Turbidity (NTU)											
Station Name	N	Mean	Std Dev	Std Error	Min	Q10	Q25	Median	Q75	Q90	Max
Murrumbidgee River at Mittagang Xing	92	16	59	6.11	3	5	6	9	11	15	566
Murrumbidgee River at Angle Xing	88	24	47	5.03	4	5	9	14	25	41	425
Goodradigbee River at Wee Jasper	95	5	4	0.38	2	2	3	4	6	9	29
Jugiong Creek at Jugiong	77	10	15	1.68	1	1	2	4	10	26	80
Muttama Creek at Coolac	75	29	24	2.74	5	7	13	21	41	63	105
Adjungbilly Creek at Darbalara	95	28	32	3.29	6	9	11	16	34	50	243
Goobarragandra River at Little River Rd	95	5	4	0.46	1	2	3	4	6	9	30
Tumut River at Oddys Bridge	95	2	1	0.12	1	1	1	2	2	3	10
Murrumbidgee River at Gundagai	95	18	20	2.03	4	6	9	12	22	33	132
Hillas Creek at Mundarlo Road Bridge	92	28	41	4.23	2	4	6	14	31	65	276
Adelong Creek at Bereena	90	29	25	2.65	6	10	14	25	34	52	145
Tarcutta Creek at Old Borambola	87	61	38	4.04	18	30	35	48	73	110	247
Murrumbidgee River DS Wagga Wagga	93	34	36	3.69	5	11	15	23	39	68	212
Colombo Creek at Morundah	94	55	33	3.36	12	28	37	50	64	80	241
Yanco Creek at Morundah	93	62	29	3.04	24	33	44	58	72	98	197
Yanco Creek at Yanco Bridge	68	88	44	5.36	8	45	59	78	117	142	234
Billabong Creek at Walbundrie	94	57	68	7.05	7	14	17	34	65	120	382
Billabong Creek at Jerilderie	94	102	50	5.19	7	49	62	94	129	175	228
Billabong Creek at Darlot	92	164	82	8.50	18	68	107	148	227	276	413
Murrumbidgee River DS Yanco Weir	94	51	116	11.96	10	14	19	29	42	71	1100
Murrumbidgee River at Gogeldrie Weir	93	51	120	12.43	6	11	17	24	39	86	1100
Murrumbidgee River at Carrathool	79	41	44	4.98	6	16	22	32	43	71	371
Murrumbidgee River DS Hay Weir	79	35	38	4.24	6	10	16	26	41	69	298
Murrumbidgee River DS Maude Weir	78	36	26	2.90	7	12	17	30	49	79	127
Murrumbidgee River DS Balranald Weir	91	36	30	3.09	3	8	14	28	50	74	162
Murrumbidgee River at Waldaira	78	41	26	2.94	10	14	21	36	53	83	126

Total Suspended Solids (mg/L)											
Station Name	N	Mean	Std Dev	Std Error	Min	Q10	Q25	Median	Q75	Q90	Max
Murrumbidgee River at Mittagang Xing	91	11	21	2.24	5	5	5	7	10	15	200
Murrumbidgee River at Angle Xing	87	18	24	2.60	5	5	7	12	22	32	220
Goodradigbee River at Wee Jasper	92	7	6	0.67	5	5	5	5	7	10	64
Jugiong Creek at Jugiong	76	11	12	1.36	5	5	5	7	13	24	84
Muttama Creek at Coolac	73	27	17	2.02	5	7	15	24	31	51	82
Adjungbilly Creek at Darbalara	93	21	29	2.98	5	8	10	14	22	32	190
Goobarragandra River at Little River Rd	93	6	3	0.36	5	5	5	5	6	10	31
Tumut River at Oddys Bridge	93	6	3	0.27	5	5	5	5	5	10	22
Murrumbidgee River at Gundagai	93	20	18	1.89	5	9	11	15	24	38	120
Hillas Creek at Mundarlo Road Bridge	89	27	39	4.18	5	5	7	15	26	62	240
Adelong Creek at Bereena	87	26	22	2.31	5	7	11	20	32	50	120
Tarcutta Creek at Old Borambola	86	58	83	8.97	9	25	30	43	62	87	780
Murrumbidgee River DS Wagga Wagga	91	35	28	2.94	5	11	17	27	42	68	170
Colombo Creek at Morundah	93	50	22	2.32	7	26	35	49	60	70	170
Yanco Creek at Morundah	92	54	24	2.45	15	24	35	51	68	86	120
Yanco Creek at Yanco Bridge	65	45	19	2.35	12	26	32	44	55	68	120
Billabong Creek at Walbundrie	86	48	51	5.47	5	13	20	30	59	89	340
Billabong Creek at Jerilderie	88	63	25	2.63	8	37	47	59	75	93	150
Billabong Creek at Darlot	40	86	40	6.30	14	44	66	75	100	150	210
Murrumbidgee River DS Yanco Weir	92	46	68	7.08	10	15	24	32	49	68	640
Murrumbidgee River at Gogeldrie Weir	91	43	81	8.49	5	11	16	21	45	74	730
Murrumbidgee River at Carrathool	80	40	39	4.32	9	17	24	33	44	55	280
Murrumbidgee River DS Hay Weir	80	30	29	3.27	5	12	17	22	31	54	220
Murrumbidgee River DS Maude Weir	82	31	26	2.88	5	10	13	24	37	68	130
Murrumbidgee River DS Balranald Weir	50	28	21	2.97	5	10	14	21	35	59	100
Murrumbidgee River at Waldaira	85	27	18	1.98	5	10	15	22	34	49	98

Dissolved Oxygen (% saturation)											
Station Name	N	Mean	Std Dev	Std Error	Min	Q10	Q25	Median	Q75	Q90	Max
Murrumbidgee River at Mittagang Xing	90	95	4.4	0.47	71	89	93	96	97	98	104
Murrumbidgee River at Angle Xing	87	98	6.2	0.67	75	90	96	99	102	104	112
Goodradigbee River at Wee Jasper	94	96	3.7	0.38	75	92	94	97	98	99	102
Jugiong Creek at Jugiong	76	97	21.9	2.52	47	82	88	94	102	111	235
Muttama Creek at Coolac	75	98	25.2	2.92	49	72	82	93	110	128	220
Adjungbilly Creek at Darbalara	94	98	6.8	0.70	80	89	94	98	101	106	116
Goobarragandra River at Little River Rd	93	98	2.6	0.27	88	96	97	98	99	101	105
Tumut River at Oddys Bridge	94	87	12.3	1.27	57	70	78	88	96	103	110
Murrumbidgee River at Gundagai	93	95	6.1	0.63	60	88	92	95	98	101	110
Hillas Creek at Mundarlo Road Bridge	90	100	13.2	1.39	67	91	95	98	103	114	187
Adelong Creek at Bereena	88	79	13.3	1.42	31	58	73	81	90	95	103
Tarcutta Creek at Old Borambola	86	92	11.8	1.27	39	82	87	92	96	104	126
Murrumbidgee River DS Wagga Wagga	91	93	9.0	0.94	21	88	91	94	96	98	108

Colombo Creek at Morundah	92	93	12.6	1.32	40	76	85	95	102	106	111
Yanco Creek at Morundah	92	93	11.7	1.22	60	77	86	95	101	107	113
Yanco Creek at Yanco Bridge	67	73	19.3	2.36	6	49	61	79	88	93	103
Billabong Creek at Walbundrie	94	84	15.3	1.58	37	64	75	87	95	101	119
Billabong Creek at Jerilderie	93	76	18.3	1.90	15	51	65	80	88	96	105
Billabong Creek at Darlot	92	78	16.1	1.68	26	58	70	81	90	94	100
Murrumbidgee River DS Yanco Weir	93	96	10.6	1.10	46	88	94	98	101	105	109
Murrumbidgee River at Gogeldrie Weir	94	94	11.6	1.19	52	83	92	97	100	103	120
Murrumbidgee River at Carrathool	82	95	11.8	1.31	21	88	92	96	100	106	118
Murrumbidgee River DS Hay Weir	80	98	29.3	3.28	10	89	95	100	102	107	305
Murrumbidgee River DS Maude Weir	81	91	17.4	1.93	9	79	89	95	99	102	116
Murrumbidgee River DS Balranald Weir	89	79	19.0	2.02	5	53	77	83	89	96	117
Murrumbidgee River at Waldaira	78	87	15.2	1.72	11	80	85	89	94	97	119

pH											
Station Name	N	Mean	Std Dev	Std Error	Min	Q10	Q25	Median	Q75	Q90	Max
Murrumbidgee River at Mittagang Xing	92	7.1	0.24	0.025	6.6	6.8	7.0	7.1	7.3	7.4	7.7
Murrumbidgee River at Angle Xing	88	7.6	0.29	0.031	6.5	7.3	7.5	7.6	7.7	8.0	8.4
Goodradigbee River at Wee Jasper	95	7.5	0.26	0.027	6.9	7.2	7.3	7.6	7.7	7.8	8.1
Jugiong Creek at Jugiong	77	8.1	0.25	0.029	7.3	7.7	7.9	8.0	8.3	8.4	8.6
Muttama Creek at Coolac	75	7.8	0.38	0.044	7.0	7.3	7.5	7.7	8.1	8.3	8.7
Adjungbilly Creek at Darbalara	95	7.7	0.36	0.037	6.9	7.3	7.5	7.6	7.9	8.3	8.7
Goobarragandra River at Little River Rd	95	7.3	0.25	0.026	6.6	7.0	7.2	7.4	7.5	7.6	7.9
Tumut River at Oddys Bridge	95	6.7	0.36	0.037	6.0	6.3	6.5	6.7	7.0	7.2	7.8
Murrumbidgee River at Gundagai	95	7.3	0.33	0.033	6.8	6.9	7.1	7.3	7.5	7.7	8.3
Hillas Creek at Mundarlo Road Bridge	92	7.7	0.37	0.038	6.9	7.2	7.5	7.7	7.9	8.2	8.9
Adelong Creek at Bereena	90	7.2	0.21	0.022	6.9	7.0	7.1	7.2	7.4	7.5	7.7
Tarcutta Creek at Old Borambola	88	7.3	0.29	0.031	6.5	6.9	7.2	7.3	7.5	7.7	8.2
Murrumbidgee River DS Wagga Wagga	93	7.3	0.39	0.041	6.4	6.9	7.1	7.3	7.5	7.8	8.8
Colombo Creek at Morundah	93	7.3	0.36	0.037	6.4	6.9	7.0	7.2	7.5	7.7	8.4
Yanco Creek at Morundah	93	7.3	0.41	0.042	6.4	6.8	7.0	7.3	7.5	7.7	8.5
Yanco Creek at Yanco Bridge	67	7.0	0.28	0.034	6.4	6.7	6.9	7.0	7.2	7.4	7.6
Billabong Creek at Walbundrie	94	7.6	0.35	0.036	6.7	7.1	7.4	7.7	7.9	8.0	8.2
Billabong Creek at Jerilderie	93	7.1	0.36	0.037	6.1	6.7	6.9	7.1	7.4	7.6	7.9
Billabong Creek at Darlot	91	7.1	0.30	0.031	6.1	6.8	6.9	7.1	7.3	7.5	7.7
Murrumbidgee River DS Yanco Weir	94	7.4	0.44	0.045	6.3	6.9	7.1	7.4	7.7	8.0	8.7
Murrumbidgee River at Gogeldrie Weir	94	7.4	0.43	0.044	6.3	6.9	7.1	7.3	7.6	7.8	8.7
Murrumbidgee River at Carrathool	83	7.4	0.41	0.045	6.4	7.0	7.2	7.4	7.7	8.0	8.5
Murrumbidgee River DS Hay Weir	79	7.4	0.33	0.037	6.4	7.0	7.2	7.4	7.6	7.8	8.3
Murrumbidgee River DS Maude Weir	81	7.4	0.30	0.034	6.7	7.0	7.3	7.4	7.6	7.8	8.4
Murrumbidgee River DS Balranald Weir	89	7.2	0.77	0.082	0.5	6.9	7.0	7.2	7.4	7.7	8.1
Murrumbidgee River at Waldaira	81	7.3	0.28	0.031	6.8	7.0	7.1	7.3	7.5	7.7	8.1

Electrical Conductivity (µS/cm)										
Station Name	N	Mean	Std Dev	Std Error	Min	Q10	Q25	Median	Q75	Q90	Max
Murrumbidgee River at Mittagang Xing	91	58	23	2.4	25	38	44	51	63	94	137
Murrumbidgee River at Angle Xing	87	116	39	4.2	37	68	87	114	144	172	204
Goodradigbee River at Wee Jasper	92	89	23	2.4	50	63	70	84	109	122	147
Jugiong Creek at Jugiong	76	1330	331	38.0	100	836	1175	1400	1560	1699	1846
Muttama Creek at Coolac	72	1444	466	55.0	309	816	1115	1546	1823	2008	2163
Adjungbilly Creek at Darbalara	92	144	34	3.5	73	100	124	142	158	188	267
Goobarragandra River at Little River Rd	92	59	16	1.6	35	46	51	57	65	72	176
Tumut River at Oddys Bridge	92	36	3.6	0.37	31	33	34	35	37	40	59
Murrumbidgee River at Gundagai	92	131	53	5.5	51	57	85	135	175	194	253
Hillas Creek at Mundarlo Road Bridge	89	278	49	5.2	155	221	243	283	306	337	425
Adelong Creek at Bereena	86	225	43	4.7	111	167	201	227	245	280	383
Tarcutta Creek at Old Borambola	86	248	48	5.1	174	196	207	236	285	310	428
Murrumbidgee River DS Wagga Wagga	91	142	56	5.9	52	63	94	150	190	208	269
Colombo Creek at Morundah	93	137	48	5.0	60	73	99	133	177	204	230
Yanco Creek at Morundah	92	138	46	4.8	61	74	104	132	173	202	230
Yanco Creek at Yanco Bridge	65	155	52	6.5	80	95	126	150	175	214	383
Billabong Creek at Walbundrie	85	1553	1020	110.6	150	275	739	1509	2230	2890	4930
Billabong Creek at Jerilderie	87	225	121	13.0	72	96	127	192	269	417	628
Billabong Creek at Darlot	91	195	78	8.1	60	109	137	180	239	289	461
Murrumbidgee River DS Yanco Weir	92	137	52	5.4	48	69	95	135	180	207	248
Murrumbidgee River at Gogeldrie Weir	92	139	51	5.3	58	72	93	129	179	202	248
Murrumbidgee River at Carrathool	80	142	48	5.3	69	80	106	137	176	209	245
Murrumbidgee River DS Hay Weir	78	148	50	5.6	70	84	110	149	178	226	245
Murrumbidgee River DS Maude Weir	79	149	48	5.4	71	88	112	144	180	218	295
Murrumbidgee River DS Balranald Weir	90	155	53	5.6	73	92	114	149	180	234	333
Murrumbidgee River at Waldaira	84	157	53	5.8	85	96	110	155	185	233	320

Table 21: Murrumbidgee River downstream Balranald Weir electrical conductivity (µS/cm) for purposes of long term salinity planning in the Murrumbidgee WRPA

Year	Salinity (EC µS/cm)		Salt Load (t/year)
	Median (50%ile)	Peak (80%ile)	Total
2001-2002	152	214	30650
2002-2003	131	162	10854
2003-2004	129	189	8526
2004-2005	156	203	10989
2005-2006	138	199	16987
2006-2007	90	155	10488
2007-2008	193	272	17763
2008-2009	99	115	7123
2009-2010	132	181	15411
2010-2011	229	275	284533
2011-2012	189	238	247083
2012-2013	157	186	139576
2013-2014	122	215	37996
2014-2015	150	185	40691
2015-2016	145	222	66679
Mean			**63023**

Table 22: Comparison of annual salt loads (t/year) in the Murrumbidgee WRPA

Year	Jugiong Creek at Jugiong	Murrumbidgee at Gundagai	Murrumbidgee at Wagga Wagga	Murrumbidgee D/S Berembed weir	Yanco Creek at Yanco Bridge	Billabong at Darlot	Murrumbidgee d/s Balranald Weir
2001-2002	7225	195966	218290	122226	16975	21858	30650
2002-2003	7955	126908	142267	77480	6653	7896	10854
2003-2004	17172	105974	135003	78609	5947	11420	8526
2004-2005	8730	115580	169036	84802	7340	5107	10989
2005-2006	26923	154456	236549	122958	10067	13529	16987
2006-2007	5551	68947	88326	43076	3346	2663	10488
2007-2008	8058	67988	71206	56141	3015	3500	17763
2008-2009	4159	58006	65414	39814	2411	2372	7123
2009-2010	14287	87344	104362	60284	3047	4016	15411
2010-2011	56100	390147	407420	80552	14753	91199	284533
2011-2012	25172	311384	232389	316202	21235	55223	247083
2012-2013	23287	205053	279044	217645	10479	25778	139576
2013-2014	16254	135523	169125	109273	5828	16338	37996
2014-2015	13652	182953	205341	37826	6100	8398	40691
2015-2016	19698	185316	217269	157091	10624	14218	66679
Mean	**16948**	**159436**	**182736**	**106932**	**8521**	**18901**	**63023**

Appendix E. Draftsman plots and Box plots by site

The mean daily discharge, turbidity, total nitrogen, total phosphorus and total suspended solids data in the Draftsman plots has been natural log transformed to normalise the distribution of the data.

The box plots show the annual 25th, 50th and 75th percentile values, with error bars indicating the maximum and minimum values for each parameter. The data set extends from 2007 to 2015, and displays within site variability. In each figure there are numerous plots with A) total nitrogen, B) total phosphorus, C) turbidity, D) total suspended solids, E) dissolved oxygen, F) pH, G) electrical conductivity measured during monthly sampling and H) continuous electrical conductivity (where measured). Red lines indicate the Basin Plan water quality targets (and target ranges) from Schedule 11 of the Basin Plan for the appropriate zone. Total suspended solids have a lower detection limit of 5 mg/L.

Murrumbidgee River at Mittagang Crossing

There was a positive correlation between total nitrogen, total phosphorus and turbidity, suggesting nutrients are mostly transported attached to suspended sediments. Turbidity was also correlated to flow, while correlations between flow and total nitrogen and total phosphorus were not as clear. There was a slight negative correlation between flow and electrical conductivity as higher flows dilute saline inputs.

Median total nitrogen and turbidity results tended to be at or below the Basin Plan targets, while total phosphorus medians were at or above the target. Nutrient and turbidity results were highest in 2014/2015. One sample collected during high flows in 2015 resulted in very high nitrogen, phosphorus and turbidity results. Dissolved oxygen levels were mostly within the desired range, with occasional lower readings in response to local drivers. The pH results fluctuated within the upper and lower limits. Electrical conductivity was low during the dry period from 2007 to 2011, but increased in 2011/2012, and continued to increase in 2015. The increasing electrical conductivity may be in response to the wetting up of the catchment after the preceding dryer years, resulting in increased base flow contributions from more saline groundwater. Even with the inflow of saline groundwater, the electrical conductivity is still low.

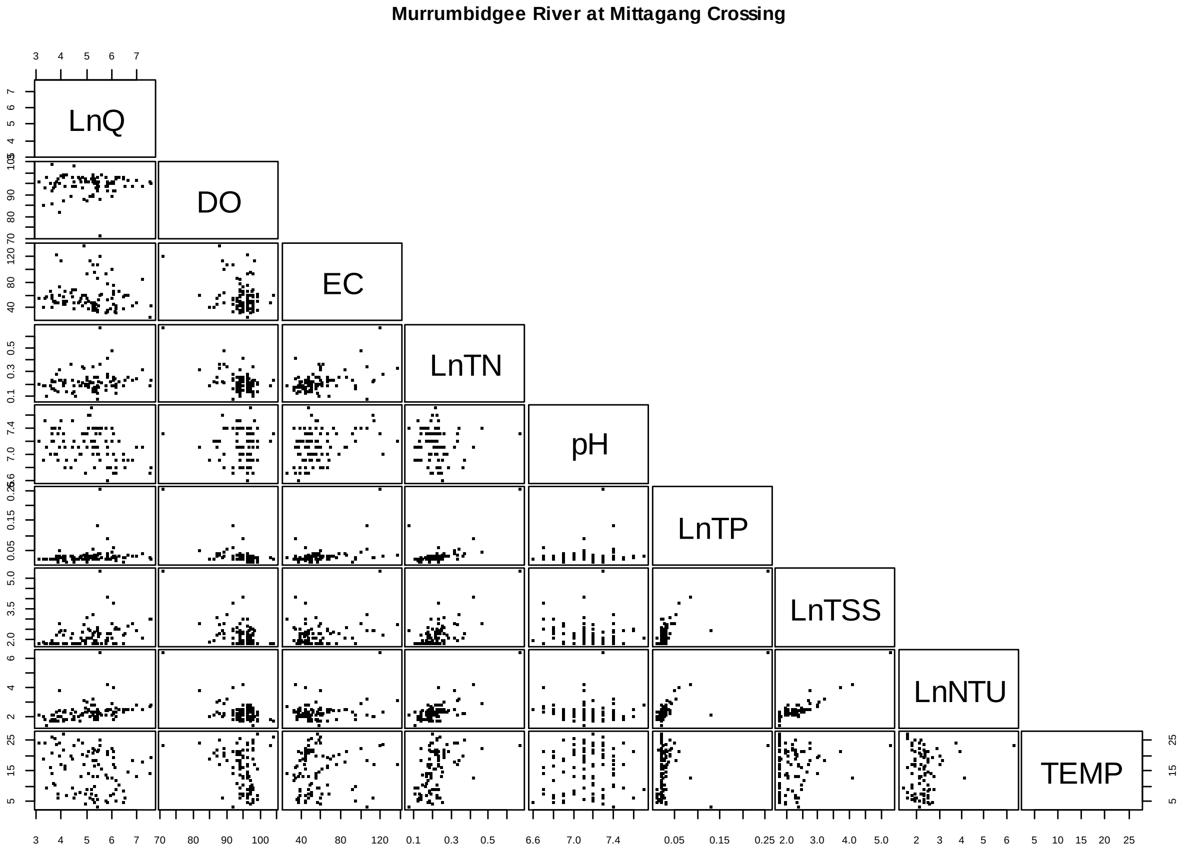


Figure 21: Draftsman plots for Murrumbidgee River at Mittagang Crossing

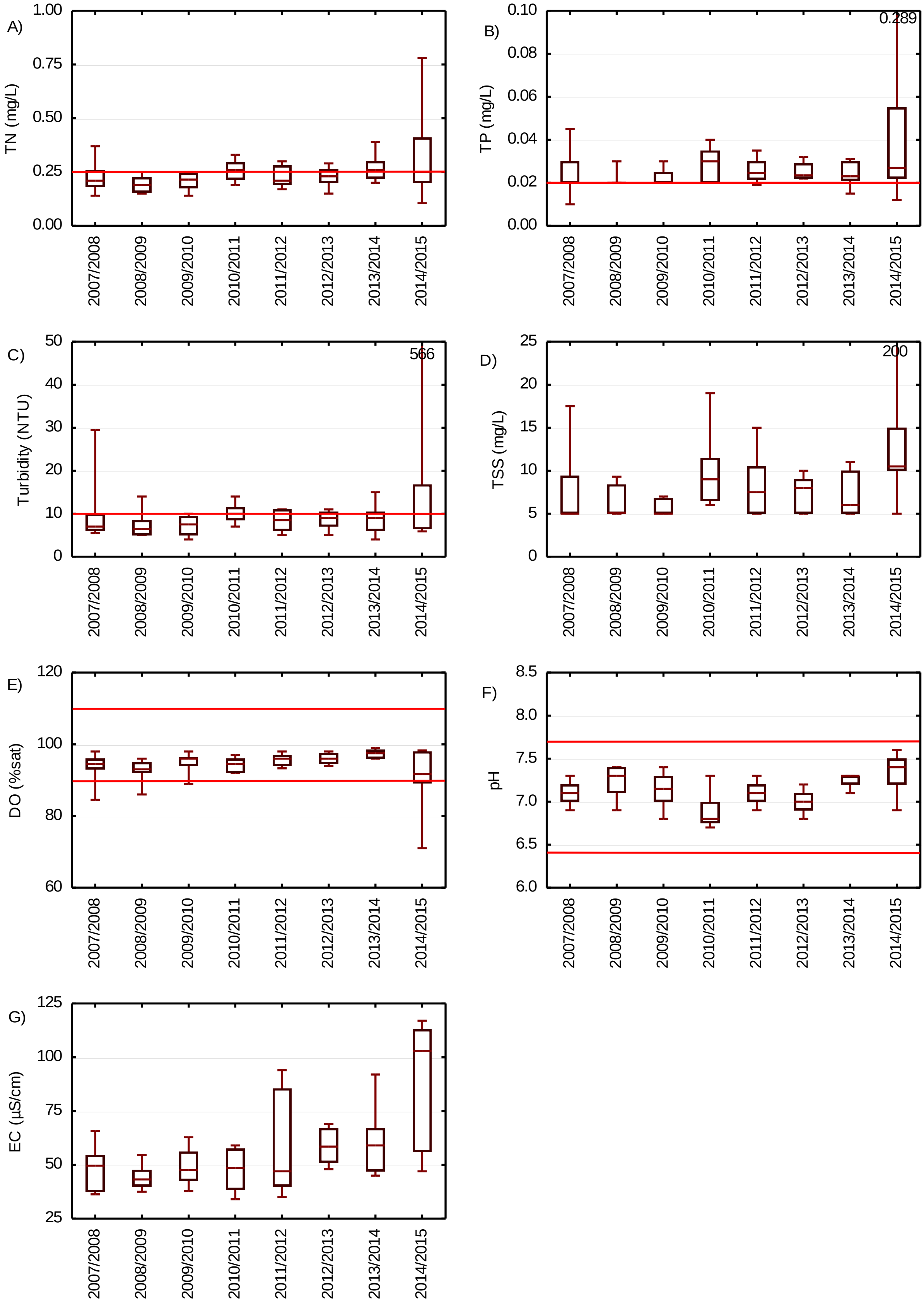


Figure 22: Water quality data for Murrumbidgee River at Mittagang Crossing

Murrumbidgee River at Angle Crossing

Flow data is not available for this monitoring site.

There was a positive correlation between total nitrogen, total phosphorus and turbidity, suggesting nutrients are mostly transported attached to suspended sediments. There was a negative correlation between dissolved oxygen and turbidity. Possibly due to decreased flow allowing suspended sediment to settle out of the water column while also reducing turbulence and re-oxygenation. Electrical conductivity is also negatively correlated to turbidity where higher flows carry increased loads of suspended sediment, while also diluting the salt load. There does not appear to be any correlation between other parameters.

The majority of total nitrogen results were less than the Basin Plan target with some higher results during the wetter years from 2010 to 2012. Total phosphorus annual medians were close to or less than the target. The annual median turbidity was less than the target all years except for 2008/2009. Dissolved oxygen is mostly within the upper and lower limits with some low readings during low flows between 2007 and 2010. The dissolved oxygen data is the inverse of the turbidity results, with the highest dissolved oxygen coinciding with the lowest turbidity. This suggests increased algal and aquatic plant growth when the water is clear. The pH is mostly within the target range and does not pose a threat to aquatic ecosystems. Electrical conductivity increases slightly with time, yet still remains low.

