Our Werribee River

A Water Quality Analysis Report

Werribee River Association

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Contents

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Acknowledgement of Country

The Werribee River Association respectfully acknowledges the original custodians of what is now known as the Werribee catchment; their rich culture, deep affinity with the land, the rivers and the sea and their spiritual connection to it.

Contributions

The data used in the report has been sourced from a variety of sources. The Werribee River Association acknowledges the assistance of: Volunteers from the Werribee River Association and Sarah Gaskill, Bridie Velik-Lord, Richard Akers and Yvonne Cabuang from Melbourne Water.

Executive Summary

River systems provide water for drinking and washing, for agricultural and industrial purposes, recreation and aesthetic pleasure and to support and maintain fisheries and other food sources. However, once a river becomes unhealthy it is no longer able to support and maintain key ecological processes. To determine the ecological health of a river system, a river health assessment is undertaken. These findings can then be used to determine rivers that are in poor health or at risk of poor health. This can help prioritise funding for river restoration and guide effective management actions.

River health is assessed using various physical, chemical, biological, social and economic variables to determine condition and provide a complete overview of the health of the system. Water quality is a key part of river health assessments as it responds to both natural processes and human disturbance. Physical properties include recording temperature and turbidity, while chemical characteristics include collecting pH dissolved oxygen levels, nitrogen and phosphorus. Biological indicators comprise of sampling for algae, phytoplankton and aquatic invertebrates.

Since European colonisation, water quality of many rivers in Australia have been impacted by urbanisation, intensive agriculture and water extraction. The Werribee River catchment has declined in water quality due to impacts from these human activities. This report has been requested by the Werribee River Association and aims to analyse water quality from the Werribee River catchment to determine if certain parameters are negatively affecting the health of the catchment.

The Werribee River catchment is located approximately 40 km south-east of Melbourne. The Werribee River originates in the central highlands of the Wombat State Forest, running 110 km before discharging to Port Phillip Bay. The majority of the catchment is used for agricultural purposes. However, the area is becoming rapidly urbanised. Despite this, the catchment still maintains several significant wetlands including internationally listed Ramsar sites. The Werribee River catchment provides an important habitat for flora and fauna including regionally and nationally significant species and a number of endangered Ecological Vegetation Classes (ECV's).

The Werribee River catchment is highly regulated with diversions to provide water for the major irrigation districts at Bacchus Marsh and Werribee. This has caused flows to be higher in the summer and lower in the winter. This has resulted in the river being highly flow stressed (reduced water flow). To improve river health, the system receives environmental flows which are delivered through a collaboration between Melbourne Water, Southern Rural Water, Western Water and the Environmental Water Holder.

The report analysed data from seven sampling points in the Werribee River catchment to provide an overview of current and long-term water quality. Data was obtained from the Water Measurement Information System, Melbourne Water and the Werribee River Association.

Parameters analysed were:

- Electrical conductivity - which measures the capacity of water to carry an electrical current and is related to the concentration of salts dissolved in water, providing a measure of salinity
- Turbidity – which is the measure of relative clarity or cloudiness of water. High levels of turbidity indicate elevated levels of suspended solids. This can affect processes such as photosynthesis which depend on light
- pH - is a measure of the acidity of the water with lower numbers more acidic and higher numbers more alkaline. A pH value of 7 is considered to be 'neutral'
- Dissolved oxygen (DO) - measures amount of oxygen in the water. DO is needed for fish, invertebrates, bacteria and plants. DO varies over a day. Low DO can cause the release of nutrients and toxicants

- Nitrogen and phosphorus – elevated levels can lead to eutrophication, which is the excessive growth of aquatic plants including phytoplankton, cyanobacteria and macrophytes such as *Azolla*. This can result in toxic blooms and a reduction in oxygen when plants die and decompose

Water quality was compared to the Victorian State Environment Protection Policy Guidelines (SEPP) and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) where no SEPP values were available.

- Electrical conductivity exceeded the SEPP objective at all sites except Lerderderg River
- SEPP objectives for turbidity were exceeded at Bacchus Marsh, Toolern Creek, Cobbledick's Ford and Wyndham Vale
- pH was within both SEPP and ANZECC guidelines at all sites except Parwan Creek and Bungey's Hole
- Dissolved oxygen was above the ANZECC minimum trigger value at all sites except Toolern Creek
- Total nitrogen exceeded both SEPP and ANZECC water quality objectives at all sites except Lerderderg River
- Nitrate/nitrite exceeded ANZECC trigger values at Lerderderg River, Bacchus Marsh, Toolern Creek and Cobbledick's Ford
- Ammonium data was only available for Bungey's Hole and was equal to the ANZECC trigger value
- Total phosphorus exceeded SEPP objectives at Parwan Creek, Toolern Creek, Cobbledick's Ford and Wyndham Vale
- Filtered reactive phosphorus was equal to the ANZECC guidelines at Bungey's Hole but was lower than the ANZECC trigger value at the remaining sites

Water quality was highest in the Lerderderg River. Located in the heavily forested Wombat State Park, the river has been less impacted by human activities above Graham's Flat. The lower Lerderderg and the upper, middle and lower parts of the Werribee River have been impacted by agriculture, tree clearing, urbanisation and water extraction. This has affected water quality with sediments and nutrients entering the river degrading the waterway and its surrounds.

The highest values for conductivity in the Werribee River catchment appeared to correspond with the millennium drought. A lack of rainfall caused low river flows resulting in higher concentrations of salts. Extraction of water for agricultural and domestic purposes, which reduces high flows and increased the likelihood of saline groundwater intrusion causing increased salinity. Runoff from industries, fertilisers and poor irrigation practices also result in higher salinity. Elevated levels can inhibit or be toxic to seed germination of most freshwater plants and can reduce the survival of fish eggs. Based on the findings of the Werribee River catchment, additional examination is required to determine what the effect high levels of electrical conductivity are having on aquatic biota.

Turbidity was highest at sites in the middle and lower reaches of the Werribee River catchment. Disturbances such as agriculture, urban development and road construction means the catchment receives a greater amount of sediment than under natural conditions. Suspended solids can directly kill fish by blocking or damaging gills, prevent successful development of fish eggs and larvae as well as modifying the natural movements and migrations of fish.

Similarly to conductivity and turbidity, the majority of sites in the Werribee River catchment exceeded SEPP objectives for total nitrogen and total phosphorus, except for Lerderderg River. Elevated levels of total nitrogen have been seen in a previous study at relatively pristine parts of the catchment, which suggests levels may be naturally high in some areas. The levels of nitrogen in the catchment are a concern with eutrophication now happening frequently. Likely sources include leaky septic tanks, the use of animal manure and inorganic nitrogen fertiliser. High concentrations of nitrogen and phosphorus can cause eutrophication, which is the excessive growth of aquatic plants. This can block light reducing photosynthesis, reduce oxygen when plants die and decompose and block waterways. The decline in dissolved oxygen can lead to extensive kills of both invertebrates and fish. Algal blooms can also be toxic to aquatic and terrestrial animals. Therefore, elevated levels of nutrients ultimately contribute to the degradation of freshwater.

Although water quality has been traditionally used to measure river health, research suggests suites of complementary variables are required to provide an accurate picture of river health. Measurement of aquatic biota to identify river health has been widely acknowledged. To gain an understanding of water quality on the health of biota in the Werribee River catchment, it is recommended macroinvertebrate sampling be conducted bi-annually following the protocol of Melbourne Water Waterwatch.

Due to the high levels of nutrients recorded in the Werribee River catchment, it is also recommended additional nutrient sampling be conducted at Bungey's Hole. This would enable the results to be placed, in context to other catchment sites, where sampling for nitrogen and phosphorus occurs. As the Werribee River Association is only able to conduct sampling in the field, additional testing should include nitrate and nitrite, which can be easily measured *in-situ*.

1 Introduction

The river system is important for human life and the functioning of society where it provides a number of goods and services including clean water for drinking and washing, water for agricultural and industrial purposes, benefits for the community by enhancing liveability and providing public open space, buffers against flooding and the capacity to support and maintain fisheries and other food sources. Once these rivers become unhealthy, they lose their ability to provide their true value (Boulton et al., 1999; Brismar, 2002; Bond et al., 2012).

1.1 River health

A healthy river (river health) is one that can support and maintain key ecological processes. It depends on its ability to (Bond et al., 2012):

- Maintain its structure and function
- Recover from disturbance
- Support local biota, human communities,
- Maintain key processes such as sediment transport, nutrient cycling, assimilation of waste products and energy exchange.

1.2 River health assessment

Maintaining and improving river health requires an accurate assessment of the current ecological state of river ecosystems (Bond et al. 2012). River health is often measured using indicators of environmental disturbance relative to benchmarks or reference condition. This provides information on its ecological state and function. Ideally, monitoring and assessment aims to (Bond et al., 2012):

- Identify rivers that are in poor health, or at risk of poor health
- Identify likely causes of poor health, e.g. sources of pollution
- Help prioritise funding for river restoration to guide effective and efficient management actions
- Assess the effectiveness of management actions, particularly when publicly funded
- Allow for reporting on river health, to support condition awareness for the managers and the public

River health monitoring can involve the assessment of physical, chemical, biological, social and economic variables (Norris and Thoms, 1999). This may include determining:

- Water and sediment quality
- Condition of aquatic flora and fauna
- Rate of stream flow
- Levels of catchment disturbance

It is important to measure these parameters in one assessment to provide a complete view of the river condition (Norris and Thoms, 1999).

1.3 Water quality

Water quality is a key attribute of aquatic ecosystems and is an important part of any river health assessment, responding to both natural processes and human disturbance. Physical, chemical and biological factors can be used to determine water quality. Physical properties include recording temperature and turbidity; chemical characteristics incorporate collecting pH, dissolved oxygen levels, nitrogen and phosphorus, whilst biological indicators comprise of sampling for algae, phytoplankton and aquatic invertebrates (Bond et al., 2012).

Significant deviation of these parameters from recommended levels can cause ecosystem degradation and may impact on the ability of a river to support and maintain ecological processes and a diverse biological community (Boulton et al., 1999; EPA, 2003). For example, where water quality is poor, the abundance and diversity of aquatic invertebrates is reduced and there is a loss of sensitive species. This affects overall ecological diversity as aquatic invertebrates are an important food source for fish and birds (Beasley and Kneale, 2002). Furthermore, in severe cases of toxic pollution or low oxygen, fish kills can occur (Chapman, 1992). The monitoring of rivers allows water resource managers to determine any decline in water quality and develop strategies for improvement including fencing off vegetated zones around waterways from stock, minimal use of chemicals and installing infrastructure for treating stormwater.

Since European colonisation, the water quality of many rivers in Australia have been impacted by activities including urbanisation, intensive agriculture and industrialisation (Morley and Karr 2002). The Werribee River catchment is typical of one of the many river systems in Australia impacted, which has led to its decline. The conditions for the river vary from '*very good*' in the upper and less developed reaches, through to '*moderate*' to '*very poor*' in the lower and highly developed reaches (Melbourne Water, 2015).

1.4 Report objectives and scope of study

The Werribee River is an urban river with a range of values, both recreational and environmental, and is the focus of this report on request of the Werribee River Association.

The report aims to analyse the water quality data from the Werribee River catchment and determine if river health is negatively affected. To determine this, data has compiled from Melbourne Water, Water Warehouse and Werribee River Association and compared against both state (State Environment Protection Policy) and national (Australian and New Zealand Environment and Conservation Council) water quality objectives (see section 3.4 for further details).

2 Werribee River

2.1 Location

The Werribee River is located approximately 40 km south-west of Melbourne and drains the southern slopes of the Great Dividing Range (Melbourne Water, 2015). It originates in the central highlands of the Wombat Forest and Blackwood Range, north of Ballan and flows for approximately 110 km in a south-east direction until it discharges into Port Phillip Bay (Sherwood et al., 2005; James & Pritchard, 2008) (Figure 2-1). It covers an area of 1424 km^2, with rainfall varying from ~1,000mm per year in the headwaters to ~450 mm per year in the downstream reaches (Jacobs, 2014).

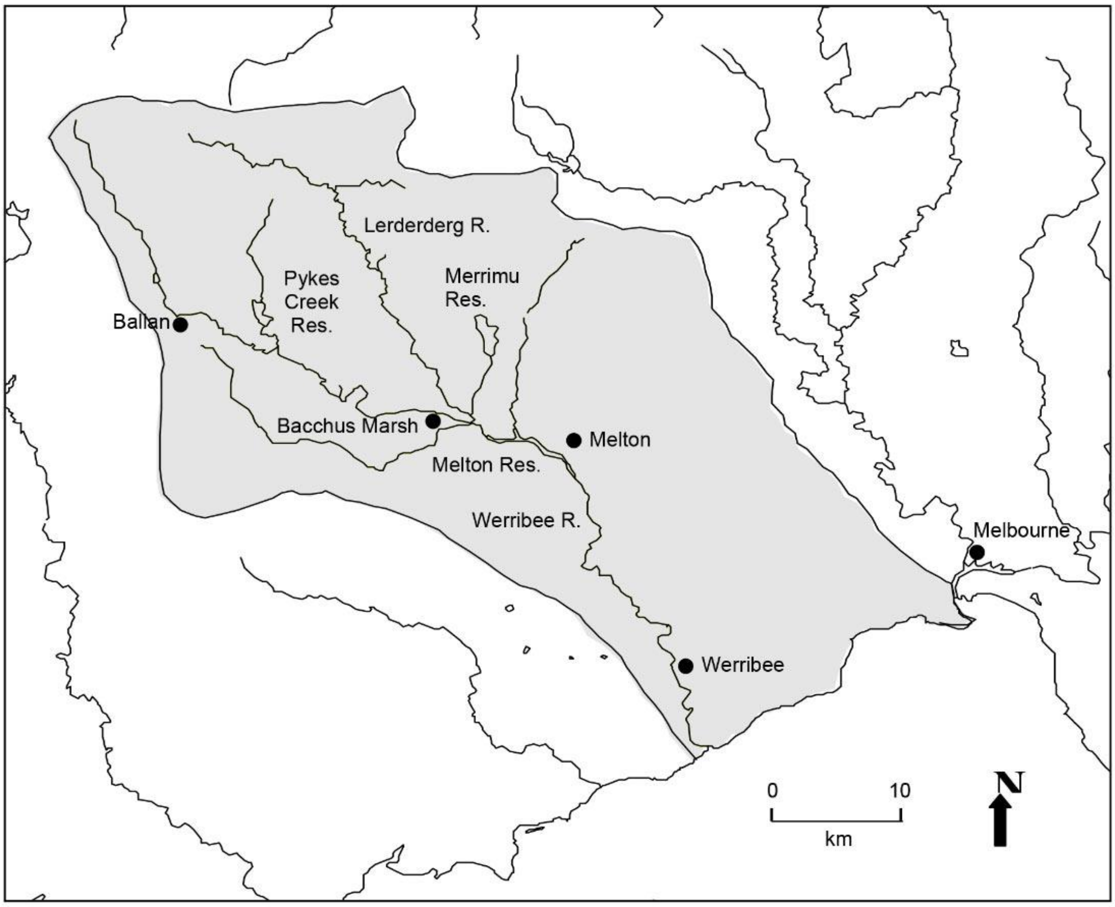

Figure 2-1. Werribee River catchment (adapted from Sherwood et al., 2005).]

2.2 Catchment attributes

Around 25% of the catchment retains its natural vegetation, with 67% used for agricultural purposes, particularly dry land grazing and 5% has been urbanised (EPA, 2009). However, urbanisation in the catchment is increasing due to the rapidly developing urban corridor from Melton to Wyndham, in the western fringes of Melbourne (SEC, 2016). Prior to European colonisation, lowland native grasslands dominated the region, but now only fragments remain (EPA, 2009).

The Werribee catchment contains several significant wetlands, including internationally-listed Ramsar sites at Melbourne Water's Western Treatment Plant, Spit Wildlife Reserve, Heathdale Glen Orden Wetlands, Cheetham Wetlands, Point Cooke Coastal Park and Truganina Swamp. These wetlands contain a number of regionally and nationally important plant and animal species, which are also popular destinations for bird watchers (EPA, 2009).

The Werribee River estuary is 8.25 km long, with an upstream limit defined by a ford located 3.5 km downstream of central Werribee. Adjacent to the estuary is the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar sites (Lloyd et al., 2008).

2.3 Hydrophysical characteristics

The Werribee River provides water for major irrigation districts at Bacchus Marsh and Werribee for several urban and rural centres (Melbourne Water, 2005). To supply these demands, the catchment is highly regulated with diversions for irrigation at Pykes Creek, Merrimu Reservoir, Melton Reservoir and at the Lower Werribee Diversion Weir. Flows are significantly decreased over the winter-spring period as water is harvested and stored. During the irrigation period over summer, they are increased as water is released from storages to supply irrigators (Melbourne Water, 2015). This has resulted in the river being highly flow stressed (reduced water flow) with estimates that as little as 10 – 15% of flow reaches the sea (J. Forrester, personal communication).

