UNIVERSITY OF CANBERRA | CENTRE FOR APPLIED WATER SCIENCE

STATE OF THE ACT'S LAKES AND WATERWAYS 2011–2021: A TECHNICAL REVIEW

FINAL: February 2022

PREPARED FOR: *ACT Office of the Commissioner for the Environment and Sustainability*

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ACKNOWLEDGEMENT OF COUNTRY

The Centre for Applied Water Science staff and students acknowledge the Indigenous people of the lands on which they live and work and express their respect for Elders past, present and emerging. We commit ourselves to working in partnership to care for Country including all lands and waters.

Foreword

Executive summary

[to be completed by the Commissioners office]

Recommendations

The recommendations summarised here are detailed and supported by evidence throughout the review. Recommendations have been separated into those that are waterbody-specific and those that apply to urban water quality management across the Canberra area.

General/Canberra wide

- Responsibilities and management for urban water in the ACT urban area is undertaken by a range of ACT Government agencies with diverse community stakeholders. To ensure a clear, consistent understanding of roles, responsibilities, threshold values and monitoring requirements to achieve legislated and policy objectives, it is recommended that the ACT Government develops a framework/roadmap of responsibilities and document roles/hierarchies that contribute to determining outcomes in Canberra's urban water quality.
- Currently, there is no threshold value for nitrogen concentrations in Canberra's urban waterways. As such, it is recommended that the ACT Government establish threshold values for nitrogen to support the management of the urban waterways.
- Despite the articulation of policy objectives to manage ecological values in Canberra's urban waterways, there is no framework available to determine what those ecological values are nor how to determine their condition. It would be valuable to establish a set of indicators of ecological condition for all types of urban waterways to guide monitoring and management activities.

Lake Burley Griffin

- The factors driving algal blooms in Lake Burley Griffin are complex, and more detailed investigations are required to clearly understand key mechanisms to facilitate ongoing management of the lake.
- Review of the design and environmental impact assessments of the planned upgrade to the sewage treatment plant upstream of Lake Burley Griffin indicate that water quality outputs will not meet nutrient concentrations sufficient to ensure compliance with water quality guidelines and the National Capital Authority management targets for Lake Burley Griffin. It is recommended that a review of and improvements to the design and implementation of the planned upgrades to the Queanbeyan sewage treatment plant be undertaken to prevent greater impacts on Lake Burley Griffin from nutrient concentrations in outflows.

Lake Tuggeranong

- Lessening the incidence of cyanobacterial blooms in Lake Tuggeranong requires a reduction of nutrient inputs from storm events into the lake. Developing an understanding of the main catchment sources of nutrients during storms is recommended.

Lake Ginninderra

- The water quality and flow monitoring of Lake Ginninderra and its inflowing creeks have received considerably less attention than the other major Canberra lakes. There are limited data available to support an evaluation of the lake's performance and, perhaps more importantly, support predictions of future issues or management decisions. Given the urban expansion of the catchment, it would be prudent to invest in monitoring Lake Ginninderra and its inflowing creeks to ensure the existing high quality of water is maintained.

Urban creeks and rivers

- The many creeks and rivers of the Canberra urban area have a range of water quality outcomes. However, there is no key strategy or plan regarding these waterways. It is recommended that information and key values associated with ACT urban rivers and creeks be developed in order to be consistent with the documented values in rural rivers.
- Macroinvertebrate data are collected as part of the ACT Monitoring Program and Waterwatch. The two programs collect quite different data sets at different locations and use different approaches to data analysis. This can result in a different evaluation of ecological health within the creeks. While it is possible the differences observed are the result of differences in site characteristics, they could also be methodological. It is recommended that, to improve communication of the monitoring results, consideration be given to how the two programs could be better integrated to inform creek management.
- Programs that collect data relating to the urban creeks and rivers exist, but they are not well integrated or linked to a strategic management framework. There is a body of work that could combine the management of the urban creeks and rivers, develop planning and management documents, and build on existing programs and data sets to provide a better approach to managing the ACT's urban creeks and rivers.
- It is recommended that the ACT Government develop up to date information on the management and urban development being undertaken within the catchment of the lower Molonglo River. In most existing reports and strategies, including the ACT Water Strategy 2014–44, the Molonglo River is considered to be a non-urban system but, given the current extent of urban development that directly affects the lower Molonglo River and planned future urban development, the non-urban status will need to be updated.

Urban ponds and wetlands

- No long-term data are currently available to assess the performance of Canberra's urban ponds and wetlands. It is recommended that a comprehensive monitoring framework and program for implementation be developed to gain a greater understanding of the ecological services provided by Canberra's urban wetlands, including water quality outcomes and ecological values.

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Glossary

Term	Description
Ammonia	The amount of ammonia in the sample.
Catchment	An area of land from which water flows to a waterbody such as a creek, river, wetland or lake.
Cyanobacteria	A division of photosynthetic bacteria (formerly known as blue-green algae) that can produce strong toxins.
Dissolved oxygen	A measure of free oxygen that is dissolved in a water sample.
Dissolved reactive phosphorus (DRP)	A measure of the orthophosphate in the sample. It is the reactive fraction of total dissolved phosphorus (TDP) and provides an estimate of the biologically available phosphorus in the sample.
Faecal coliform	A bacteria which is associated with human and animal wastes.
Total phosphorus (TP) and Total nitrogen (TN)	A measure of the total amount of phosphorus and nitrogen present in the sample. An oxidative digestion of the sample is completed before measurement.
Total dissolved phosphorus (TDP) and Total dissolved nitrogen (TDN)	The dissolved fraction measured after the sample is passed through (typically) a 0.45 μm filter. While this fraction includes colloids and is not truly dissolved, 0.45 μm filters are commonly used in nutrient studies to obtain an indication of the dissolved portion of the nutrients in a sample.
Nitrate and nitrite (NOx)	The concentration of oxidized forms of nitrogen in the sample.
Total organic carbon (TOC)	A measure of the total amount of carbon in organic compounds in a water sample.
Total suspended solids (TSS)	A measure of the suspended particles (that are not dissolved) in a sample of water that can be trapped by a filter.

Acknowledgements

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1. Introduction

In February 2021, the ACT Minister for the Environment requested the Office of the Commissioner for Sustainability and Environment (OCSE) undertake an investigation on the state of lakes and waterways in the ACT. The Centre for Applied Water Science (CAWS) at the University of Canberra (UC) has been contracted by the OCSE to contribute to the investigation by undertaking a review of the water quality and ecological condition of ACT lakes and main urban waters.

The condition of Canberra's waterways was last reviewed in 2012, with a report issued by the Commissioner for Sustainability and the Environment on the state of the watercourses and catchments for Lake Burley Griffin (Neil 2012). The current review is designed to update that work and expand it to the other major urban waterways of the ACT.

1.1. Scope

The aim of this review is to provide an updated understanding of the condition of the aquatic ecosystems of the ACT, particularly the receiving waters within the urban environment and areas of land development. The review is limited to those waterbodies within the Canberra urban area that provide social and ecological services and are influenced by urban water inputs. The review is based on information from existing monitoring and research reports, as well as monitoring data that have been published since 2012. In doing so, we have incorporated a review of the monitoring and research activities that are currently being undertaken to identify key gaps and areas for improvement.

The review is focused on the major urban waterways of Canberra and includes:

- the major lakes: Lake Burly Griffin, Lake Tuggeranong and Lake Ginninderra
- the urban creeks: including Ginninderra Creek, Tuggeranong Creek, Sullivans Creek, Yarralumla Creek and others for which monitoring data are available
- Molonglo River upstream and downstream of Lake Burley Griffin
- the constructed urban ponds and wetlands within the urban areas.

The review examines the changing conditions observed in the identified waterways over the last decade and considers these in response to factors such as urban change, land development and climate change.

1.2. About this report

This report describes the findings of this review. It is structured to provide an overall evaluation of the state of Canberra's urban waterways, grouped by waterbody or group of waterbodies. This evaluation is supported by a series of technical appendices that provide waterbody-specific details. For the more technically-minded reader, starting with the technical appendices then reading the overall evaluation is recommended.

2. Assessing the state of the ACT's urban waterways

Urban waterways are the rivers, lakes and wetlands that occur in urban environments or receive stormwater runoff from an urbanised catchment. Urbanisation poses significant challenges for waterways. The high proportion of impervious surfaces in urban areas results in high peak flows that often carry elevated concentrations of sediment, nutrients and other pollutants (Paul and Meyer 2001; Walsh et al. 2005). These peak flows and polluted waters pose risks to people, infrastructure and downstream ecosystems.

Many of the waterways that occur in urban areas have been specifically constructed or modified to manage the impacts of urban runoff. Urban streams can be lined with concrete to efficiently and effectively transport flows away from houses and other suburban development, while urban lakes and ponds are built to attenuate flood peaks and protect downstream waterways. These constructed waterways can become highly valued by the community, and urban waterways are increasingly being recognised as providing a range of positive outcomes for urban communities, and for playing a central role in shaping sustainable cities (Haase 2015). If well maintained, urban waterways and the land around them provide opportunities for recreation, environmental education and enhancing social wellbeing (Foley and Kistemann 2015; Haeffner et al. 2017; Hunter et al. 2019). This is in addition to their roles in climate regulation, pollution control, flood risk mitigation and habitat provision.

The urban waterways of Canberra are highly modified, frequently fabricated aquatic ecosystems, ranging from large open lakes that provide a focal point for the national capital to small concrete-lined creeks that efficiently transport water away from suburban developments. The variety of lakes, ponds, streams, wetlands and rivers deliver both stormwater management outcomes and community amenity and important ecosystem services. Importantly, the Canberra community values these waterways for the recreational opportunities they afford, as well as the biodiversity and corresponding visual amenity they provide (Schirmer et al. 2018). The combination of stormwater management, community amenity and ecosystem services are the 'values' held by the urban waterways, and this confers a set of expectations around the way they function, the types of ecosystems they support and their water quality.