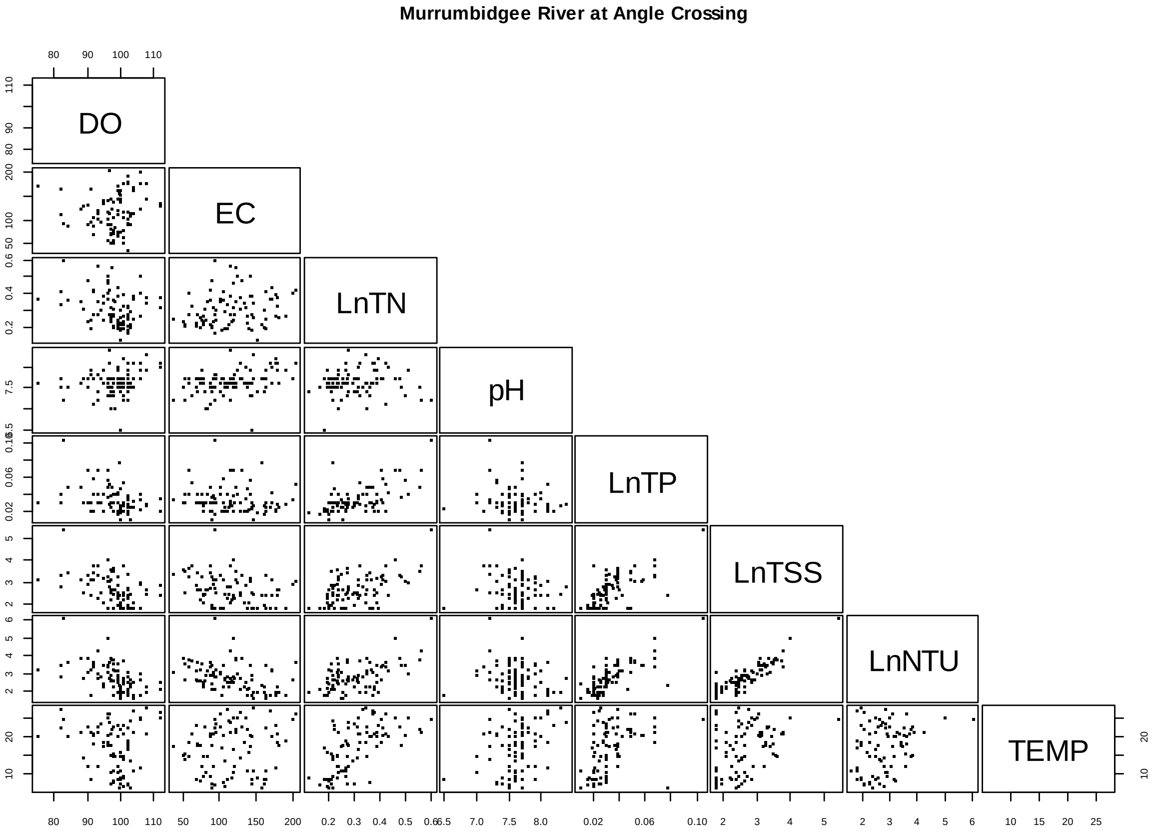


Figure 23: Draftsman plots for Murrumbidgee River at Angle Crossing

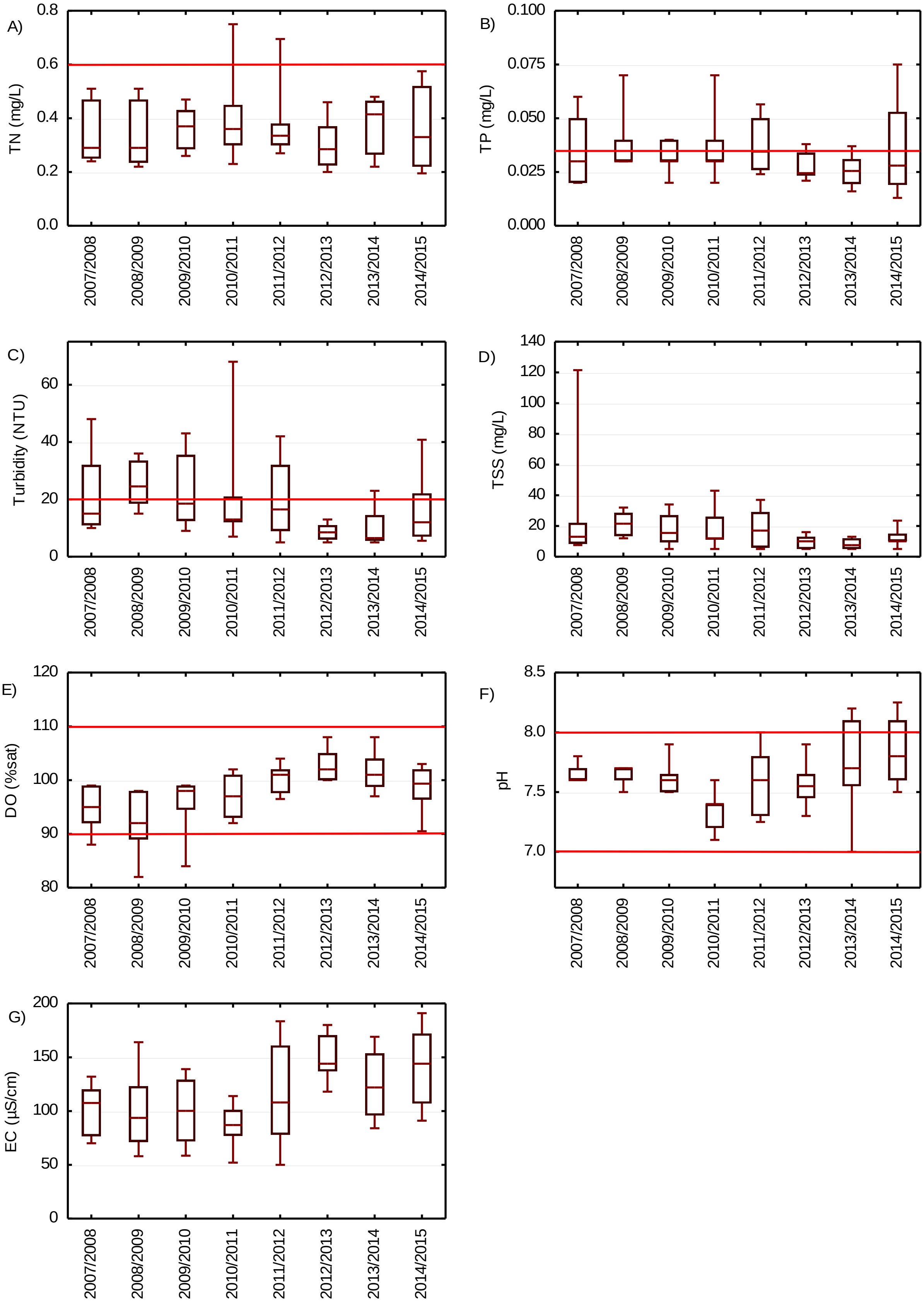


Figure 24: Water quality data for Murrumbidgee River at Angle Crossing

Goodradigbee River at Wee Jasper

One outlying total nitrogen, total phosphorus, turbidity and total suspended solids result has been removed from the data set used to produce the draftsman plots to maintain focus on the core data.

Total nitrogen appears to be positively correlated to flow and turbidity, but there was not a clear correlation to total phosphorus, suggesting variable transport mechanisms between the two nutrients. There was also a positive correlation between turbidity and flow. There was a negative correlation between flow and electrical conductivity indicating contributions from shallow saline groundwater during low flows and dilution at high flows.

The box plots show the quality of the water in the Goodradigbee River was good. Total nitrogen, total phosphorus and turbidity results are all well below the Basin Plan targets, and pH and dissolved oxygen results are mostly within the upper and lower limits. Electrical conductivity does fluctuate slightly through time yet remains low.

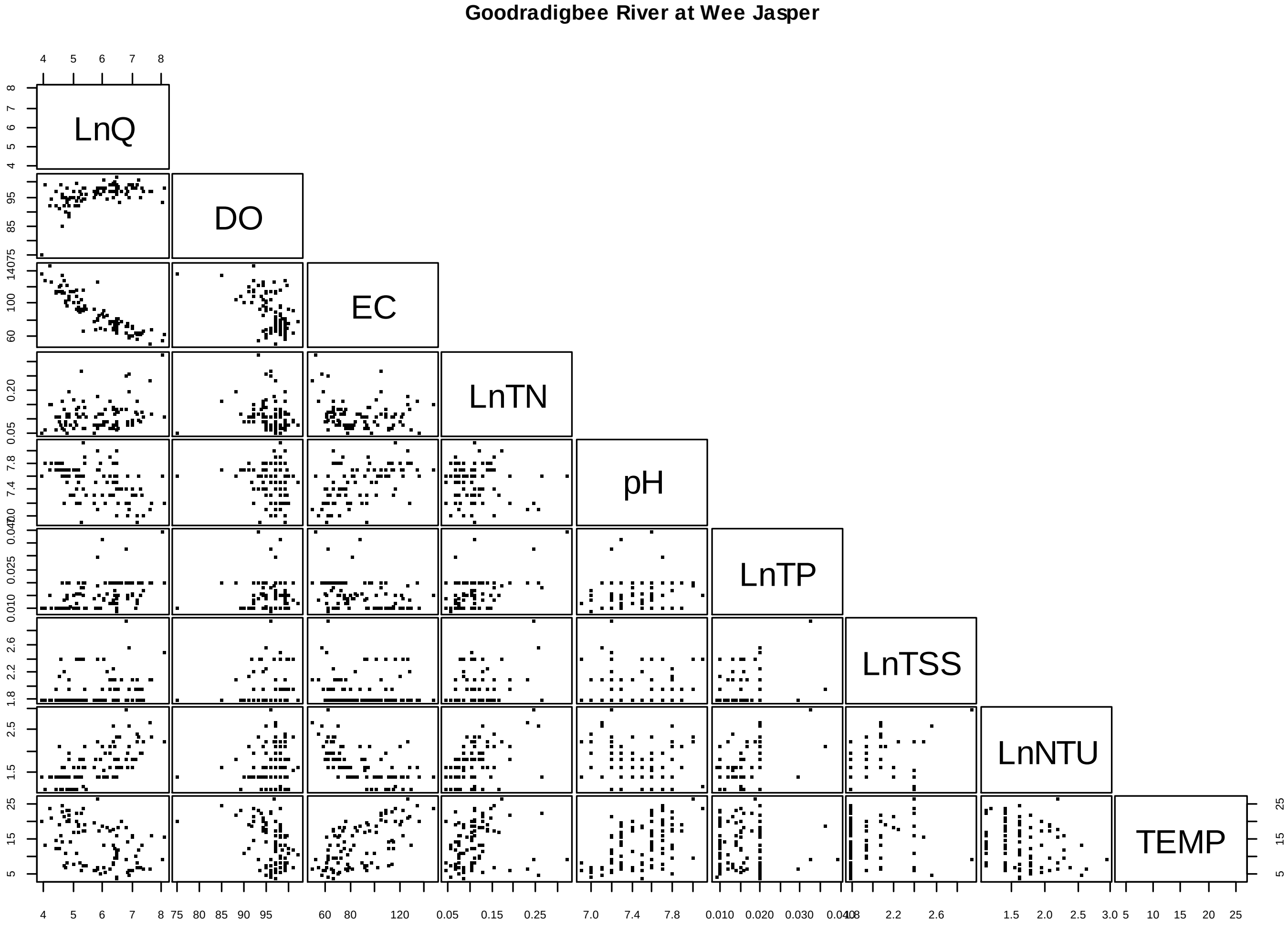


Figure 25: Draftsman plots for Goodradigbee River at Wee Jasper

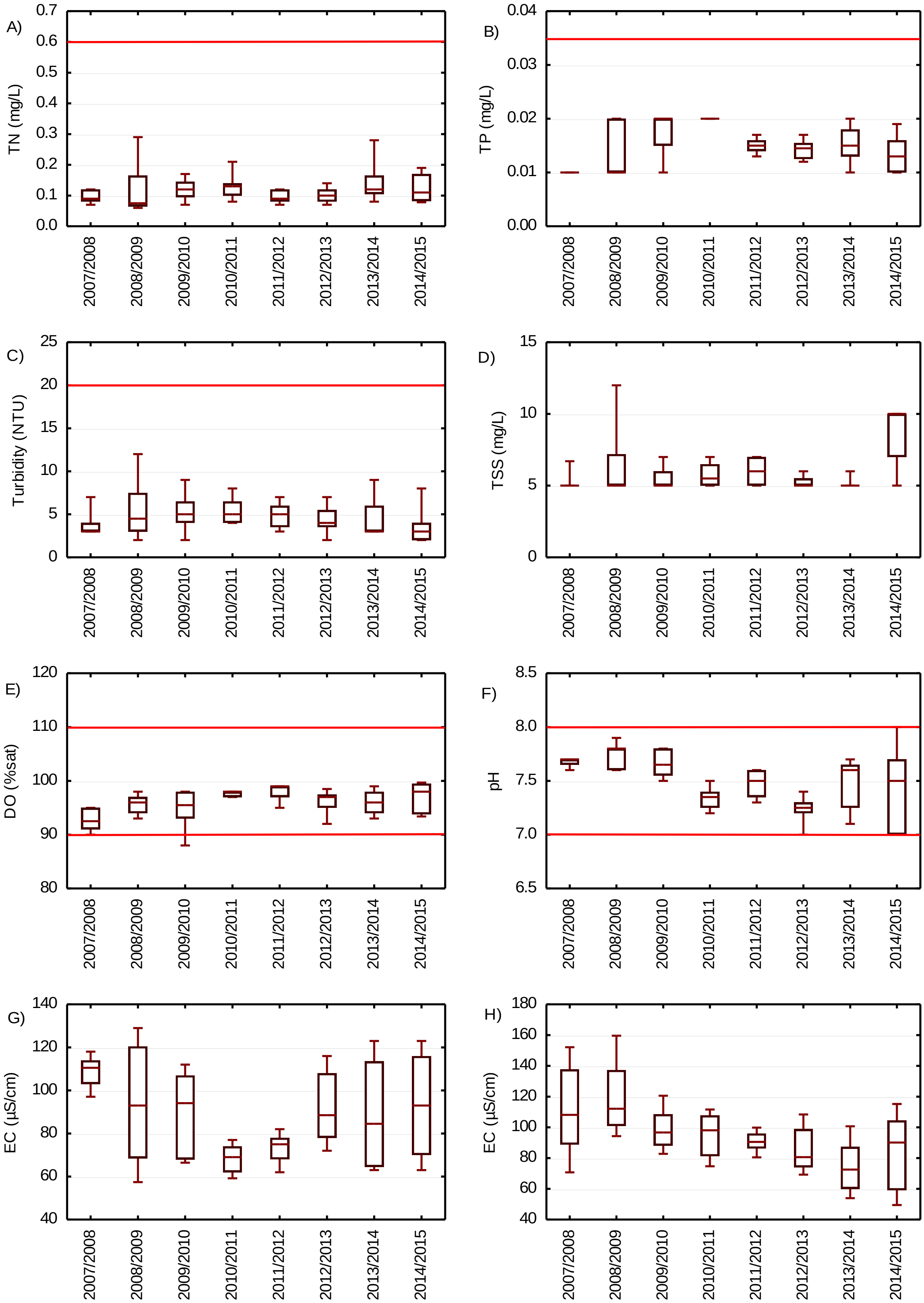


Figure 26: Water quality data for Goodradigbee River at Wee Jasper

Jugiong Creek at Jugiong

There was a strong positive correlation between total nitrogen, total phosphorus, turbidity and flow in the draftsman plots, indicating runoff was the major transport mechanism for nutrients attached to soil particles. Electrical conductivity remains high at low flows, and only decreases when flows are high enough to dilute the saline water at this site. There was a negative correlation between electrical conductivity and turbidity which could be a consequence of this flow relationship. Turbid high flows dilute salt concentrations, decreasing the electrical conductivity. In addition, high concentrations of salt can cause suspended sediments to settle out of the water column.

The box plots show the median total nitrogen results were less than the Basin Plan targets all years except for 2010/2011 as a result of high flow. Total phosphorus results were less than the Basin Plan targets most years, and as for nitrogen, the highest results were in 2010/2011. The median dissolved oxygen was within the upper and lower targets most years. The pH of Jugiong Creek was slightly basic with annual medians exceeding the upper target. The electrical conductivity results were consistently high, with the annual median exceeding the irrigation target all years. The high electrical conductivity and pH suggest inputs of alkaline salts from shallow groundwater.

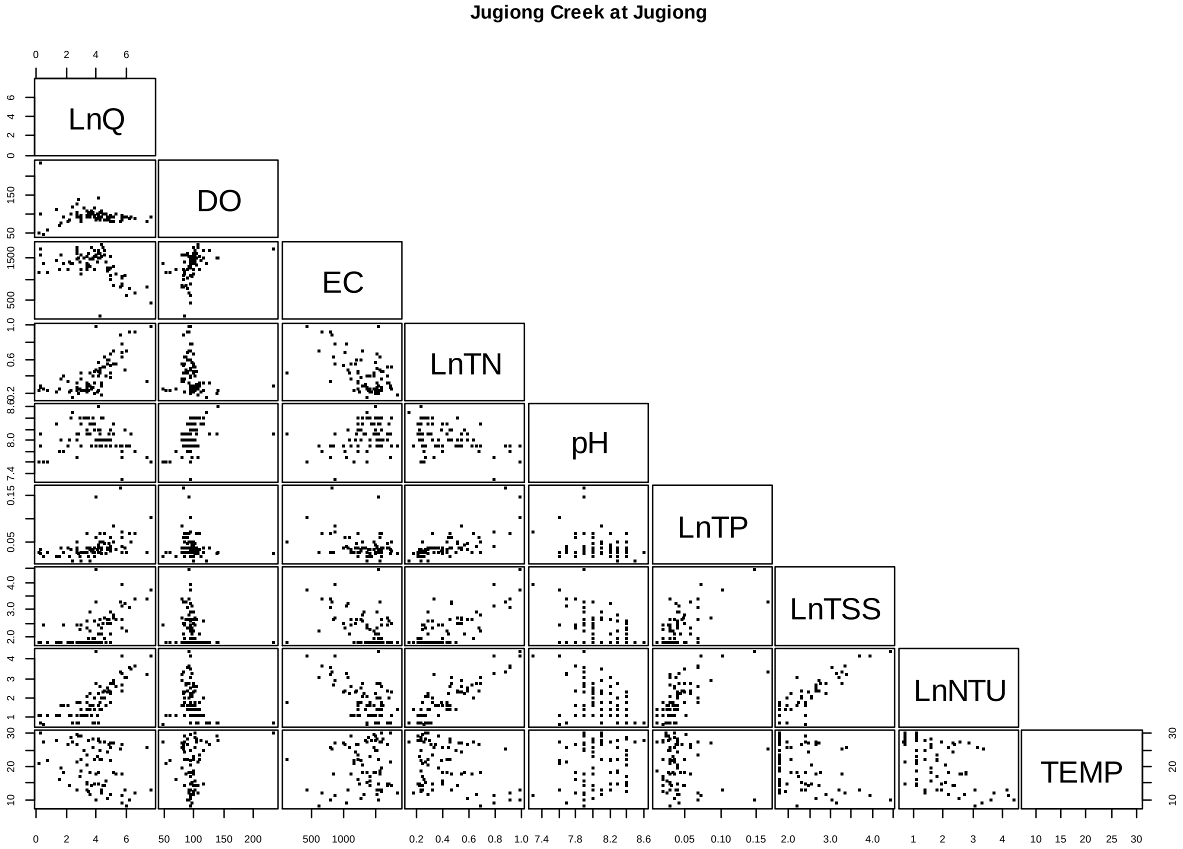


Figure 27: Draftsman plots for Jugiong Creek at Jugiong

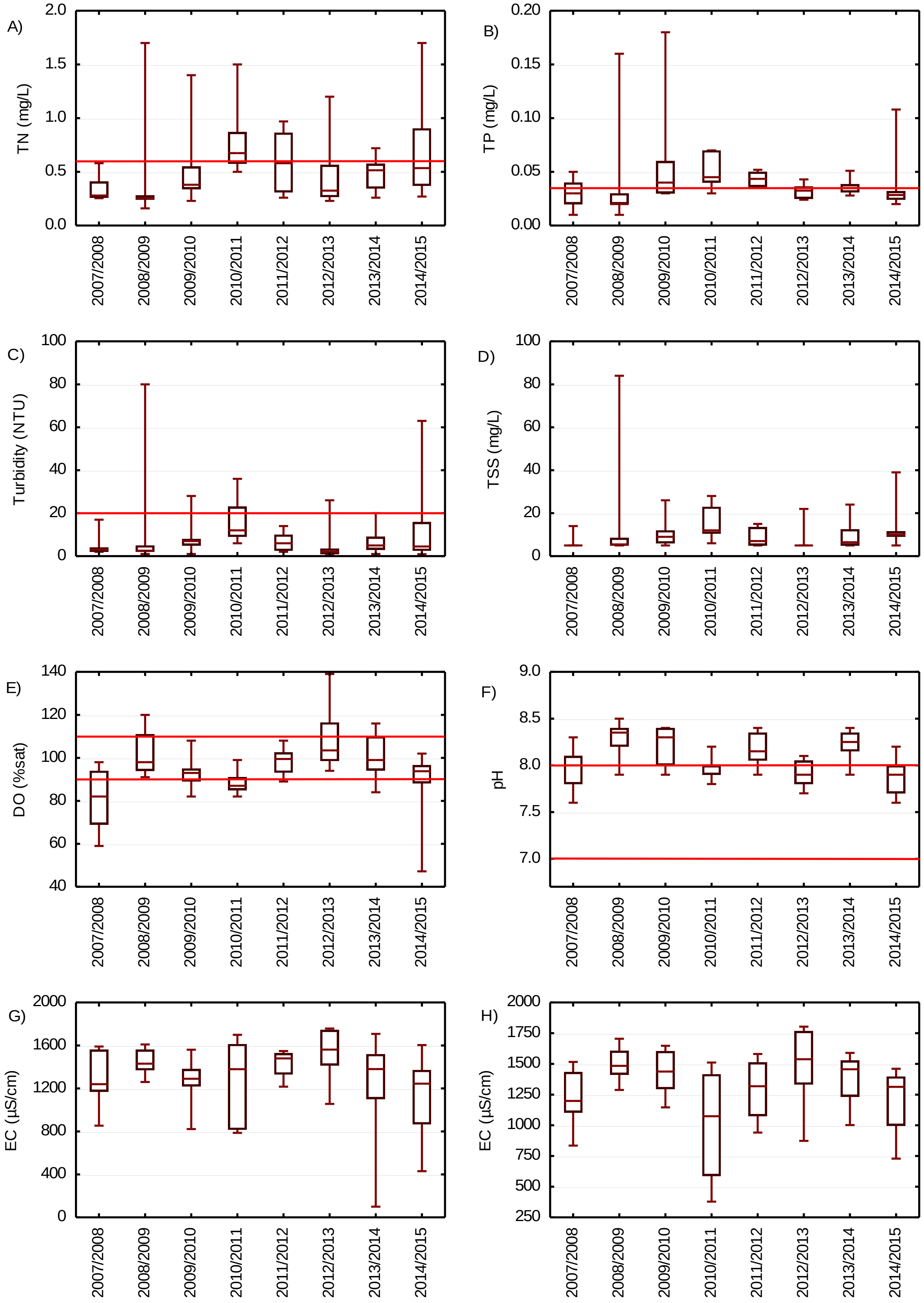


Figure 28: Water quality data for Jugiong Creek at Jugiong

Muttama Creek at Coolac

Muttama Creek showed a positive correlation between total nitrogen, turbidity and flow but not the same relationship between total phosphorus and turbidity, indicating differing transport mechanisms between the two nutrients. Similar to Jugiong Creek, which is an adjoining catchment, electrical conductivity remains high at low flows, and only decreases when flows are high enough to dilute the saline water. There was also a negative correlation between electrical conductivity and turbidity. The pH increases at high dissolved oxygen levels, providing evidence that algal growth at the site might be pushing the dissolved oxygen above the upper limit.

The annual median total phosphorus results exceed the Basin Plan targets every year and total nitrogen every year except for one. Turbidity results were lower during the low flow years from 2007 to 2010, but exceeded the Basin Plan target every year from 2011 to 2015. Dissolved oxygen was mostly within the upper and lower targets, though there were some high and low readings in response to local drivers. The electrical conductivity results were consistently high, with the annual median exceeding the irrigation target all years. There was a slight increase in annual median electrical conductivity after the flooding in 2010/2011 recharged shallow groundwater and increased saline contributions to river base flow.

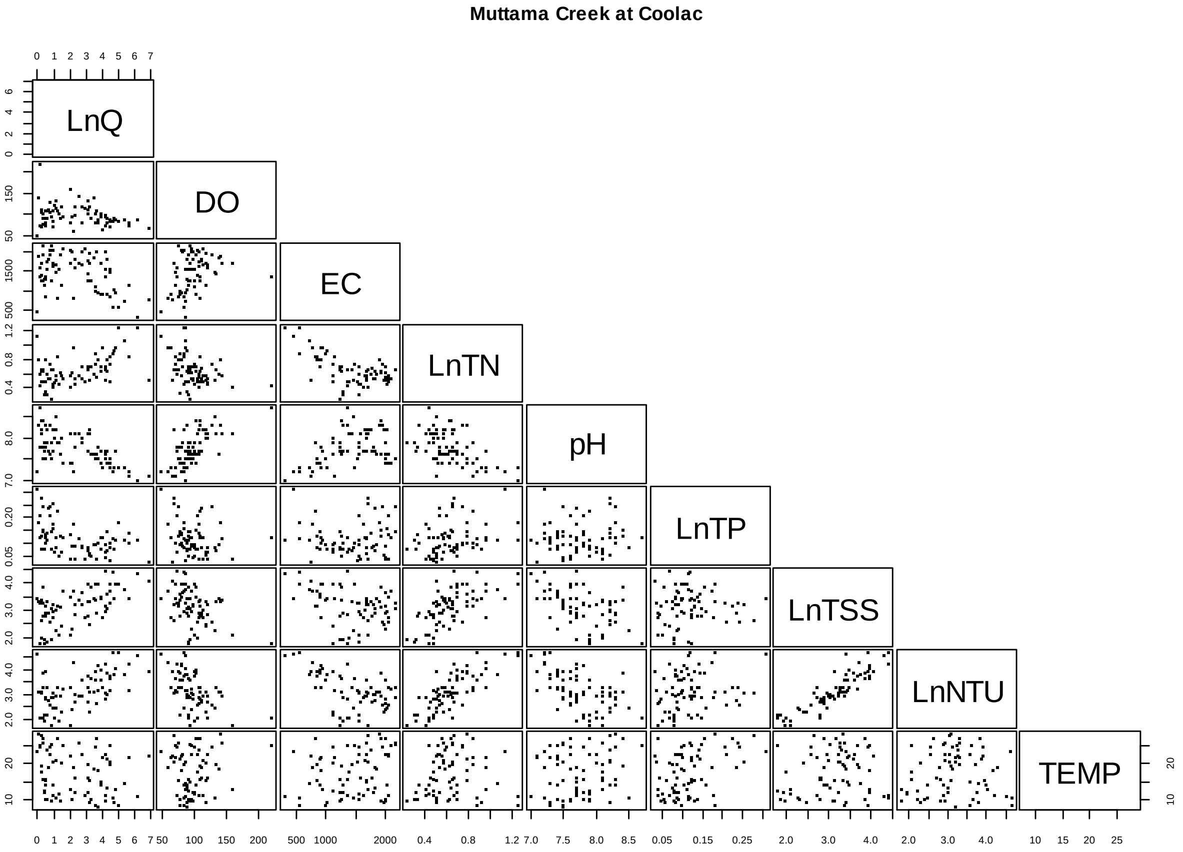


Figure 29: Draftsman plots for Muttama Creek at Coolac

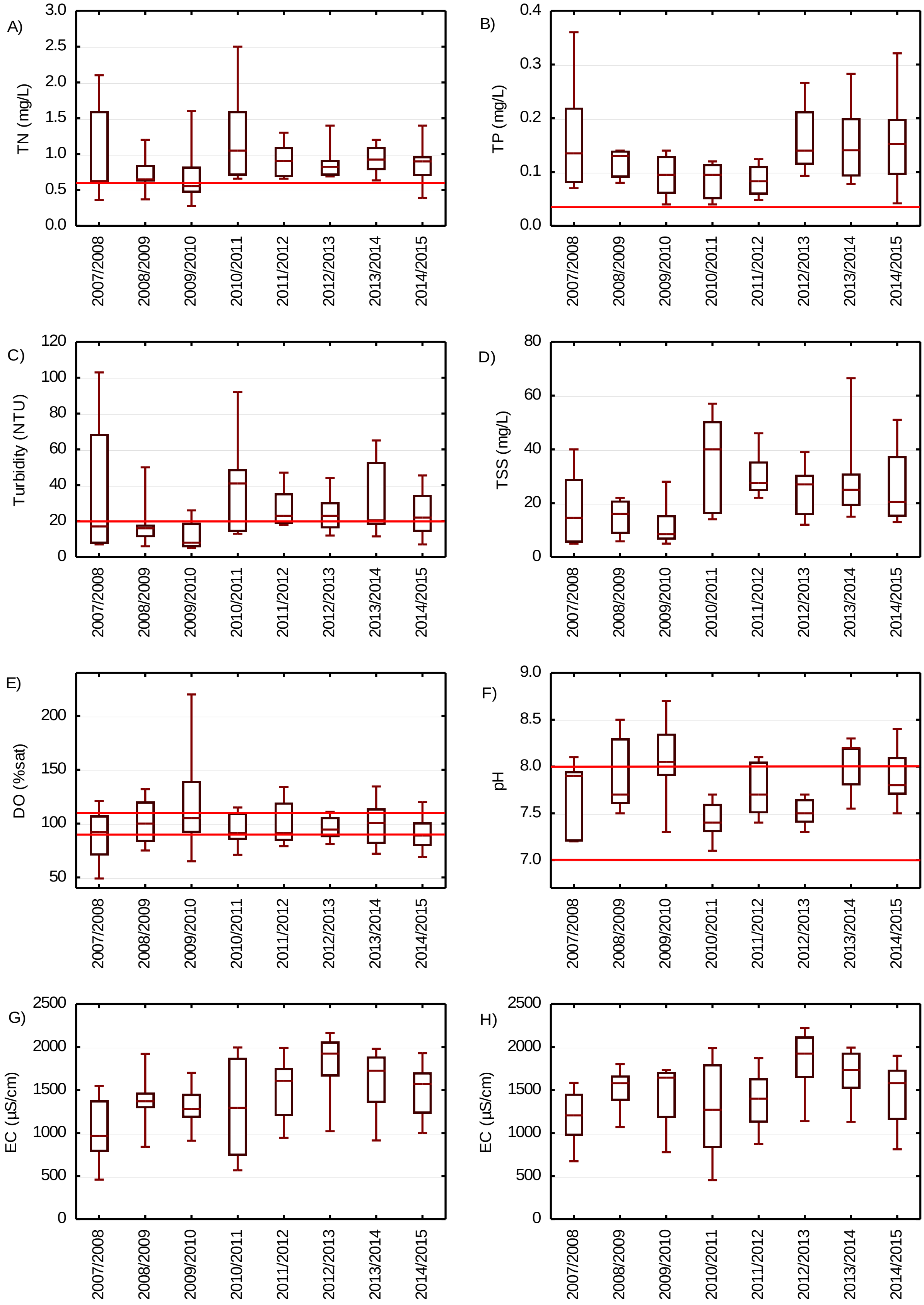


Figure 30: Water quality data for Muttama Creek at Coolac

Adjungbilly Creek at Darbalara

The draftsman plots show clear correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. This suggests nutrients attached onto soil particles is the most likely transport mechanism in the catchment. Electrical conductivity was negatively correlated to flow suggesting contributions from saline groundwater during low flow periods and dilution at high flows. The pH increased at high dissolved oxygen results, providing evidence that algal growth at the site was pushing some oxygen levels above the upper target limit.