The Millennium Drought, which extended from 1997 to 2009, significantly impacted the ecological values of the Werribee River. Although catchment inflows have been closer to the long-term average in recent years, the system is still recovering (Jacobs, 2014). To improve the health of the Werribee River, the system receives additional water through environmental flows to support ecological processes. These are delivered through a collaboration between Melbourne Water, Southern Rural Water, Western Water and the Environmental Water Holder.

Box 1. Environmental flows can be used in regulated river systems to support their ecological processes by mimicking the natural flow conditions of the river. High flows provide triggers for fish breeding and supply water for fish passage, to enable movement to upstream and downstream habitat. Low flows in summer maintain fish refuges and connect habitats. Spring floods regenerate wetlands and floodplains and replenish the river channel (Environment Victoria, 2018).

2.4 Cultural heritage in the Werribee River catchment

2.4.1 Aboriginal heritage

Prior to European colonisation, a single bloc of Aboriginal people consisting of five language groups were the traditional custodians of the entire Port Phillip region as far north as Euroa (Ecology Partners, 2011). These groups were said to form a confederacy or nation, called Kulin (Ecology Partners, 2011). The people from the eastern Kulin alliance have lived in the Werribee catchment for at least 30,000 years. At the time of European arrival, the Werribee River lay between the traditional lands of three of the Kulin nation language groups; the Wathaurong, Woiwurrung and Boonwurrung. The high density of archaeological material including fish traps, artefacts and burial sites along their banks and escarpments demonstrate that Kororoit Creek and Werribee River had large campsites.

2.4.2 European heritage

European colonisation began in the region during the mid-1830s, with plains and foothills being occupied by squatters from 1840 (EPA, 2009). In the 1890s, farmers from the Ballarat area began to move into the district, establishing dairying and agriculture. Production of vegetables commenced when an irrigation scheme was established around 1910. A state research farm was established in 1912 and ex-servicemen were granted land in the area after World War 1 (Melbourne Water 2009). Aviation instruction began at Point Cook in 1913, where the Royal Australian Airforce established its first base in 1921 (EPA, 2009).

2.5 Biodiversity values

Although there has been a loss of native freshwater fish species in the system, the Werribee River catchment still provides an important habitat for native flora and fauna, including nationally significant species. The upper reaches provide habitat for native fish such as the River Blackfish and Mountain Galaxias. Lower reaches in and around Werribee, are home to regionally significant platypus populations. Estuarine and lower freshwater reaches support a healthy recreational fishery, including Estuary Perch, Black Bream and King George Whiting. Other key species in the catchment include the Growling Grass Frog, Striped Legless Lizard and Golden Sun Moth (Ecology & Heritage Partners, 2011). A number of Ecological Vegetation Classes are considered endangered in the region, including Coastal Saltmarsh (EVC 09), Estuarine Wetland (EVC 010), Seagrass Meadow (EVC 845), and Floodplain Riparian Woodland (EVC 056) (Melbourne Water, 2015).

3 Methods

3.1 Water quality data sources

Data from seven sampling sites were analysed, providing an overview of current and long-term water quality in the Werribee River catchment (Figure 3-1). Water quality monitoring in the Werribee River catchment is conducted by a variety of agencies and data was obtained from three key sources, described below.

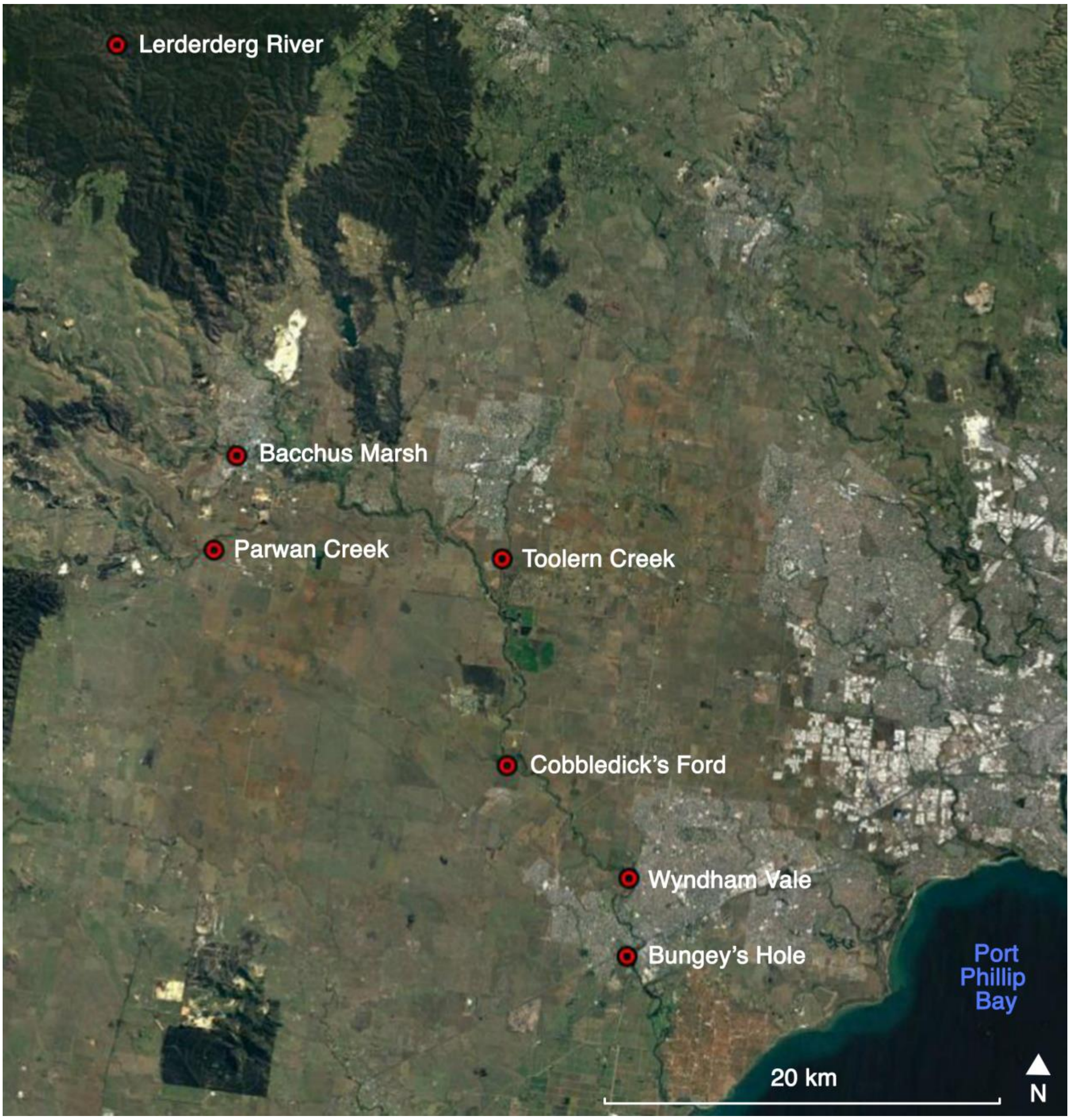

Figure 3-1. Analysed water quality measuring sites located within the Werribee River catchment (Google Earth, 2018).

3.1.1 Water Measurement Information System (WMIS)

Online data published by the Department of the Environment, Land, Water and Planning (DELWP), which monitors and reports on the health and availability of Victoria's water resources through a number of programs and partnerships. WMIS is the primary access point to discover, access and download surface and groundwater monitoring data in Victoria.

3.1.2 Melbourne Water

Water quality data supplied by Melbourne Water and collected as part of their river health and monitoring program. The aim of the program is to monitor rivers and creeks to determine if there are any changes in condition, or whether waterway improvement programs need adjusting.

3.1.3 Werribee River Association (WRivA)

Data collected by volunteers from the WRivA as part of Melbourne Water Waterwatch, a successful community engagement program where citizen scientists are supported and encouraged to become actively involved in local waterway monitoring. Quality Assurance and Quality Control guidelines have been developed by Melbourne Water Waterwatch to ensure confidence in collected data.

3.2 Data selection and availability

The three datasets (see 3.1, further described below) varied in location, parameters, timeframe and frequency of sampling.

3.2.1 Water Measurement Information System (WMIS)

Sites in the Werribee River catchment were identified through the map search feature and data downloaded. Only data from active sites with current water quality data were used. A summary of available data is shown in Downloaded and analysed data from the Victorian Water Management Information System (WMIS).

Table 3-1. Downloaded and analysed data from the Victorian Water Management Information System (WMIS).

Site Number	Site Name	Date range and frequency of monitoring	Parameters
231213	Lerderderg River at Sardine Creek O'brien Crossing	1990 - 2017, monthly. Approximately 330 data points	pH, dissolved oxygen, temperature, turbidity, electrical conductivity, colour, total suspended solids, NO2+NO3, Kjeldahl N, Total phosphorous, FRP
231200	Werribee River at Bacchus Marsh	2005 - 2017, monthly. Approximately 160 data points	pH, dissolved oxygen, temperature, turbidity, electrical conductivity, colour, total suspended solids, NO2+NO3, Kjeldahl N, Total phosphorous, FRP
231234	Parwan Creek at Parwan	1994 - 2017, monthly. Approximately 186 data points	dissolved oxygen, temperature, turbidity, colour, total suspended solids, NO2+NO3, Kjeldahl N, Total phosphorous, FRP
231231	Toolern Creek at Melton South	1990 - 2017, monthly. Approximately 330 data points	dissolved oxygen, temperature, turbidity, colour, total suspended solids, NO2+NO3, Kjeldahl N, Total phosphorous, FRP
231208	Werribee River at Cobbledick's Ford	2005 - 2017, monthly. Approximately 160 data points	pH, dissolved oxygen, temperature, turbidity, electrical conductivity, colour, total suspended solids, NO2+NO3, Kjeldahl N, Total phosphorous, FRP

3.2.2 Melbourne Water monitoring data

Water quality data was supplied from Melbourne Water as part of their river health and monitoring program. On the Werribee River at Riverbend Historical Park, Wyndham Vale, regular monitoring has been completed for Arsenic (As), Cadmium (Cd), Chromium (Cr), Zinc (Zn), water temperature, pH, turbidity, dissolved oxygen (DO), electrical conductivity (EC), total nitrogen (TN), nitrate/nitrite (NOx), total phosphorus (TP), filtered reactive phosphorus (FRP). Parameters have been monitored from 2007 (TN from 2015 only) and monitoring was conducted monthly, unless stated otherwise.

3.2.3 Werribee River Association (WRivA) – Melbourne Water Waterwatch

Water quality data from the Werribee River at Bungey's Hole, Chirnside Park, was supplied from WRivA as part of the Melbourne Water Waterwatch Monitoring Program. Monitoring was conducted monthly from 2008 – 2010, and 2014 – ongoing for air temperature, water temperature, turbidity, pH, EC, DO, ammonium (NH_3), reactive phosphorus.

3.3 Analysed water quality parameters

3.3.1 Electrical conductivity

Electrical conductivity (EC) measures the capacity of water to carry an electrical current. Conductivity is directly related to the concentration of salts dissolved in water and provides a measure of salinity in a system. Salt can enter river systems from natural processes such as the weathering of rocks, rainfall and groundwater rainfall and groundwater. However, human disturbance has increased the movement of salts into rivers. Small amounts of dissolved salts in natural waters are vital for the life of aquatic plants and animals. Exposures to levels outside their optimised range will have negative consequences. Salinity also affects water chemistry and water density, making electrical conductivity a useful indicator of overall water quality.

3.3.2 Turbidity

Measured in Nephelometric Turbidity Units (NTU), turbidity is the measure of the relative clarity or cloudiness of water. Turbidity is an important indicator of water quality as high levels can indicate an elevation of suspended solids. This can affect the amount of light that is able to penetrate through water, limiting ecological processes such as photosynthesis and reducing dissolved oxygen levels, which can be harmful to aquatic life. Material that cause water to be turbid includes clay, silt, finely divided inorganic and organic matter, algae and plankton.

3.3.3 pH

The measure of acidity in the water is known as pH and is reported as a number between 0 and 14. A value of 7 is considered ‘neutral’ with lower numbers more acidic, and, higher numbers more alkaline. The normal range for pH in surface water is 6.5 to 8.5 where values outside this range can be detrimental to aquatic organisms. Changes in pH can also affect critical water chemistry processes. For example, low pH levels can increase the solubility and toxicity of chemicals and heavy metals in the water, making them more available for uptake by plants and animals. High pH levels can damage gills and skin of aquatic organisms and cause death in levels over 10. Higher pH also increases the toxicity of ammonia.

3.3.4 Dissolved oxygen (DO)

Dissolved oxygen (DO) measures the amount of oxygen dissolved in the water. Dissolved oxygen in rivers is necessary for fish, invertebrates, bacteria and plants. For example, fish obtain oxygen for respiration through their gills, while plants and phytoplankton use DO for respiration when there is no light for photosynthesis. Dissolved oxygen varies naturally over a diurnal (day) period. Low DO can cause the release of nutrients and toxicants from sediments into the water column.

3.3.5 Nitrogen and phosphorus

In aquatic ecosystems, nitrogen and phosphorus are essential to the growth and survival of living organisms. However, high concentrations can lead to eutrophication, which is the excessive growth of aquatic plants including phytoplankton, cyanobacteria (‘blue-green algae’) and macrophytes such as *Azolla*. This can cause toxic effects on biota from some cyanobacteria, a reduction in dissolved oxygen concentrations when plants die and decompose and clogging of waterways by excessive macrophyte growth. Sources can include sewage discharge, animal waste and agricultural fertilizers. There are three forms of nitrogen that are routinely measured in rivers: ammonia, nitrates and nitrites. Total nitrogen is also reported and is the sum of ammonia, organic and reduced nitrogen and nitrate-nitrite. Phosphorus exists in either a particulate phase or dissolved phase. Total phosphorus is the measure of dissolved and particulate phosphorus.

3.4 Comparison to water quality objectives

Water quality data from the Werribee River catchment was analysed and compared to State Environment Protection Policy - Waters of Victoria guidelines (SEPP) (EPA Victoria, 2003). When no SEPP objectives were available or set, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) were used.

SEPP provides water quality objectives for Victorian rivers and streams to ensure ecosystem protection (EPA Victoria, 2003). SEPP provides data in quartiles to evaluate their objectives – this means that values are either above the 25th percentile (25% have lower data values and 75 % of the data have higher values) or below the 75th percentile (75% of the data values are lower where 25 % have higher values). These objectives are set according to geographical location, with values and recommended limits depending on the site region.

The Victorian government is currently reviewing the SEPP guidelines and consultation on the draft SEPP is open for public consultation till 19 June 2018. The Werribee River catchment will be located in the 'Central Foothills and Coastal Plains' region (see Table 3-2). As the policy has not yet been finalised, the existing SEPP guidelines (EPA Victoria, 2003) have been used for this report.

For the current SEPP guidelines, the Werribee River catchment is located in the 'Cleared Hills and Coastal Plains' area. The guidelines provide objectives for total phosphorus (TP), total nitrogen (TN), dissolved oxygen (DO), pH, electrical conductivity (EC) and turbidity (EPA Victoria, 2003) (Table 3-2).

ANZECC (2000) water quality guidelines also provide a framework for assessing water quality based on the physical, chemical and biological characteristics of a waterway. ANZECC trigger values relate to median data (50th percentile), or a specified range (set minimum and maximum values). ANZECC provides default water quality objectives for specific geographic locations and waterbody types.

For the ANZECC guidelines, water quality objectives for lowland rivers in south-east Australia were used. This includes TP, filtered reactive phosphorus, TN, nitrates/nitrites (NOx), ammonium (NH_4^+), DO, salinity, turbidity and pH. Where nitrite/nitrate (NOx) and total kjehldahl nitrogen (TKN), were recorded as separate components at a site, these were summed to derive a TN concentration.

Table 3-2. Summary comparison of current SEPP, draft SEPP and ANZECC parameters.

Parameter	Data	SEPP (Rivers and Streams) Cleared Hills and Coastal Plains	DRAFT SEPP (Waters) Lowlands of the Werribee River	ANZECC default lowland rivers, SE Australia
TP (µg/L)	75th percentile	≤ 45	≤60	50
FRP (µg/L)	Median			20
TN (µg/L)	75th percentile	≤ 600	≤ 1100	500
NOx (µg/L)	Median			40
$NH4^+$ (µg/L)	Median			20
DO% saturation	25th percentile	≥85	≥ 70	85
	Maximum	110	110	110
Electrical conductivity (µS/cm)	75th percentile	≤ 1500	110	125 - 2200
Turbidity	75th percentile	≤ 10	≤ 25	6 - 50
pH	25th percentile	≥ 6.5	≥ 6.8	6.5
	75th percentile	≤ 8.3	≤ 8.0	8.0

3.5 Data analysis

Long term water quality data was analysed to determine water quality conditions in the Werribee River catchment and changes over time. This data was also compared between sites to understand conditions at different locations in the catchment. Water quality data was compared to SEPP objectives (EPA Victoria, 2003) and ANZECC trigger values (ANZECC, 2000) to determine whether recommended guidelines were met.