2.1 Approach

A multi-faceted approach was used in this review to assess the state of waterways in the ACT. A review of existing policy documents, scientific investigations and compliance requirements was undertaken. Considerable attention was directed at a detailed quantitative analysis of monitoring data to understand the trends in water quality conditions since 2012. To focus the assessment, the values associated with the waterways were linked to a set of indicators of condition (Table 1). The intended uses (sometimes termed 'designated uses') for each of the waterbodies defined the values, that were then linked to expected functions, water quality and ecological character. These were then linked to primary indicators (the immediate measures that indicate if the waterway meets expectations) and secondary indicators (measures of factors that may contribute to the capacity of the waterway to meet expectations). These condition indicators formed the focus of this document review and the quantitative analysis. Further details about the indicators and threshold values are detailed in Technical Appendix A — water quality indicators and threshold indicators.

Table 1. Values associated with Canberra's urban waterways and indicators of condition.

Values/Expectations	Primary indicators	Secondary indicators
Stormwater management		
Water quality improvement	Cyanobacteria concentrations Nutrient concentrations Heavy metal concentrations Turbidity/Total Suspended Solids	
Community amenity: recreation involving primary and secondary contact		
The water does not pose a risk to human health	Cyanobacteria concentrations Faecal coliforms *Enterococci* bacteria pH Lake closures	Nutrient concentrations Pollutant concentrations
Community amenity: visual attractiveness		
No algal scums **Colour and odours** **Clear water** **Lack of visual pollutants** **Presence of a diversity of habitat** **Presence of a diversity of animals** **Lack of nuisance plant growth**	Cyanobacteria concentrations Turbidity/Total suspended solids Litter Colour and odour Aquatic macrophytes and riparian plants Fish, frogs and birds	Nutrient concentrations Pollutant concentrations Chlorophyll a
Freshwater aquatic ecosystems: habitat and suitable water quality		
Diversity of plants **Riparian condition** **Lack of nuisance plant growth**	Cyanobacteria concentrations Phytoplankton Aquatic macrophytes Riparian plants	Chlorophyll a
Water quality appropriate to the protection of freshwater aquatic ecosystems	Dissolved oxygen concentration Electrical conductivity pH Nutrient concentrations Toxicant concentrations Turbidity/Total suspended solids Macroinvertebrate community	

2.2 Document review

Reports and published scientific literature were sourced from the author's own report repositories, those available to the OCSE, and ACT Government reports and searching the published scientific literature. These were reviewed to provide:

1. the historical context relating to water quality and ecological character of Canberra's urban waterways
2. information about the current water quality and ecological character of Canberra's urban waterways
3. information about the future threats to the water quality and ecological character of Canberra's urban waterways.

2.3 Data Analysis

Water quality and ecological data were compiled from a variety of sources for use in this review (Table 2). The primary data sources were the NCA monitoring data set (2010–2021), the ACT Water quality database (2010–2021), the ACT Waterwatch database (2010–2021) and the Urban stormwater research data set from UC (2017–2020). These comprised time series water quality and ecological data from waterways across Canberra. The water quality data were augmented with meteorological data (Bureau of Meteorology), stream discharge data (Bureau of Meteorology) and spatial data sets (ACT and NSW Governments).

Water quality and ecological data were reviewed to select sites with continuous or frequently collected data for the 2010/11 to 2020/21 period. Where available, additional data sets were used to augment understanding of specific catchments or locations.

Water quality data

Time series of all monitoring parameters were initially produced from the water quality data sets from 2010/11 to 2020/21 to highlight patterns in the data, relationships between parameters and any results that may inform key waterway processes. Time series data were analysed to determine the proportion of time where water quality met acceptable levels and to identify trends that may provide an indication of future trajectories. These analyses are included in the technical appendices for each of the specific waterbodies.

Ecological data

Time series were produced from the ecological data sets for the period 2010–2020/1 to highlight patterns in the data and key trends that may inform key processes. These analyses are included in the technical appendices for each of the specific waterbodies.

Table 2. Details of the data sets used in this review.

Data set	Attributes	Time period	Source
NCA monitoring data set	Nutrients from in-lake sampling Dissolved oxygen concentrations Phytoplankton data Water quality attributes	2010–2021	NCA data
ACT Water Quality database	Water quality attributes Phytoplankton data	2011–2021	ACT Government Lakes and Rivers Water quality monitoring program
ACT Waterwatch database	Water quality attributes Riparian vegetation condition Macroinvertebrate data	2011–2021	ACT Waterwatch
Lake Tuggeranong research project data	Nutrients from catchment and in-lake sampling Dissolved oxygen Phytoplankton data	2017–2020	University of Canberra (Ubrihien et al. 2019b)
Urban ponds research project data	Nutrient concentrations (Total nitrogen, total phosphorus, dissolved reactive phosphorus, nitrate and nitrite and ammonia)	2017–2019	University of Canberra (Ubrihien et al. 2019a)
Bowen Park	Nutrient concentrations: Telopea Creek	2018–2019	ACT Healthy Waterways Landuse Monitoring Program
Weather and stream discharge	Rainfall Temperatures Stream discharge	2010–2021	Bureau of Meteorology (http://www.bom.gov.au) ACT Healthy Waterways Landuse Monitoring Program
Spatial data	Landuse	N/A	ACT Government online mapping resources (https://actmapi-actgov.opendata.arcgis.com/) NSW Government data server (https://datasets.seed.nsw.gov.au/dataset/nsw-landuse-2017-v1p2-f0ed)

3. Weather context

The past 10 years have been characterised by a series of extremes in weather conditions across the ACT (Figure 1 and Figure 2). Temperatures across the region have been above to well above average in eight of the 10 years, but rainfall has been highly variable. Very wet conditions prevailed between 2010 and 2012 as the millennium drought broke, and wet conditions also occurred in 2016 and 2020. The period from 2017 to 2019 were increasingly hot and dry, culminating in the hottest year on record in 2019, leading into the major summer bushfires of 2019–20. Such extremes place the regions waterways under considerable stress, with stream flows ranging from some of the highest to lowest on record.

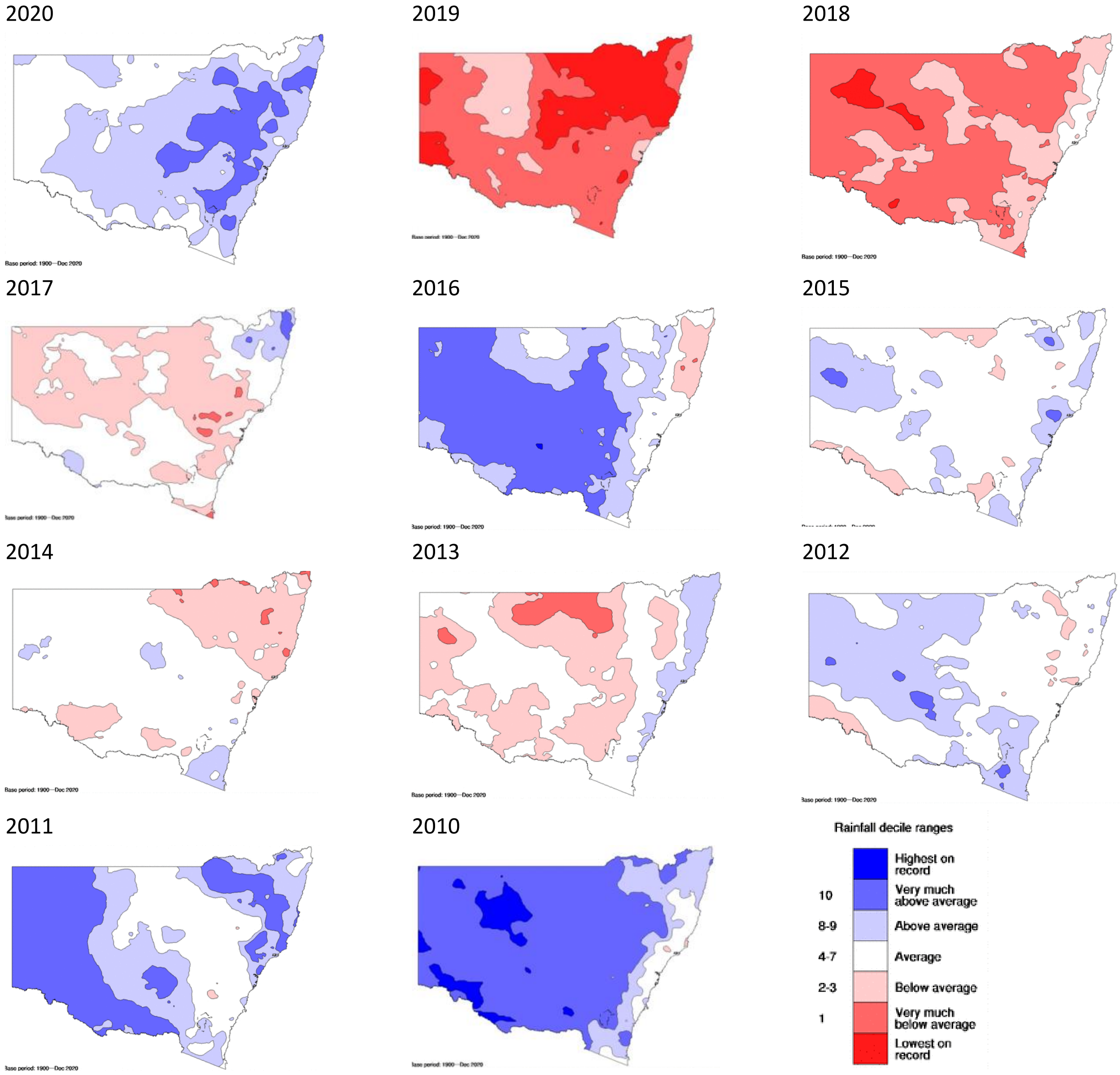
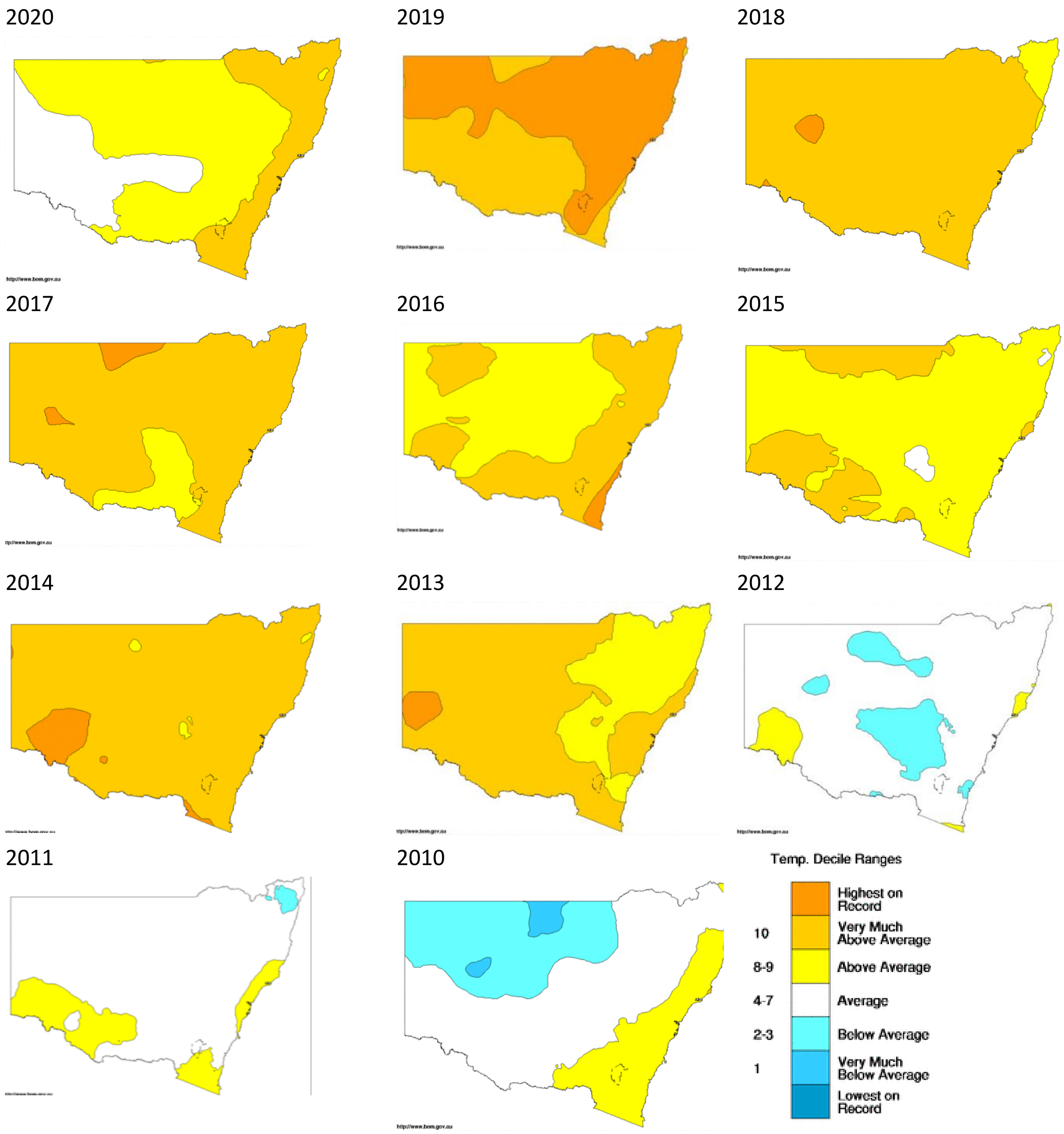