The annual median total nitrogen results were less than the Basin Plan target every year, except for the high flow year of 2010/2011. Inversely the total phosphorus annual median exceeded the target every year except for one. Similar to total nitrogen, the turbidity medians were mostly below the target with the highest in the high flow year. The pH and dissolved oxygen results fluctuated between years but mostly within the upper and lower target limits. There was a slight increase in annual median electrical conductivity after the flooding in 2010/2011 recharged shallow groundwater and increased saline contributions to river base flow. However, the results remain low and pose no threat to irrigation use or aquatic ecosystems.

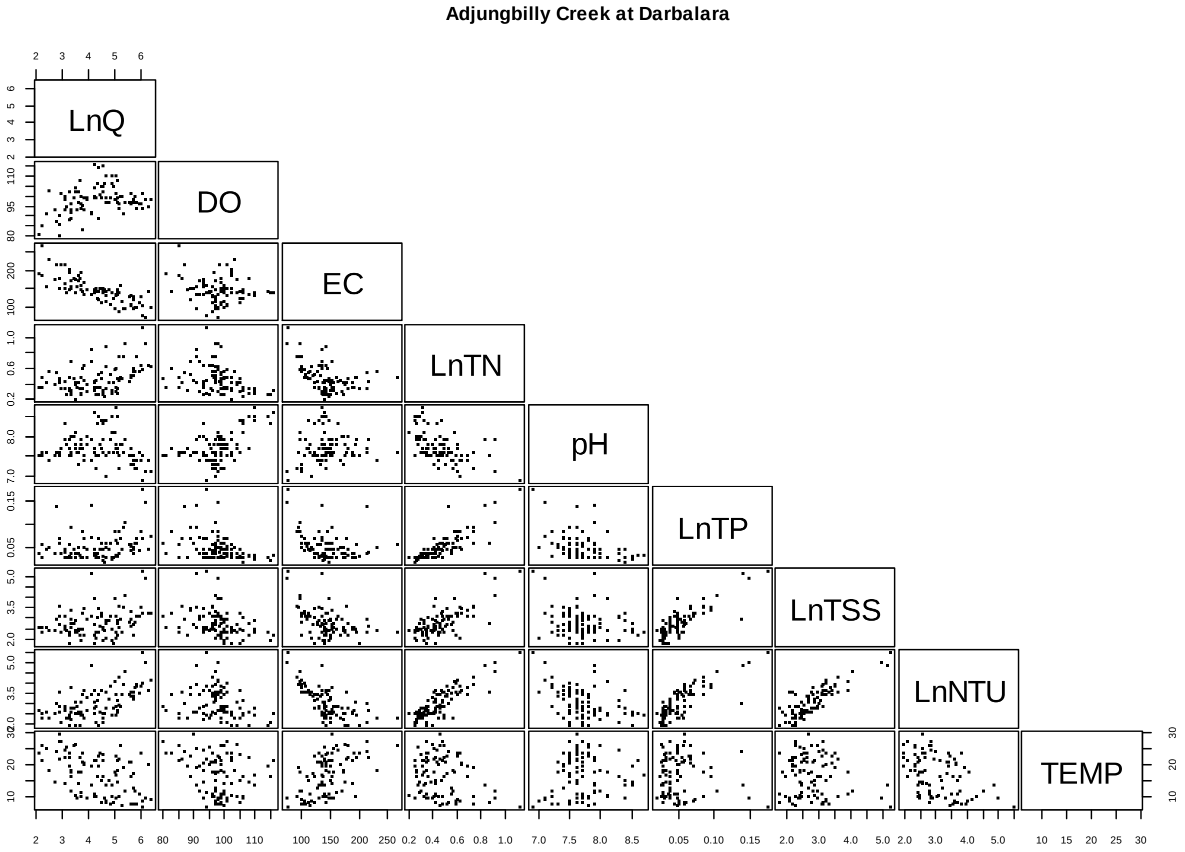


Figure 31: Draftsman plots for Adjungbilly Creek at Darbalara

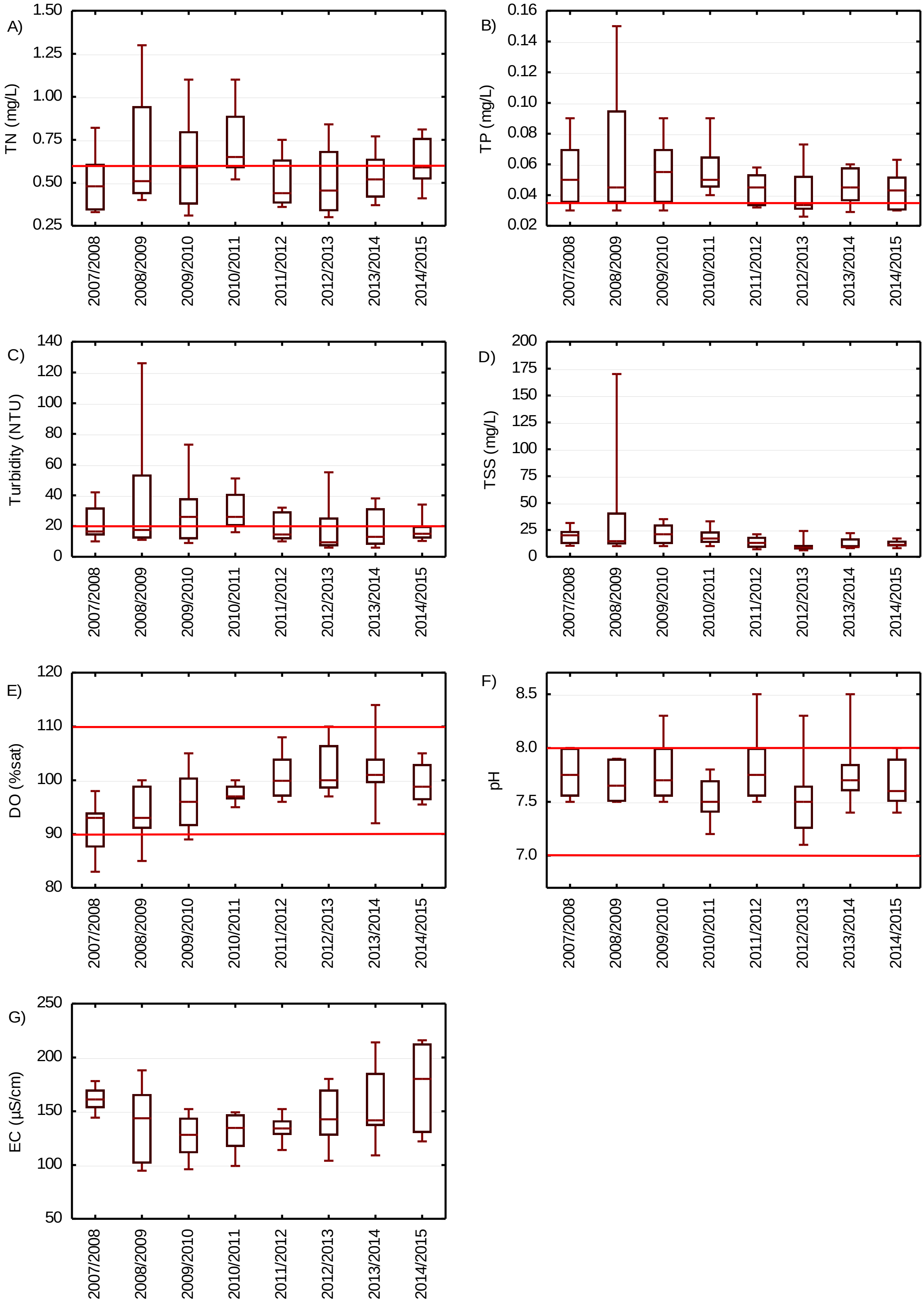


Figure 32: Water quality data for Adjungbilly Creek at Darbalara

Goobarragandra River at Little River Road

Due to little fluctuation in the data, the draftsman plots do not show clear correlations between many of the water quality attributes. Turbidity increases with increased flow, while electrical conductivity was negatively correlated to flow

The box plots show the quality of the water in the Goobarragandra River was good. Total nitrogen, total phosphorus and turbidity results are all well below the respective Basin Plan targets, and pH and dissolved oxygen results are mostly within the upper and lower limits. Electrical conductivity does fluctuate slightly through time yet remains low.

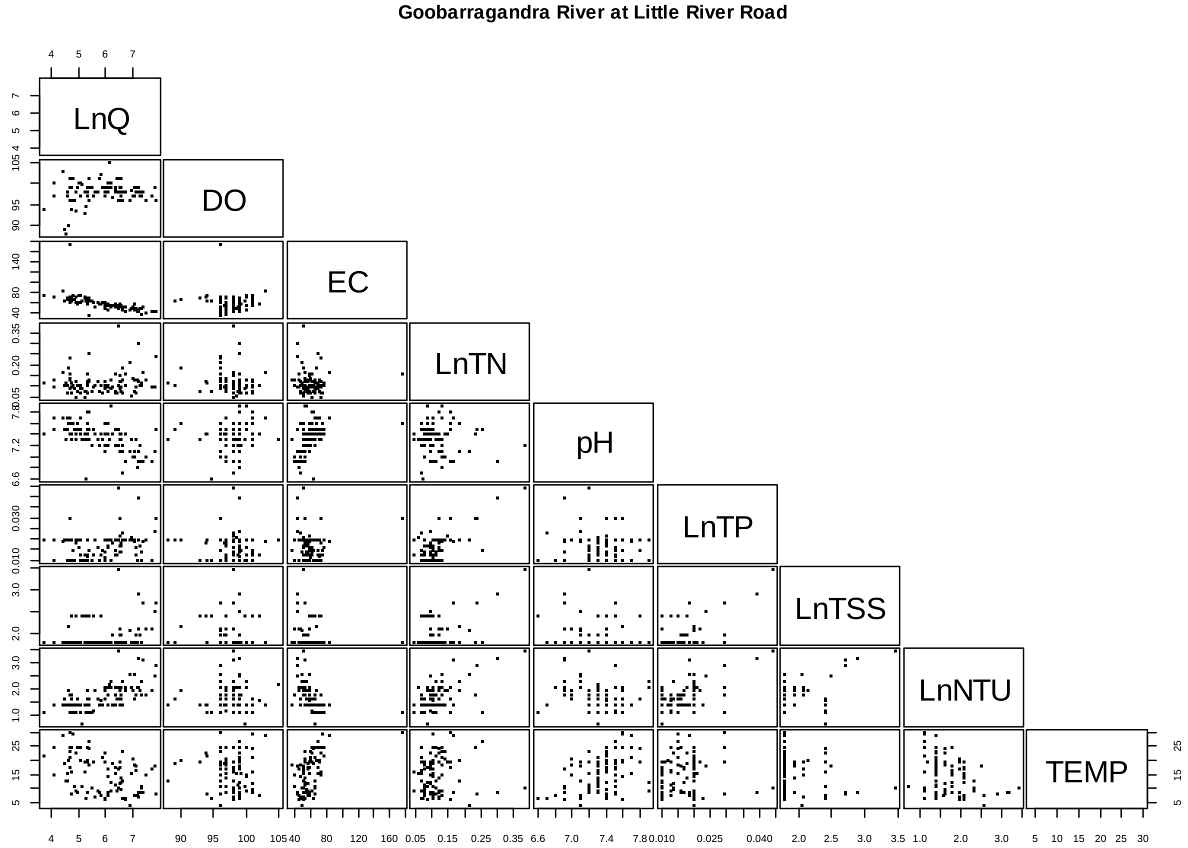


Figure 33: Draftsman plots for Goobarragandra River at Little River Road

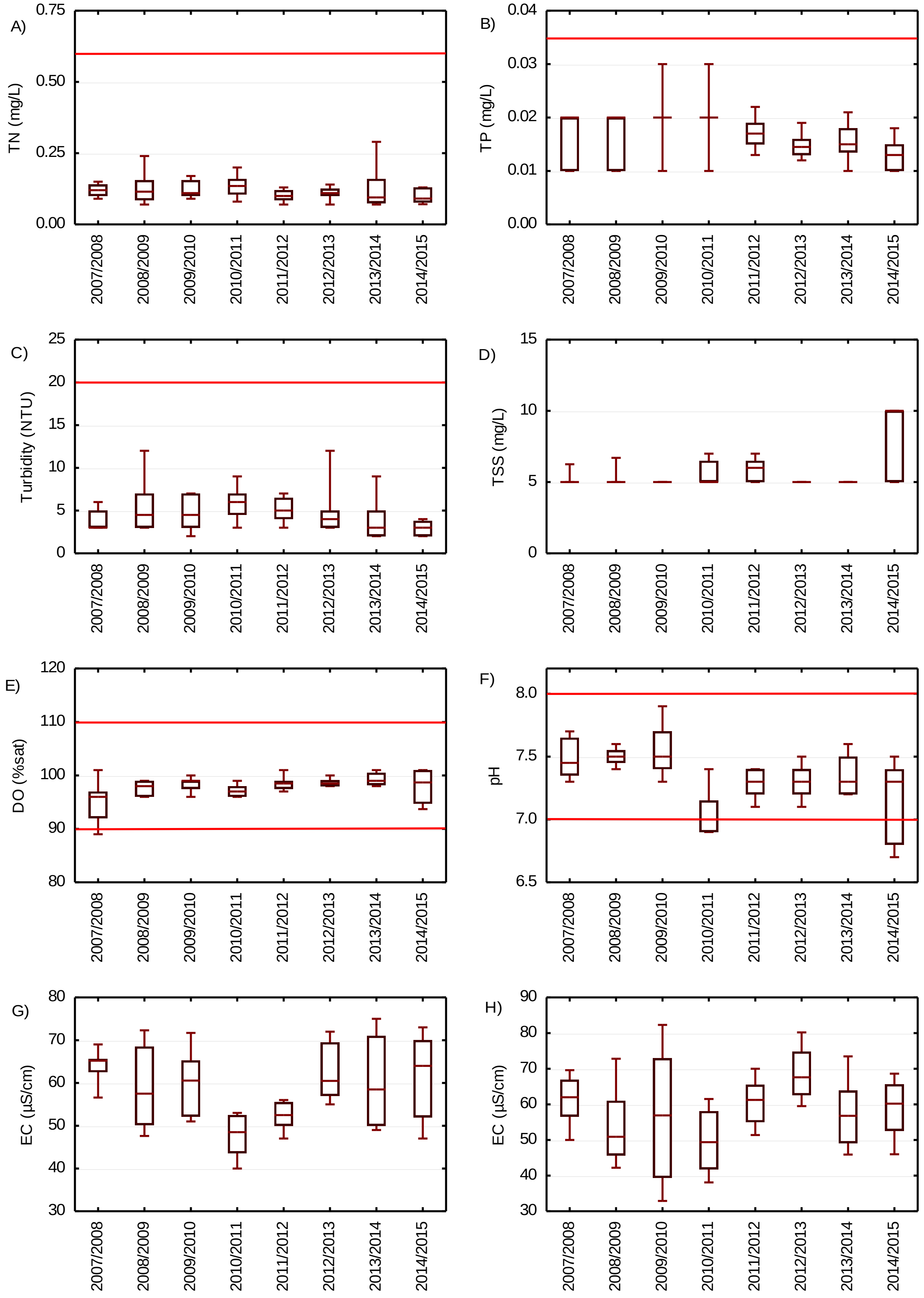


Figure 34: Water quality data for Goobarragandra River at Little River Road

Tumut River at Oddys Bridge

The draftsman plots for the Tumut River show a clear correlation between total nitrogen and total phosphorus. The Oddys Bridge monitoring site is located approximately 1.3 km downstream of Blowering Dam. Nutrients are able to be transferred downstream from the dam through the outlet works. The turbidity and total suspended solids results downstream are low and stable as sediment and organic matter settles to the bottom of the dam and only released downstream during flooding when the dam is spilling. Similarly the electrical conductivity is also stable and doesn't show correlation to other factors such as flow. Dissolved oxygen is more likely impacted by the depth of the offtake than flow or catchment management factors.

The boxplots show the total nitrogen and phosphorus concentrations were high between 2007 and 2011. During this period Blowering Dam was less than 50% capacity. The intake structure of the dam comprises a 41 m high open intake tower with trashrack covered inlets from 33 to 74 m below full supply level. The low storage level would have meant that the bulk of the water release would have been nutrient rich water from the bottom of the storage. The flooding and subsequent filling of Blowering Dam in later 2010 would have allowed the release of water from higher in the water column, avoiding the nutrient rich water on the bottom. Similarly the range of dissolved oxygen results would be influenced by the offtake depth of the water. The median electrical conductivity results are very low and show a decrease in concentrations after 2010. The pH in the Tumut River is low in response to the low pH of water in Blowering Dam.

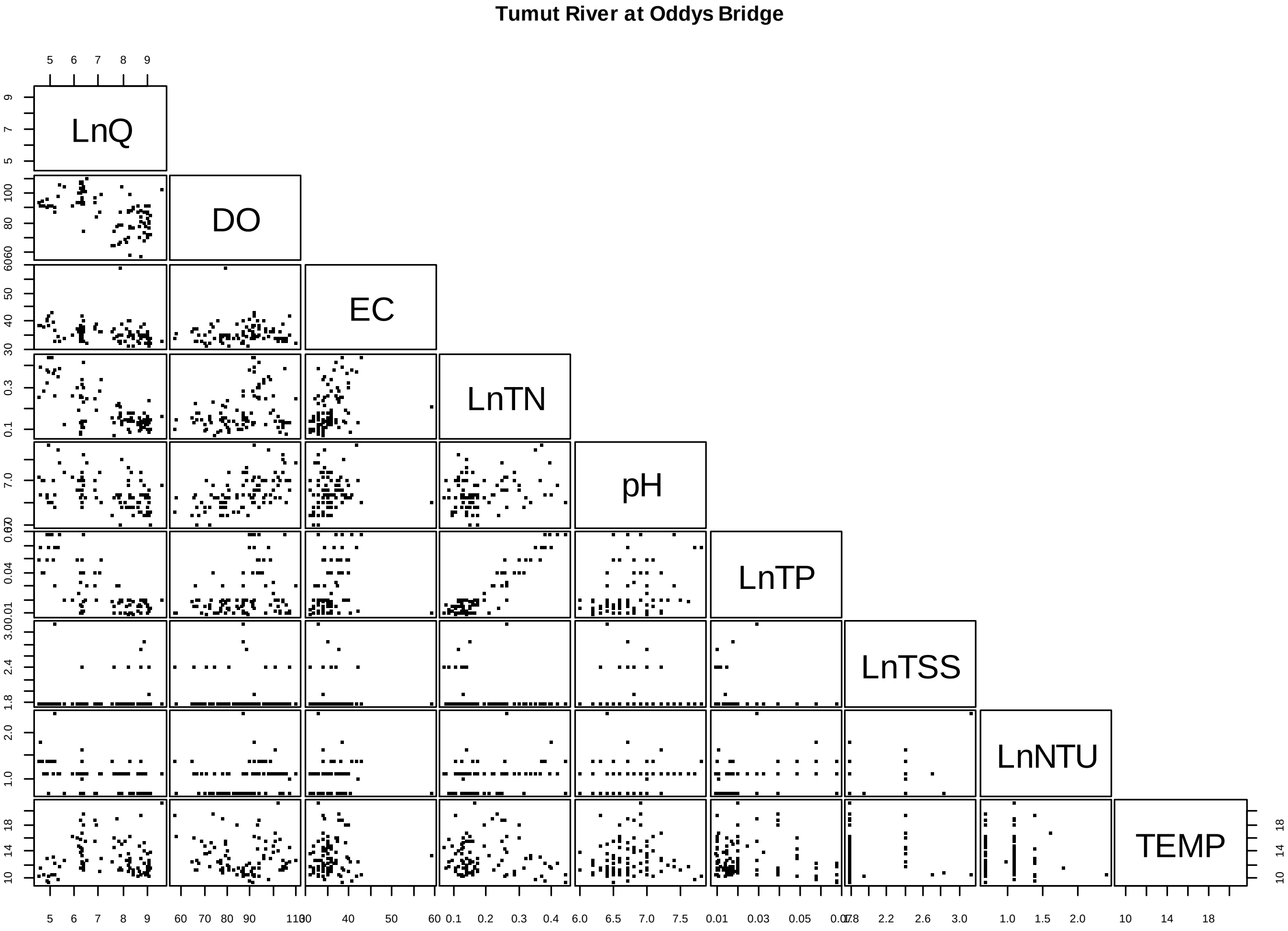


Figure 35: Draftsman plots for Tumut River at Oddys Bridge

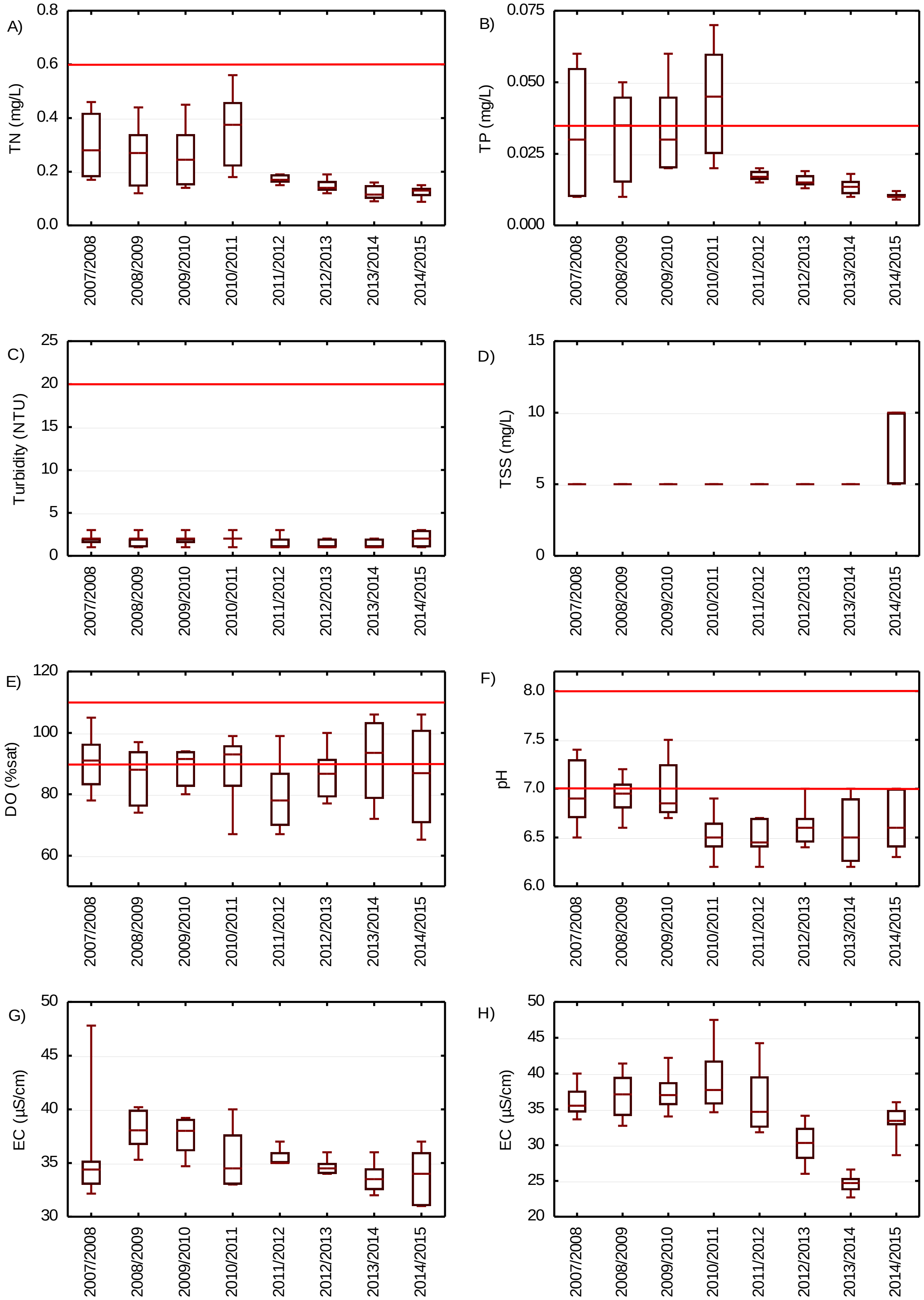


Figure 36: Water quality data for Tumut River at Oddys Bridge

Murrumbidgee River at Gundagai

The draftsman plots show clear correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. This suggests nutrients attached onto soil particles is the most likely transport mechanism at the site. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen, total phosphorus and turbidity results are all below the respective Basin Plan targets, except for 2010/2011. Median dissolved oxygen and pH is within the upper and lower limits. Electrical conductivity fluctuates through time. As Gundagai is located downstream of the confluence of the Tumut and Murrumbidgee Rivers, the electrical conductivity would more likely be determined by the origin of the water (Blowering Dam, Burrunjuck Dam or tributary inflow) rather than local environmental factors.