A summary table of statistical data is presented for each water quality parameter (minimum, 25th percentile, median, 75th percentile and maximum values). A plot of individual data points to display long term water quality data for each site and parameter between the periods of 1990-2017 is also shown. Sites have been separated into upper catchment (above Exford weir) and lower catchment.

For the periods 2007 to 2017, a plot of the annual 75th percentile data is compared against the SEPP objective. Where no SEPP objective is available, the annual median value has been calculated and compared to the corresponding ANZECC trigger guideline.

4 Results

4.1 Electrical conductivity

Electrical conductivity (EC) field data taken was available at all sites except Cobbledick's Ford. Electrical conductivity exceeded SEPP objectives at all sites for the median (50th percentile) and 75th percentile of the data, except Lerderderg River (see Table 4.1).

Table 4-1. Electrical conductivity (µS/cm) compared to SEPP objectives in the Werribee River catchment, including minimum, 25th percentile, median, 75th percentile and maximum.

	SEPP	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledick's Ford	Wyndham Vale	Bungey's Hole
Count			318	150	102	329	ND	109	61
Min			73	148	107	105	ND	180	400
25th%ile			130	948	4363	780	ND	950	1160
Median		2200	160	**1536***	**5500***	**1952***	ND	**1600***	**1770***
75th%ile	≤ 1500		208	**2202***	**6053***	**4500***	ND	**2800***	**2300***
Max			2061	8043	9000	10800	ND	5000	11300
Data source			WMIS	WMIS	WMIS	WMIS	WMIS	MW	WRivA

* Indicates non-compliance with SEPP objective

With the exception of Lerderderg River, there was a consistent long-term trend of EC exceeding the SEPP objective for all sites (see Figure 4-1). Note the SEPP objective applies to the 75th percentile of the data, not the individual data points plotted.

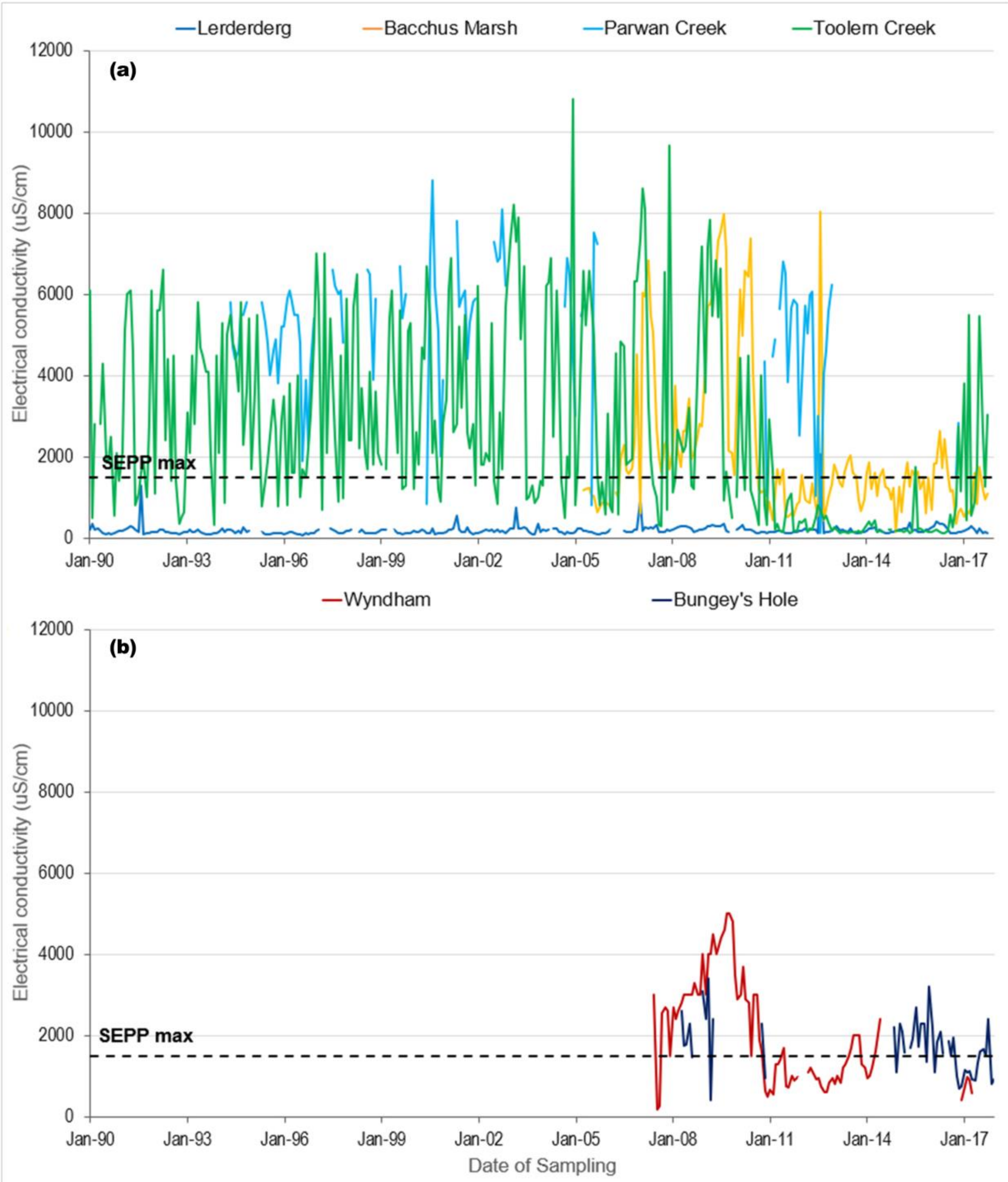

Figure 4-1. Electrical conductivity (µS/cm) at sites in the Werribee River (a) upper catchment and (b) lower catchment (WMIS 1990-2017; MW 2007-2017; WRivA 2010-2017) and comparison to the SEPP objective.

Between 2007 and 2012, electrical conductivity at Bacchus Marsh, Toolern Creek and Wyndham exceeded the SEPP objective. Despite a decline after this, levels at Toolern Creek now appear to be increasing. Levels at Bungey's Hole also exceeded the SEPP objective (see Figure 4-2).

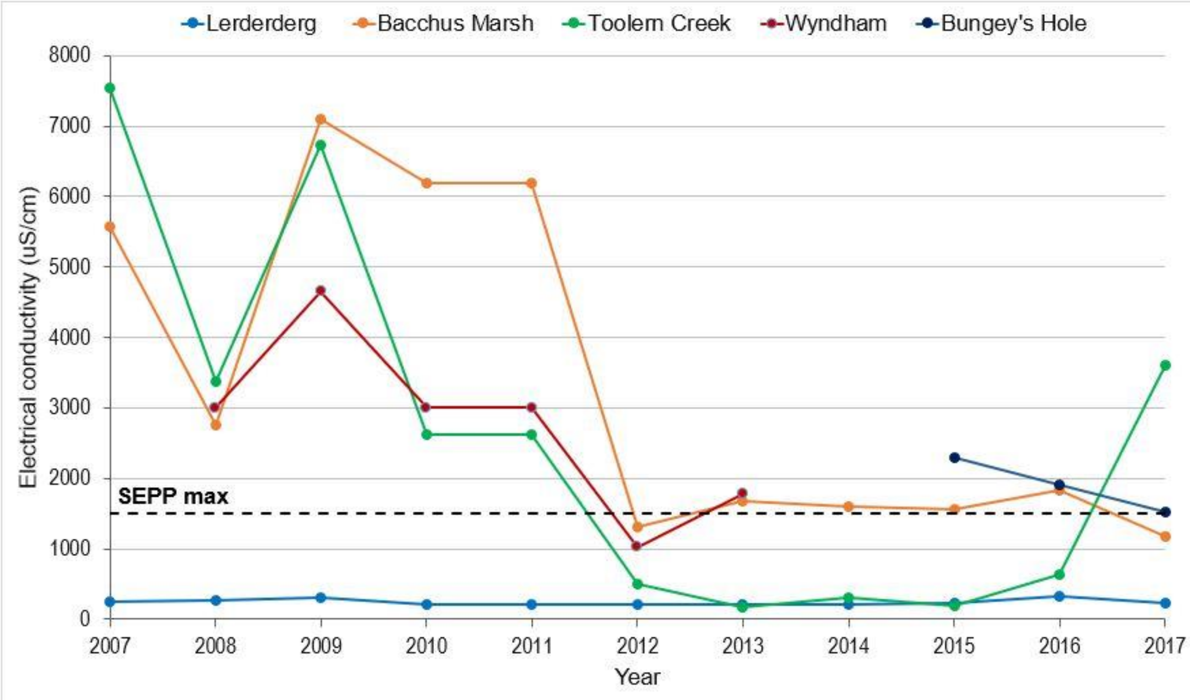

Figure 4-2. Electrical conductivity 75th percentile value (µS/cm) at sites in the Werribee River catchment (2015-2017) and comparison to the SEPP objective.

4.2 Turbidity

Turbidity levels are set in both SEPP and ANZECC water quality objectives. The SEPP objective for turbidity is less than 10 NTU. ANZECC guidelines specify a range of 6-50 NTU.

Turbidity exceeded SEPP objectives at Bacchus Marsh, Toolern Creek, Cobbledick's Ford and Wyndham Vale (see Table 4-2).

Table 4-2. Turbidity (NTU) compared to SEPP and ANZECC water quality objectives in the Werribee River catchment, including minimum, 25th percentile, median, 75th percentile, and maximum.

	SEPP	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledick's Ford	Wyndham Vale	Bungey's Hole
Count			317	149	102	330	150	109	62
Min			1.2	2.3	0.5	0.8	1.8	2.0	0.0
25th%ile		6	2.4	10.8	**1.0**$^{\Delta}$	**3.2**$^{\Delta}$	7.3	6.0	**5.0**$^{\Delta}$
Median			3.7	15.0	1.9	7.2	11.2	10.0	10.0
75th%ile	≤ 10	50	6.0	**23.3***	8.1	**20.9***	**24.5***	**20.0***	10.0
Max			102.0	86.1	510.0	737.0	198.0	170.0	35.0
Data source			WMIS	WMIS	WMIS	WMIS	WMIS	MW	WRivA

* Indicates non-compliance with SEPP objective; $^{\Delta}$ indicates non-compliance with ANZECC trigger value

There is a long-term trend of elevated turbidity at Bacchus Marsh, Toolern Creek, Cobbledick's Ford and Wyndham Vale (see Figure 4-3). Note the SEPP objective applies to the 75th percentile of the data, not the individual data points plotted.

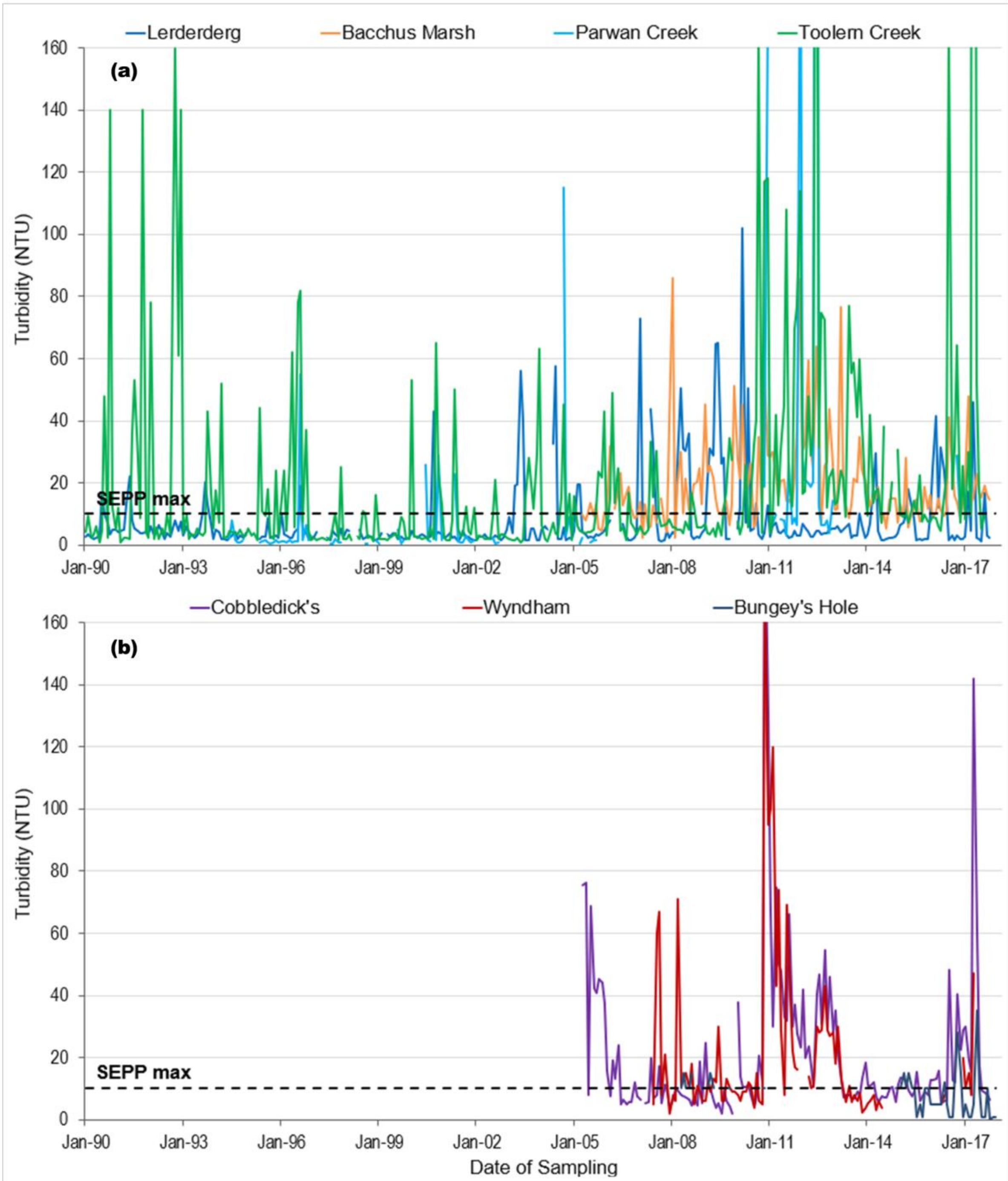

Figure 4-3. Turbidity (NTU) at sites in the Werribee River (a) upper catchment and (b) lower catchment (WMIS 1990-2017; MW 2007-2017; WRivA 2010-2017) and comparison to the SEPP objective.

Turbidity at the majority of sites consistently exceeds the SEPP objective. Between 2012 and 2015, there was a general trend of turbidity declining. Since 2015, turbidity has increased at Bacchus Marsh, Toolern Creek and Cobbledick's Ford. In 2017, turbidity at Bungey's Hole was below the SEPP objective (see Figure 4-4).

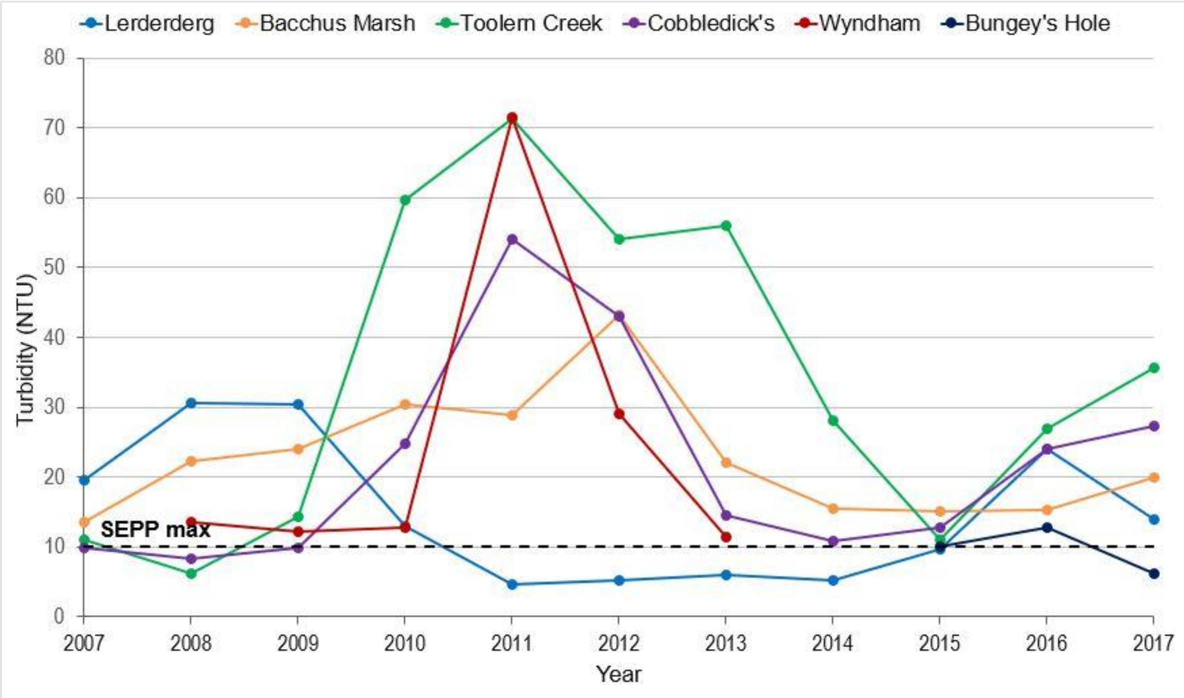

Figure 4-4. Turbidity (NTU) 75th percentile values at sites in the Werribee River catchment (2015-2017) and comparison to the SEPP objective and ANZECC trigger value.