Figure 1. Rainfall deciles for NSW and the ACT from 2010 to 2020.
Images sourced from the Bureau of Meteorology (http://www.bom.gov.au/climate/maps/)


2020 2019 2018

2017 2016 2015

2014 2013 2012

2011 2010

Figure 2. Temperature deciles for NSW and the ACT for from 2010 to 2020.
Images sourced from the Bureau of Meteorology (http://www.bom.gov.au/climate/maps/)

4. The state of ACT lakes

This review covers the state of the three main lakes in the ACT: Lake Burley Griffin, Lake Tuggeranong and Lake Ginninderra. The technical analysis underpinning the assessment is included in Appendices B, C and D, and the reader is encouraged to refer to the material in the appendices to better understand the interpretation provided here.

Water storage in the Canberra urban area is dominated by three constructed urban lakes, which capture a large portion of urban runoff (Table 3).

Table 3. Lake surface area, catchment area and urban catchment area for the three main Canberra lakes.

	Catchment area (km^2)	Urban catchment area (km2)	Lake surface area (km^2)	Ratio urban area/Lake surface area
Lake Burley Griffin	183.5	9.1	6.64	0.72
Lake Ginninderra	98.8	45	1.05	0.023
Lake Tuggeranong	61	31	0.57	0.018

4.1 Lake Burley Griffin

Lake Burley Griffin is an artificial lake in the centre of Canberra that was created by the construction of a dam on the Molonglo River. It was first filled in 1964 and forms the centrepiece of Walter Burley Griffin's design for Canberra, representing a focal point for the local community and the many visitors to the national capital. While the lake is an important aesthetic and recreational feature for Canberra, it also serves to improve the quality of water flowing downstream from the urban centre and provides valuable habitat for a variety of water-dependent species.

The lake has a total surface area of 6.64 km^2, an average depth of 4 metres and a maximum depth of almost 18 metres near Scrivener Dam (National Capital Authority 2020). It drains a catchment area of approximately 1,866 km^2 (Maher et al. 1992; Neil 2012), comprising a mix of urban (5%), rural (68%) and conservation/recreation (27%) land uses (Appendix B).

Major inflows to the lake include the Molonglo River (which receives water from the Queanbeyan River and Woolshed Creek), Jerrabomberra Creek and Sullivans Creek (Table 4 and Figure 3). There is also a range of smaller urban streams and stormwater drains that deliver water to the lake. Most of the flow into the lake comes from the Molonglo River (Table 4), contributing more than 90% of the inflows in most years. However, during dry years, the proportion of inflows from the urban catchments increases notably, with estimated contributions of up to 27%.

It is important to note that the input from the Queanbeyan Sewage Treatment Plant is below the gauging station at Oaks Estate, therefore the inflows recorded from the Molonglo River do not incorporate the contribution from the plant.

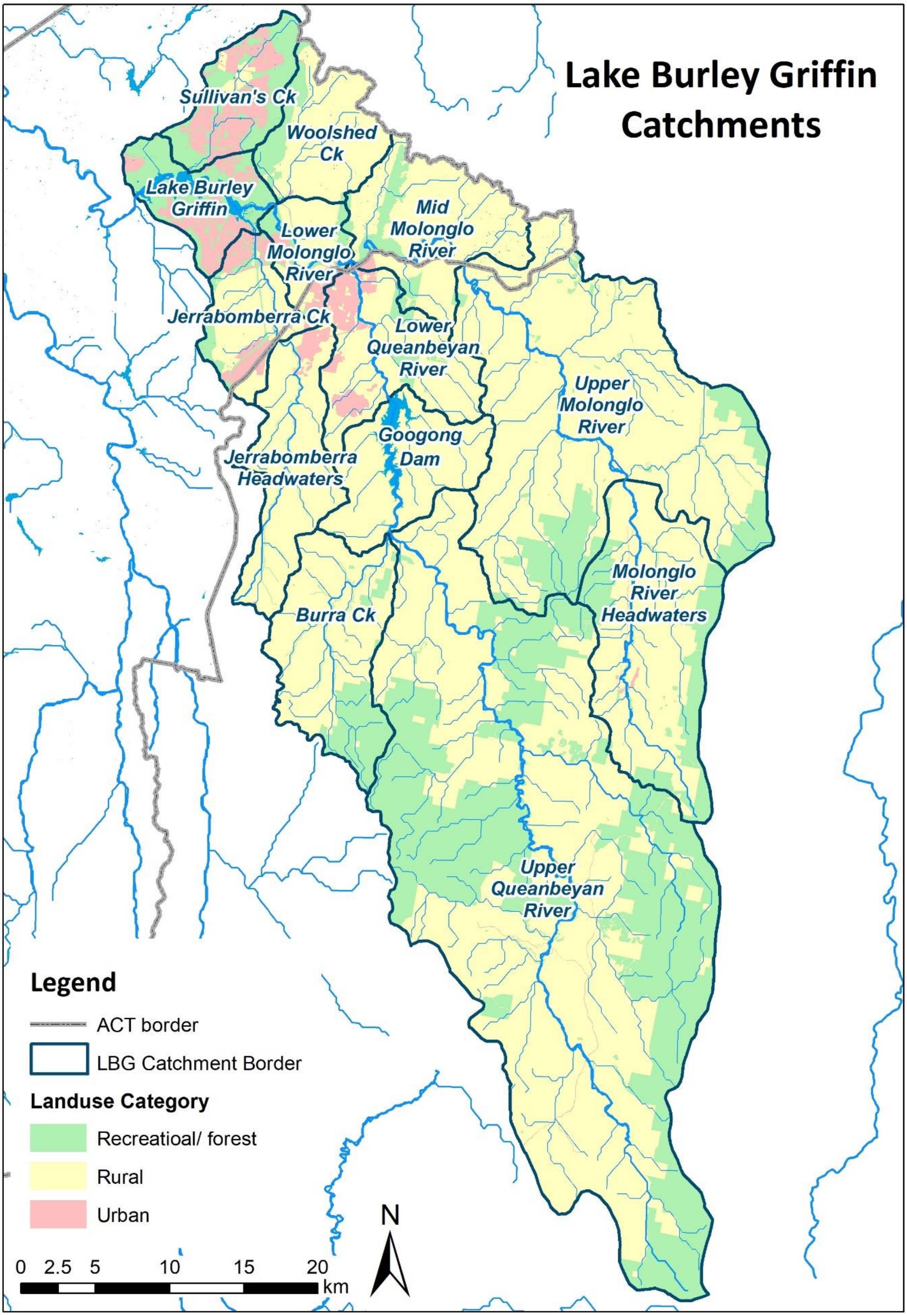


Figure 3. Map of the main catchments draining into Lake Burley Griffin showing the distribution of different landuse categories.

Table 4. Hydrological metrics for the major inflows to Lake Burley Griffin.
Data sourced from the Bureau of Meteorology Water Data Online (http://www.bom.gov.au/waterdata/). Note that data for 2021 are only to 15 December.