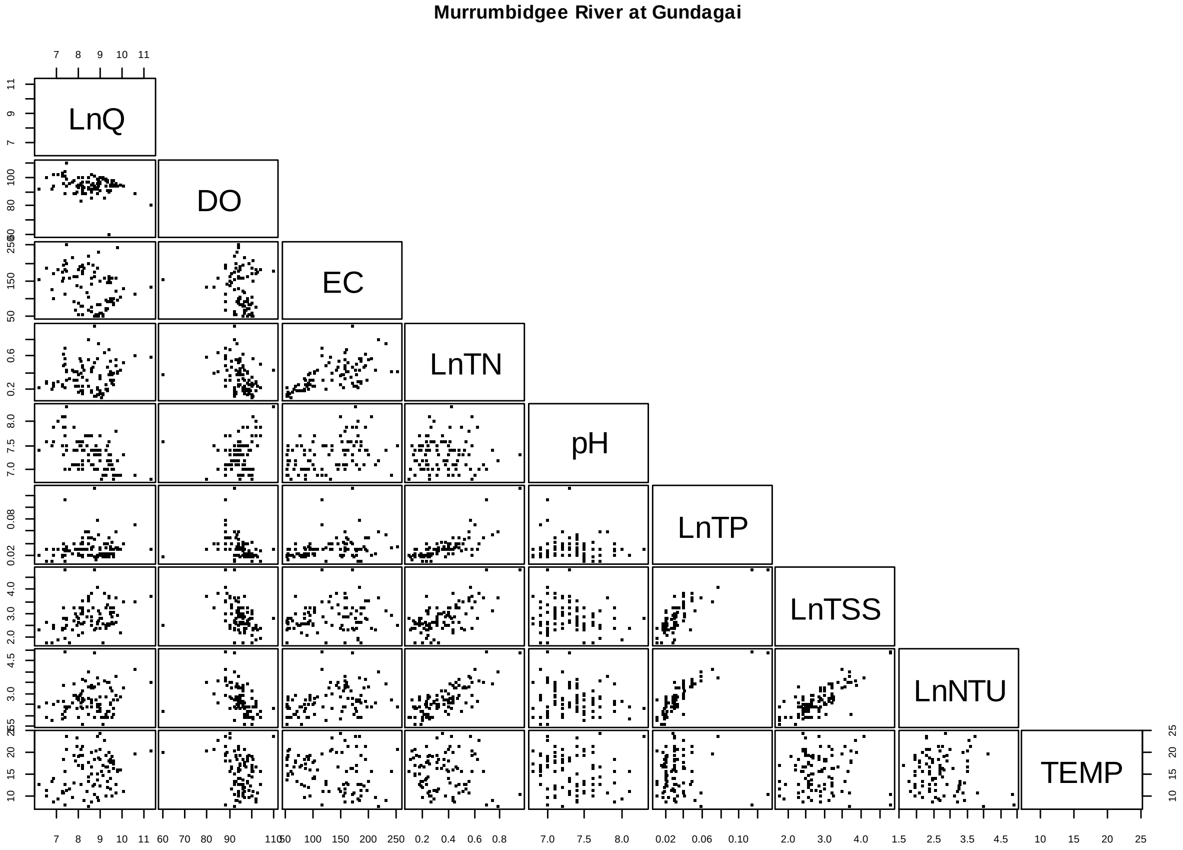


Figure 37: Draftsman plots for Murrumbidgee River at Gundagai

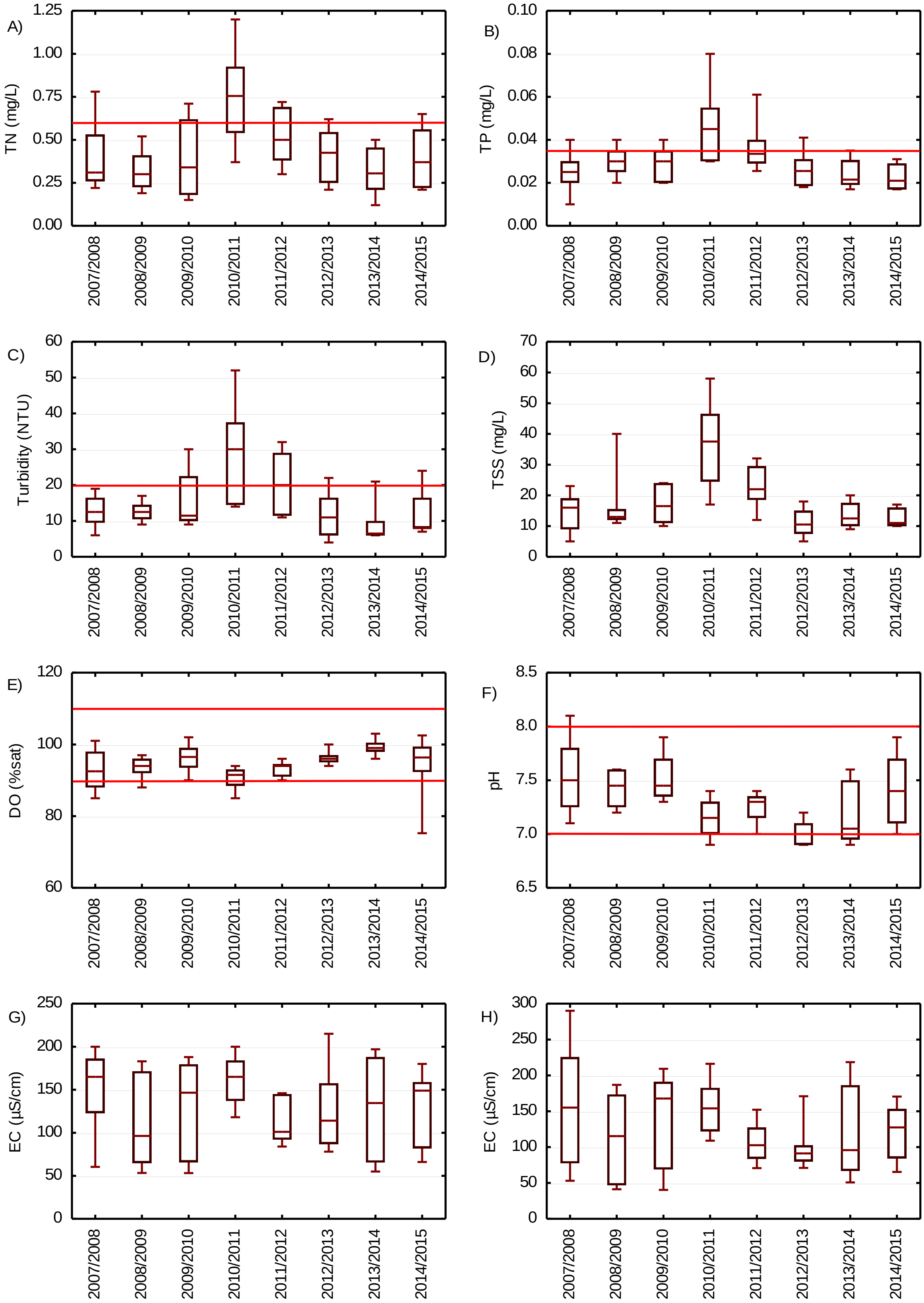


Figure 38: Water quality data for Murrumbidgee River at Gundagai

Hillas Creek at Mundarlo Road Bridge

The draftsman plots show clear positive correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. This suggests nutrients attached onto soil particles is the most likely transport mechanism in the catchment. Electrical conductivity was negatively correlated to flow suggesting contributions from saline groundwater during low flow periods and dilution at high flows.

The annual median total nitrogen and turbidity results were less than the Basin Plan target every year, except for the high flow years from 2010 to 2012. The total phosphorus annual median exceeded the target every year. The pH and dissolved oxygen results fluctuated between years, but mostly within the upper and lower target limits. There was a slight drop in annual median electrical conductivity in 2010/2011 and a slight increase from saline contributions to river base flow from shallow groundwater. The results remain low and pose no threat to irrigation use or aquatic ecosystems.

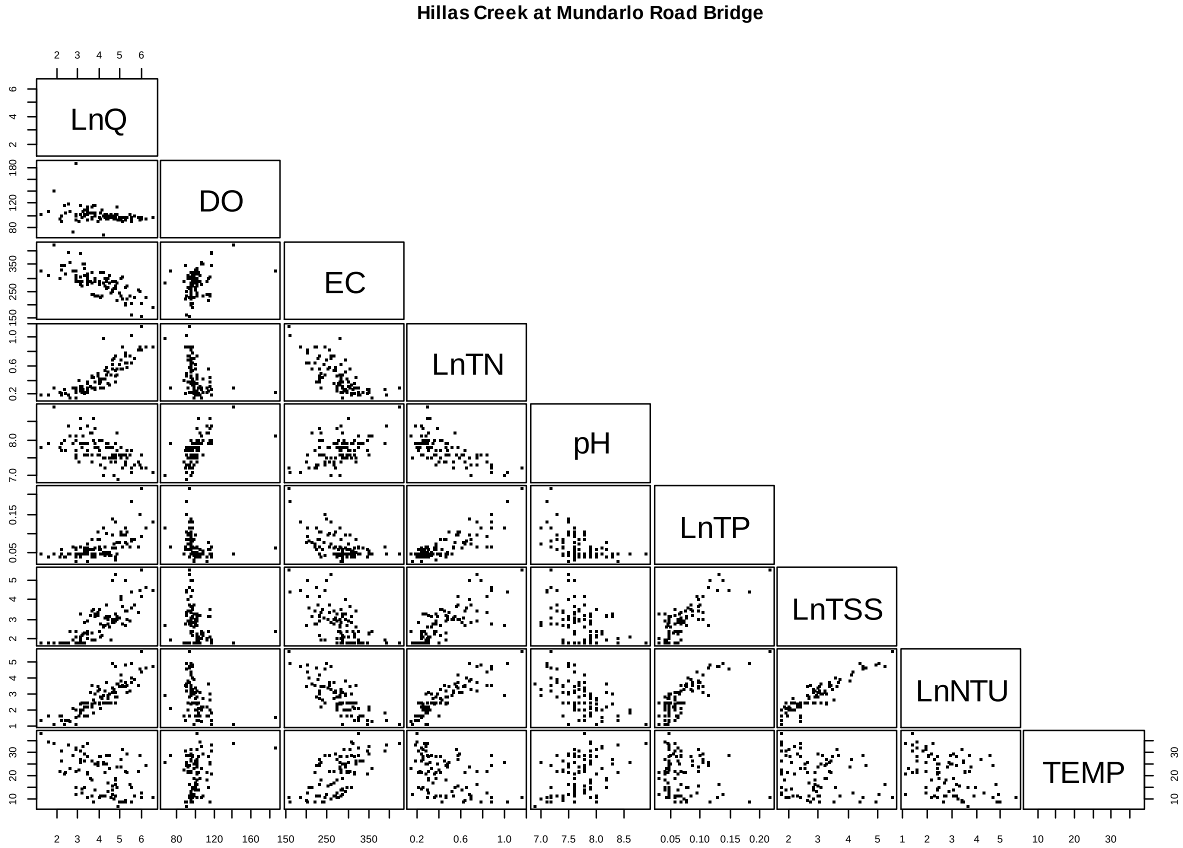


Figure 39: Draftsman plots for Hillas Creek at Mundarlo Road Bridge

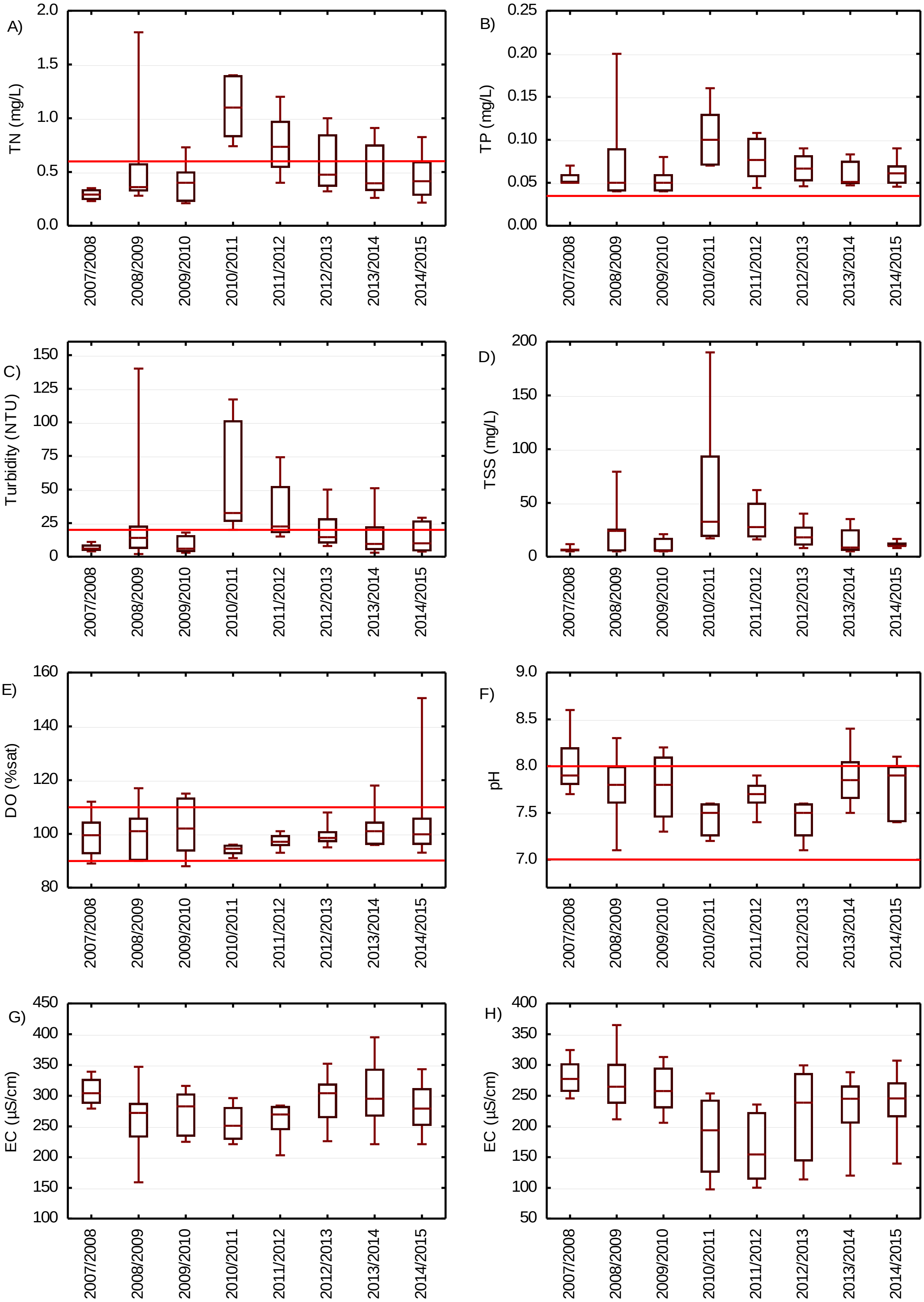


Figure 40: Water quality data for Hillas Creek at Mundarlo Road Bridge

Adelong Creek at Bereena

Flow data is not available for this monitoring site.

There was a positive correlation between total nitrogen, total phosphorus and turbidity, suggesting nutrients are mostly transported attached to suspended sediments. There does not appear to be any correlation between other parameters.

The annual median total nitrogen results were less than the Basin Plan target every year, except for the high flow year from 2010 to 2011. The total phosphorus annual median exceeded the target every year. Turbidity was low from 2007 to 2010 and then increased above the target when flow returned to Adelong Creek. Dissolved oxygen levels were less than the lower limit for most years. The pH was stable, with most results between 7 and 7.5. Electrical conductivity results were at their lowest from 2008 to 2010 as the dry weather continued, disconnecting the surface water from the shallow groundwater.

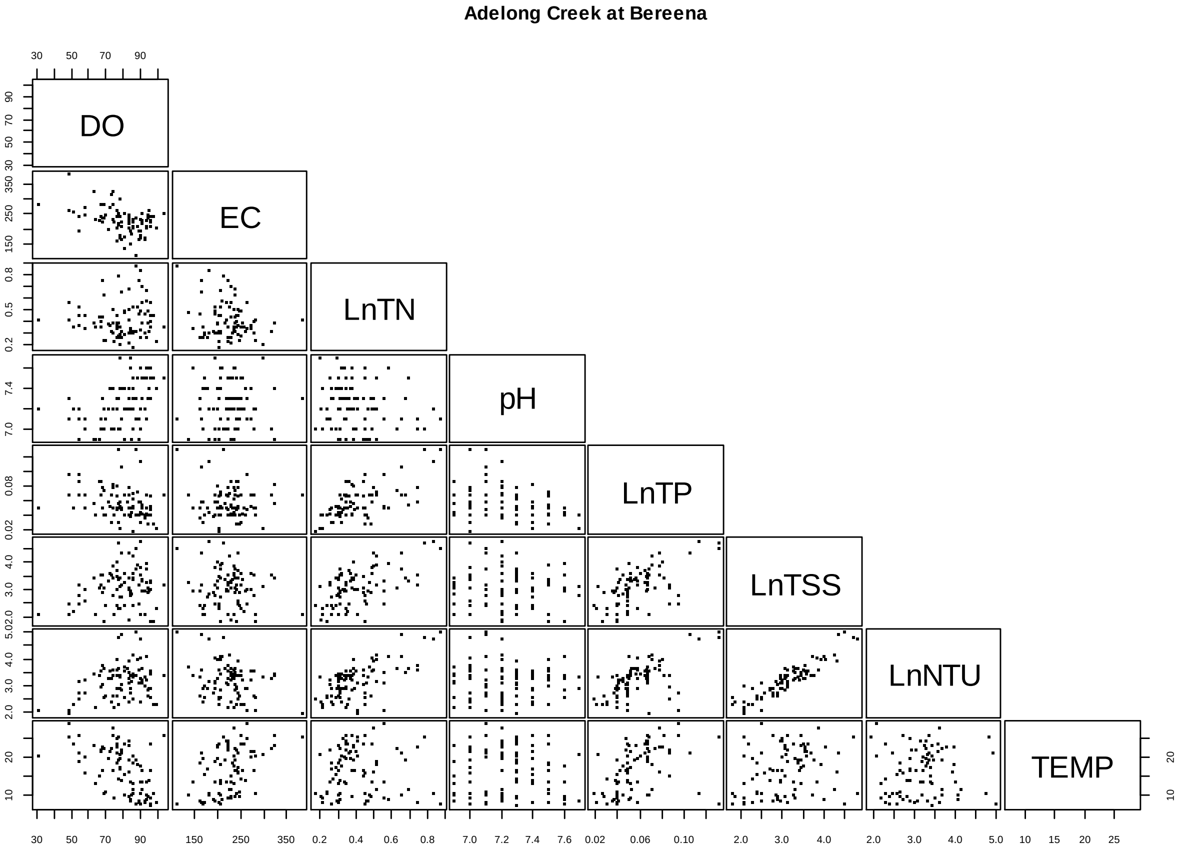


Figure 41: Draftsman plots for Adelong Creek at Bereena

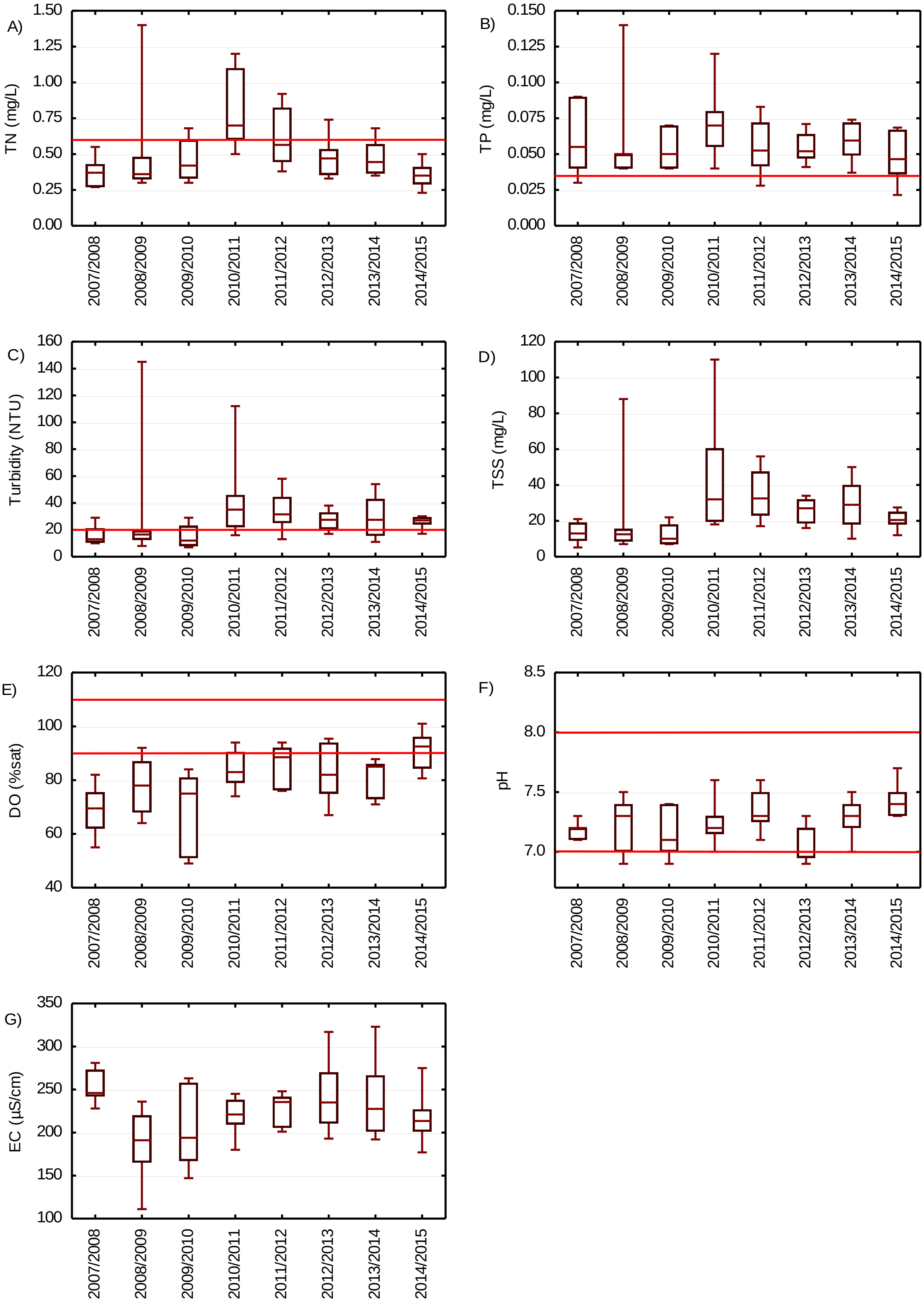


Figure 42: Water quality data for Adelong Creek at Bereena

Tarcutta Creek at Old Borambola

The draftsman plots show a positive correlation between total nitrogen, total phosphorus and turbidity. These three parameters were also correlated to flow. There was a negative correlation between flow and electrical conductivity.

The annual median turbidity and total phosphorus exceed the Basin plan target every year. Total nitrogen only exceeded the target in 2010/2011. Median pH and dissolved oxygen was within the upper and lower limits for ecosystem protection. Electrical conductivity decreased through time.

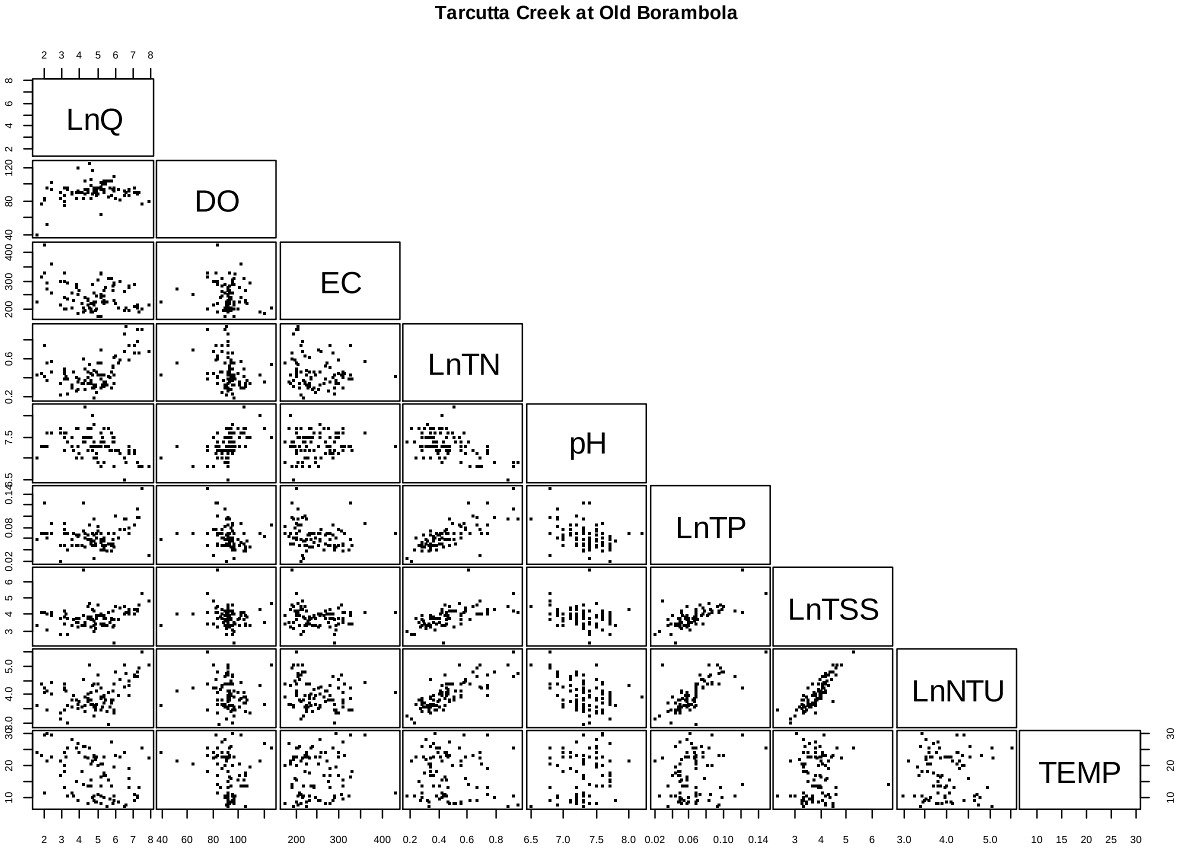


Figure 43: Draftsman plots for Tarcutta Creek at Old Borambola

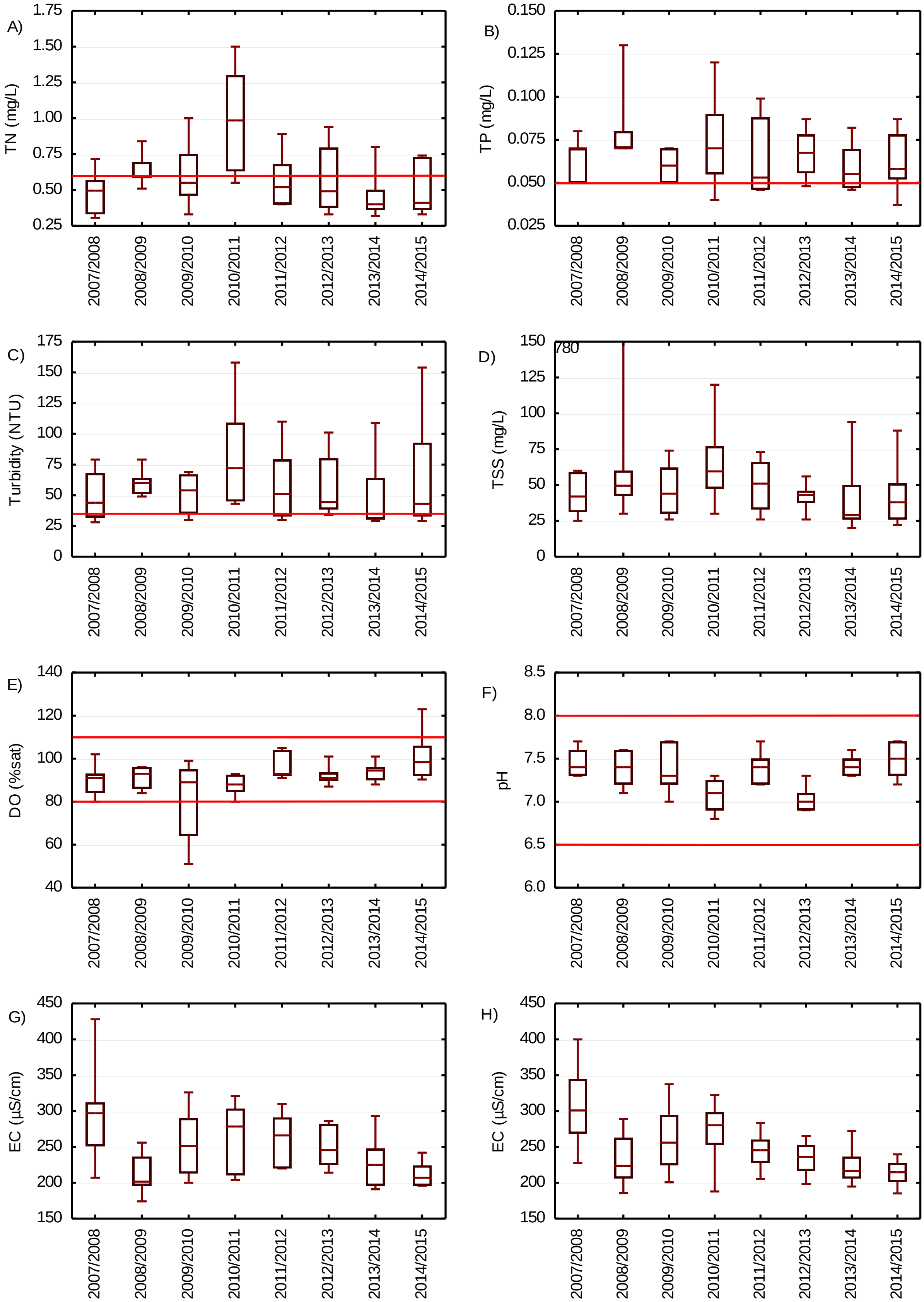


Figure 44: Water quality data for Tarcutta Creek at Old Borambola

Murrumbidgee River downstream Wagga Wagga

The draftsman plots show clear correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. Dissolved oxygen levels are stable throughout the sampling period. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen, total phosphorus and turbidity results are all below the respective Basin Plan targets, except for 2010/2011. Median dissolved oxygen and pH was within the upper and lower limits. Electrical conductivity shows minor fluctuations through time. As Wagga Wagga is on the regulated Murrumbidgee, releases from Blowering and Burrinjuck Dams will largely determine the electrical conductivity.