4.3 pH

To protect aquatic organisms, water quality objectives are set for maximum and minimum pH levels. The SEPP objectives specify a 25th percentile value of ≥ 6.5 and a 75th percentile value of ≤ 8.3. ANZECC objectives specify that pH values should be within the range of 6.5 and 8.

At the majority of sites, pH was within recommended guidelines for SEPP. The exception was Parwan Creek and Bungey's Hole (see Table 4-3).

Table 4-3. pH compared to SEPP and ANZECC water quality objectives in the Werribee River catchment, including minimum, 25th percentile, median, 75th percentile, and maximum.

	SEPP	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledicks Ford	Wyndham Vale	Bungey's Hole
Count			308	149	98	317	150	109	60
Min		6.5	5.0	6.1	6.8	3.5	6.6	6.5	6.8
25th%ile	≥ 6.5		6.8	7.5	8.1	7.3	7.7	7.7	7.9
Median			7.0	7.6	8.3	7.5	7.9	7.9	8.2
75th%ile	≤ 8.3		7.4	7.8	**8.4***	7.8	8.0	8.1	**8.4***
Max		8	10.3	8.8	8.8	8.9	9.2	9.2	9.3
Data source			WMIS	WMIS	WMIS	WMIS	WMIS	MW	WRivA

* Indicates non-compliance with SEPP objective

There is a long tern trend of pH remaining within recommended guidelines (see Figure 4-5). Note the SEPP objective applies to the 25th and 75th percentile of the data and not individual data points.

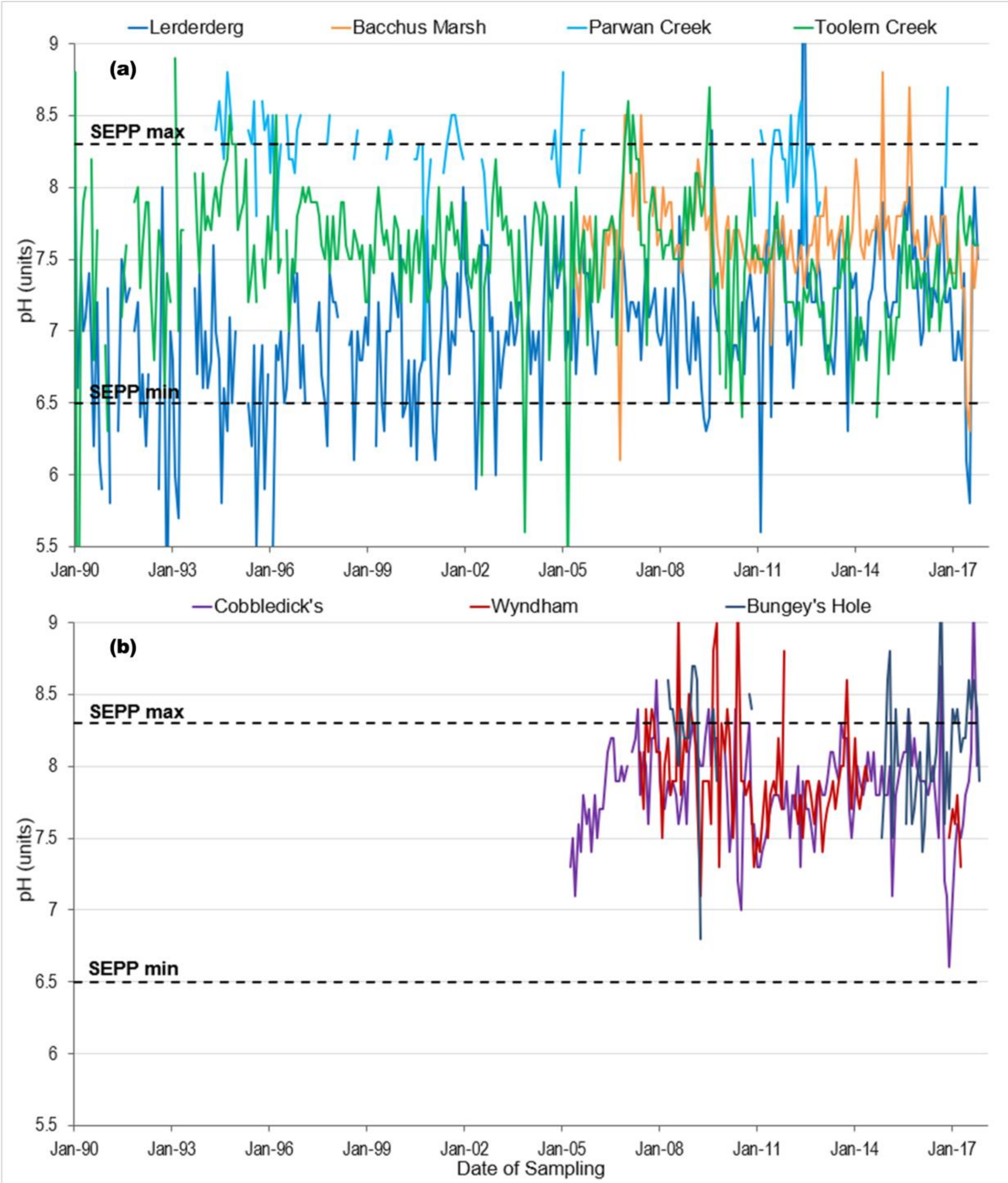

Figure 4-5. pH (units) at sites in the Werribee River (a) upper catchment and (b) lower catchment (WMIS 1990-2017; MW 2007-2017; WRivA 2010-2017), with truncated scale, showing comparison to the maximum and minimum SEPP objective.

Between 2007 and 2017, annual pH values were within the SEPP objectives at the majority of sites (see Figure 4-6).

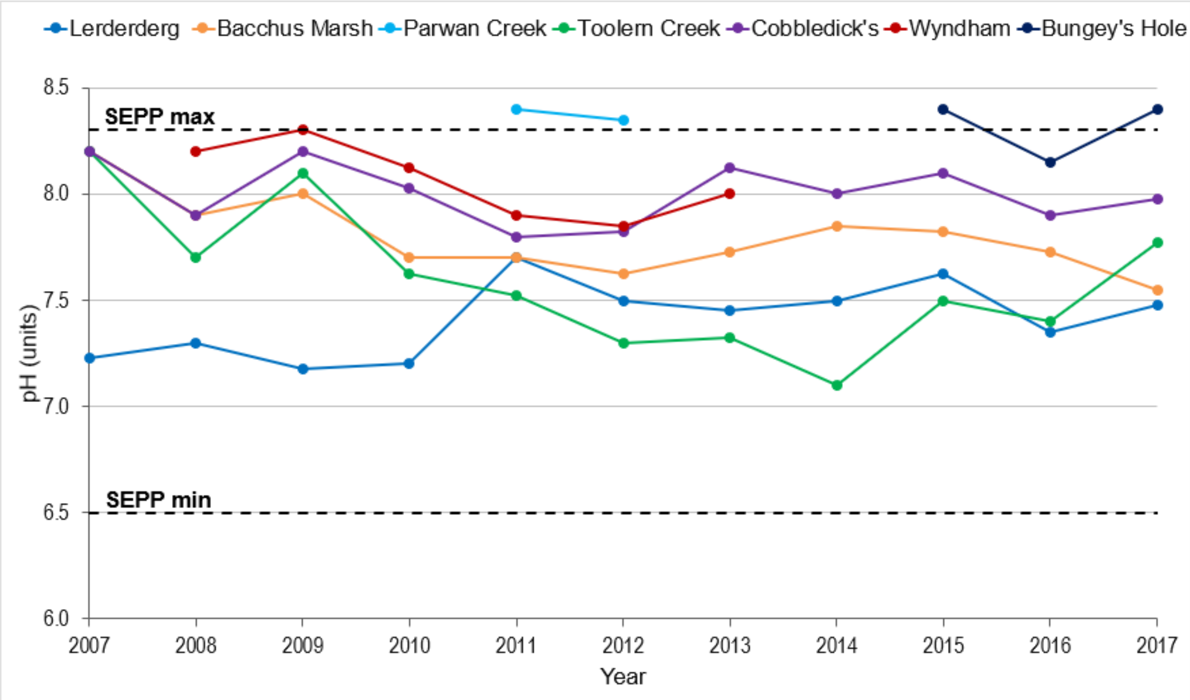

Figure 4-6. pH (units) 75th percentile values at sites in the Werribee River catchment (2015-2017), showing comparison to the ANZECC maximum and minimum trigger value.

4.4 Dissolved oxygen (DO)

The ANZECC and SEPP guidelines, both state objectives for DO in terms of percentage saturation (90-100%). However, the only available data from the Victorian WMIS and Werribee River Association has been measured in ppm (mg/L), which cannot be easily converted to percentage saturation. Dissolved oxygen measurement is difficult to interpret due to the large natural variation that occurs in DO levels over a diurnal (day) period, and the effect temperature also has on levels.

Temperature data (where available) from sites in the Werribee River catchment shows minimum temperatures of between 0.5 and nine degrees, and, maximum water temperatures of between 25 and 29 degrees. 100% DO saturation at these temperatures would be approximately 7.75 - 8.25 mg/L (at maximum temperatures) and 11.5 -14.25 mg/L (at minimum temperatures). DO is generally within this level, although minimum values fall well below this (see Table 4-4).

The 1992 ANZECC guidelines recommend DO should not normally be permitted to fall below 6 mg/L or 80-90% saturation, determined over at least one diurnal (day) period.

Table 4-4. Dissolved oxygen (mg/L) compared to the ANZECC trigger value in the Werribee River catchment including, minimum, 25th percentile, median, 75th percentile, and maximum.

	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledicks Ford	Wyndham Vale	Bungey's Hole
Count		315	150	98	323	150	109	62
Min		0.5	4.9	4.9	1.0	4.1	4.2	3.0
25th%ile	≥ 6	6.5	7.1	8.7	**5.3***	7.0	6.	6.0
Median		9.4	8.1	10.4	7.4	8.2	7.4	8.0
75th%ile		10.8	9.3	11.6	8.9	9.7	8.5	10.0
Max		14.3	13.9	14.7	13.2	14.1	14.1	10.0
Data source		WMIS	WMIS	WMIS	WMIS	WMIS	MW	WRivA

* Indicates non-compliance with SEPP objective

Although there are individual data points which fall below the ANZECC trigger value, there is a consistent long-term trend of DO being higher than recommended guidelines at all sites (see Figure 4-7). Note the ANZECC trigger value applies to the median data and not the individual data points plotted.

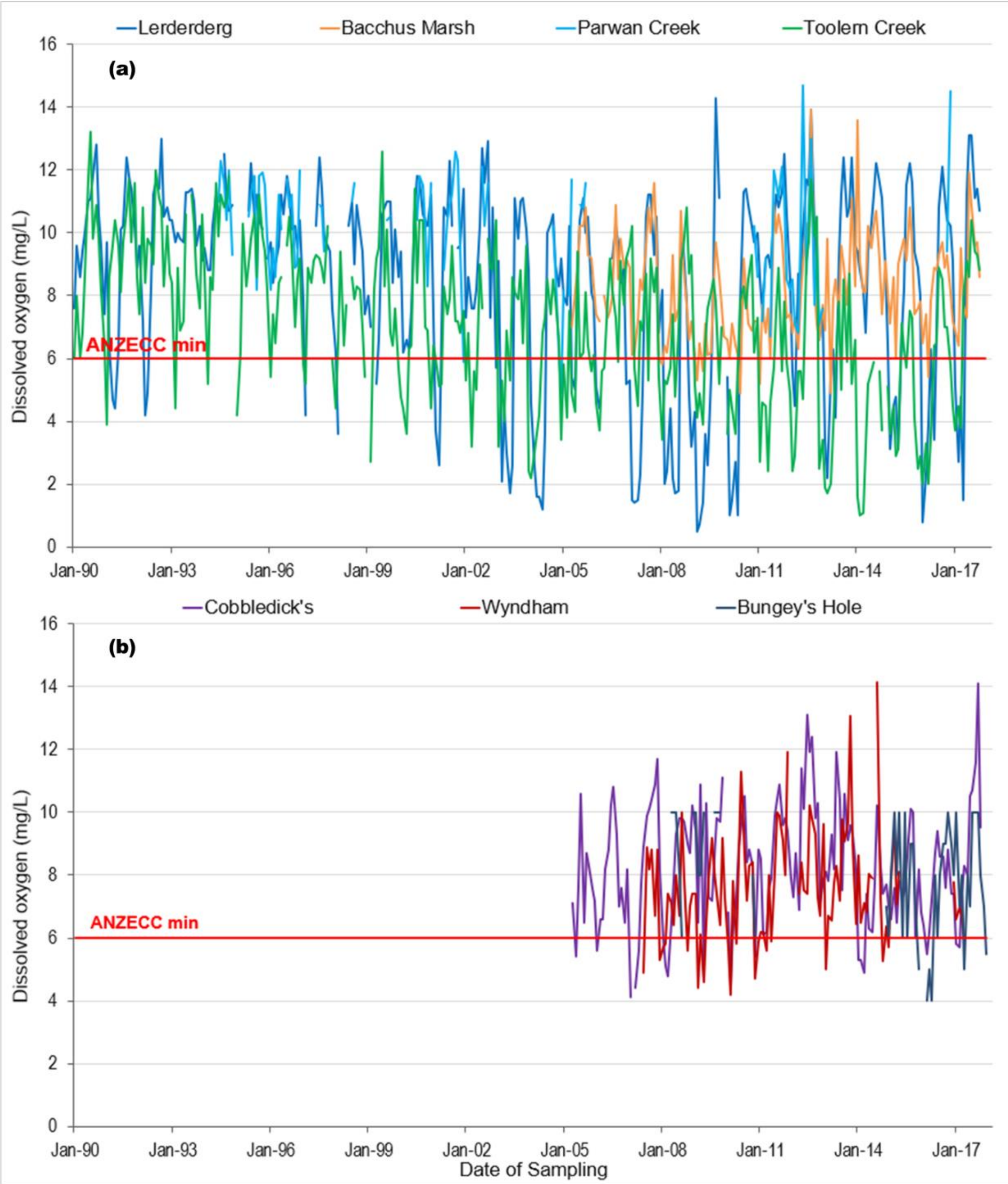

Figure 4-7. Dissolved oxygen at sites in the Werribee River (a) upper catchment and (b) lower catchment the (a) upper and (b) lower Werribee River catchment (WMIS 1990-2017; MW 2007-2017; WRivA 2010-2017) and comparison to ANZECC trigger value.

Between 2007 and 2017, dissolved oxygen was consistently higher than the ANZECC recommended minimum trigger value at the majority of sites (see Figure 4-8).

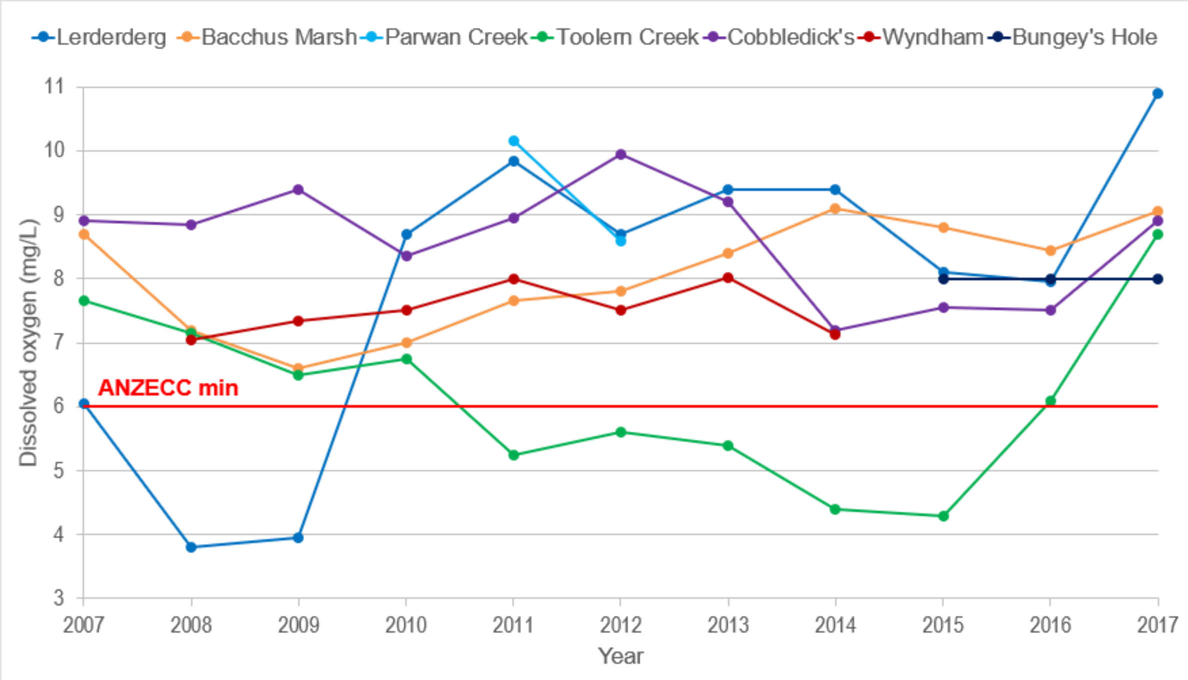

Figure 4-8. Dissolved oxygen (mg/L) 75th percentile values at sites in the Werribee River catchment (2015-2017), showing comparison to the ANZECC minimum trigger value.