Annual Flow metrics					
Station (period of record)		Mean (ML/yr)	Median (ML/yr)	Max (year)	Min (year)
Molonglo River	Oaks Estate 410729 (1964–2021)	112,930	72,898	617,518 (1974)	3,733 (2004)
Jerrabomberra Creek	Hindmarsh Drive 410790 (2014–2021)	3,717	1,841	9,925 (2020)	569 (2016)
Sullivans Creek	Barry Drive 410775 (1987–2021)	5,174	4,134	12,914 (2021)	1,178 (2006)
Outflow: Molonglo River	Below Coppins Crossing 410756 (1979–2019)	117,795	70,746	566,380 (1989)	8,160 (1982)

Lake Burley Griffin is considered to be an essential part of what defines Canberra (NCA 2009) and is highly valued for its recreational use and aesthetic qualities. The lake is managed by the National Capital Authority (NCA) on behalf of the Commonwealth of Australia, who have responsibility for the lake itself and the foreshore areas. The ACT and NSW Governments are responsible for managing the catchment areas that drain into the lake.

The approach to managing the lake is set out in the National Capital Plan (NCA 2016). This document identifies the lake as an integral part of the design of Canberra and a key focus of planning for the National Capital. The 2016 plan identifies a series of objectives for Lake Burley Griffin and its foreshores that aim to enhance and develop the connection to the lake. These include extending waterfront activities and developing visitor and recreation experiences associated with the lake. These rely on the protection of water quality in the lake, a point that is explicitly noted in the 2016 plan through objectives to 'maintain the water quality in a manner designed to protect Lake Burley Griffin and Foreshore's visual and symbolic role' (NCA 2016 p 167).

The Lake Burley Griffin Water Quality Management Plan (NCA 2011) is the main document that sets out the objectives and strategies for managing water quality, and it remains current in 2021. It draws objectives from the 1995 Lake Burley Griffin Management Plan (NCA (1995);

Table 5), along with national and local water quality guidelines, to establish benchmarks for water quality parameters and recommend actions required to achieve those benchmarks.

Table 5. Key requirements for the quality of water in Lake Burley Griffin, as outlined in the Lake Burley Griffin Water Quality Management Plan (NCA 2011).

- Promoting the ornamental and visual values of the lake, as intended by the National Capital Plan.
- Maintaining the lake as a viable and stable ecosystem that encourages the development of plant and animal species in order to protect the ecological, aesthetic and scientific values of the lake and its foreshores.
- Having an acceptable 'quality of flow' regime that enables the lake to be utilised as a water quality control pond to maintain, as far as practicable, downstream water quality and flow.
- Maintaining acceptable water quality to support the recreational and commercial functions of the lake.

4.1.1 The current state of Lake Burley Griffin

The state of Lake Burley Griffin can be assessed using evaluation questions that address how well the lake meets the key requirements shown in

Table 5 above:

- Is the water in the lake of acceptable quality to support its recreational and commercial functions?
- Do the aquatic ecosystems and water quality of the lake provide the expected ornamental and visual values?
- Does the lake display stable aquatic ecosystems that provide the expected ecological, aesthetic and scientific values of the lake and its foreshores?
- How effectively is the lake acting as a water quality control pond to maintain downstream water quality and flow?

Addressing these questions draws on supporting material included in the Lake Burley Griffin Technical Appendices (Appendix B).

Is the water in the lake of acceptable quality to support its recreational and commercial functions?

Lake Burley Griffin has a history of water quality problems that have affected the recreational and commercial functions of the lake, including nuisance plant growth (a function of high nutrient concentrations), cyanobacterial blooms and faecal pollution. The current lake water quality issues that affect recreation and commercial activities are confined to cyanobacterial blooms and high Enterococci concentrations, with concentrations of all other water quality parameters typically within the acceptable range for recreational and commercial activities.

Between 2010 and 2020, Lake Burley Griffin was closed to recreational activities for at least some of the recreational season each year due to either cyanobacterial blooms or high Enterococci concentrations. Closures have varied in duration: the lake has generally been open to recreation for more than 70% of the recreation season and, in five of the past 10 years, has been open to recreation for more than 90% of the recreation season. Based on inference from the data presented in Neil (2012), closures have been more frequent in the past 10 years than the preceding 10 years, suggesting that there is an increase in cyanobacterial problems in the lake.

Previous OCSE reporting (Neil 2012) identified that, as an inland urban lake subject to high summer temperatures and solar radiation, mild wind speeds in late summer and autumn and high nutrient concentrations, algal blooms are likely to persist in Lake Burley Griffin. This has played out in the lake over the past 10 years, with high to extreme concentrations of cyanobacteria occurring in most years, albeit not always resulting in significant periods of lake closures. While it had been suggested by Neil (2012) and Dyer et al. (2020) that blooms were related to dry years, this has not been evident in the past two years, suggesting that the drivers of blooms in the lake is complex and more detailed investigations are required to clearly understand the key mechanisms.

Recent research suggests that the key driver of cyanobacterial blooms in the lake may be the release of nutrients that are stored in lake sediments. If this is the case, it is likely that blooms will continue to occur with increasing frequency unless interventions are undertaken to manage the supply of nutrients from the sediments. Importantly, the authors of the research have noted that their findings are limited by the lack of water column data that would enable them to test this hypothesis and better inform management options (Dyer 2020).

Between 2011 and 2018, there was a steady decline in phosphorus concentrations in the surface waters of the lake, suggesting substantial improvements in the nutrient status of the lake. This was promising because concentrations were approaching levels at which cyanobacterial blooms could become phosphorus limited. The reasons for the reduction in phosphorus concentrations are not clear and, unfortunately, the surface water phosphorus concentrations increased in 2020 and 2021 (Figure 27). This may be a function of the increased rainfall and runoff that occurred in these years. Further details including data trends are available in Technical Appendix B.

Do the aquatic ecosystems and water quality of the lake provide the expected ornamental and visual values?

While the expected ornamental and visual values of Lake Burley Griffin are poorly articulated in the Lake Burley Griffin Water Quality Management Plan, it is assumed that the primary expectations are that the lake is free of algal blooms and rubbish. The aquatic ecosystems and water quality of the lake provide the expected ornamental and visual values for the national capital more than 90% of the time. The annual cyanobacterial blooms experienced by the lake detract from the ornamental and visual values of the lake, but it should be noted that they are only a problem for the lake for relatively short periods of time in each year (typically late summer into autumn).

The shores of Lake Burley Griffin range from the paved and manicured foregrounds of Canberra’s landmark buildings in the central basin to the urban parklands and beaches of the east and west basins. The paved and manicured foregrounds provide the expected ornamental and visual values of the central basin while being almost completely devoid of natural ecosystems processes. The parklands comprise a mix of native and exotic vegetation, the condition of which is defined by the level of management effort. Like all urban parklands, they are subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation.

Does the lake display stable aquatic ecosystems that provide the expected ecological, aesthetic and scientific values of the lake and its foreshores?

There has been minimal change in the aquatic ecosystems of Lake Burley Griffin over the past 30 years. The loss of aquatic macrophytes that were prevalent in the east basin and between Springbank Island and the Acton Foreshore in the 1980s has not been reversed, suggesting that the lake is now in a relatively stable phytoplankton dominated state. The algal communities occurring in the lake vary throughout the year, displaying the expected algal successional processes of a reasonably nutrient rich environment. It is notable that the prevalence of extreme cyanobacterial concentrations has increased over the past 10 years and is likely to be a regular feature, given the phosphorus concentrations in the lake’s surface waters.

How effectively is the lake acting as a water quality control pond to maintain downstream water quality and flow?

One of the key functions of Lake Burley Griffin is to improve water quality along its length, as sediment and nutrients settle in the lake’s slow flowing waters. The expected water quality improvements are reflected in water quality guidelines that specify lower values for turbidity and nutrients in the west basin than the east basin. While there is generally a reduction in mean annual turbidity along the lake, with values higher in the east basin than the west basin, nutrient concentrations largely remain unchanged across the lake.

However, the water quality attenuation performance of the lake is complex. Despite the observed reduction in mean annual turbidity along the lake, the turbidity recorded in the Molonglo River downstream of the lake is broadly like that of the inflows from the Molonglo River upstream and from Sullivans Creek. Nitrogen concentrations in the Molonglo River downstream of the lake are typically slightly lower than those entering from the Molonglo River upstream and are generally like those of Sullivans Creek. Importantly the lake effectively mitigates the potential effects of phosphorus from its urbanised tributaries, with phosphorus concentrations in the Molonglo River downstream of the lake very similar to those recorded in the Molonglo River upstream of the lake and considerably lower than those from its urbanised tributaries. In combination, the lake is effectively acting as a water control pond and is mitigating some of the effects of urbanisation for the downstream receiving waters.

4.1.2 Knowledge gaps

The data review conducted by Dyer (2020) suggested that internal sources of nutrients are likely to be an important driver of cyanobacteria blooms in Lake Burley Griffin; but there is a reasonable uncertainty associated with the data because of very limited data from the bottom waters of the lake. These authors recommended that additional data collection is needed to confirm that internal sources of nutrients are driving cyanobacteria blooms. This requires the relative contributions of internal and external sources of available nutrients are quantified for the lake.

Annual weather conditions are a major determinant of the relative contributions of inflows to the lake. A greater proportion of the inflows to the lake are from urban areas during dry years than during the wetter years. However, the relative contributions from the urban areas are currently estimates as there is only information about inflows from Sullivans Creek, a few years of data from Jerrabomberra Creek (which has limited urban development within the catchment) and minimal data from Telopea Creek. Given the importance of the urban catchments for delivering nutrients (likely in a dissolved form) and carbon to Lake Burley Griffin, an understanding of the urban inflows to the lake from the stormwater network on the south of the lake is needed.

The steady decline in phosphorus concentrations in the surface waters of the lake between 2011 and 2019 had the potential to provide considerable benefit to the lake. The decline is matched in the concentrations of phosphorus recorded in the Molonglo River upstream of the lake, but the reasons for the decline are not clear. It is possible that the major driver has been the lower flows for much of this time period, as the years in which higher flows were recorded have had higher phosphorus concentrations. Given the concentrations of phosphorus in 2018 and 2019 were approaching levels at which it is expected the algal blooms would be limited by the availability of nutrients, further investigation to understand the drivers of the lower phosphorus may assist in the ongoing management of nutrient concentrations and algal blooms in the lake.