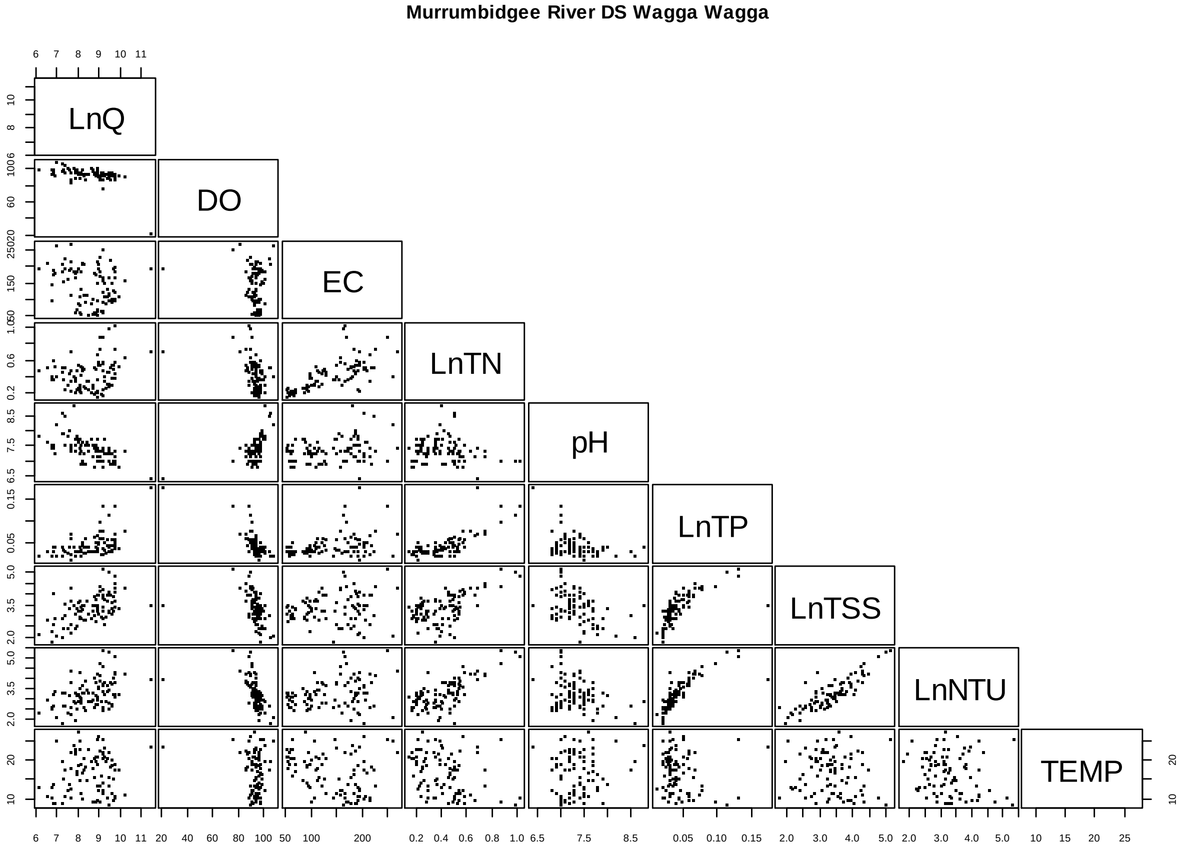


Figure 45: Draftsman plots for Murrumbidgee River downstream Wagga Wagga

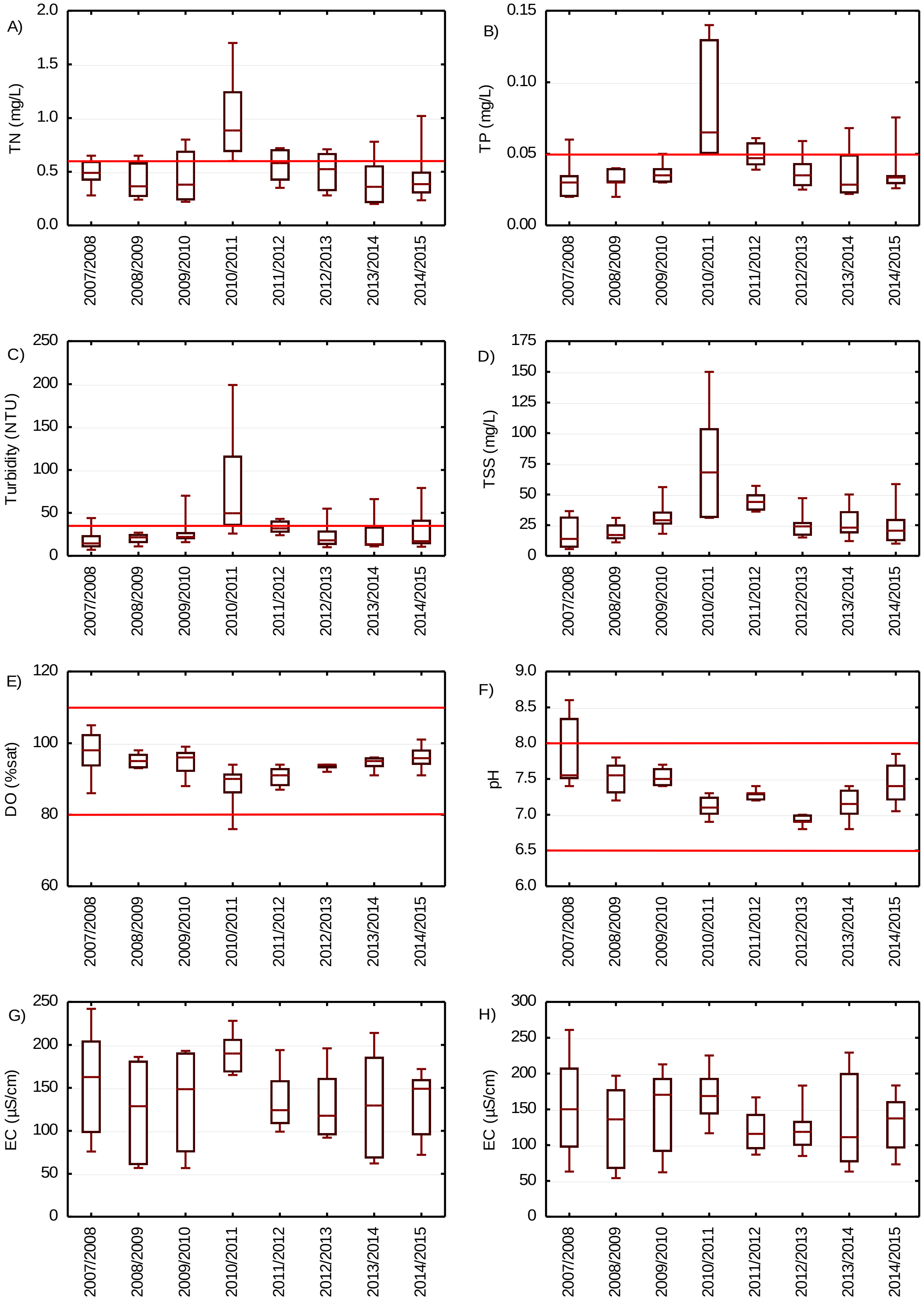


Figure 46: Water quality data for Murrumbidgee River downstream Wagga Wagga

Colombo Creek at Morundah

The draftsman plots show correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. There was a positive correlation between dissolved oxygen and pH, but no correlation between electrical conductivity and flow.

Colombo Creek receives regulated flows via diversions into Yanco Creek from the Murrumbidgee River at Yanco Weir. Water in Yanco Creek then either continues down Yanco Creek or splits into Colombo Creek. Total nitrogen, total phosphorus and turbidity are all fairly stable, apart from during the flooding in 2010 and 2011. Turbidity levels exceeded the Basin Plan target every year. Nitrogen and phosphorus exceed the targets during high flow. The pH fluctuates within the upper and lower limits. Dissolved oxygen is mostly within the upper and lower targets apart from during the flooding in 2010/2011. Inundation of vegetation in the riparian zone and associated floodplain may have resulted in reduced oxygen levels in the river. As the flows are largely via river regulation, with little connectivity to groundwater, the electrical conductivity is stable through time.

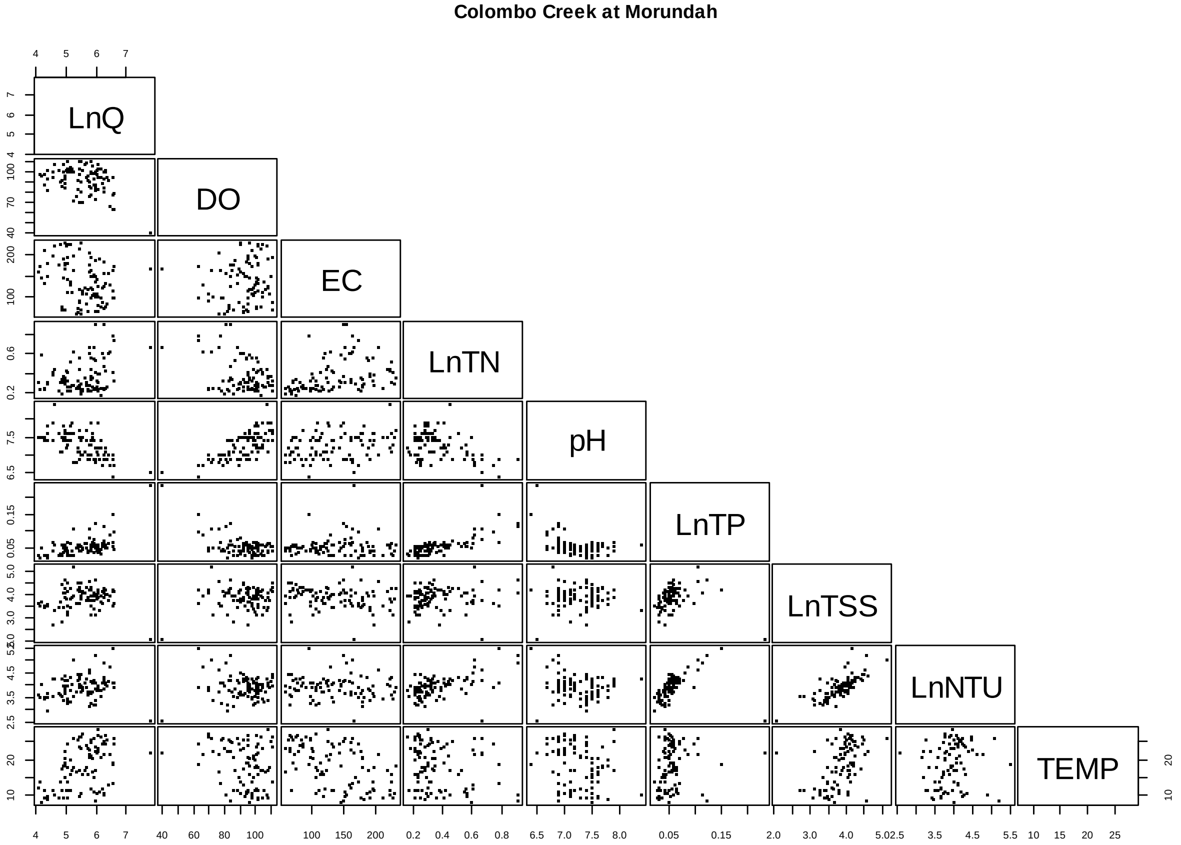


Figure 47: Draftsman plots for Colombo Creek at Morundah

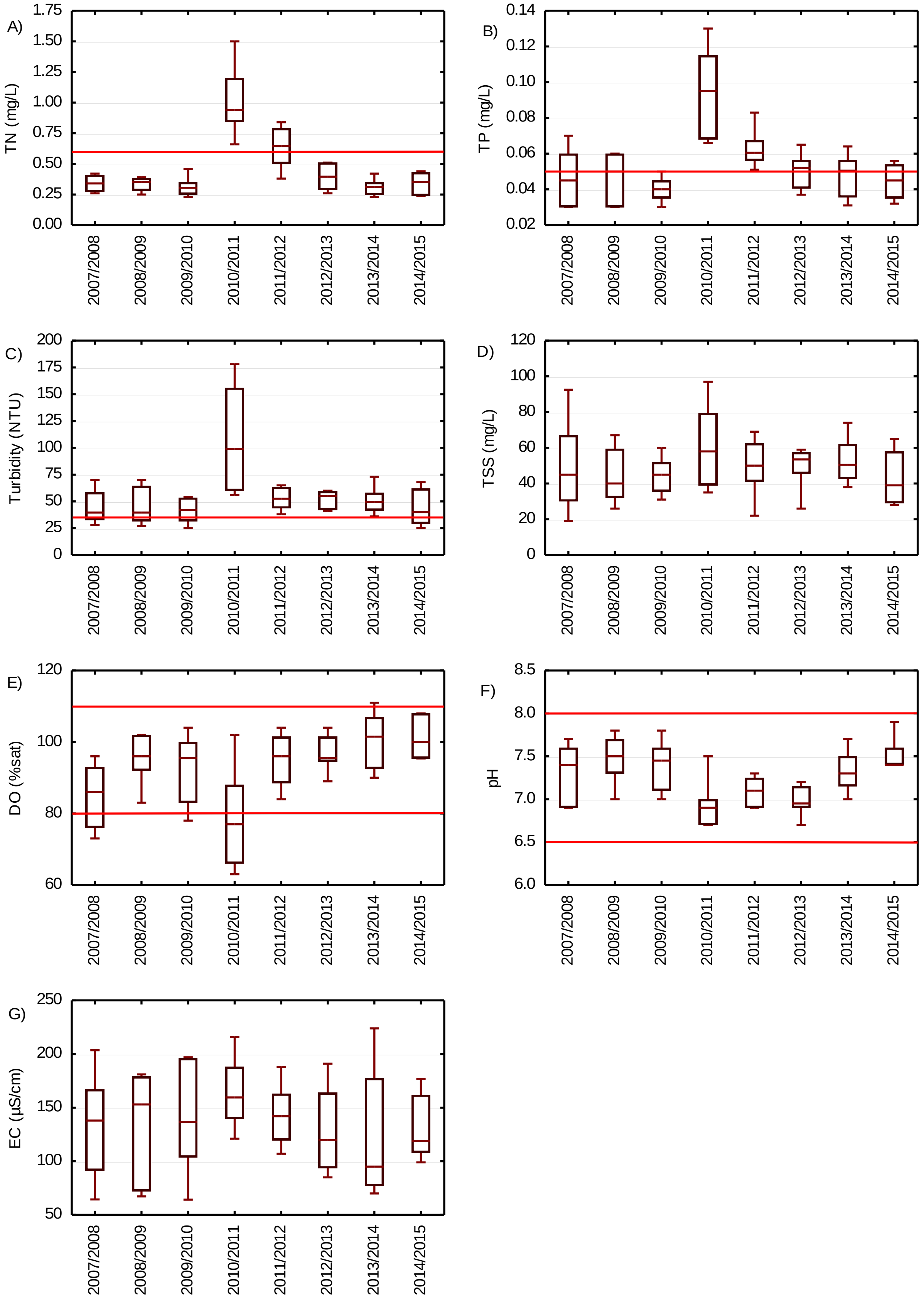


Figure 48: Water quality data for Colombo Creek at Morundah

Yanco Creek at Morundah

The draftsman plots show correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. There was a positive correlation between dissolved oxygen and pH, but no correlation between electrical conductivity and flow.

The Yanco Creek and Colombo Creek sites at Morundah are in close proximity to each other, making the quality of the water at both sites similar. Total nitrogen, total phosphorus and turbidity are all fairly stable, apart from during the flooding in 2010 and 2011. Turbidity levels exceeded the Basin Plan target every year. Nitrogen and phosphorus exceed the targets during high flow. The pH fluctuates within the upper and lower limits. Dissolved oxygen is mostly within the upper and lower targets apart from during the flooding in 2010/2011. Inundation of vegetation in the riparian zone and associated floodplain may have resulted in reduced oxygen levels in the river. As the flows are largely via river regulation, with little connectivity to groundwater, the electrical conductivity is stable through time.

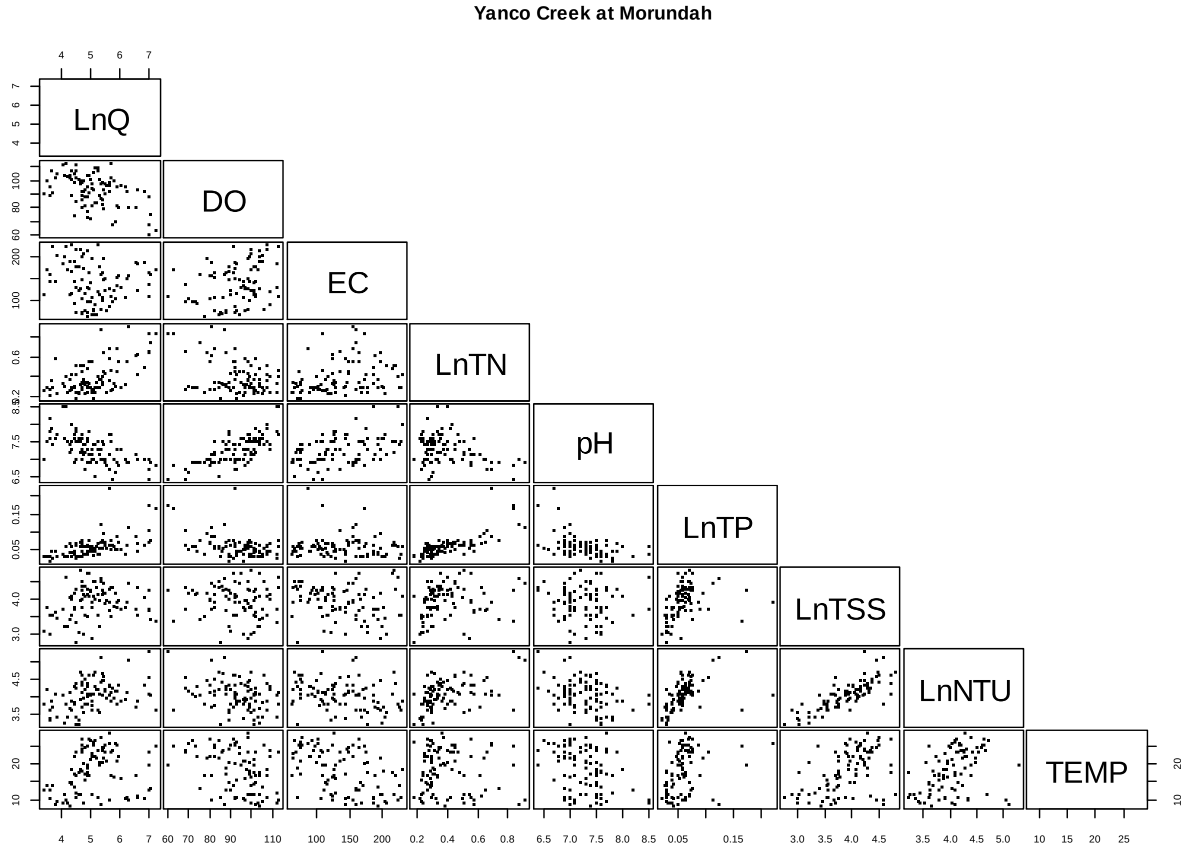


Figure 49: Draftsman plots for Yanco Creek at Morundah

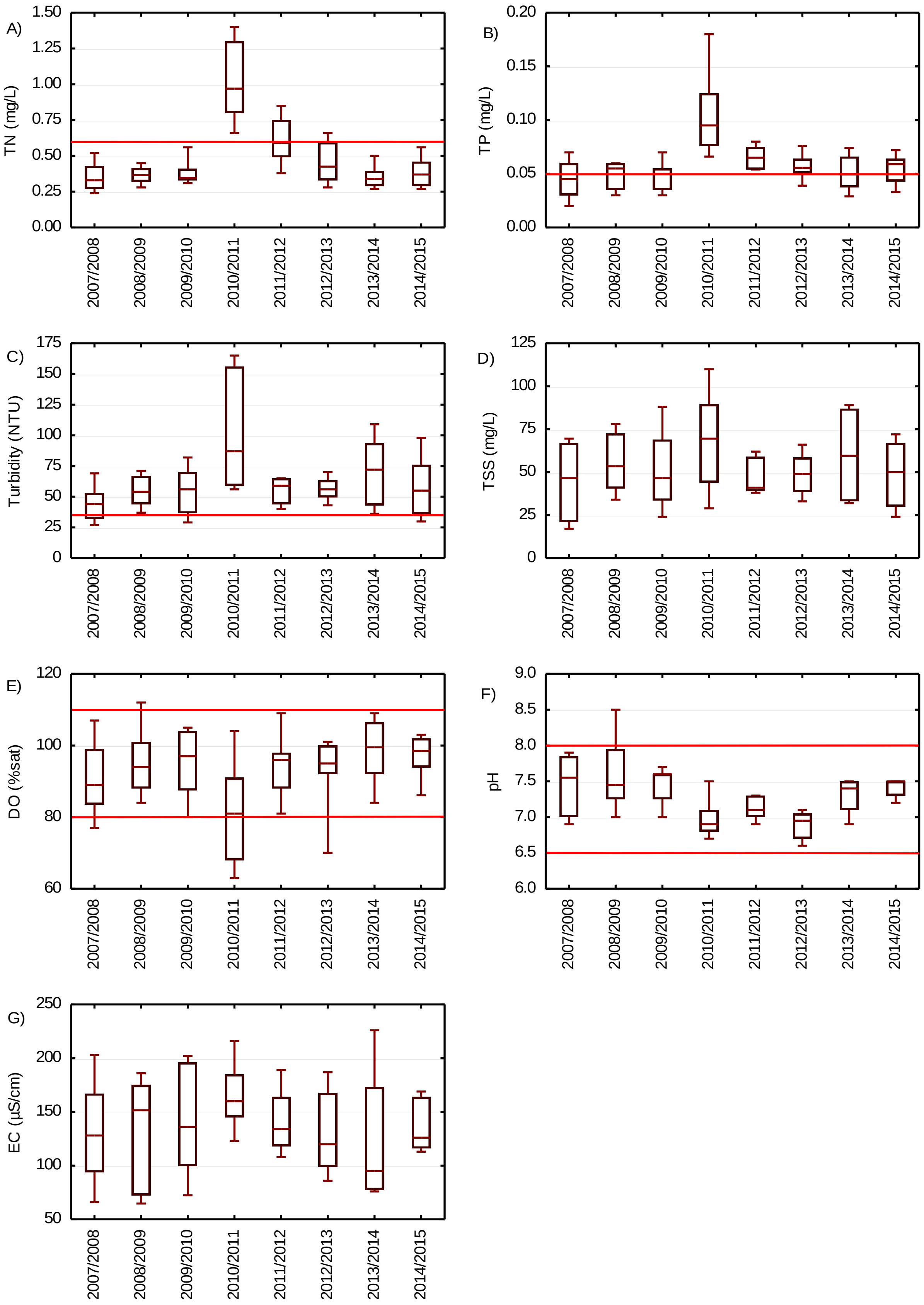


Figure 50: Water quality data for Yanco Creek at Morundah

Yanco Creek at Yanco Bridge

This site was added to the routine water quality monitoring program in 2009.

The draftsman plots show a positive correlation between total nitrogen, total phosphorus and turbidity. Total nitrogen and total phosphorus are also correlated to flow, but turbidity was not. Electrical conductivity was positively correlated to flow.

The total nitrogen annual median only exceeded the target in the higher flow years of 2010 to 2012. Most total phosphorus and turbidity results exceeded the respective targets. The pH is consistently around 7 with some results below the lower target of 6.5. Dissolved oxygen levels were less than the lower target for the first three years of monitoring at this site. Following the flooding, the annual median dissolved oxygen increased, however there were still some results less than the lower limit of 80% saturation. Yanco Creek receives regulated flow from the Murrumbidgee River. As there is little fluctuation in electrical conductivity, this suggests there is little surface water and groundwater interaction.