4.5 Nutrients

4.5.1 Total nitrogen (TN)

Total nitrogen (TN) is a measure of all forms of nitrogen in the water. This includes dissolved organic and inorganic, including nitrate/nitrite and ammonia, and particularly nitrogen suspended in the water column.

SEPP specifies a guideline objective for 75th percentile TN concentration of ≤ 600µg/L (0.60 mg/L). The ANZECC trigger value for TN is ≤500µg/L (0.50 mg/L).

TN was available at all sites except Bungey's Hole.TN exceeded the SEPP objective at all sites except Lerderderg River (see Table 4-5). Values were highest at Parwan Creek.

Table 4-5. Total Nitrogen (µg/L) compared to SEPP and ANZECC water quality objectives in the Werribee River catchment, including minimum, 25th percentile, median, 75th percentile, and maximum.

	SEPP	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledicks Ford	Wyndham Vale	Bungey's Hole
Count			315	150	102	327	153	16	ND
Min			37.0	39.0	303.0	172.0	13.0	450.0	ND
25th%ile			228.0	420.8	463.5	560.0	500.0	617.5	ND
Median		≤500	320.0	**511.5**$^{\Delta}$	**629.5**$^{\Delta}$	**700.0**$^{\Delta}$	**623.0**$^{\Delta}$	**690.0**$^{\Delta}$	ND
75th%ile	≤600		443.5	**654.0***	**942.3***	**941.5***	**914.0***	**895.0***	ND
Max			3727	3200	7070	4700	7000	1700	ND
Data source			WMIS	WMIS	WMIS	WMIS	WMIS	MW	WRivA

* Indicates non-compliance with SEPP objective; $^{\Delta}$ indicates non-compliance with ANZECC trigger value. ND = no data available.

With the exception of the Lerderderg River, there is a consistent long term of TN exceeding the guidelines (see Figure 4-9). Note the SEPP objective applies to the 75th percentile of the data, not the individual data points plotted.

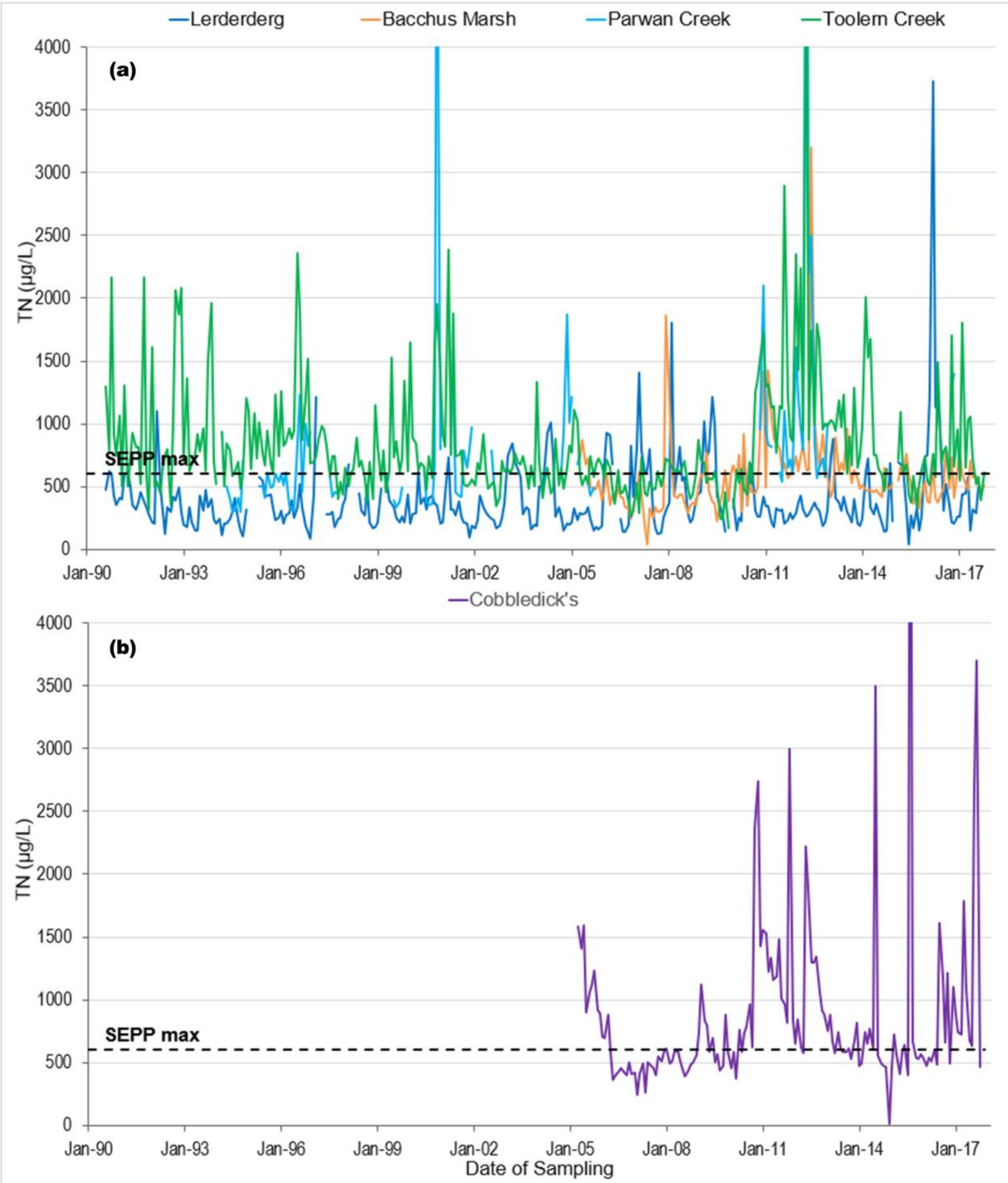

Figure 4-9. Total nitrogen at sites in the Werribee River (a) upper catchment and (b) lower catchment (WMIS 1990-2017; MW 2007-2017), showing comparison to the SEPP objective and ANZECC trigger value.

Between 2007 and 2017, TN has consistently exceeded the SEPP objective at the majority of sites. Despite a decline, concentrations at Cobbledick's Ford and Toolern Creek, appear to again be increasing (see Figure 4-10).

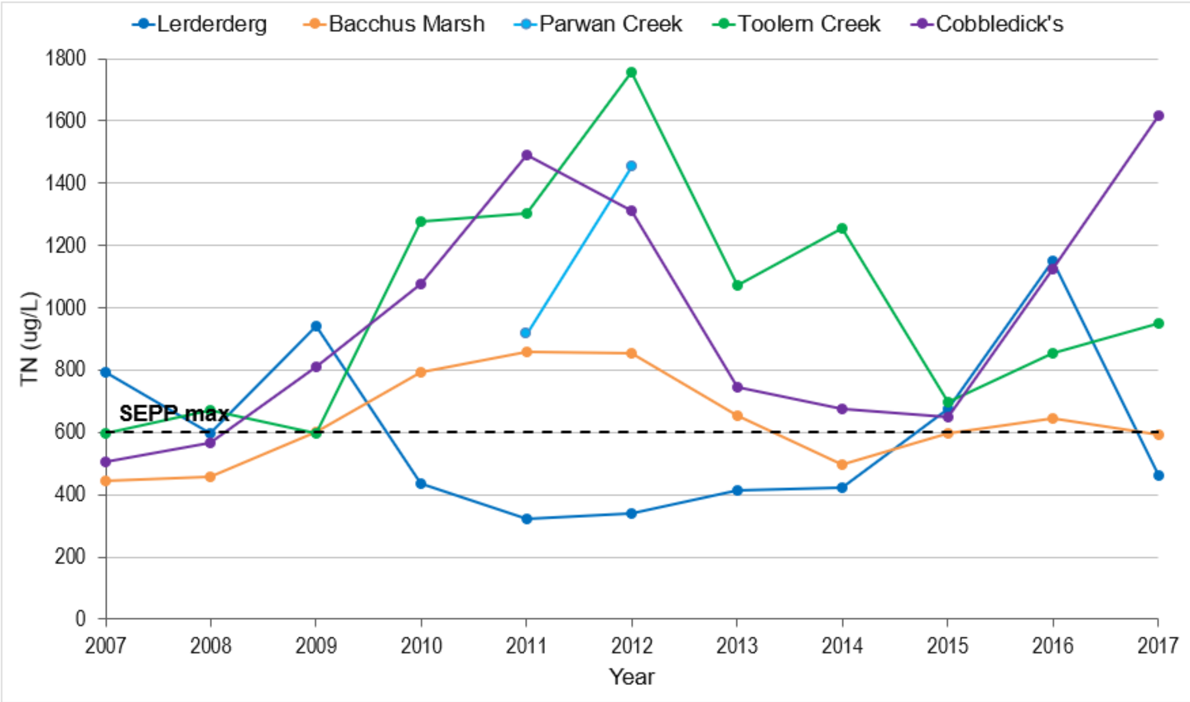

Figure 4-10. Total nitrogen (µg/L) 75th percentile values at sites in the Werribee River catchment (2015-2017), showing comparison to the SEPP objective and ANZECC trigger value.

4.5.2 Nitrite/Nitrate (NOx)

There is no SEPP objective for NOx but an ANZECC trigger value of 20 µg/L applies. NOx was available at all sites except Bungey's Hole. NOx exceeded ANZECC guidelines for all sites except Parwan Creek and Wyndham Vale (see Table 4-6). Values are highest at Toolern Creek. Note the ANZECC trigger value applies to the median vale, not the individual data points.

Table 4-6. Nitrate/nitrite (µg/L) compared to the ANZECC trigger value in the Werribee River catchment, including minimum, 25th percentile, median, 75th percentile, and maximum.

	SEPP	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledicks Ford	Wyndham Vale	Bungey's Hole
Count			311	148	98	323	151	92	ND
Min			2.0	2.0	3.0	2.0	2.0	0.0	ND
25th%ile			10.0	8.0	3.0	14.0	5.0	5.0	ND
Median		40	**30.0**$^{\Delta}$	**39.5**$^{\Delta}$	7.0	**60.0**$^{\Delta}$	**30.0**$^{\Delta}$	17.5	ND
75th%ile	ND		130.0	120.0	10.0	180.0	230.0	147.8	ND
Max			460.0	1900	6200	3400	6200	2923	ND
Data source			WMIS	WMIS	WMIS	WMIS	WMIS	MW	WRivA

$^{\Delta}$ Indicates non-compliance with ANZECC trigger value. ND = no data.

With the exception of Parwan Creek and Wyndham Vale, there is a consistent long-term trend of NOx exceeding the ANZECC trigger value (see Figure 4-11). Note the ANZECC trigger value applies to median values, not the individual data points plotted.

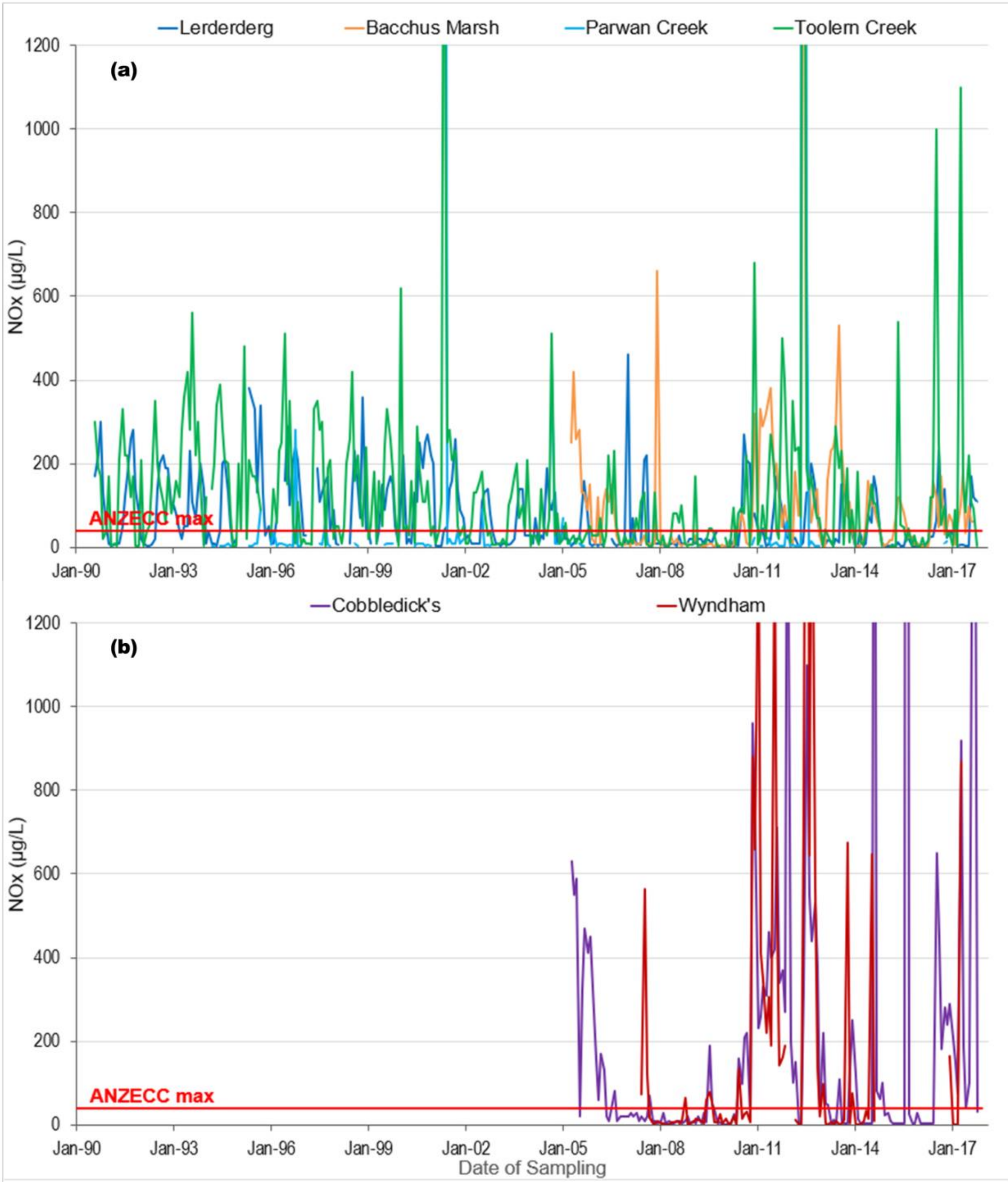

Figure 4-11. Nitrate/nitrite (NOx) at sites in the Werribee River (a) upper catchment and (b) lower catchment (WMIS 1990-2017; MW 2007-2017), showing comparison to the ANZECC trigger value.

In 2011, nitrate/nitrate (NOx) concentrations peaked at Bacchus Marsh, Cobbledick's Ford and Wyndham. Despite a period of decline, TN appears to be increasing, with values currently exceeding the ANZECC trigger value at Bacchus Marsh, Toolern Creek, and Cobbledick's Ford (see Figure 4-12).