4.2 Lake Tuggeranong

Lake Tuggeranong is an artificial lake in the south of Canberra, adjacent to the Tuggeranong Town Centre, created by the damming of Tuggeranong Creek in 1987. The lake was filled in 1990, coinciding with the urban development of the region (SMEC 1988). The lake is surrounded by a commercial district to the west, which has seen high density urban infill occurring since 2019. On the eastern side of the lake, there is a mix of urban dwellings and recreational spaces.

Lake Tuggeranong was originally designed as a settling basin to trap soil and debris from the surrounding urban catchments before it entered the Murrumbidgee River. In doing so, it provides water quality improvement to stormwater discharge from the local catchments and urban centres. Lake Tuggeranong was also designed to provide a space for recreation, exercise, play and conservation for the Tuggeranong Community, proximal to the southern town centre. Primary contact recreation[1] occurs at several beaches around the lake, with kayakers using the whole of the lake. In recent years, the ACT Government has allowed the use of electric powered watercraft on Canberra's urban lakes, including Lake Tuggeranong. Users are now permitted to take on electric powered fishing boats to provide an additional recreational use. The main body of Lake Tuggeranong is surrounded by a 6.7 kilometre recreational circuit that is used by walkers, joggers/runners and cyclists. As well as the circuit, Tuggeranong Park is located on the lake foreshore, which has a man-made beach, BBQ's, toilets, a skate park, a children's playground and a stage for community events. These amenities are used throughout the year by residents seeking quality outdoor living in well-kept surrounds.

The character, amenity and aesthetics of the lake, its foreshores and its recreational uses are greatly valued by the Tuggeranong Community. Lake Tuggeranong has a history of water quality issues, with frequent closures to recreational use because of high concentrations of cyanobacteria (Ubrihien et al. 2019b). This is of significant concern for residents, who are keen to see improvements.

The lake has a total surface area of 0.57 km^2, with a maximum depth of 13 metres near the centre of the lake and a capacity of 1.8 gigalitres (Bureau of Meteorology 2021). It drains a catchment area of approximately 61 km^2, comprising a mix of urban (50%), rural (20%) and conservation/recreation (30%) landuses (Figure 4). The major inflows include Tuggeranong Creek (the original flow path dammed to create the lake), Village Creek, Kambah Creek and Oxley inflow. These inflows all largely carry and discharge stormwater. All inflows to Lake Tuggeranong are ungauged, although Tuggeranong Creek has a water level recording station at the Weir (Table 6). There are also a range of additional smaller urban streams and stormwater drains that deliver water to the Lake. Flow downstream of the lake is just under 10,000 megalitres/year (Table 6).

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[1] Primary contact recreation is defined as whole-body contact with the water. It involves frequent immersion or the possibility of ingesting water. Examples include swimming and windsurfing as well as novice participation in some water sports.

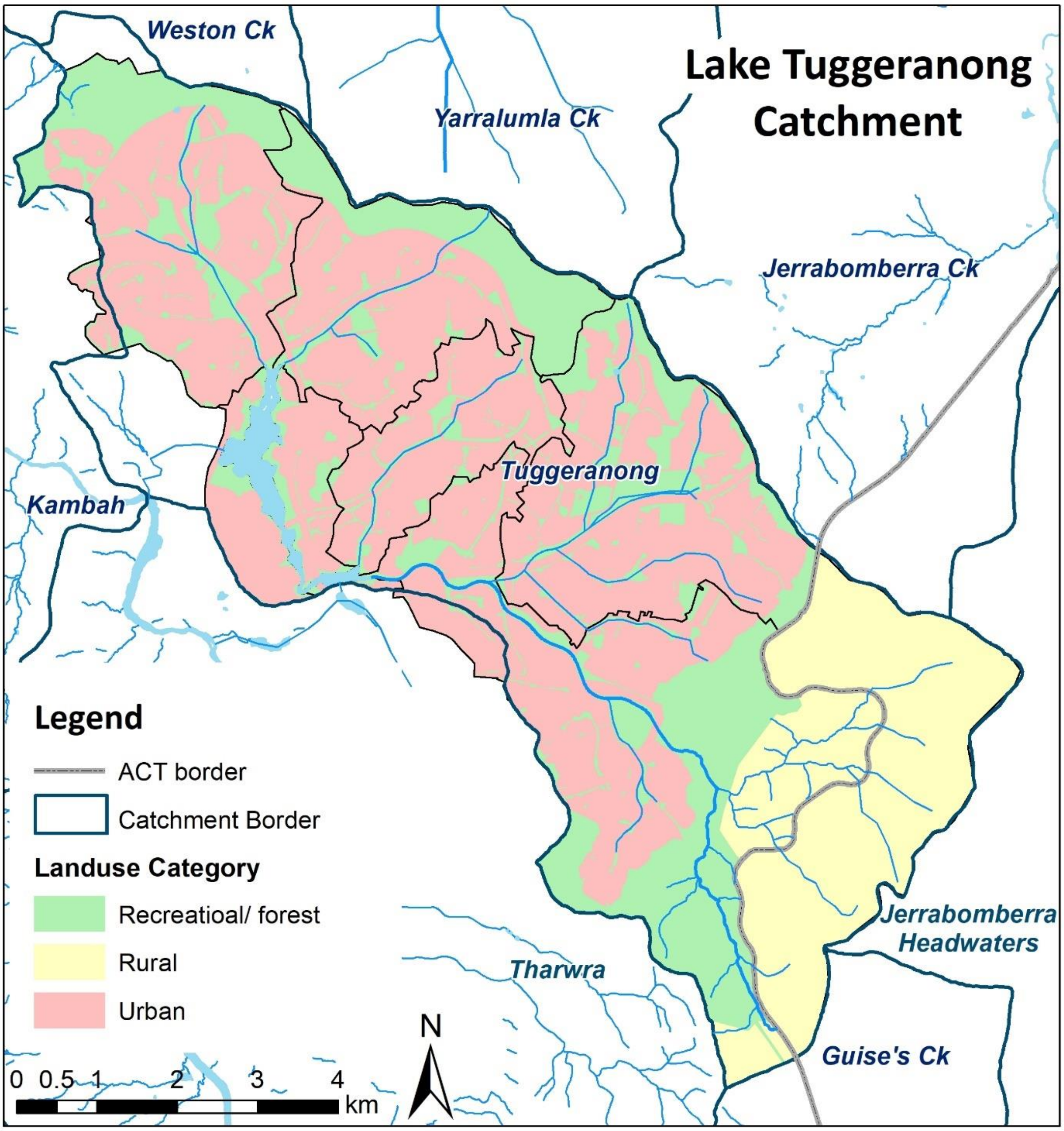

Figure 4. Map of the main catchments draining into Lake Tuggeranong showing the distribution of different landuse categories.

Table 6. Hydrological metrics for the major inflows to Lake Tuggeranong.
Data sourced from Environment, Planning and Sustainable Development Directorate (https://www.data.act.gov.au/Environment/ACT-Streamflow-and-Rainfall-Data-Daily-Data/v9nd-cfqv)

Annual Flow metrics					
Station (period of record)		Mean (ML/yr)	Median (ML/yr)	Max (year)	Min (year)
Tuggeranong Creek	Lake Tuggeranong Weir 410771 water level only	unavailable	unavailable	unavailable	unavailable
Village Creek	Not measured	unavailable	unavailable	unavailable	unavailable
Kambah Creek	Not measured	unavailable	unavailable	unavailable	unavailable
Wanniassa Stormwater	Not measured	unavailable	unavailable	unavailable	unavailable
Outflow: Tuggeranong Creek	Tuggeranong Creek U/S Sewer Crossing 410779 (1986–2021)	9,867	9,295	24,903 (2010)	2,817 (2019)

Lake Tuggeranong is an important recreational, visual and functional asset for Canberra and the Tuggeranong community. The ACT Government is responsible for the management of the lake, the foreshore areas and the surrounding catchments. The approach to managing the lake is documented in Canberra's Urban Lakes and Ponds Plan of Management (ACT Government 2001), an update of which was published in draft form in 2019 (ACT Government 2019b). While the most recent draft is yet to be finalised, the authors have used it to identify the recreational, cultural and management values associated with Lake Tuggeranong (Table 7). The primary values are the aspects of the lake that support the visual landscape, providing a wide range of informal recreational activities associated with lakes. The secondary values include aspects of the lake:

- with Indigenous and historic cultural association
- that facilitate sporting, fishing and recreational activities
- that support ecological function, including water quality and aquatic plant and animal populations
- that allow for flood mitigation and control in the Tuggeranong area.

The tertiary values include the attraction of interstate and international tourism and commercial services provided to lake visitors.

Table 7. Key requirements for the quality of water in Lake Tuggeranong as outlined in the Canberra's Urban Lakes and Ponds Plan of Management (ACT Government 2001).

- The visual landscape that provides for a wide range of informal recreational activities associated with lakes.
- Aspects of the lake that facilitate public use of the lake for recreation (sporting, fishing and recreational activities).
- Aspects of the lake that support ecological function, including water quality and aquatic plant and animal populations.
- Prevent and control floods by providing a reservoir to receive flows from rivers, creeks and urban run-off in the Tuggeranong area.
- Prevent and control pollution of waterways.

4.2.1 The current state of Lake Tuggeranong

The state of Lake Tuggeranong can be assessed by evaluating how well the lake, in its current state, meets the key requirements shown in Table 7 above:

- Are the water and surrounds of the lake of acceptable quality to support the recreational and visual functions of the lake?
- How effectively is the lake acting as a water quality control pond to maintain downstream water quality?
- Does the lake display stable aquatic ecosystems and water quality that provide the expected ecological and habitat values?

Addressing these questions draws on supporting material included in the Lake Tuggeranong Technical Appendices (Appendix C).

Are the water and surrounds of the lake of acceptable quality to support the recreational and visual functions of the lake?