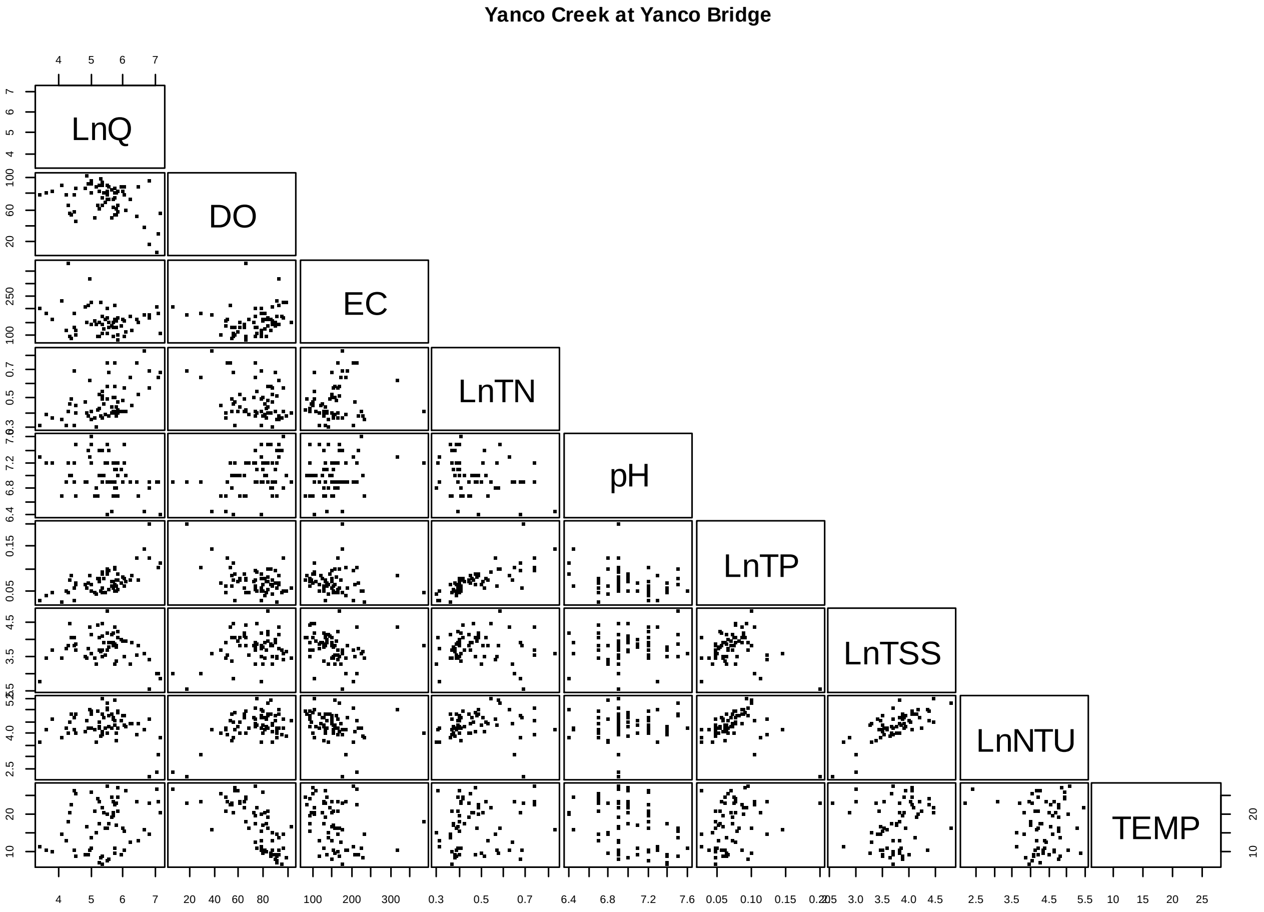


Figure 51: Draftsman plots for Yanco Creek at Yanco Bridge

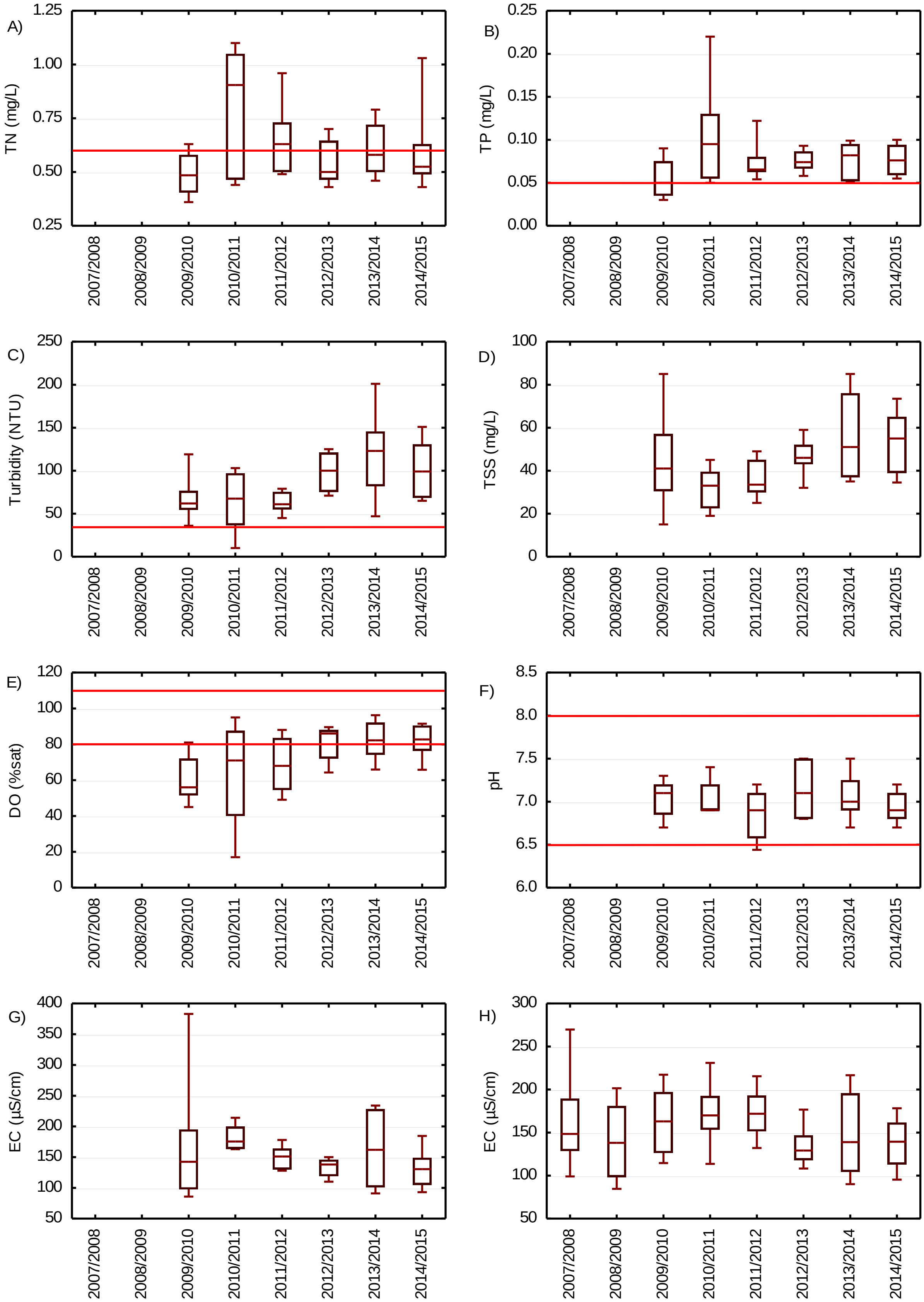


Figure 52: Water quality data for Yanco Creek at Yanco Bridge

Billabong Creek at Walbundrie

There is a positive correlation between total nitrogen, total phosphorus and turbidity with all three attributes positively correlated to flow. There is a strong negative correlation between electrical conductivity and flow.

The total nitrogen annual median exceeded the Basin Plan target every year with total phosphorus exceeding the target in all years except for one. The annual turbidity was less than the Basin Plan targets in the low flow years from 2007 to 2010. Increased flow in subsequent years resulted in median turbidity levels above the target. Low dissolved oxygen results from 2007 to 2010 indicate that during low flow, respiration is outpacing production. Electrical conductivity is one of the highest of all routine monitoring sites in the Murrumbidgee WRPA, with similar concentrations to Jugiong and Muttama Creeks. The high conductivity from shallow saline groundwater may have been further concentrated through evaporation between 2007 and 2009. Future monitoring will show if the electrical conductivity returns to levels similar to those prior to the flooding. The annual median pH is greater than the upper limit most years. The saline groundwater may have high concentration of alkaline salts which increases the pH.

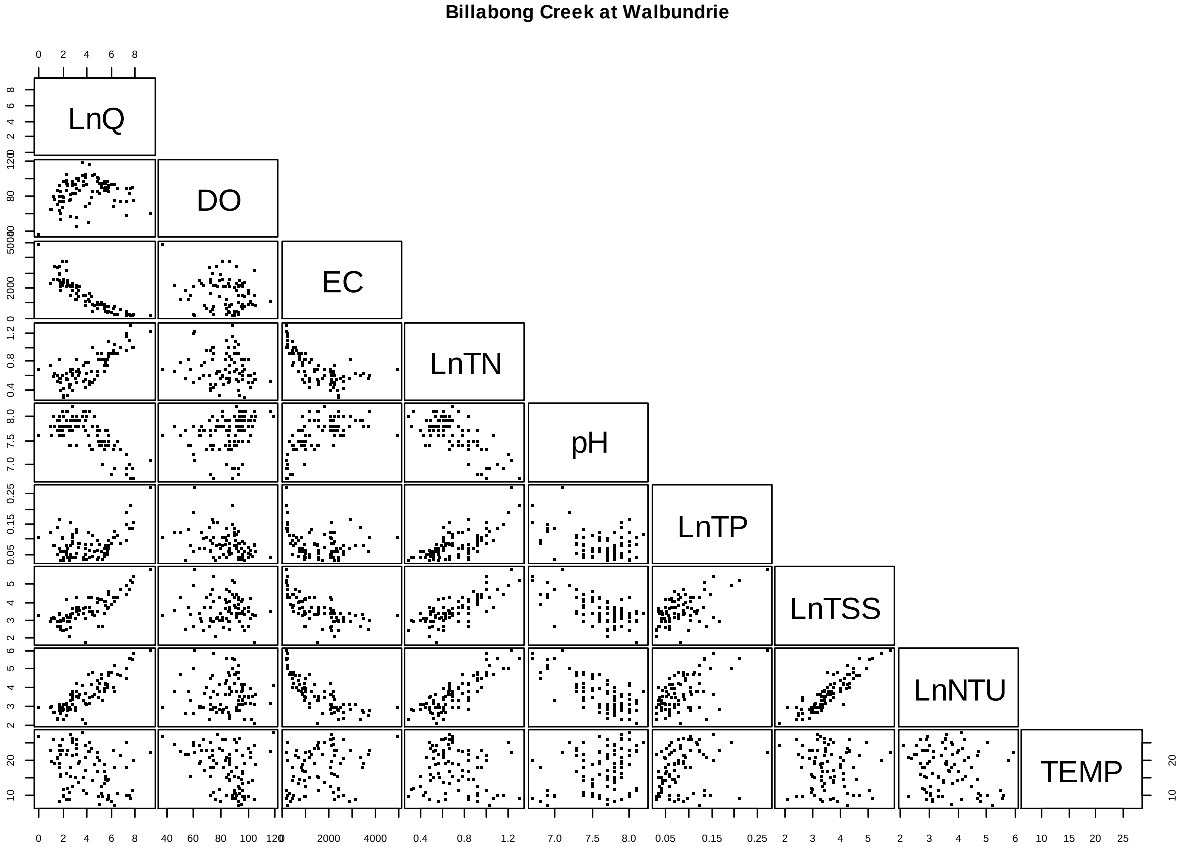


Figure 53: Draftsman plots for Billabong Creek at Walbundrie

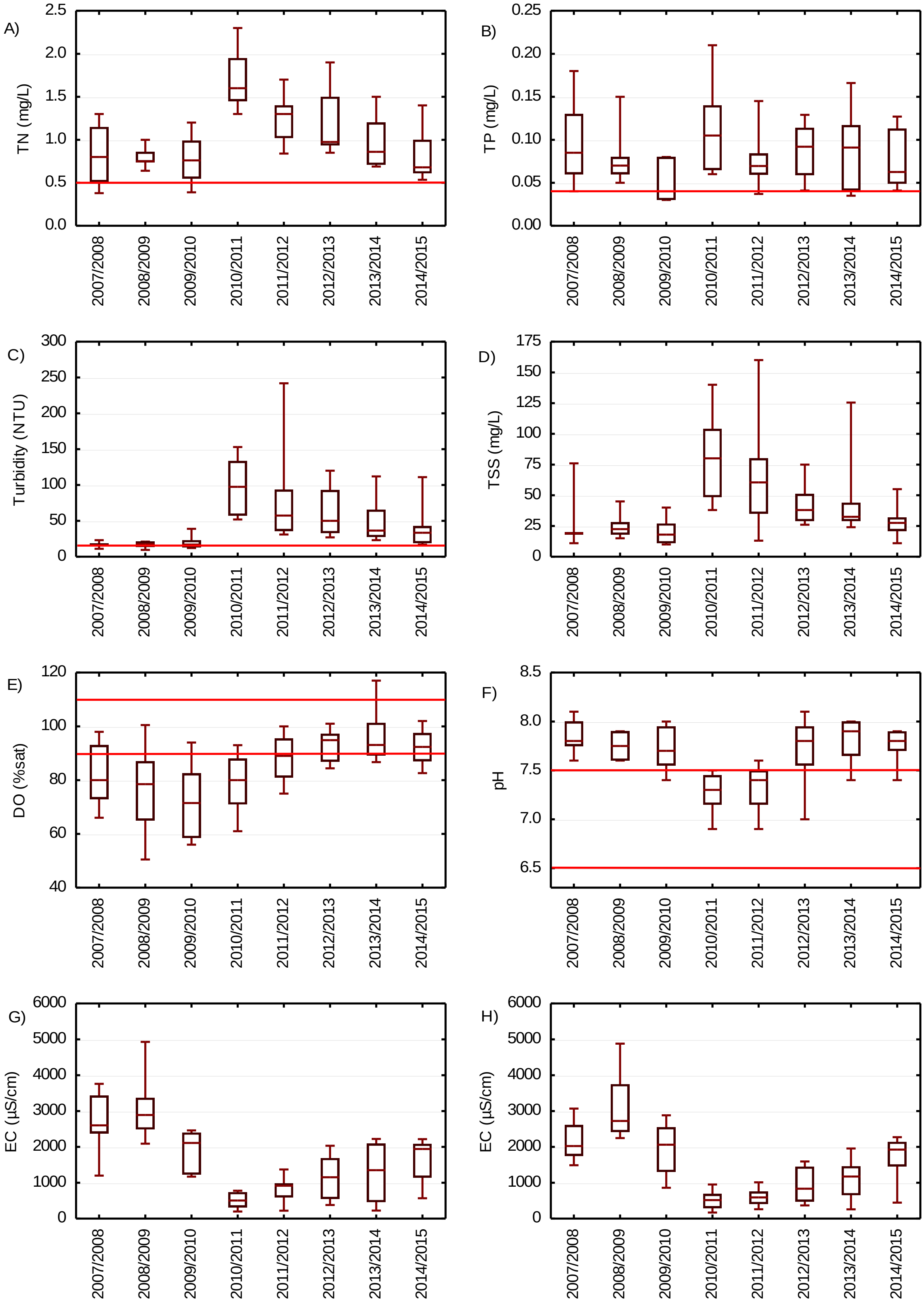


Figure 54: Water quality data for Billabong Creek at Walbundrie

Billabong Creek at Jerilderie

There was a positive correlation between total nitrogen, total phosphorus and turbidity. These three attributes were also correlated to flow. There was a positive correlation between dissolved oxygen and pH, but not a correlation between electrical conductivity and flow.

The Jerilderie monitoring site is located downstream of the junction of Billabong Creek and the Colombo Creek. The regulated inflows from Colombo Creek are diluting the salts derived from the upper Billabong Creek catchment (Walbundrie) resulting in much lower electrical conductivity, making the water more suitable for irrigation. Total nitrogen and total phosphorus annual medians exceeded the Basin Plan targets all years except one. Turbidity exceeded the target all years. Dissolved oxygen was less than the lower limit all years except for 2014/2015. During the flooding in 2010/2011 dissolved oxygen levels got very low and may have been impacting on the health of aquatic ecosystems. In addition to diluting salts, flows from Colombo Creek also decreased the pH to within the upper and lower limits.

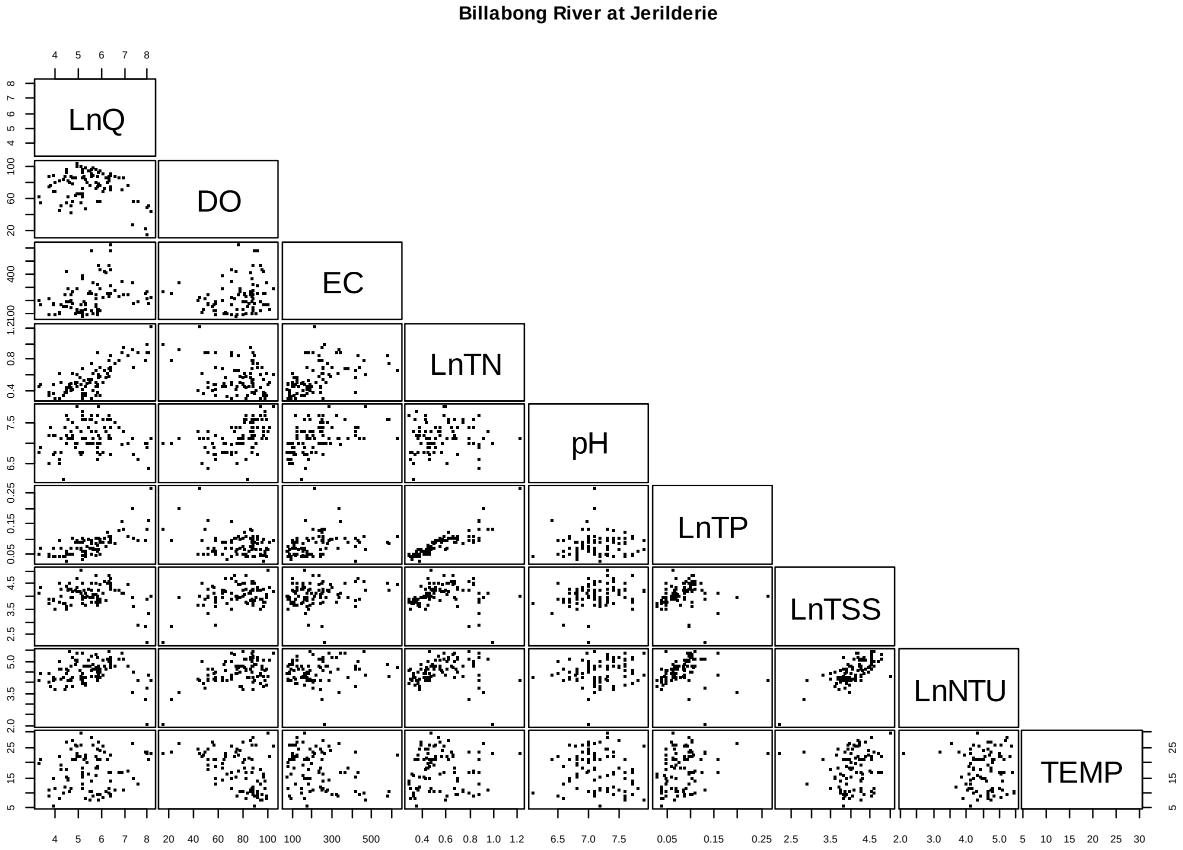


Figure 55: Draftsman plots for Billabong Creek at Jerilderie

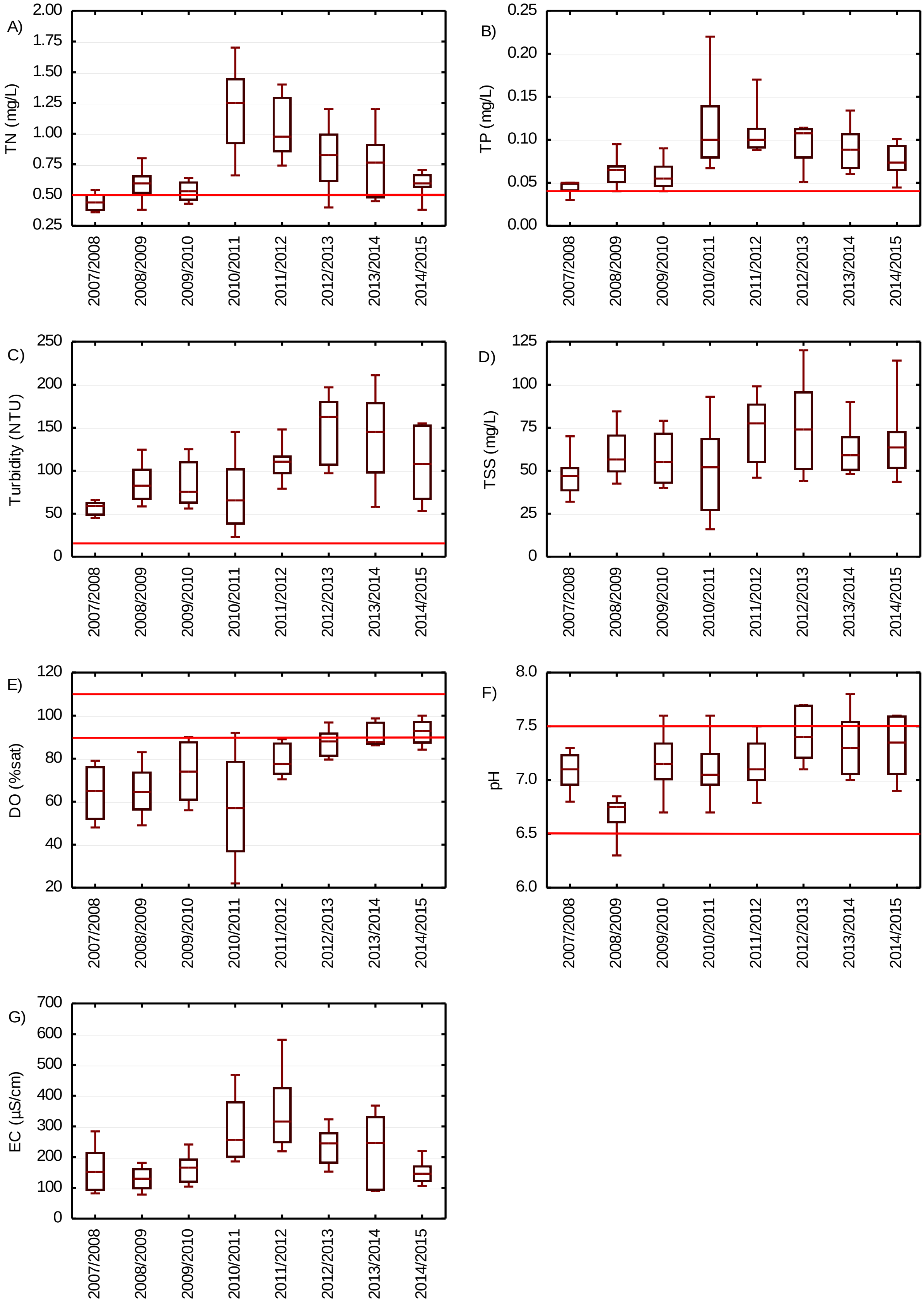


Figure 56: Water quality data for Billabong Creek at Jerilderie

Billabong Creek at Darlot

Total nitrogen, total phosphorus and total suspended solids were added to this site in 2011. The short data set for these parameters means that correlations between attributes are not clear. There was a positive correlation between total nitrogen, total phosphorus and turbidity, but not a correlation to flow. There was no correlation between electrical conductivity and flow.

Annual median total nitrogen, total phosphorus and turbidity exceed the respective Basin Plan targets all years. The Darlot monitoring site is at the downstream end of Billabong Creek catchment where it receives the cumulative impacts of human activity upstream. Dissolved oxygen results were generally less than the lower Limit of 90% saturation. Low flow, minimising water turbulence in lowland rivers, in conjunction with high turbidity reducing light penetration into the water column, inhibiting aquatic plant growth, could be causing the lower dissolved oxygen results. The pH results were mostly between the upper and lower limits. Electrical conductivity fluctuated between years as a consequence of flow diversions in the upper catchment rather than local drivers such as groundwater interactions. Billabong Creek joins the Edward River in the Murray WRPA downstream of the Darlot monitoring site.

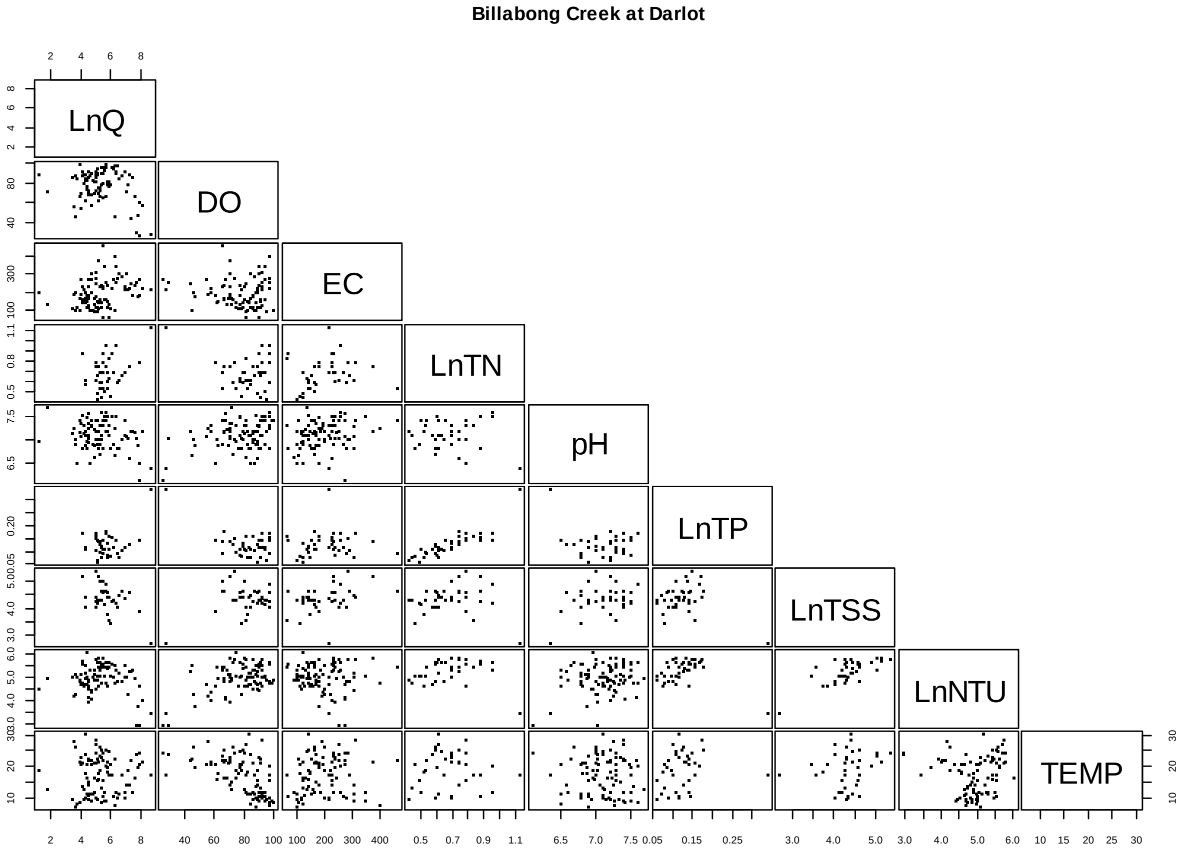


Figure 57: Draftsman plots for Billabong Creek at Darlot

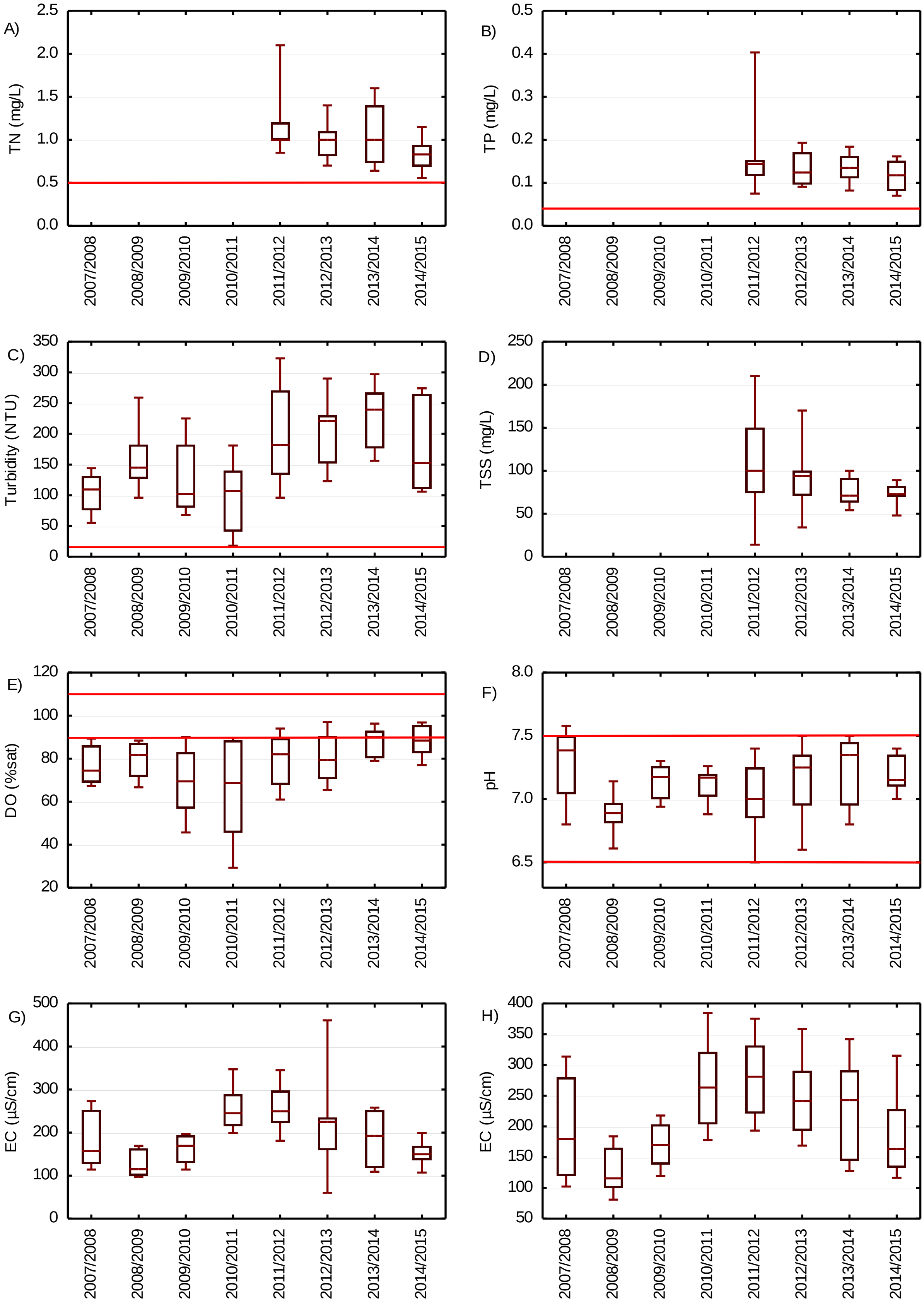


Figure 58: Water quality data for Billabong Creek at Darlot

Murrumbidgee River downstream Yanco Weir

The draftsman plots show clear correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. Dissolved oxygen levels show a positive correlation with pH. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen, total phosphorus and turbidity results are all below the respective Basin Plan targets, except for during the flooding in 2010/2011. Median dissolved oxygen and pH is within the upper and lower limits. Electrical conductivity shows only minor fluctuations through time as a result of releases from Blowering and Burrinjuck Dams.