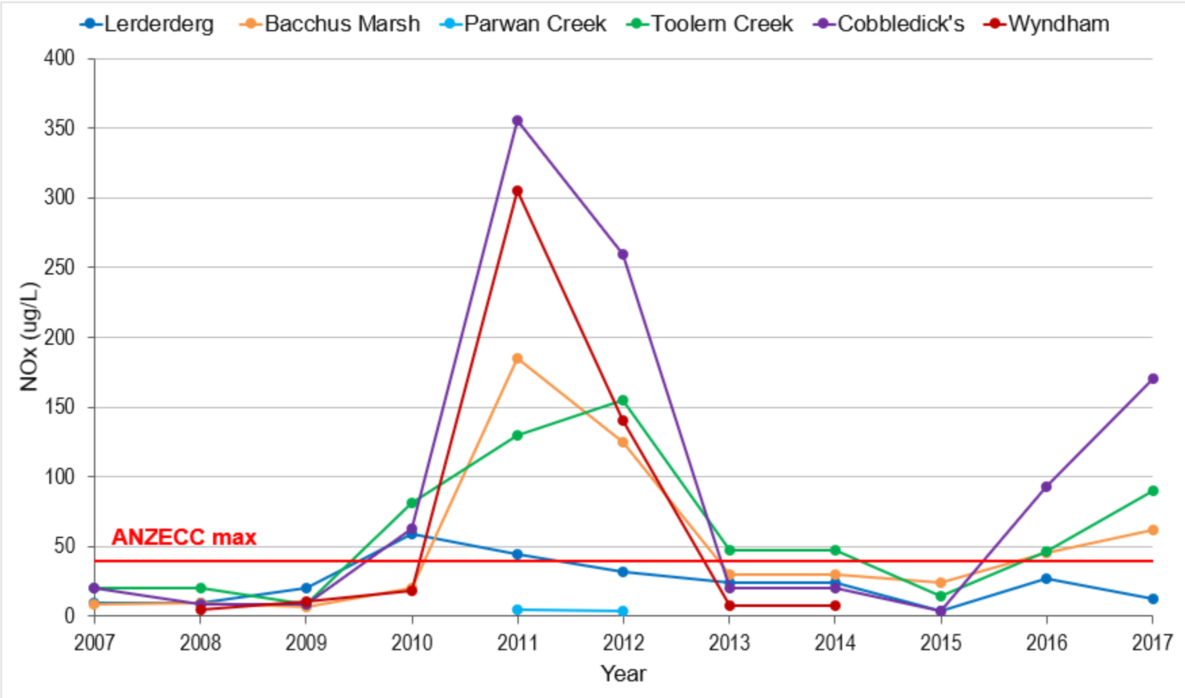

Figure 4-12. Nitrate/nitrite (NOx) (µg/L) 75th percentile values at sites in the Werribee River catchment (2007-2017), showing comparison to the ANZECC trigger value.

4.5.3 Ammonium (NH^{+}_{4})

Ammonia/Ammonium exists in two forms, NH_3 (Ammonia) and NH_4 (Ammonium). Melbourne Water Waterwatch tests for NH4 which itself is not toxic to the aquatic environment. However, with a change in temperature or pH, it can become Ammonia which in elevated concentrations is toxic to animals and kills fish. Sewerage, grey water and animal waste is often the main source of ammonium in waterways.

The only available ammonium data is from the Werribee River Association, which is taken at Bungey's Hole. No SEPP guidelines are set for ammonium, but a trigger value is specified in the ANZECC guidelines of 20 µg/L. There were spikes in the data, showing that the ANZECC trigger value was exceeded at certain data points. From 55 data points the median ammonium value was 20 µg/L, which is the same as the ANZECC trigger value (see Figure 4-13).

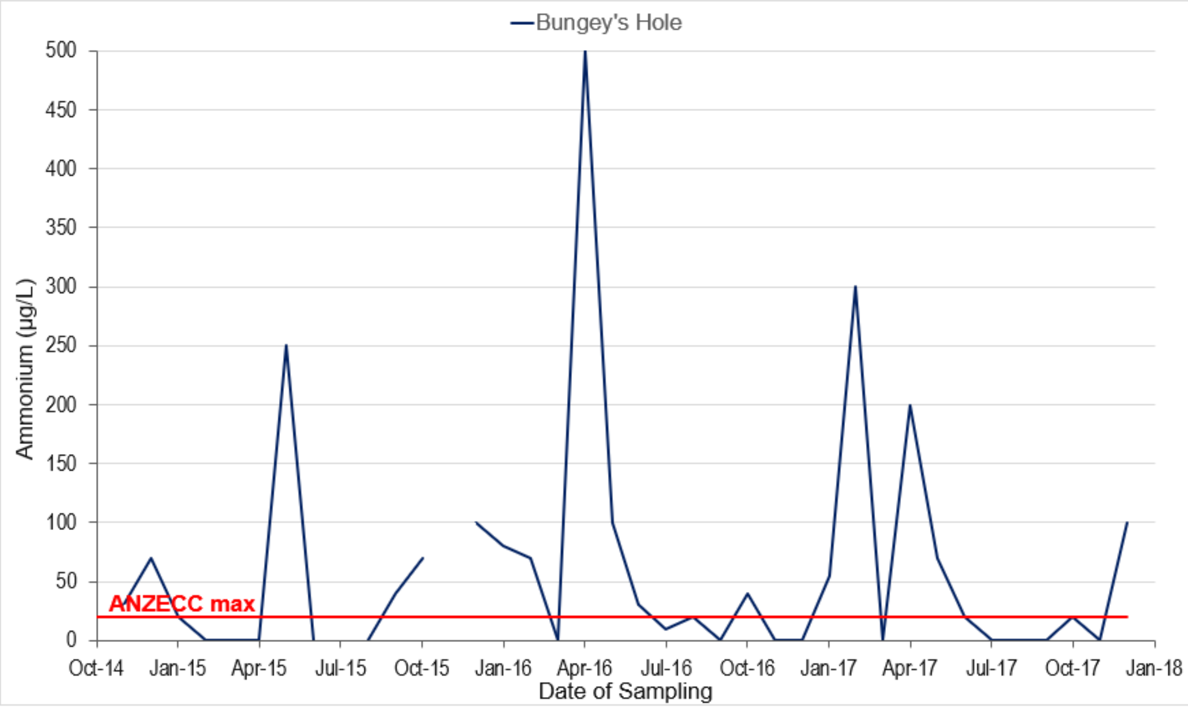

Figure 4-13. Ammonium ($NH^+{}_4$) Werribee River at Bungey's Hole (WRivA 2014-2017) showing comparison to the ANZECC trigger value (20 µg/L).

In 2016, there was an increase in ammonium concentrations at Bungey's Hole, with values exceeding the ANZECC trigger value (see Figure 4-14).

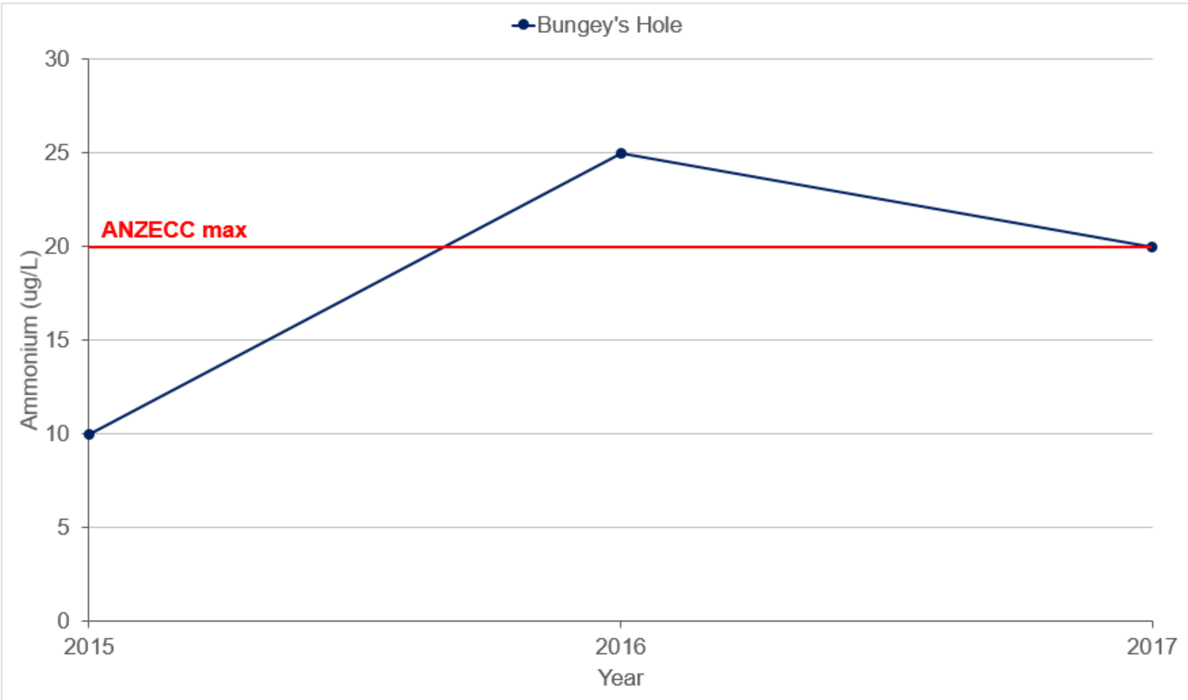

Figure 4-14. Ammonium ($NH^+{}_4$) (µg/L) median values at Bungey's Hole (2015-2017) showing comparison to the ANZECC trigger value.

4.5.4 Total Phosphorus (TP)

For TP, water quality objectives are set under both the SEPP (75th percentile ≤ 25 µg/L) and ANZECC (median ≤ 50 ug/L). TP exceeded SEPP objectives at the majority of sites except Lerderderg River and the Werribee River at Bacchus Marsh (see Table 4-7).

Table 4-7. Total phosphorus (µg/L) compared to SEPP and ANZECC water quality objectives in the Werribee River catchment, including minimum, 25th percentile, median, 75th percentile, and maximum.

	SEPP	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledicks Ford	Wyndham Vale	Bungey's Hole
Count			315	150	102	328	153	103	ND
Min			5.0	10.0	5.0	9.0	5.0	15.0	ND
25th%ile			9.0	20.0	10.0	35.5	40.0	44.5	ND
Median		≤50	10	28.5	20.0	**58.5$^{\Delta}$**	**54.0$^{\Delta}$**	**62.0$^{\Delta}$**	ND
75th%ile	≤45		20.0	44.0	**54.5***	**90.5***	**81.0***	**110.0***	ND
Max			590	131	340	5600	4500	2600	ND
Data source			WMIS	WMIS	WMIS	WMIS	WMIS	MW	WRivA

* Indicates non-compliance with SEPP objective; $^{\Delta}$ indicates non-compliance with ANZECC trigger value. ND = no data.

There is a long-term trend of SEPP objectives for total phosphorus being exceeded (see Figure 4-15). Note guidelines for SEPP apply to the 75th percentile values and not the individual data points plotted.

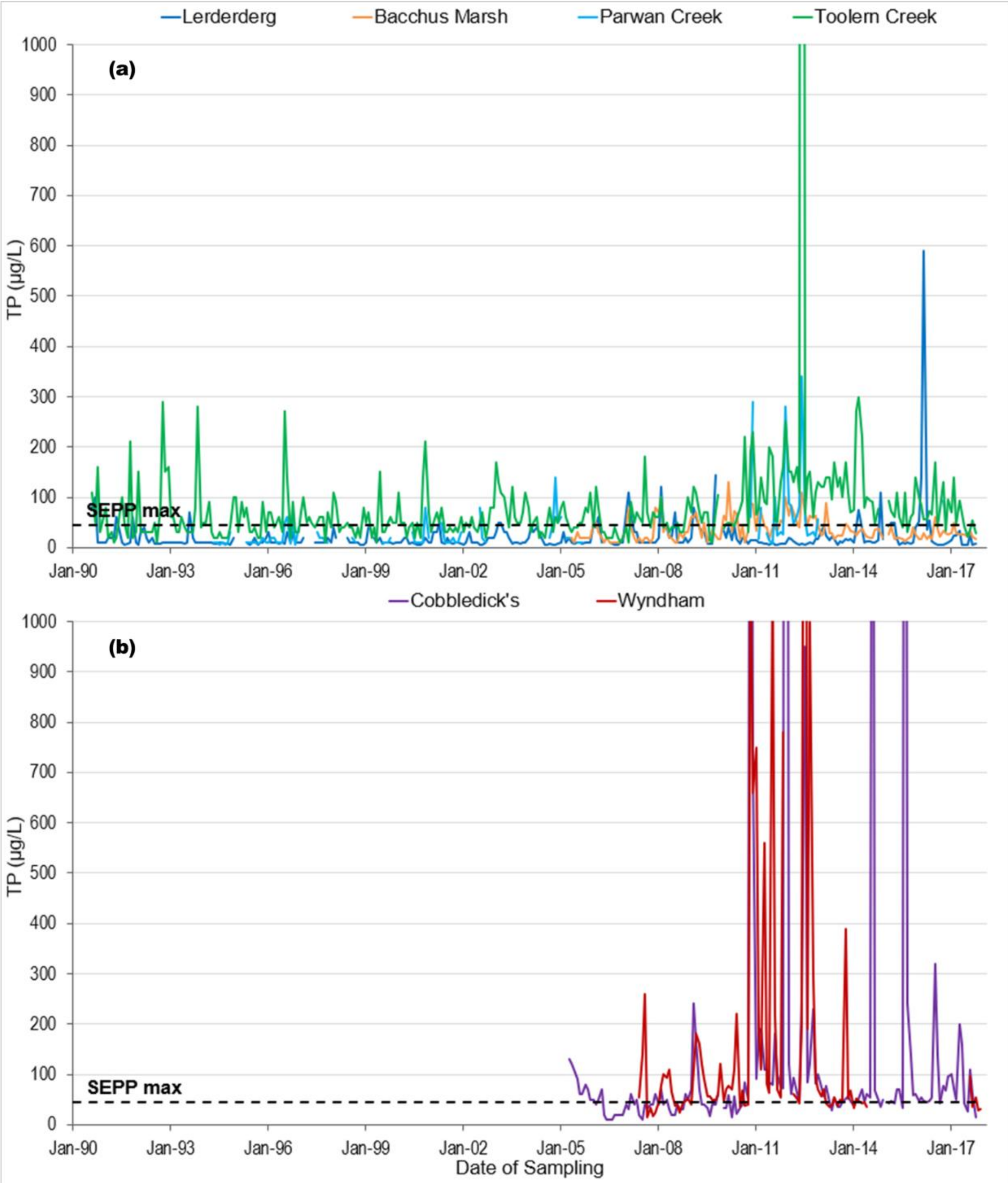

Figure 4-15. Total phosphorus (TP) at sites in the Werribee River (a) upper catchment and (b) lower catchment (WMIS 1990-2017), showing comparison to the SEPP objective.

Between 2007 and 2017, concentrations of TP have continually exceeded the SEPP objectives at the majority of sites. The highest peak was seen at Wyndham in 2011 (see Figure 4-16).

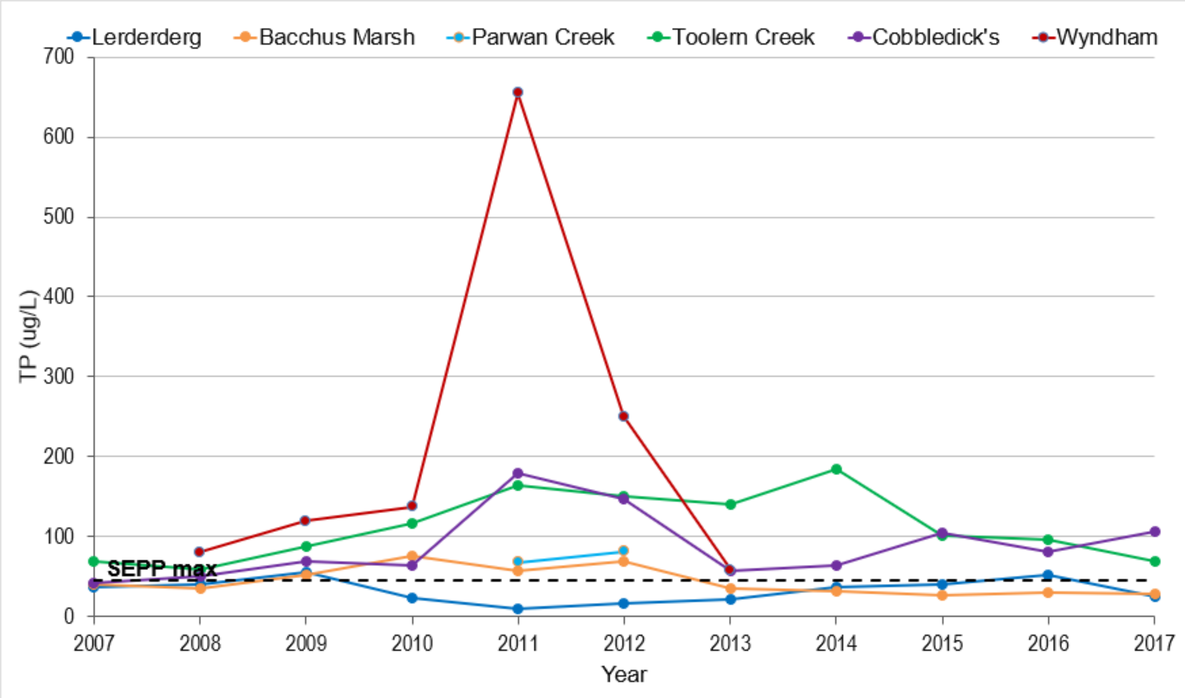

Figure 4-16. Total phosphorus (TP) (µg/L) 75th percentile values at sites in the Werribee River catchment (2015-2017) showing comparison to the SEPP objective.