Lake Tuggeranong has a reputation for poor water quality, and regularly suffers from cyanobacterial blooms and faecal pollution that result in regular closures over the summer recreational period. Closure data are only available for the lake from 2015, and these data indicate that Lake Tuggeranong has been closed to recreational activities for a substantial proportion of each of the summer recreational seasons. In some years, the lake has been closed for more than 80% of the recreational season. The main cause of the lake closures has been high cyanobacterial concentrations.

Not only do the regular cyanobacterial blooms affect the recreational amenity of the lake, but they are also unsightly and of broader public health concern. These regular blooms mean that the water quality of the lake is not of acceptable quality to support the expected recreational functions and visual amenity of the lake.

The cyanobacterial blooms in Lake Tuggeranong are driven by high concentrations of nutrients, particularly phosphorus, which is derived from the surrounding catchment areas. Nutrient concentrations within the lake waters are regularly above the acceptable levels for urban lakes and are sufficiently high to support a bloom throughout the year. It is likely that water temperatures are one of the key limiting factors for cyanobacterial blooms in the lake and, with increasing temperatures across the region due to climate change, the duration of blooms in Lake Tuggeranong may continue to increase, rendering it even less able to support the expected recreational functions and visual amenity.

The shores of Lake Tuggeranong comprise a mix of native and exotic vegetation, the condition of which is defined by the level of management effort. Like all urban parklands, they are subject to the pressures of human activities that introduce rubbish and other pollutants, exotic and invasive plants, as well as create informal pathways among the riparian vegetation. The Rapid Assessment of Riparian Condition (RARC) for the lake undertaken by Waterwatch identifies the riparian zone as *poor* to *degraded* with low scores for habitat, cover and nativeness of the vegetation. In such managed parkland environments, this approach to evaluating the riparian condition will always give low scores and is not the best way of evaluating the condition.

How effectively is the lake acting as a water quality control pond to maintain downstream water quality?

Lake Tuggeranong has long been dominated by water quality issues and constant closures due to potentially toxic blue-green algae outbreaks (Ubrihien et al. 2020).

The design of the lake was to reduce nutrient and sediment loads from urban stormwater runoff passing into the Murrumbidgee River. Without flow data for the major inflows to Lake Tuggeranong, it is difficult to determine the nutrient loads entering the lake. Estimates by Ubrihien et al. (2019b) are that between 300 and 600 kg/year of phosphorus and 2,000 and 45,000 kg/year of nitrogen were being delivered to the lake from the inflowing creeks between 2018 and 2020. They also estimated that between 90 and 300 tonnes of suspended sediments were delivered to the lake. However, the research project did not collect data downstream of the lake, and existing data sets were not of a suitable quality to enable downstream loads to be calculated. Consequently, it is not possible to determine how well the lake is trapping nutrients and suspended sediments.

The data sets available are not well suited to evaluating how well the lake is performing at removing phosphorus and nitrogen or improving turbidity levels. Waterwatch data are biased toward sampling of low flows, and the research of Ubrihien at al. (2019b and 2020) shows most nutrients and suspended sediment are being delivered to the lake under high flow conditions. The data sets of Ubrihien et al. (2019b) suggest that concentrations of nutrients entering the lake are higher than the concentrations in the surface waters of the lake, which is positive, but this requires further investigation to determine the water quality performance of the lake.

Does the lake display stable aquatic ecosystems and water quality that provide the expected ecological and habitat values?

The aquatic ecosystems of Lake Tuggeranong are beset by frequent and persistent cyanobacterial blooms. This does not appear to have changed in the past 10 years, suggesting that the lake is a now displaying a stable phytoplankton dominated ecosystem. The prevalence of the cyanobacterial blooms indicates that the lake is not displaying the aquatic ecosystems and water quality that would provide the expected ecological and habitat values of the lake.

4.2.2 Knowledge Gaps

Results from the three years of detailed research on Lake Tuggeranong (Ubrihien et al. 2020) indicate that nutrient inputs from the catchment during rainfall events are the major driver of cyanobacteria blooms in the lake. Once a bloom commences, subsequent inputs from event flows provide the nutrients that support the ongoing bloom and internal cycling of nutrients can occur, along with the release of nutrients from sediments to provide further support for the bloom. The authors recommend that reducing the incidence of cyanobacterial blooms requires a reduction of nutrient inputs from storm events to the lake. To do this requires an understanding of the main catchment sources of nutrients during storms. Preliminary investigations (Ubrihien et al. 2020) indicate there are no major point sources of nutrients in the catchments, but that the entire urban area is contributing. Possible sources include leaching from leaves and other organic debris, fertilisers, animal faeces and sediments. Reducing inputs when there are many possible sources will involve broad scale behaviour change from the community. Further work is required to identify these behaviour changes in order to understand those that will generate the greatest reductions in nutrient loading.

Limited flow data are available for Lake Tuggeranong, with water level data available for Tuggeranong Weir and the other major inflow (Village Creek) ungauged. There are considerable logistical challenges in determining inflows to Lake Tuggeranong, with complex stormwater piping combined with overland flows making such determinations complicated and expensive. This also makes it difficult to ascertain the sediment and nutrient loads entering the lake. To approximate the nutrient loads, Ubrihien et al. (2020) developed a mass balance model that shows there is considerable variability in annual loads to the lake, depending on the weather and inflow conditions. While such a model provides useful information, the authors noted there was large variation in the approximate discharge for Village Creek that resulted in a relatively large amount of uncertainty around the water movement through the lake and the relative discharge from the major inflows. To improve these estimates and gain a better understanding of water and nutrient movements through the system, improvements in these estimates are required. This information would provide valuable information when designing interventions to reduce external nutrient loads to Lake Tuggeranong.

Further, limited nutrient concentration data are available downstream of the lake, with Waterwatch data limited by sampling approaches and the focus on low flow sampling. In combination, these knowledge gaps mean it is not possible to evaluate the effectiveness of the lake at trapping sediment and nutrients. This was highlighted in the research of Ubrihien et al. (2020) and remains an important gap in the understanding of the lake and its current performance in maintaining downstream water quality.

4.3 Lake Ginninderra

Lake Ginninderra was built in 1974, and was designed to provide visual and recreational amenity, offering a scenic focus for the Belconnen Town Centre. The Lake forms a U-shape, with a central peninsula and two main parks on the eastern and western sides of the lake. The primary recreational activities conducted on the lake include walking/jogging, picnics and barbeques, cycling, fishing and boating (including kayaking, canoeing, and yachting). There are also designated sections for swimming (Schirmer et al. 2018) that are monitored for suitable water quality conditions.

Lake Ginninderra has an average depth of 3.5 m, a surface area of 105 hectares (ACT Government 2016) and drains a catchment of approximately 9,800 hectares. It receives major inflows from Ginninderra Creek and urban stormwater discharge from the surrounding southern and eastern suburbs of Belconnen, including UC and the Belconnen Town Centre. The catchment area comprises a mix of urban (47%), rural (<1%), and conservation/recreation (53%) landuses (Figure 5). There are limited flow data available to evaluate the contributions from the various inputs, with the only upstream gauging station located on Ginninderra Creek near the Barton Highway. The downstream gauge is located on Ginninderra Creek at Charnwood Road near Jarramlee, some 7 km downstream of the outlet from the Ginninderra Creek dam wall. The mean annual flow at the Barton Highway gauging station is around 70% of the flow near Jarramlee (Table 8).

Table 8. Hydrological metrics for the major inflows to Lake Ginninderra.
Data sourced from Environment, Planning and Sustainable Development Directorate (https://www.data.act.gov.au/Environment/ACT-Streamflow-and-Rainfall-Data-Daily-Data/v9nd-cfqv)

Annual Flow metrics					
Station (2011–2021)		Mean (ML/year)	Median (ML/year)	Max (year)	Min (year)
Upstream Lake Ginninderra	Ginninderra Creek upstream Barton Highway (410751)	11,946.75	9,601.751	24,752.81 (2021)	5,369.896 (2019)
Downstream Lake Ginninderra	Ginninderra Creek at Charnwood Road (near Jarramlee) (41750)	17,556.93	13,623.22	33,718.63 (2016)	5,540.167 (2019)