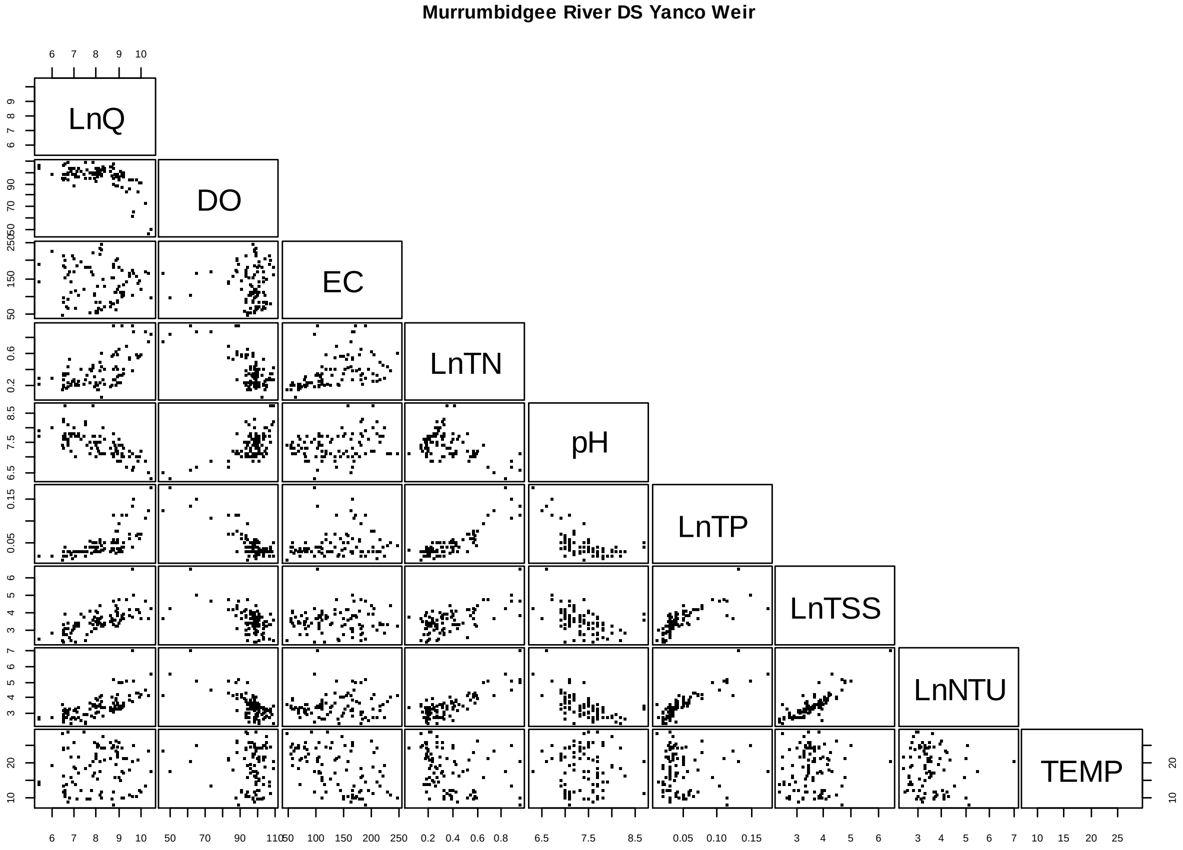


Figure 59: Draftsman plots for Murrumbidgee River downstream Yanco Weir

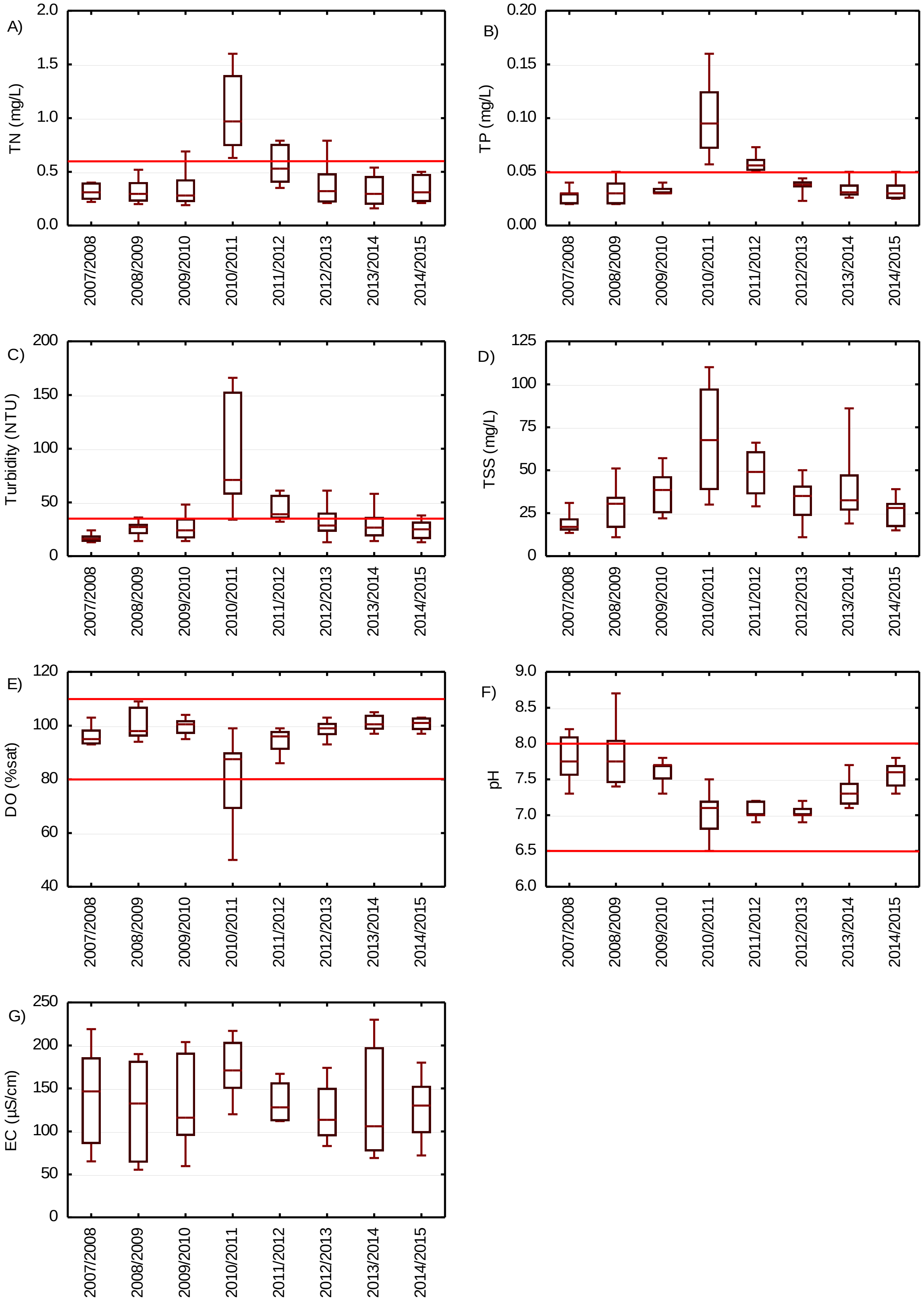


Figure 60: Water quality data for Murrumbidgee River downstream Yanco Weir

Murrumbidgee River downstream Gogeldrie Weir

The draftsman plots show clear correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. Dissolved oxygen levels show a positive correlation with pH. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen, total phosphorus and turbidity results are all below the respective Basin Plan targets, except for during the flooding in 2010/2011. Median dissolved oxygen and pH is within the upper and lower limits. Electrical conductivity shows only minor fluctuations through time.

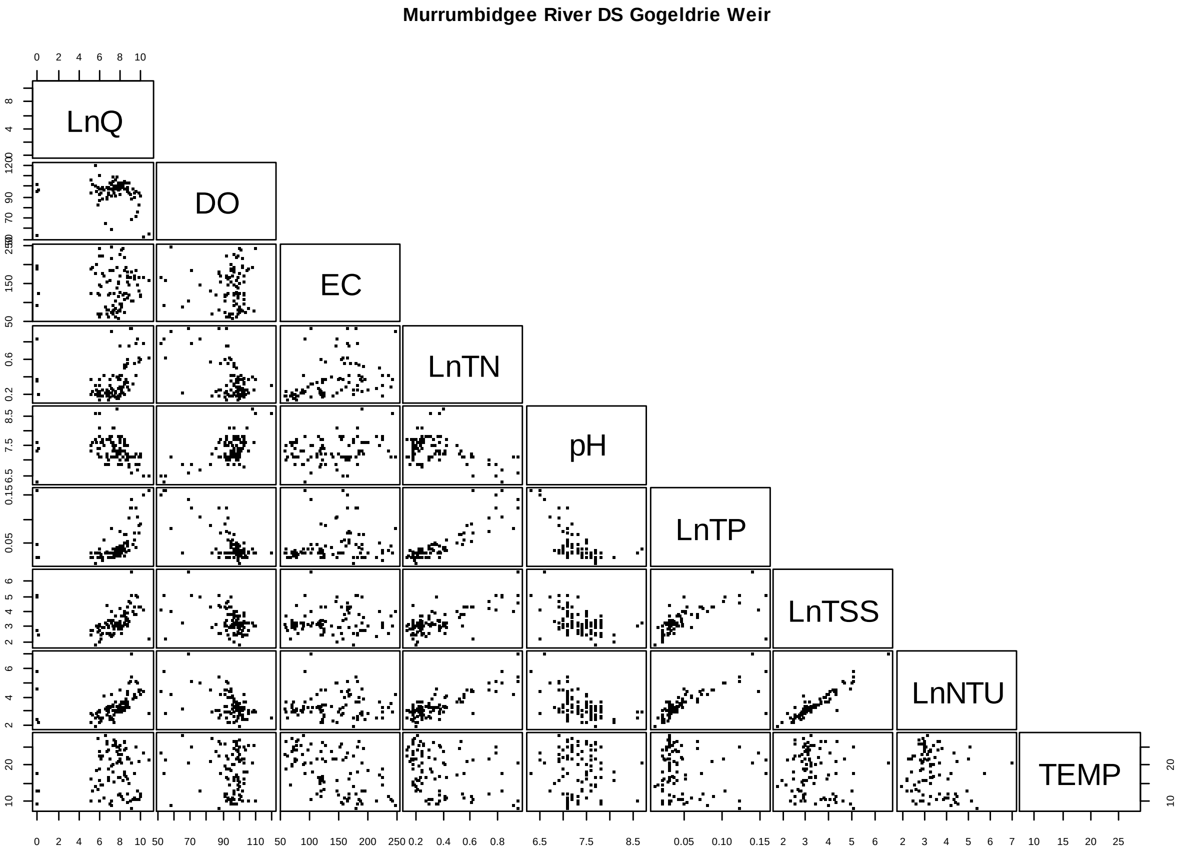


Figure 61: Draftsman plots for Murrumbidgee River downstream Gogeldrie Weir

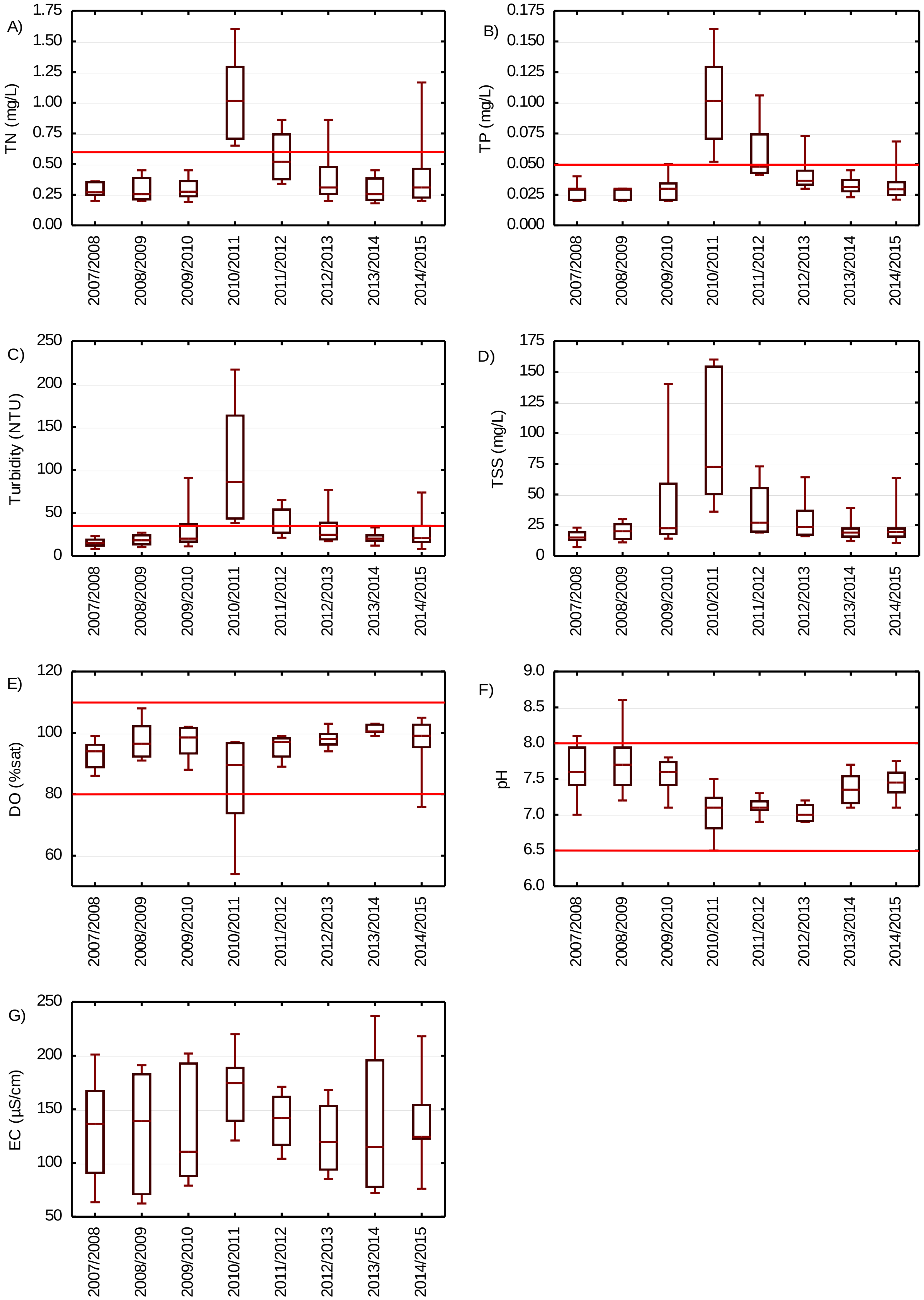


Figure 62: Water quality data for Murrumbidgee River downstream Gogeldrie Weir

Murrumbidgee River at Carrathool

The draftsman plots show positive correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen was below the Basin Plan targets for all years except during the flooding in 2010/2011. The annual median total phosphorus and turbidity exceeded the target three years. Dissolved oxygen was generally stable around 100% saturation apart from one very low result during flooding. The pH was mostly within the upper and lower limits. Electrical conductivity shows only minor fluctuations through time.

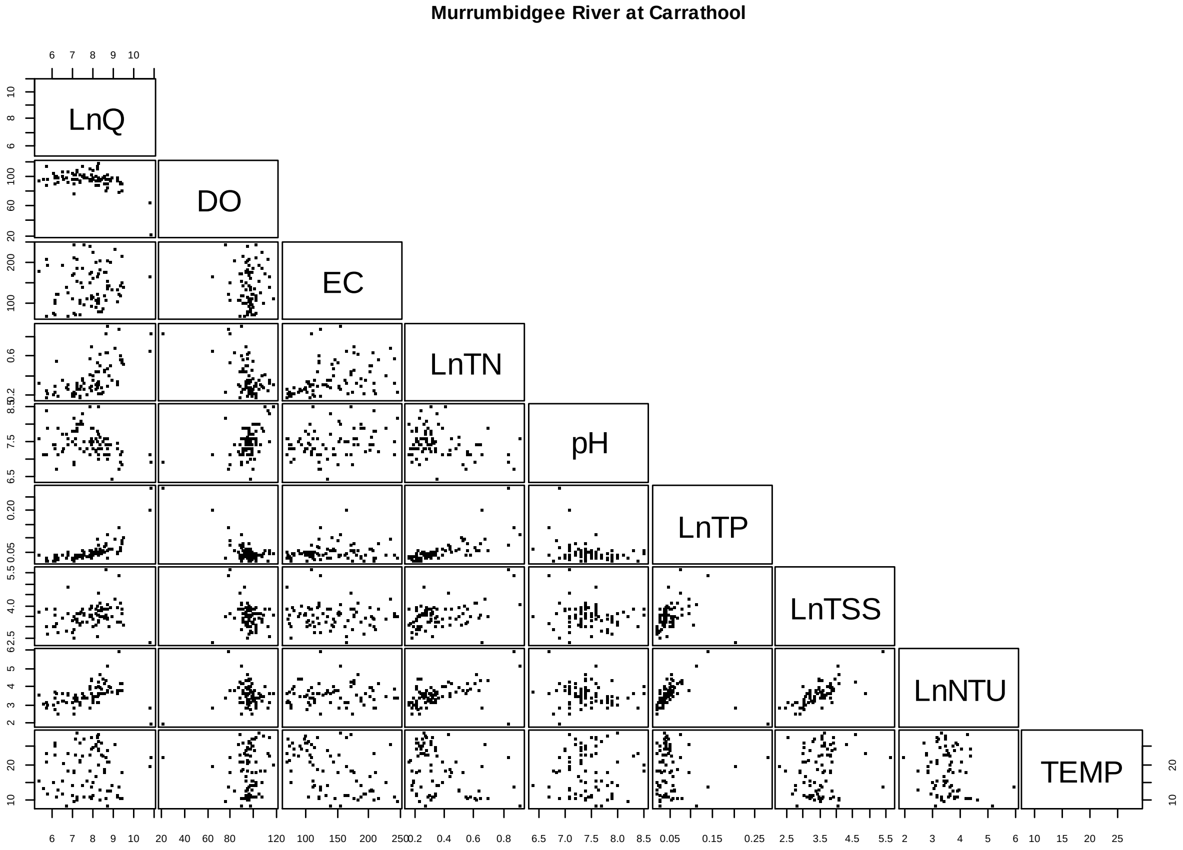


Figure 63: Draftsman plots for Murrumbidgee River at Carrathool

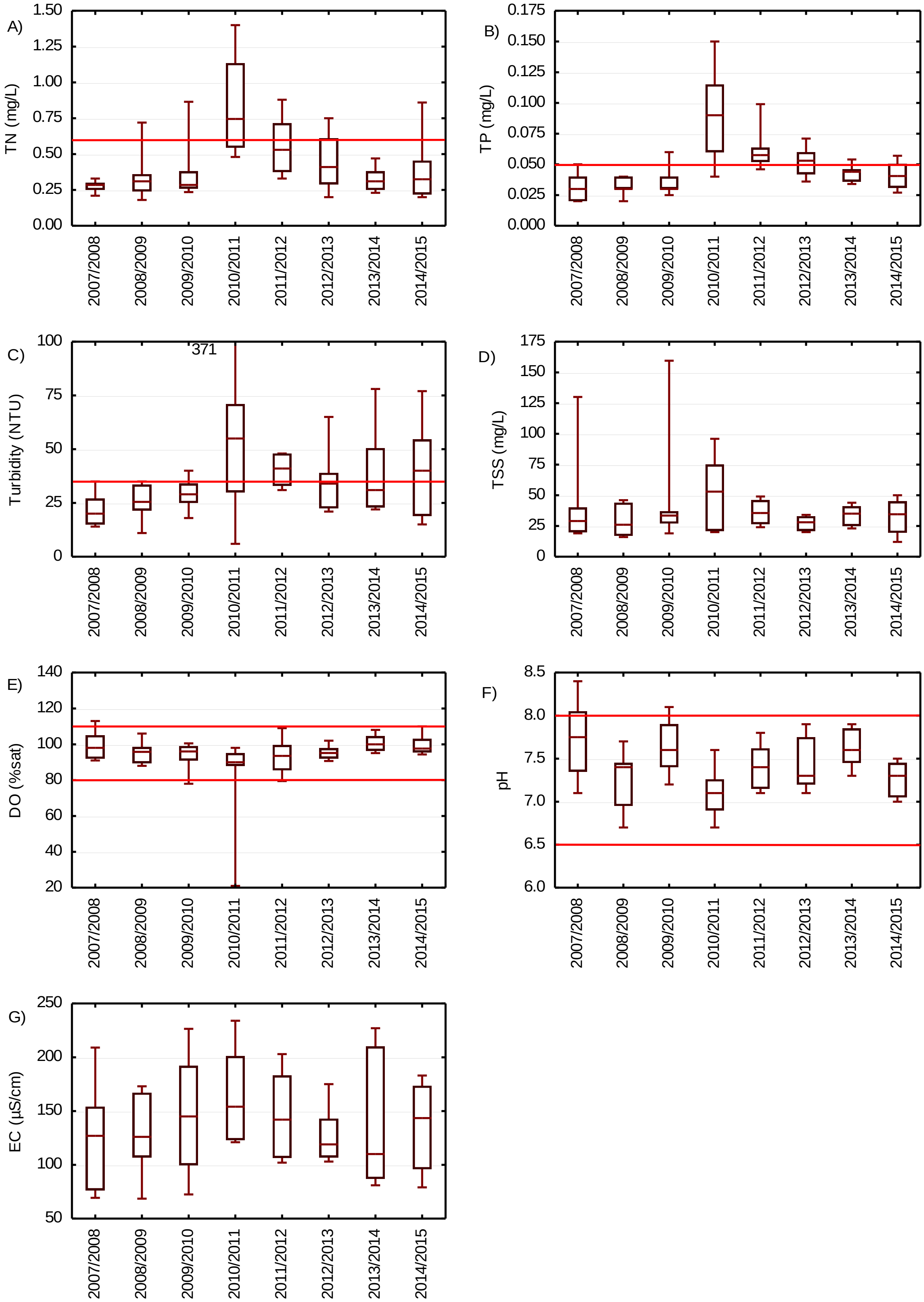


Figure 64: Water quality data for Murrumbidgee River at Carrathool

Murrumbidgee River downstream Hay Weir

The draftsman plots show positive correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. The dissolved oxygen levels are very stable and do not show correlation to any other attributes. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen and turbidity was below the Basin Plan targets for all years, except during the flooding in 2010/2011. The annual median total phosphorus exceeded the target two years. Dissolved oxygen was generally stable around 100% saturation apart from low results during flooding and one super saturated result in 2012/2013. The pH was mostly within the upper and lower limits. Electrical conductivity shows only minor fluctuations through time.