4.5.5 Reactive phosphorus

Reactive phosphorus is the form of phosphorus used by plants. Although it is produced by natural processes, it is also found in sewage. Melbourne Water Waterwatch tests for reactive phosphorus as it is easily tested for in the field. The only available reactive phosphorus data is from the Werribee River Association which is taken at Bungey's Hole. The SEPP guideline for total phosphorus (45 µg/L) can be used to compare levels of reactive phosphorus.

There were spikes in the data, showing that the SEPP objective was exceeded at certain data points. From 54 data points the minimum was 0, the 25th percentile was 10, the median value was 35 µg/L, the 75th percentile was 97.5 µg/L and the maximum was 250 µg/L (see Figure 4-17).

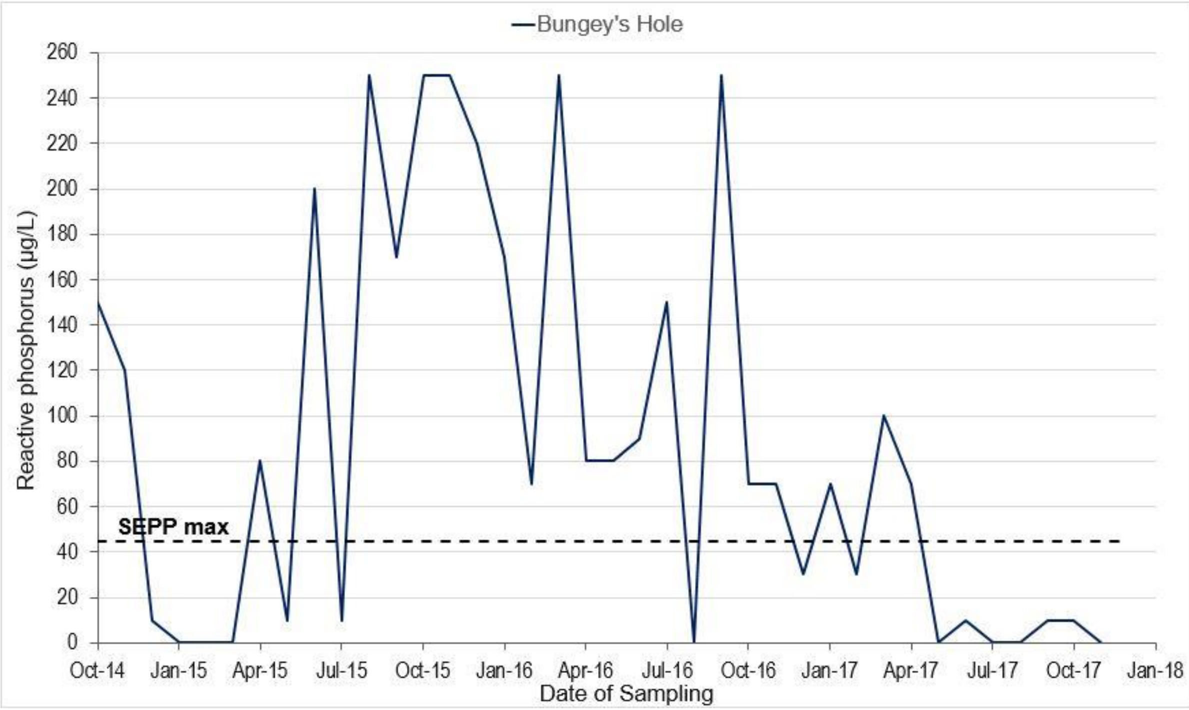

Figure 4-17. Reactive phosphorus Werribee River at Bungey's Hole (WRivA 2014-2017) showing comparison to the SEPP objective for total phosphorus (45 µg/L).

Over the past three years, reactive phosphorus at Bungey's Hole has shown a decrease and it is currently lower than the SEPP objective (see Figure 4-18).

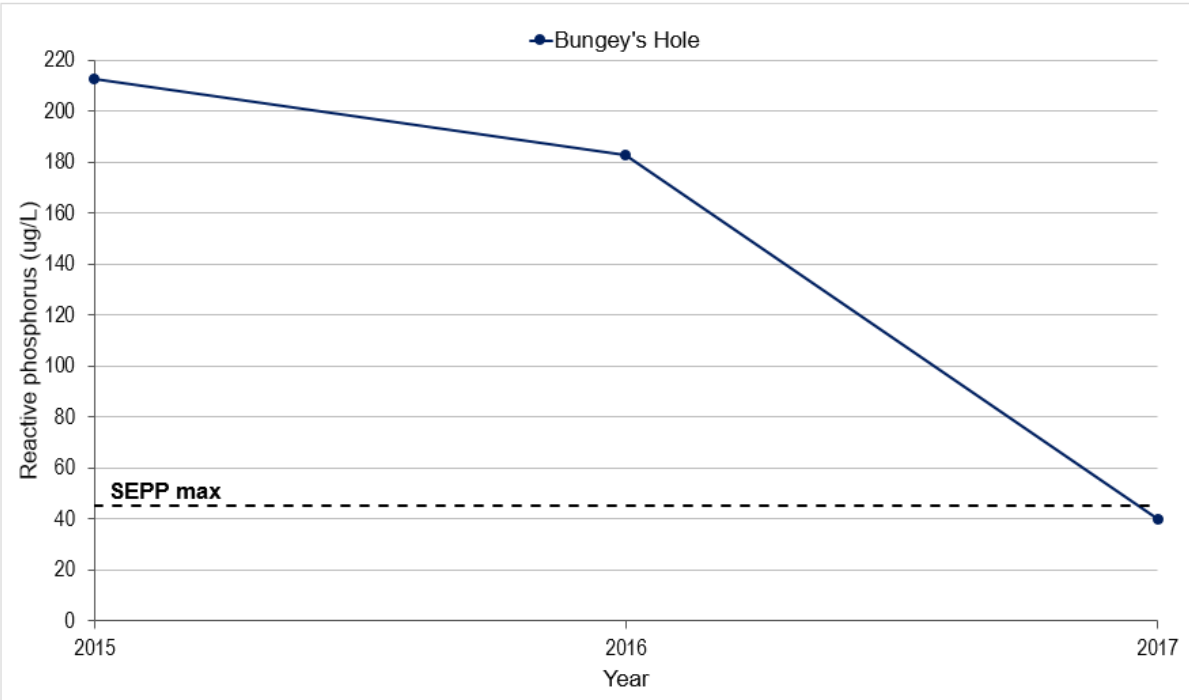

Figure 4-18. Reactive phosphorus (µg/L) 75th percentile values at Bungey's Hole, Werribee River showing comparison to the SEPP objective.

4.5.6 Filtered reactive phosphorus (FRP)

No SEPP guidelines are set for FRP, but a trigger value is specified in the ANZECC guidelines of 20 µg/L. FRP was lower than the ANZECC trigger vale at all sites (see Table 4-8).

Table 4-8. Filtered reactive phosphorus (µg/L) compared to ANZECC trigger values in the Werribee River catchment, including minimum, 25th percentile, median, 75th percentile, and maximum.

	SEPP	ANZECC	Lerderderg River	Bacchus Marsh	Parwan Creek	Toolern Creek	Cobbledicks Ford	Wyndham Vale
Count			306	150	102	325	153	103
Min			1.0	1.0	3.0	3.0	1.0	0.0
25th%ile			3.0	3.0	3.0	4.0	3.0	1.50
Median		20	3.0	3.0	3.0	9.0	7.0	7.0
75th%ile	ND		3.0	4.0	6.8	12.0	15.0	35.0
Max			50	42	85	4600	4000	2600
Data source			WMIS	WMIS	WMIS	WMIS	WMIS	MW

Δ indicates non-compliance with ANZECC trigger value. ND = no data.

Although the ANZECC trigger value is exceeded for certain data points, overall FRP is lower than the recommended guidelines (see Figure 4-19).

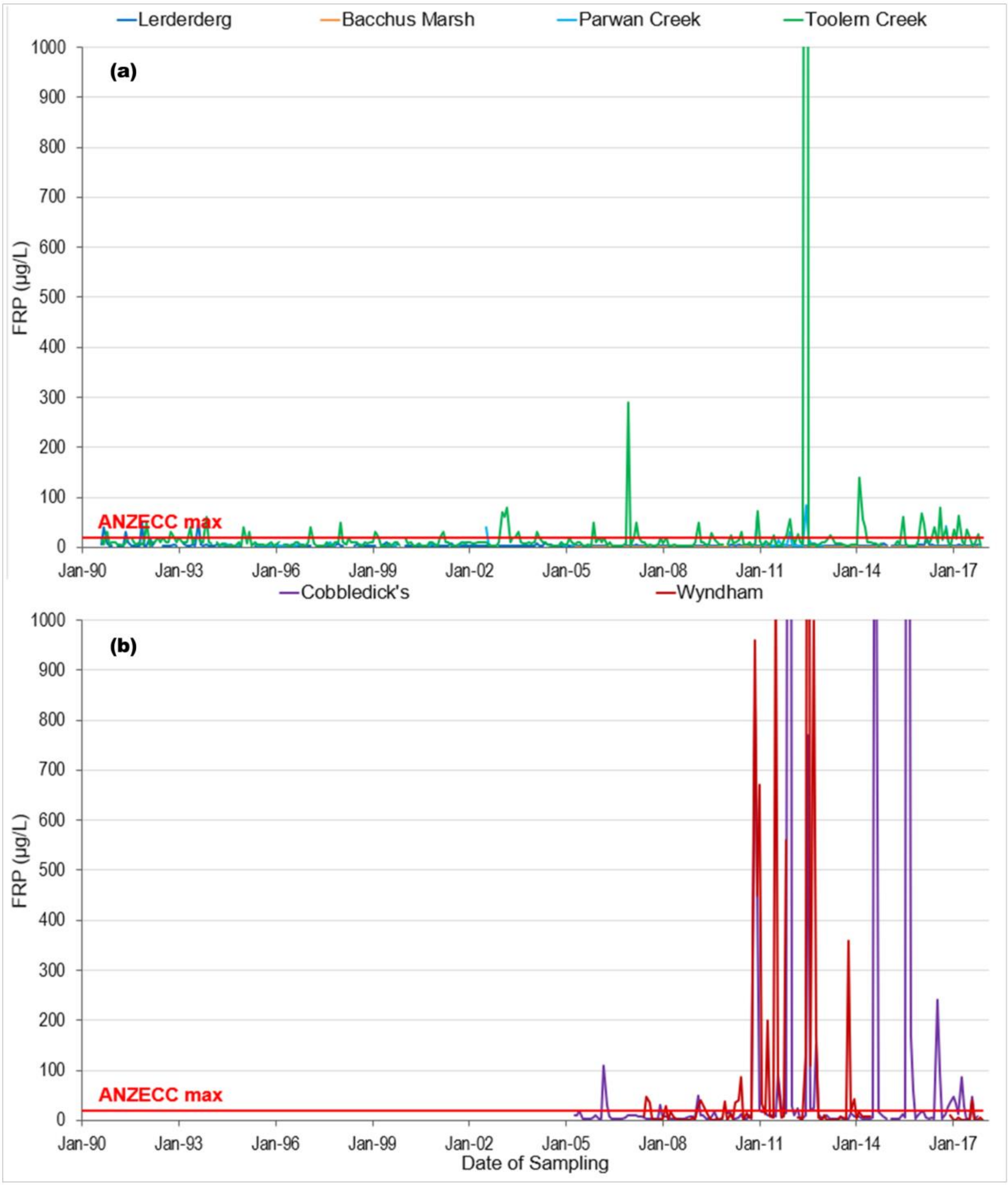

Figure 4-19. Filtered Reactive Phosphorus (FRP) at sites in the Werribee River (a) upper catchment and (b) lower catchment (WMIS 1990-2017; MW 2007-2017; WRivA 2008-2010 and 2014-2017), showing comparison to the ANZECC trigger value.

Between 2007 and 2017, FRP was below the ANZECC trigger value. However, in recent years, concentrations at Toolern Creek and Cobbledick's Ford have been increasing (see Figure 4-20).

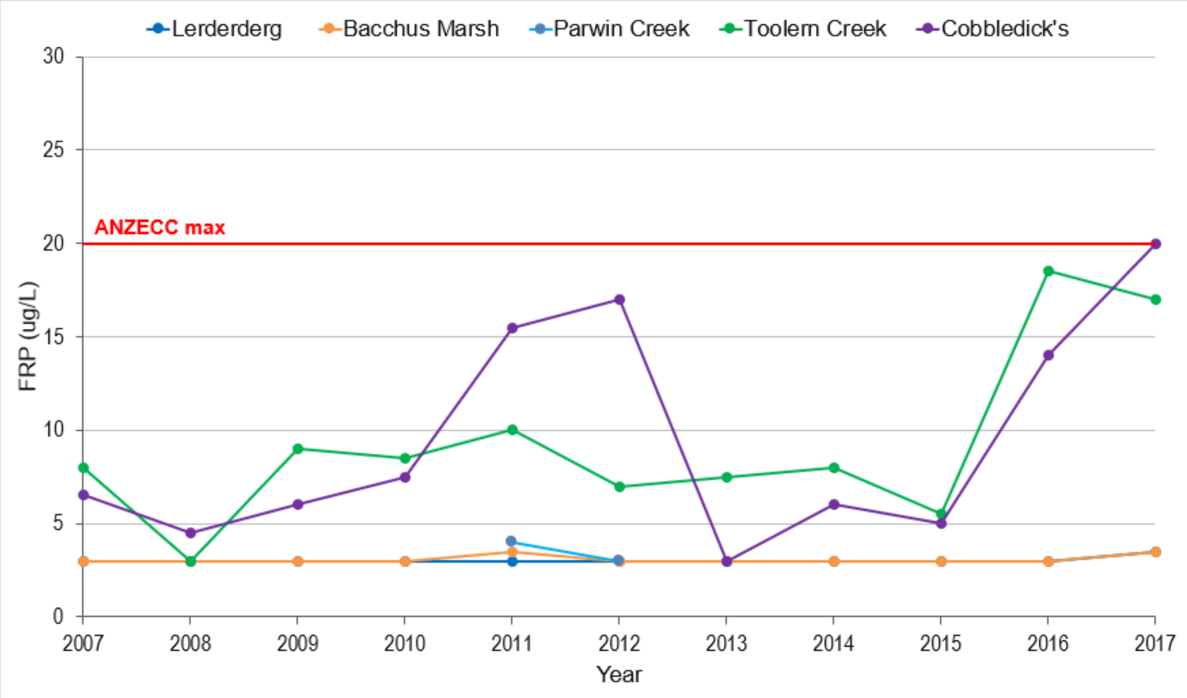

Figure 4-20. Filtered Reactive Phosphorus (FRP) (µg/L) median values at sites in the Werribee River catchment (2015 - 2017), showing comparison to ANZECC trigger value.

5 Discussion

Water quality in the Werribee River catchment exceeded SEPP and ANZECC objectives for conductivity, turbidity, nitrogen and phosphorus at the majority of sites, except for Lerderderg River. Lerderderg River is located in a heavily forested section of the Wombat State Park, which results in reduced impacts from human activity above the Lerderderg weir. These areas have lower surface runoff, with higher evaporation rates than annual crops and pastures. This decreases recharge to groundwater and run off, so water quality in these regions is often higher (Goss, 2003).

Agriculture, tree clearing, urbanisation and water extraction occurs in the lower Lerderderg and upper, middle and lower parts of the Werribee River catchment. Agriculture such as crops and livestock damaging creeks can impact water quality as sediments and nutrients enter local waterways. Nutrients can also enter through discharges from septic tanks (EPA, 2018). Unauthorised river crossings and industries that extract water have also resulted in altered water regimes and poor water quality, degrading the waterway and surrounds (Ecology Partners, 2011; Melbourne Water, 2015).

5.1 Electrical conductivity

Electrical conductivity exceeded SEPP at all sites except for Lerderderg River. Basalt soils dominate the geology of the Werribee River catchment and salinity levels in the region are often naturally higher than in non-basalt regions. The highest values for conductivity in the Werribee River catchment also appeared to correspond with the Millennium drought, which lasted from late 1996 to mid-2010. A lack of rainfall causes low river flows, resulting in a higher concentration of salts and south-east Australia (including Victoria) was particularly badly affected (BOM, 2015). In 2010 and 2011, conditions changed due to the La Niña phase of the El Niño-Southern Oscillation (ENSO), which gave Australia its wettest two-year period on record. Rainfall was particularly heavy in south-east Australia and this period appears to correspond with lower conductivity values. In the last few years, the region has returned to a pattern of below average rainfall (BOM, 2015) and conductivity levels appear to be increasing again.