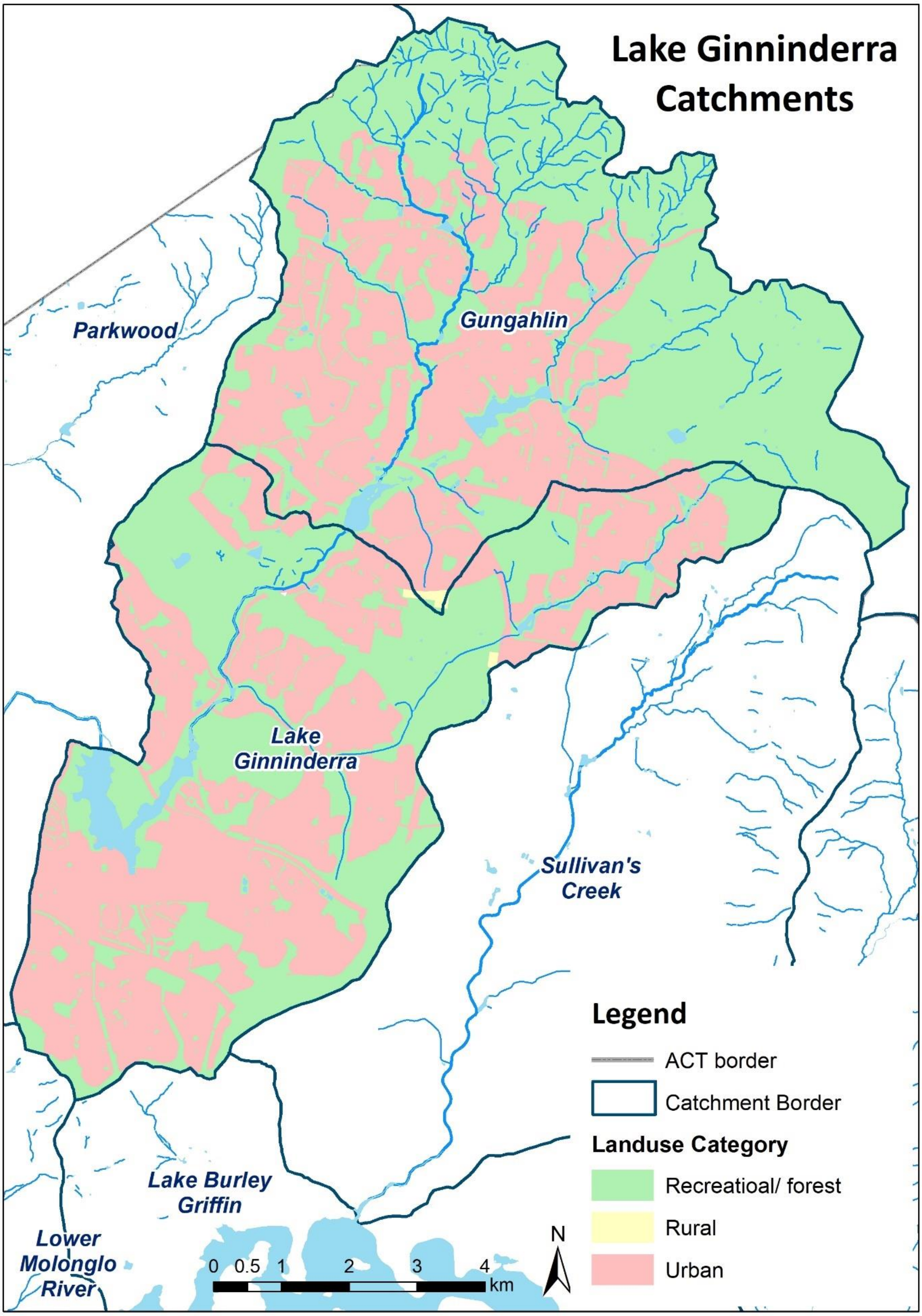

Figure 5. Map of the main catchments draining into Lake Ginninderra showing the distribution of different landuse categories.

Lake Ginninderra provides an important focus for the Belconnen Region and is valued by the local community for its recreational use and aesthetic qualities. The lake is managed by the ACT Government and Transport Canberra and City Services (TCCS), and the ACT Government is also responsible for managing the catchment areas that drain into the lake.

The values outlined in the Draft Canberra's Urban Lakes and Ponds Plan of Management (ACT Government 2019b) highlight the various recreational, cultural and management values associated with Lake Ginninderra. The primary values are the aspects of the lake supporting the visual landscape that provide for a wide range of informal recreational activities associated with lake, the water quality management and protection of downstream waterways and the provision of habitat for a range of fauna and flora. Proposed future development of the Belconnen Lakeshore Precinct could potentially create recreational and tourism opportunities for the area. As these opportunities rely on the primary and secondary levels of contact with the water, water of sufficient quality to meet the regulations/guidelines as set by the ACT Guidelines for Recreational Water Quality (ACT Government 2014a) are required.

Table 9. Key requirements for the quality of water and freshwater ecosystems of Lake Ginninderra, as outlined in the Draft Canberra Urban Lakes and Ponds Management Plan, ACT Government (2019b).

- The visual landscape provides for a wide range of informal recreational activities associated with the lake.
- Aspects of the lake that facilitate public use of the lake for recreation (sporting, fishing and primary contact recreational activities).
- Aspects of the lake that support ecological function, including water quality and aquatic plant and animal populations.
- Prevent and control pollution, protecting downstream waterways.

4.3.1 The current state of Lake Ginninderra

The state of Lake Ginninderra can be assessed by evaluating how well the lake, in its current state, meets the key requirements shown in Table 9 above:

- Do the aquatic ecosystems and water quality of the lake provide the expected recreational and visual functions?
- Do the aquatic ecosystems and water quality of the lake support the expected values by providing habitat for flora and fauna?
- How effectively is the lake acting to protect downstream water quality?

Addressing these questions draws on supporting material included in the Lake Ginninderra Technical Appendices (Appendix D).

Do the aquatic ecosystems and water quality of the lake provide the expected recreational and visual functions?

Unlike Lake Burley Griffin or Lake Tuggeranong, Lake Ginninderra has not had a history of significant water quality issues that have resulted in extensive lake closures. The current lake water quality issues that affect recreation and the aesthetic values of the lake are confined to rare cyanobacterial blooms and regular high Enterococci concentrations, with concentrations of all other water quality parameters typically within the acceptable range.

Lake closures occur each year but are neither frequent nor extensive. Closure data are only available for the recreational seasons from 2015 to 2021, which shows that the lake is typically open for more than 75% of the recreational season. Between 2015 and 2021, Lake Ginninderra was closed to recreational activities for at least some of the recreational season each year because of either cyanobacterial blooms or high Enterococci concentrations. Closures have been more frequently associated with high Enterococci concentrations, occurring in each of the past seven years. Closures because of high cyanobacteria concentrations have only occurred in four of the past seven years, but these appear to have been precautionary, as the cell count data would not have supported closures in all four years.

The shores of Lake Ginninderra vary from the highly modified areas around Belconnen Town Centre, John Knight Park and the beaches to the more natural landscape of the Yellow Box Gum woodland on the peninsula to the north of the lake. The paved edges of the lake adjacent the restaurants, food outlets and shops north of Emu Bank Drive are often plagued with rubbish from the nearby food outlets, detracting from the visual amenity of the area. The urban parklands and beaches provide mixed ornamental and visual values, the condition of which is defined by the level of management effort and intensity of human activity. Areas that are adjacent to key recreational areas (with parking) and a high intensity of both human activity and regular maintenance activities provide reasonable visual amenity but tend to be dominated by introduced species and managed ecosystems.

The peninsula of Lake Ginninderra provides a more natural landscape that is dominated an overstory of native species. The northern arm of the lake is dominated by fringing reeds with patchy riparian tree cover and the areas adjacent the old naval tracking station are completely devoid of tree cover. While these areas generally display a more self-sustaining ecosystem, they are still subject to the pressures of human activities that introduce rubbish and other pollutants, as well as exotic and invasive plants. A suite of informal pathways occurs around the northern arm of the lake and, as the suburb of Lawson continues to develop, these areas are likely to receive greater recreational demands and will require additional management effort.

Do the aquatic ecosystems and water quality of the lake support the expected values by providing habitat for flora and fauna?

The banks of Lake Ginninderra are mainly composed of grasses and shrubs, with many being introduced species. Birds such as the Crested Shrike-tit and White Winged Triller utilise the shrubs and trees surrounding the lake, while the Superb Parrots and Regent Honeyeater use the ironbark plantings as a food source (ACT Government 2016). Patches of native vegetation exist, including the woodland on the peninsula on the northern end of the lake with Yellow Box Gum. This mix of introduced and native species is consistent with many of the managed parklands of the ACT.

Waterwatch provides the only systematic and regular evaluation of the lake's ecological condition. Catchment Health Indicator Program (CHIP) reports for the past three years have presented the site condition for the lake as *fair* (C rating).

The Rapid Appraisal of Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent, good, fair, poor,* or *degraded* conditions. The appraisal occurs every two years and was assessed at Lake Ginninderra in 2015, 2017, 2019 and 2021. In these years, the overall condition of the vegetation was considered *poor*. However, in such managed parkland environments, the RARC is not the best way of evaluating the condition of riparian areas.

In contrast with Lake Tuggeranong and Lake Burley Griffin, most of the Lake Ginninderra margin has fringing reedbeds that provide habitat for waterbirds and animals such as turtles, frogs and macro-invertebrates. Their presence is indicative of a lower trophic state and better ecological condition.

How effectively is the lake acting as a water quality control pond to maintain downstream water quality?

Data that would inform the water quality performance of Lake Ginninderra are confined to the main stem of Ginninderra Creek, with no information available on the water quality from the stormwater network on the southern side of the lake. Further, inflow and outflow data from Ginninderra Creek are biased to low flow periods which does not enable a fair evaluation of the lake's performance. The data suggest that the lake is not having an adverse effect on water quality during low flow periods, but the data are not suited to a more comprehensive evaluation.

4.3.2 Knowledge gaps

Lake Ginninderra is commonly thought of as being in better condition than Canberra's other urban lakes, with few closures due to high cyanobacteria concentrations. This has been partly attributed to a lower degree of urban development within the catchment, but the recent urban expansion in the Ginninderra Creek headwaters may mean there are additional pressures on the lake. Historically, Lake Ginninderra's cyanobacterial community was dominated by *Aphanocapsa* species, while Lake Burley Griffin and Lake Tuggeranong were dominated by *Dolichospermum* and *Microcystis* species. More recently, *Microcystis* species in Lake Ginninderra have become more frequent and, with the increasing urban development in the Lake Ginninderra catchment, concerns exist for future water quality. One of the challenges of predicting such issues is often a lack of data that would enable the catchment and lake water chemistry to be characterised and therefore provide context for predictions and future management. Lake Ginninderra and its inflowing creeks have received considerably less attention regarding water quality and flow monitoring compared with the other major Canberra lakes. Consequently, there are limited data available that could support an evaluation of the lake's performance and, perhaps more importantly, predictions or management decisions. Given the urban expansion of the catchment, it would be prudent to invest in monitoring Lake Ginninderra and its inflowing creeks to ensure the existing high quality of water is maintained.

5. The state of the ACT's urban creeks and rivers

There are eight major urban creeks and rivers in the ACT that traverse the major catchment areas. These include the Molonglo River (upstream and downstream of Lake Burley Griffin) and Sullivans, Weston, Yarralumla, Ginninderra, Tuggeranong and Kippax Creeks (Figure 6). This review covers the state of Ginninderra Creek, Molonglo River (upstream and downstream of Lake Burley Griffin), Sullivans Creek and Tuggeranong Creek. The technical analysis underpinning the assessments are included in Appendices E to J, and the reader is encouraged to refer to the appendix material to better understand the interpretation provided here. Far less extensive data sets are available for Weston Creek, Yarralumla Creek and Kippax Creeks, and so are not evaluated here.