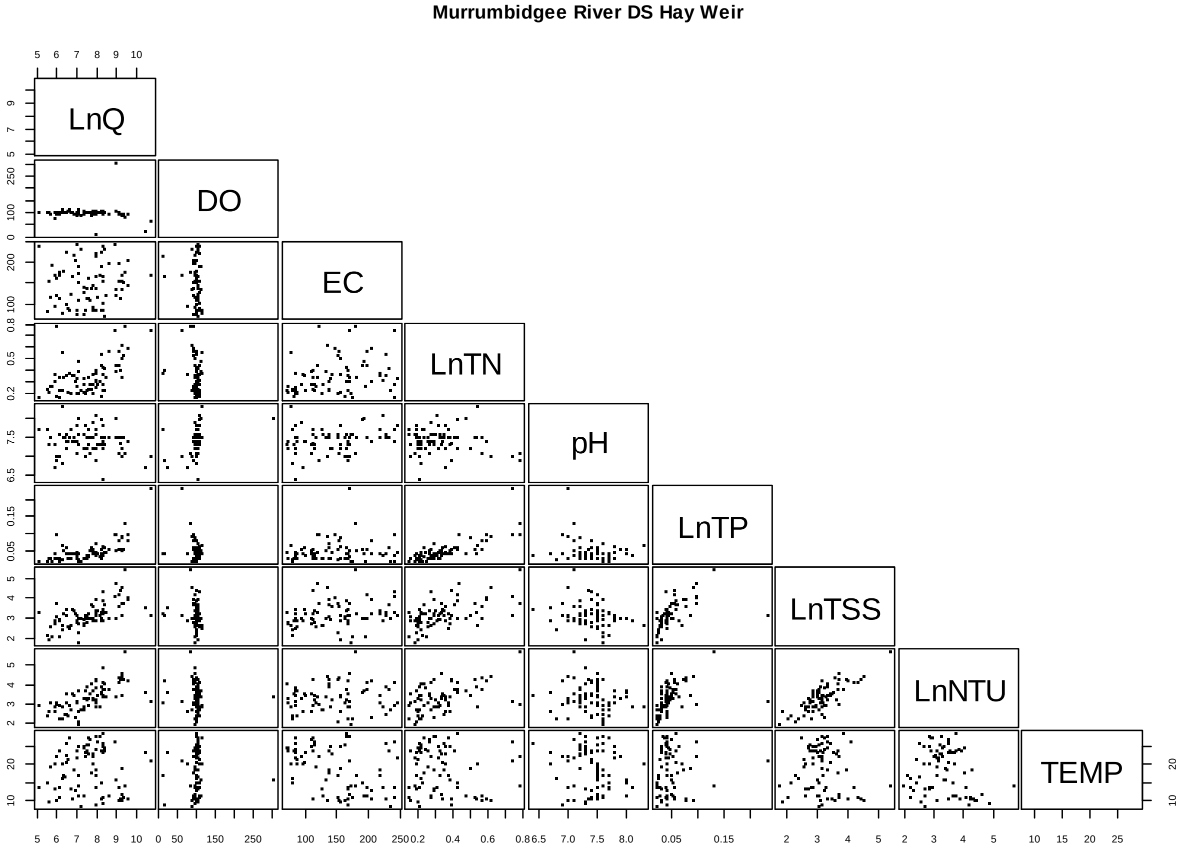


Figure 65: Draftsman plots for Murrumbidgee River downstream Hay Weir

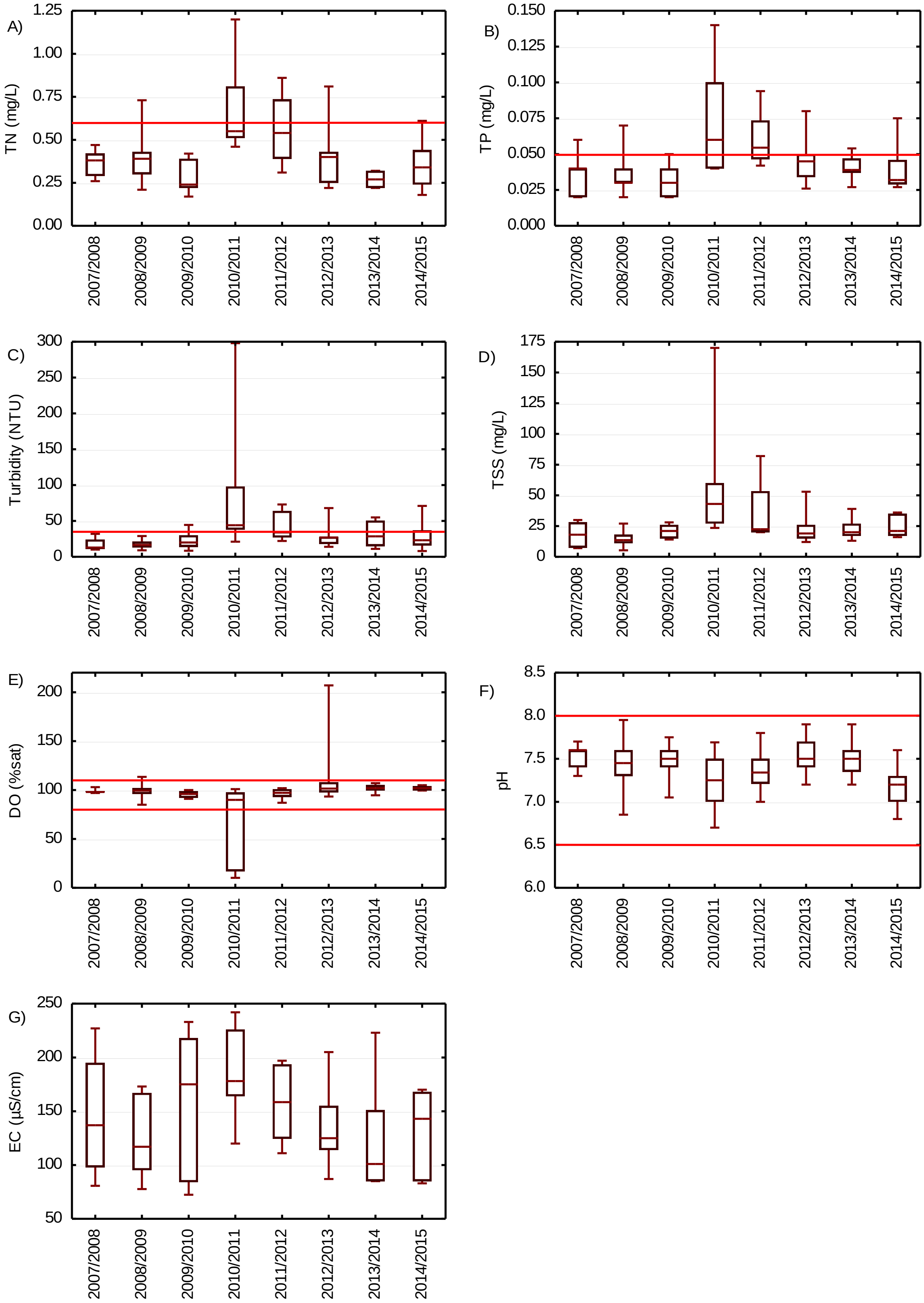


Figure 66: Water quality data for Murrumbidgee River downstream Hay Weir

Murrumbidgee River downstream Maude Weir

The draftsman plots show positive correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. The dissolved oxygen levels are very stable and do not show correlation to any other attributes. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen was below the Basin Plan targets for all years, except during the flooding in 2010/2011. The annual median total phosphorus and turbidity exceeded the target two years. Dissolved oxygen was generally stable around 90 to 100% saturation apart from low results during flooding. The pH was mostly within the upper and lower limits. Electrical conductivity shows only minor fluctuations through time.

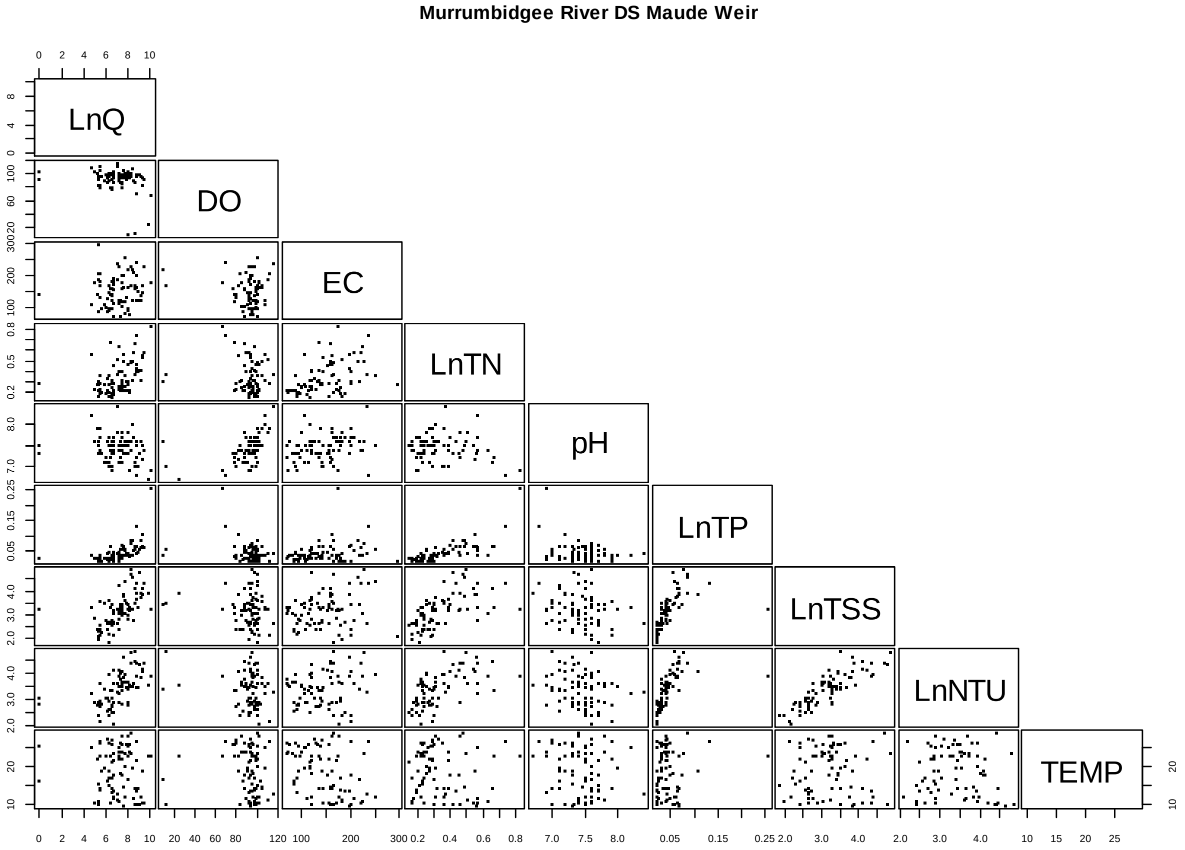


Figure 67: Draftsman plots for Murrumbidgee River downstream Maude Weir

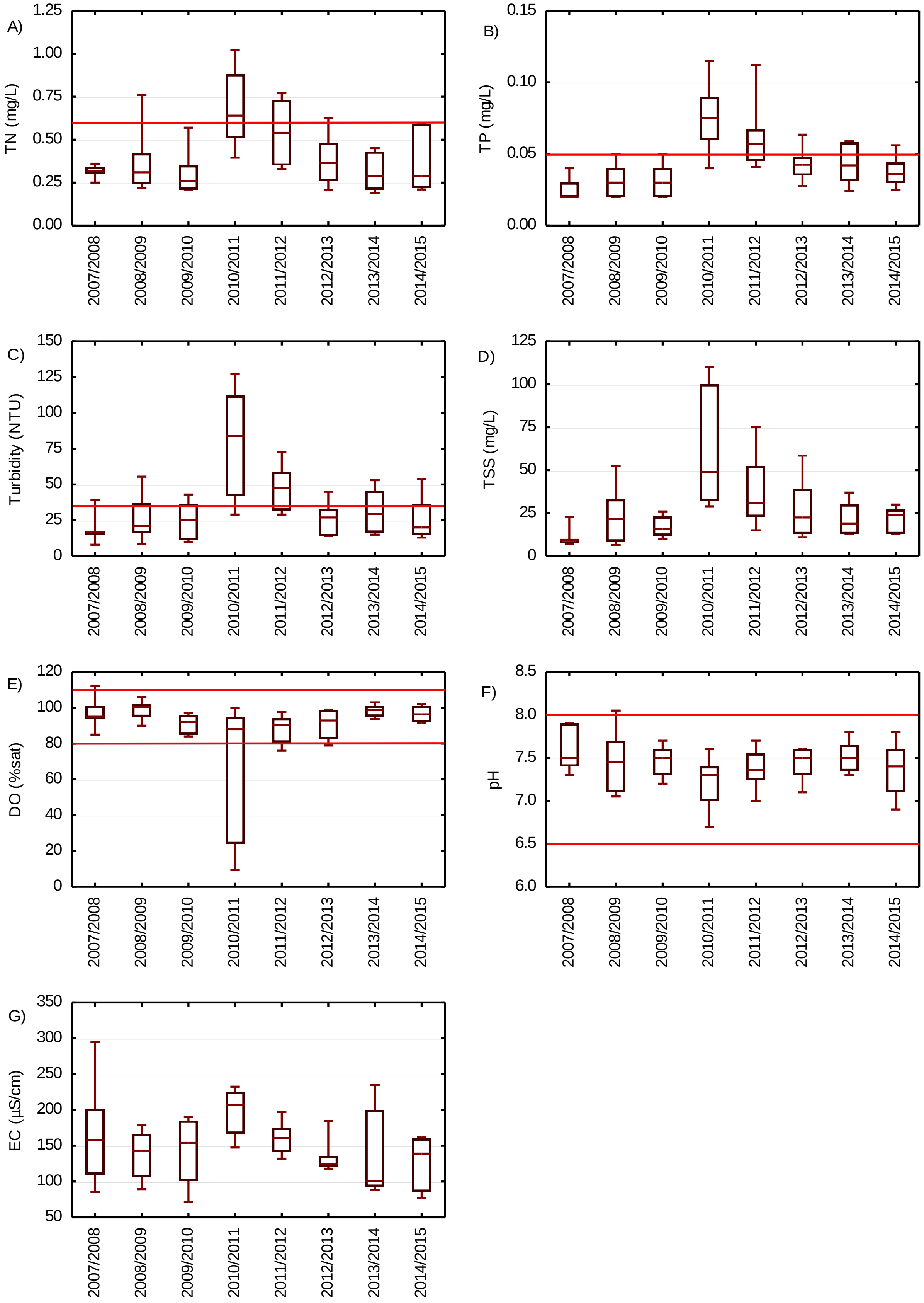


Figure 68: Water quality data for Murrumbidgee River downstream Maude Weir

Murrumbidgee River downstream Balranald Weir

The draftsman plots show positive correlations between total nitrogen, total phosphorus and turbidity, with all three parameters positively correlated to flow. The dissolved oxygen levels show a slight positive correlation to pH. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen was below the Basin Plan targets for all years, except during the flooding in 2010/2011. The annual median total phosphorus exceeded the target two years and turbidity in three years. Dissolved oxygen was less stable than the upstream sites on the Murrumbidgee River with low results during flooding and following years. The pH was mostly within the upper and lower limits. Electrical conductivity shows minor fluctuations through time.

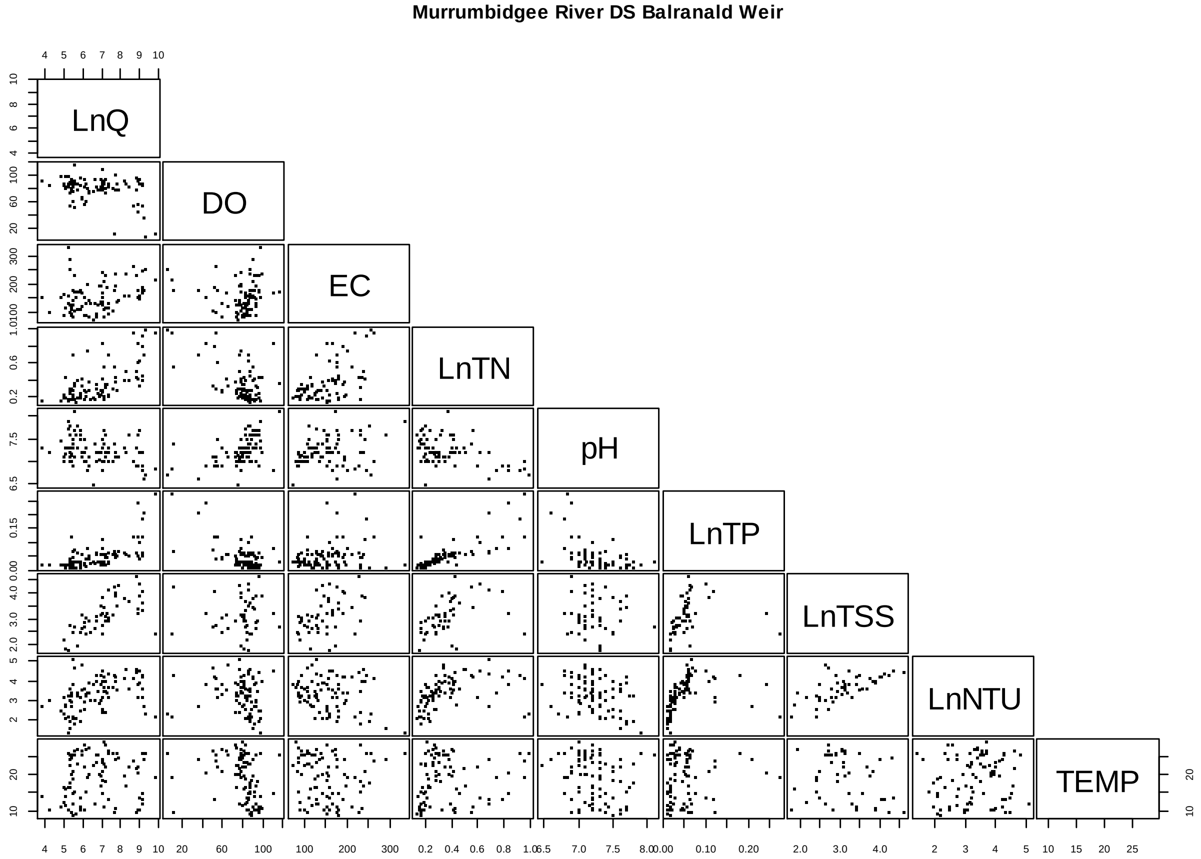


Figure 69: Draftsman plots for Murrumbidgee River downstream Balranald Weir

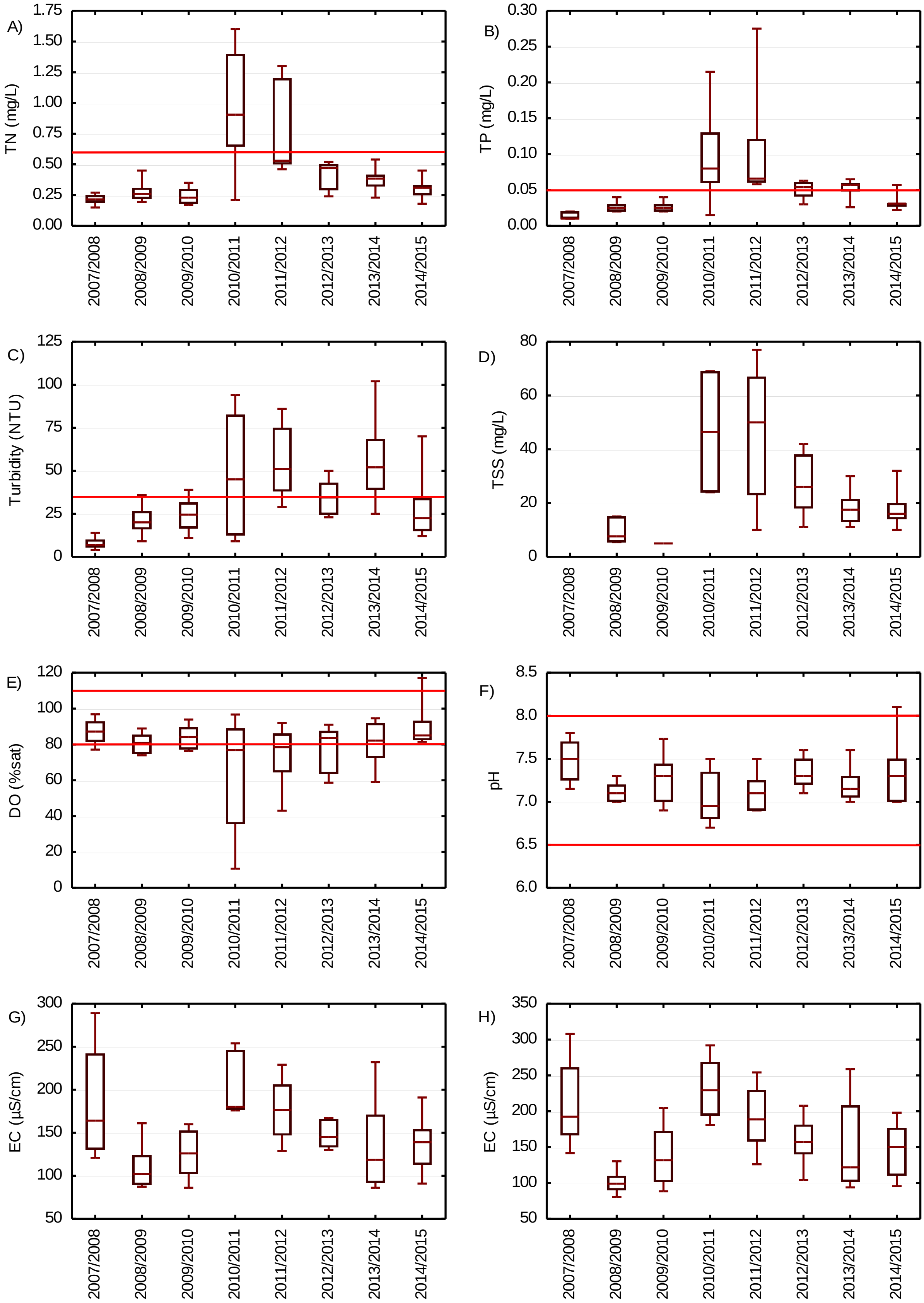


Figure 70: Water quality data for Murrumbidgee River downstream Balranald Weir

Murrumbidgee River at Waldaira

The draftsman plots show positive correlations between total nitrogen, total phosphorus and turbidity. Nitrogen and phosphorus show a correlation with flow but turbidity does not. Electrical conductivity does not show a correlation to flow.

The annual median total nitrogen was below the Basin Plan targets for all years, except during the flooding in 2010/2011 and the following year. The annual median total phosphorus and turbidity exceeded the target four years. Dissolved oxygen was generally stable around 90% saturation apart from low results during flooding The pH was within the upper and lower limits. Electrical conductivity shows minor fluctuations through time.

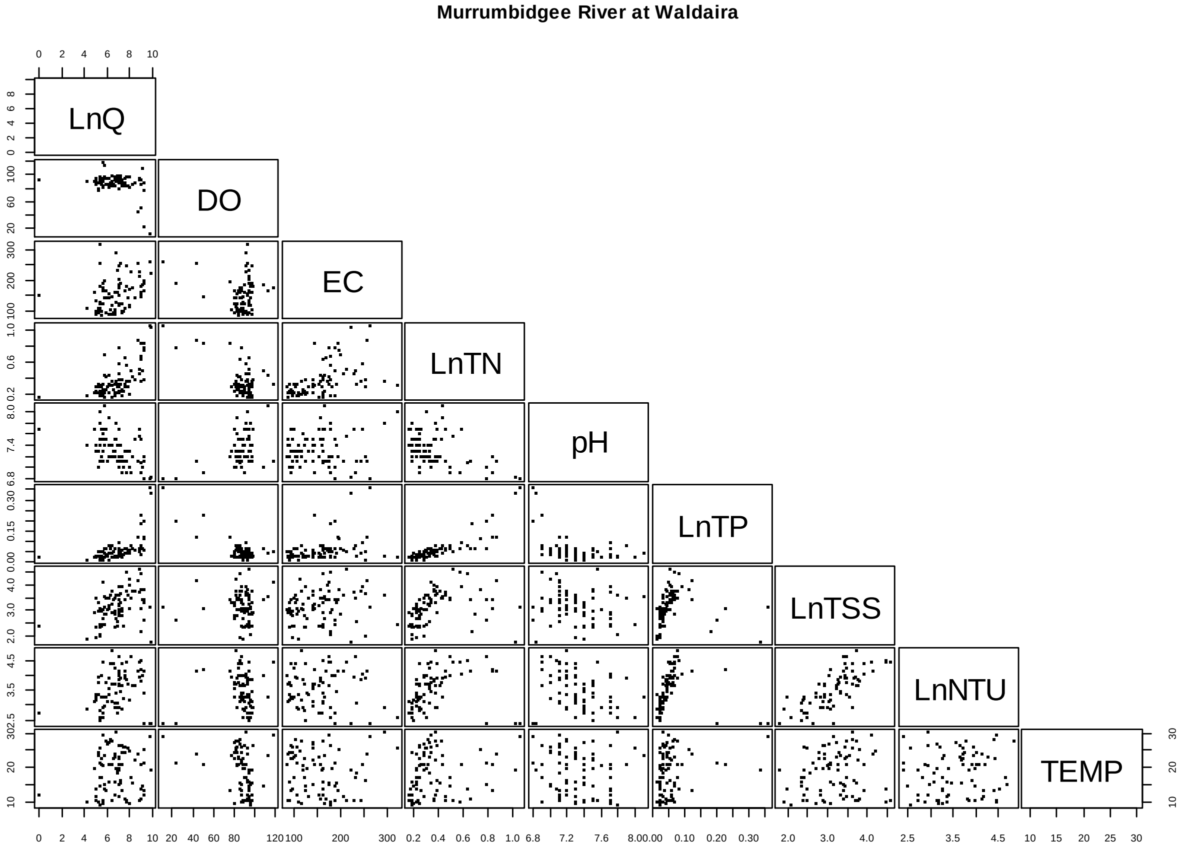


Figure 71: Draftsman plots for Murrumbidgee River at Waldaira

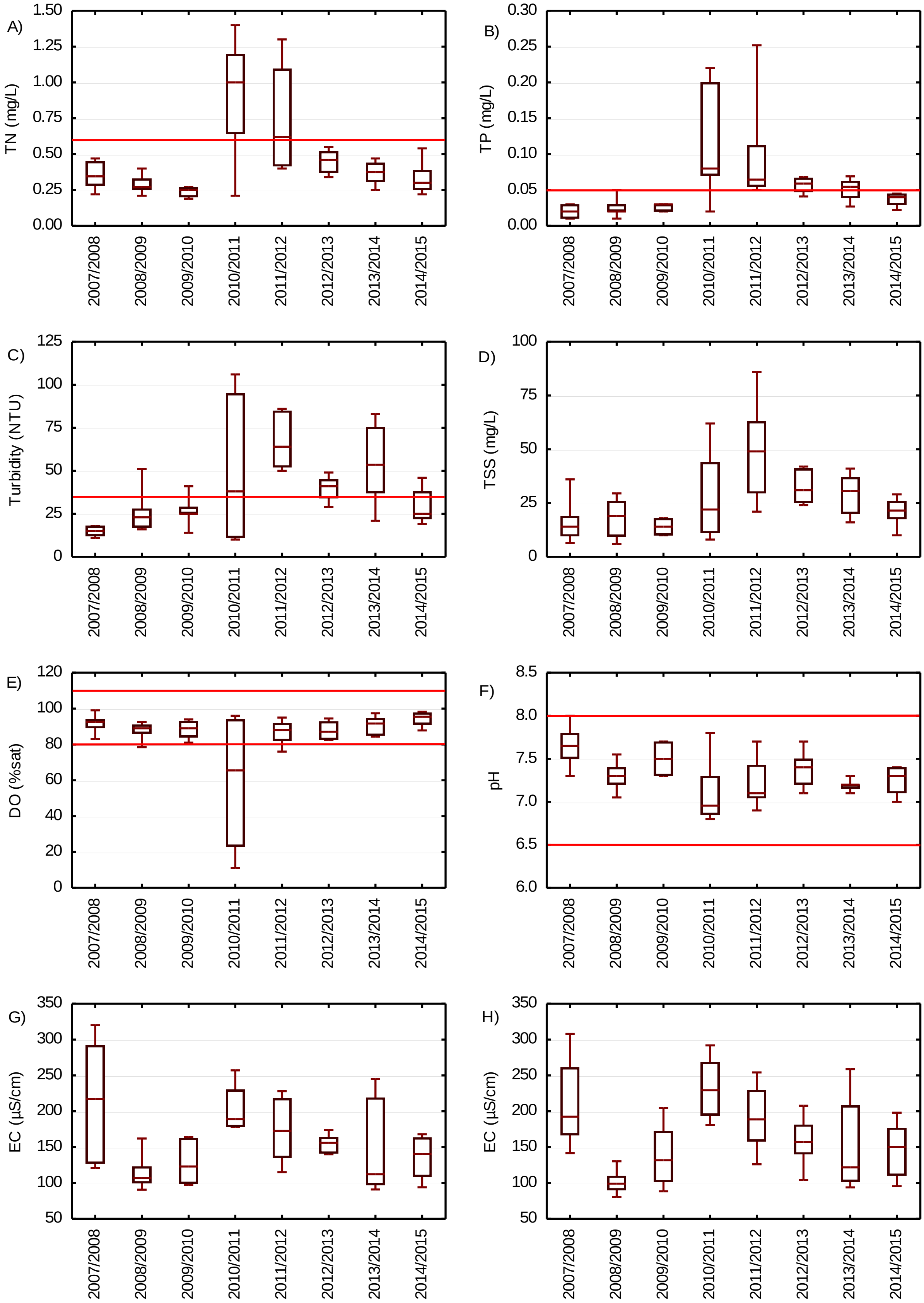


Figure 72: Water quality data for Murrumbidgee River at Waldaria