The Werribee River is also highly regulated, with extraction of water for agricultural and domestic purposes. This increases the likelihood of saline groundwater intrusion and reduces high flows which flush the system (Nielson, 2003). In many river systems, alternation of flows, though modification of temporal and spatial patterns has reduced the periods of high-flow/low salinity. This reduction in the frequency of high-flow (flushing events) is causing an accumulation of salt in river systems and a gradual increase in the mean concentration over time (Nielson, 2003). Other elements which increase salinity include pollution of surface water by runoff from industries, poor irrigation practices and runoff from intensively applied fertilisers and soil conditioners (PPWCMA, 2010).

Due to naturally higher levels of salinity, biota in the Werribee River catchment have adapted to these conditions. Freshwater crabs are found throughout the Werribee River and Toolern Creek, while fairy and shield shrimps also can be found in some smaller catchments (R. Akers personal communication, 2018). Despite naturally high levels, it is likely agricultural practices are contributing to the elevated concentrations seen in the catchment. Data suggests that values exceeding 1500 µS/cm (i.e. the SEPP objective value) are likely to adversely affect many freshwater biota (Nielson, 2003). Elevated levels of salinity can affect both aquatic plants and benthic animals with early life stages shown to be more sensitive than mature stages. For example, high salinity is usually inhibitory or toxic to seed germination of most freshwater plants. It can also inhibit emergence of microfauna from dormant eggs. Furthermore, the early stages of development for fish has been shown to be more sensitive to salt than the mature stages, with high levels reducing the likelihood of eggs surviving (Nielson, 2003).

ANZECC (2000) guidelines recommend that where trigger values are exceeded, further investigation should be conducted to determine impacts (Dunlop et al., 2005). Based on the results for Werribee

River catchment, additional examination is required to determine the effect of the high levels of electrical conductivity on aquatic biota. The use of environmental flows in the Werribee River during the summer is recommended to prevent water salinity becoming too high and threatening native fish populations (Jacobs, 2014).

5.2 Turbidity

Turbidity exceeded SEPP at Bacchus Marsh, Toolern Creek, Cobbledick's Ford and Wyndham Vale, with highest values at sites in the middle and lower reaches of the Werribee River catchment. The majority of the catchment is highly modified and many floodplains have been lost due to agriculture, urban development, road construction and recreational parks and facilities (NDDH, 2005, Jacobs, 2014). These disturbances combined with efficient drainage networks, results in the Werribee River catchment receiving a greater amount of sediment than under natural conditions (Jacobs, 2014). Lower base flows in the river also prevent the sediment from being transported out of the system, causing sections of stream bed to be clogged or smothered by fine sediment (Jacobs, 2014).

The loss of habitat due to increased sedimentation can result in a loss of biodiversity and a decrease in the aesthetic value of aquatic resources. Suspended solids can have a range of impacts, including (MPCA 2008):

- direct fish kills through due to blocked or damaged gills;
- reduced fish growth rates and their resistance to disease;
- prevention of fish egg and larvae development;
- modification of fish movements and migration;
- impacts on food availability;
- smothering of animal habitats, eggs and larvae.

High levels of turbidity can also reduce light availability which limits aquatic primary production, resulting in follow-on effects to aquatic food webs (Dunlop et al., 2005). Based on the levels seen in the Werribee River catchment, additional examination is needed to determine the likely impact the high levels of turbidity may be having on aquatic biota (EPA, 2003).

Methods to reduce the introduction of suspended solids from entering rivers include the use of conservation tillage measures and allowing urban runoff time to settle out before it reaches surface waters (NDDH, 2005).

5.3 Nutrients

Total nitrogen exceeded SEPP guidelines at all sites except for Lerderderg River. Nitrate and nitrite exceeded ANZECC guidelines at Lerderderg River, Bacchus Marsh, Toolern Creek and Cobbledick's Ford. Total phosphorus exceeded SEPP objectives at all sites except Lerderderg and Bacchus Marsh. Filtered reactive phosphorus was only exceeded at Bungey's Hole.

As seen in the previous results, at the majority of sites in the Werribee River catchment high levels of nitrogen and phosphorus were found. Nitrogen and Phosphorus levels have previously exceeded water quality objectives in the Werribee River catchment (EPA, 2000). This study (see EPA 2000) found water quality objectives for nitrogen were exceeded at two sites located in relatively pristine parts of the catchment (River at Bunding Blakeville Road and Little River at Little River Gorge). This suggests that nitrogen levels may be naturally high in some parts of the catchment (EPA, 2000). Regardless, high nitrogen levels in the Werribee River catchment are a concern, especially as eutrophication now happens frequently.

As the catchment is dominated by agricultural and urban land uses, high levels of nitrogen and phosphorus are not surprising. Sources of nitrogen may include: leaky septic tanks; the use of animal manure and inorganic nitrogen fertilisers; and runoff from construction sites (Carmargo, 2006).

Phosphorus additions likely include fertilizers manufactured from phosphorus, animal manures, and waste products from animals supplemented with phosphorus-enriched feed (Rabalais, 2002). Both nitrogen and phosphorus can enter rivers and streams via wastewater effluents and soil erosion (Rabalais, 2002).

In aquatic systems, nitrogen and phosphorus are essential nutrients for the growth and survival of aquatic plants. In a healthy system, these nutrients occur in small amounts. However, in high concentrations, nitrogen and phosphorous lead to the rapid growth of aquatic plants including phytoplankton, cyanobacteria ('blue-green algae') and macrophytes (Rabalais, 2002). Known as eutrophication, this process can degrade water quality, threatening desirable aquatic fauna and flora. Impacts include toxic effects from cyanobacteria, reduction in dissolved oxygen concentrations due to plants decomposition, reducing in-stream light availability and changes in biodiversity.

A decline in dissolved oxygen can cause extensive kills of both invertebrates and fish, reducing access to suitable habitat required for food, growth and reproduction of aquatic organisms (Carmargo, 2006). However, dissolved oxygen levels at all sites were above the recommended guidelines.

Nonetheless, concern has been expressed about potentially toxic blue-green algae blooms in the Werribee River catchment waterways. Algae can cause toxicity to aquatic and terrestrial animals through absorbing toxins from the water, drinking water with toxins or ingesting algal cells via feeding activity. Therefore, reducing levels of nutrients in rivers is important as elevated levels impacts aquatic organisms, ultimately contributing to the degradation of essential freshwater, estuarine and coastal ecosystem processes (Carmargo, 2006).

6 Recommendations

6.1 Measurement of additional parameters

Water quality has been traditionally used to measure river health. However, research suggests a suite of complementary variables is typically required to provide an accurate and robust picture of river health (Bond et al. 2012). Measurements of aquatic biota to identify structural or functional integrity of ecosystems is widely suggested, with a strong emphasis on sampling macroinvertebrate assemblage composition as an indicator of river health (Norris and Thoms, 1999; Boulton 1999). Aquatic invertebrates are ideal organisms for biological monitoring as they are sensitive to a variety of human disturbances. They are easy to sample, typically abundant and are critical to stream functioning (Morley and Karr, 2002; EPA, 2003).

To gain a better understanding of the consequences of water quality on aquatic biota, biannual macroinvertebrate sampling of Werribee River sites is recommended. Sampling should include a series of sites with a range of human activities, to better understand biological responses to human disturbances (Karr, 1999).

Melbourne Water run a Waterbug Census as part of Waterwatch and use an Agreed Level Taxonomy (ALT). This method should be used for macroinvertebrates sampling. The approach enables reliable identification of live specimens in the field without need for a microscope. ALT data sheets record data at two levels, including a measure of habitat diversity and a measure of biotic diversity including a SIGNAL score (Gooderham et al., 2010). SIGNAL is a simple scoring system for macroinvertebrate ('water bug') samples from Australian rivers, which provides a measure water quality in sampled rivers. Rivers with high signal scores are likely to have low levels of salinity, turbidity and nutrients such as nitrogen and phosphorus. They are also likely to be high in dissolved oxygen (Chessman, 2003). If macroinvertebrate assemblages indicate a healthy river, other ecological and human values are likely to be protected (Boulton, 1999).

6.2 Additional water quality testing

The Werribee River Association already tests for ammonium and reactive phosphate as these can be easily sampled in the field. However, due to the high levels of nutrients at sites in the catchment, it is recommended that testing for nitrate and nitrite also be conducted at Bungey's Hole. Nitrate/nitrite can be tested in the field as it does not require digestion and the findings will provide a clearer understanding of nutrient levels at Bungey's Hole. It is an important parameter to measure as it has shown correlation to algal overgrowth, and because nitrite- is toxic to fish.

7 Conclusion

The middle and lower reaches of the Werribee River catchment displayed the poorest water quality with values for electrical conductivity, turbidity and nitrogen and phosphorus, being exceeded at the majority of sites. The Werribee River catchment has been highly modified and impacts from intensive agriculture and urbanisation appear to be affecting water quality. Likely inputs include sediments and nutrients from agricultural activities and urbanisation. Extraction of water from the catchment is also likely to be degrading the waterway. The exception to this was the Lerderderg River, located in the upper catchment and least affected by human activities.

Sampling for aquatic invertebrates by the Werribee River Association, or associated volunteer groups, to complement their water quality sampling program is highly recommended. Additional water quality testing for nitrate and nitrite would also provide a clearer understanding of nutrient levels at Bungey's Hole and enable the findings to be placed in context to other catchment sites, where sampling for nitrogen and phosphorus occurs.

With rapid urbanisation of the Werribee River catchment, it is vital that a collaborative and holistic approach is taken to the management of the waterways, for the health of a growing community. Continued research is vital to determine the impacts that urbanisation, population growth, climate change and other threats are having on the catchment. The Werribee River Association will continue to initiate or be involved in research which will assist management authorities and others to benefit the health of the catchment.

References

Australian Government Bureau of Meteorology (BOM). 2015. Recent rainfall, drought and southern Australia's long-term rainfall decline, Commonwealth of Australia. Available at: http://www.bom.gov.au/climate/updates/articles/a010-southern-rainfall-decline.shtml [accessed 2nd February 2018].

ANZECC (2000). National Water Quality Management Strategy. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. [online] Available at: http://www.environment.gov.au/system/files/resources/53cda9ea-7ec2-49d4-af29-d1dde09e96ef/files/nwqms-guidelines-4-vol1.pdf [Accessed 22 January 2018].

ANZECC 1992. Australian water quality guidelines for fresh and marine waters. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council, Canberra.

Beasley, G. & Kneale, P. 2002. Reviewing the impact of metals and PAHs on macro invertebrates in urban watercourses. Progress in Physical Geography, 26, 236-270.

Bond, N., Speed, R., Gippel, C., Catford, J., Wei, L., Shichuang, W., Bunn, S. 2012. 'Assessment of river health in the Gui River', International WaterCentre, Brisbane, Australia. Available from: http://watercentre.org/portfolio/rhef/attachments/technical-reports/gui-river-river-health-report [accessed 2nd February 2018].

Boulton, A. J. 1999. An overview of river health assessment: philosophies, practice, problems and prognosis. *Freshwater Biology*, 41, 469-479.

Brismar, A. 2002. River systems as providers of goods and services: A basis for comparing desired and undesired effects of large dam projects. *Environmental Management*, 29, 598-609.

Chapman, D. 1992. 'Water quality assessments: a guide to use of biota, sediments and water in environmental monitoring' (2nd eds). United Nations Educational, Scientific and Cultural Organization, World Health Organization, United Nations Environment Program. Available at: http://www.who.int/water_sanitation_health/resourcesquality/watqualassess.pdf [accessed 26th February 2018].

Chessman B. 2003. 'SIGNAL 2 – A Scoring System for Macro-invertebrate ('Water Bugs') in Australian Rivers', Monitoring River Heath Initiative Technical Report no 31, Commonwealth of Australia, Canberra. Available at http://155.187.2.69/water/publications/environmental/rivers/nrhp/pubs/signal.pdf [accessed 19th February 2018]

Commissioner for Environmental Sustainability Victoria (2016). State of the bays. Victorian State Government, Melbourne. Available at http://www.ces.vic.gov.au/publications/state-bays-2016 [accessed 14th May 2018]

Dunlop, J., McGregor, G. and Horrigan, N. 2005. Potential impacts of salinity and turbidity in river ecosystems, The State of Queensland, Queensland State Government, pp 72. Available at https://www.ehp.qld.gov.au/water/pdf/potential-impacts-sal-tur.pdf [accessed 13th February 2018].

Ecology & Heritage Partners, 2013. 'Werribee River shared trail strategy'. Report for Melton City Council, Melton, Victoria, Australia, pp 95. Available at: http://www.melton.vic.gov.au/files/assets/public/council/about-council/council-meetingsminutes/2013/27-august-2013/item_11-16_-_appendix_1_-_werribee_river_trail_strategy.pdf [accessed 2nd February 2018]

Environment Protection Agency (EPA). 2009. 'Better bays and waterways – a water quality improvement plan for Port Phillip Bay and Western Port', EPA, Melbourne, Australia, pp. 148. Available at: http://www.epa.vic.gov.au/our-work/programs/~/media/Files/water/coasts/docs/BetterBaysWaterways-WQIP-FINAL.pdf [accessed 19th February 2018]

Environment Protection Agency (EPA). 2003. 'State Environment Protection Policy (waters of Victoria)', Policy Impact Assessment, EPA, Melbourne, Australia, pp. 101. Available at: http://www.epa.vic.gov.au/~/media/Publications/905.pdf [accessed 5th February 2018]

Environment Protection Agency (EPA). 2003. 'State Environment Protection Policy (waters of Victoria)', Policy Impact Assessment, EPA, Melbourne, Australia, pp. 101. Available at: http://www.epa.vic.gov.au/~/media/Publications/905.pdf [accessed 5th February 2018]

Gooderham, J., Sloane, T. and Tsyrlin, E. 2010. 'The ALT Method (Agreed Level Taxonomy)', The Waterbug Company, Australia. Available at: http://www.thewaterbug.net/attachments/ALT_methods_v1.2.pdf [accessed 19th February 2018]

Goss, K. F. 2003. Environmental flows, river salinity and biodiversity conservation: managing trade-offs in the Murray-Darling basin. *Australian Journal of Botany*, 51, 619-625.

Jacobs, 2014. 'Werribee River environmental flows review: Flow recommendations report'. Report to Melbourne Water, Melbourne, pp 104

Kuruppu, U., Haque, M.M. and Rahman, A. 2016. 'Water quality in urban rivers: a case study for the Hawkesbury-Nepean River System in Australia'. In Leung, J.Y.S. (Ed), Water resource problems and solutions, pp 15-26., OMICS Group eBooks, CA, USA. Available from: https://www.esciencecentral.org/ebooks/water-resources-problems-and-solutions/water-quality-in-urban-rivers-a-case-study-for-the [accessed 2nd February 2018]

Lloyd, L.N., Anderson, B.G., Cooling, M., Gippel, C.J., Pope, A.J. and Sherwood, J.E. 2008. 'Environmental Water Requirements of the Werribee River Estuary: Final Estuary Environmental Flows Assessment Report'. Lloyd Environmental Pty Ltd Report to Corangamite CMA, Colac, Victoria, Australia, pp 116

Melbourne Water, 2015. 'Werribee River Environmental Water Management Plan, Melbourne Water, Melbourne, pp 150

Nielsen, D. L., Brock, M. A., Rees, G. N. & Baldwin, D. S. 2003. Effects of increasing salinity on freshwater ecosystems in Australia. *Australian Journal of Botany*, 51, 655-665

Norris, R. H. & Thoms, M. C. 1999. *What is river health*? Freshwater Biology, 41, 197-209

North Dakota Department of Health (NDDH), 2005. 'Total Suspended Solids', North Dakota State Government, USA. Available at: https://www.ndhealth.gov/WQ/SW/Z6_WQ_Standards/WQ_TSS.htm [accessed 2nd February 2018]

Port Phillip and Westernport Catchment Management Authority, 2010. 'Port Phillip and Western Port salinity report', pp 29. Available from: http://www.ppwcma.vic.gov.au/Resources/PublicationDocuments/69/PPW%20Salinity%20Report_Section%201-3.pdf [accessed 15th December 2018]

Karr, J. R. 1999. Defining and measuring river health. *Freshwater Biology*, 41, 221-234.

Sherwood, J., Crook, D., Fairbrother, P. 2005. 'Werribee River Estuary Environmental Flows Requirements'. Report to Melbourne Water, Melbourne, pp 69.

Victorian Environmental Protection Authority (EPA), 2009. 'Better bays and waterways: a water quality improvement plan for Port Phillip Bay and Western Port'. Melbourne Water, Melbourne, pp 148. Available at: http://www.epa.vic.gov.au/our-work/programs/~/media/Files/water/coasts/docs/BetterBaysWaterways-WQIP-FINAL.pdf [accessed 5th February 2018]

Victorian Environmental Protection Authority (EPA), 2000. 'The health of streams in the Werribee catchment', EPA, Melbourne. Available at: http://www.epa.vic.gov.au/our-work/publications/publication/2000/june/698 [accessed 25th January 2018]