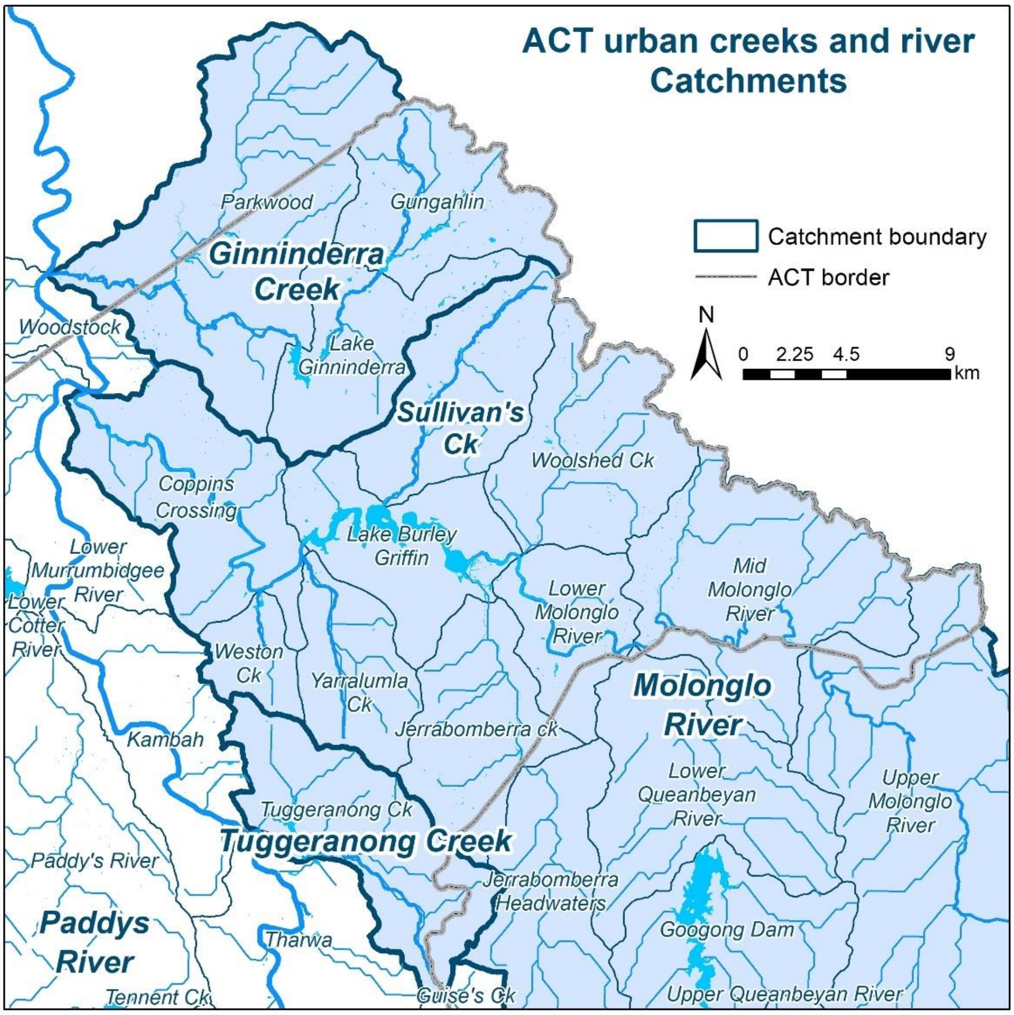

Figure 6. Map of the ACT urban creeks and rivers.

Canberra's urban creeks and rivers are a combination of natural and modified managed aquatic environments delivering varied recreational and cultural values to the community. These creeks and rivers provide habitat for flora and fauna, and provide the community with opportunities to participate in recreational activities such as cycling, jogging and walking (Schirmer et al. 2018).

Urban creeks and rivers within the ACT deliver a wide range of values to both the population and the environment. These include habitat availability, flood mitigation, improvement of aesthetics, improving recreational opportunities, engagement of Indigenous and other cultural values, protecting ecological values and contributing to the liveability of the ACT community (ACT Government 2014b). The ACT Water Strategy stipulates that a community that values and enjoys clean, healthy catchments and waterways should be provided access to this resource, on which residents can undertake water-based or water-dependent recreational activities without concern for their health as a result of encountering contaminated water. This also means that riparian and aquatic ecosystems are provided with safe, clean water that allows these ecosystems and associated biodiversity to be healthy and resilient (ACT Government 2014b).

The ACT Government is responsible for managing the urban creeks and rivers but there is currently no direct strategy or Act that encompasses the management of these areas. While planning and management documents exist for Canberra's urban lakes and ponds, similar documentation does not exist for the urban creeks and rivers. The ACT Aquatic and Riparian Conservation Strategy (ACT Government 2018a), which generally deals with the rivers and streams of the ACT, does not cover urban waterways. This means the urban waterways are managed under the broader remit of the ACT's 2014–2044 Water Strategy Outcomes (ACT Government 2014 p 2 and p 4):

Outcome 1: Healthy catchments and waterbodies

Strategy 1: Achieve integrated catchment management across the ACT and region

Strategy 2: Protect and restore aquatic ecosystems in urban and nonurban areas region

Strategy 3: Manage stormwater and flooding region

Outcome 2: A sustainable water supply used efficiently

Strategy 4: Secure long term water supplies

Strategy 5: Manage and promote water services efficiently and sustainably

Outcome 3: A community that values and enjoys clean, healthy catchments and waterways

Strategy 6: Provide clean and safe water for the ACT

Strategy 7: Engage the community on understanding and contributing to a more sustainable city

These Outcomes suggest requirements for the quality of water and aquatic ecosystems within Canberra’s urban creeks and rivers (Table 10).

Table 10. Requirements for the quality of water and aquatic ecosystems of Canberra’s urban creeks and rivers. It should be noted that these requirements are inferred and are not part of the ACT Government planning documents.

- Maintaining acceptable water quality to support a wide range of informal recreational activities associated with creeks and rivers.
- Maintaining viable and sustainable aquatic ecosystems.
- Maintaining aspects of the creeks and rivers that support ecological functions including water quality and aquatic plant and animal populations.
- Prevent and control floods by providing clear flow pathways for urban runoff.

The state of Canberra’s urban creeks and rivers can be assessed using evaluation questions that address how well the creeks and rivers meet the requirements shown in These Outcomes suggest requirements for the quality of water and aquatic ecosystems within Canberra’s urban creeks and rivers (Table 10).

Table 10:

- Are the aquatic ecosystems and water quality suitable to support the recreational functions of the creeks and rivers?
- Is the water of sufficient quality to support the aquatic ecosystems of the creeks and rivers?

These (or similar) evaluation questions will be addressed for the four main urban creeks and rivers in the following sections.

5.1 Ginninderra Creek

Ginninderra Creek is a partly perennial stream that begins near the northern boundary of the ACT and NSW in the Mulligan's Flat Nature Reserve. In contrast to many other urban streams, it retains a relatively natural form, rather than having been concrete lined to manage the high flows from urban runoff. It drains a catchment area of approximately 224[2] km^2, flowing in a south-westerly direction through Gungahlin and Belconnen before flowing west to join the Murrumbidgee River in NSW. The catchment comprises a mix of urban (34%), rural (30%) and conservation/recreation landuses (36%) (Figure 7). It is reported that more than 42% of ACT residents live in the catchment of Ginninderra Creek (O'Reilly et al. 2021).

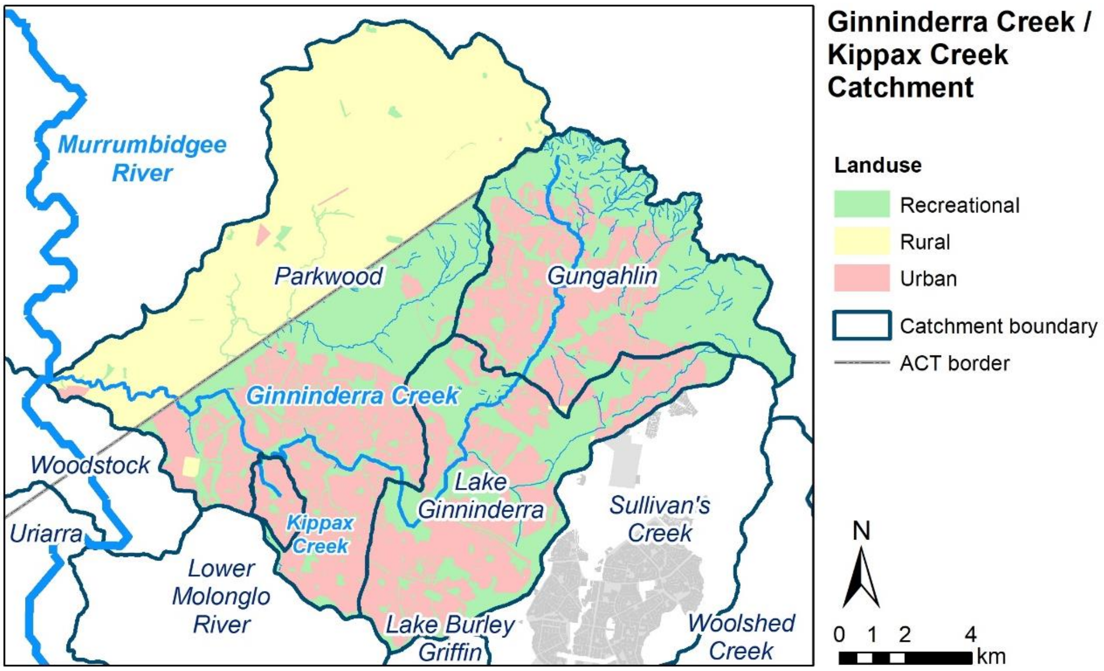

Figure 7. Map of Ginninderra Creek catchment showing the distribution of different landuse categories.

Several named tributaries contribute flow to Ginninderra Creek, including Gooromon Ponds Creek, Gold Creek, Gungaderra Creek, Cow Flat Creek and Bedulluck Creek. As there is only a single gauging station in the catchment (located on Ginninderra Creek upstream of the confluence with Gooromon Ponds Creek), the relative contribution from the different tributaries is unable to be determined. Mean annual flow in the lower reaches of the creek is around 15,000 ML/year, and 7,000 ML/year at the Barton Highway gauging station (Table 11). There has been a notable increase in annual flows from 2010 onwards (Figure 8) that may be a result of the urban development that has occurred in the upper catchment over this time period.

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[2] Most documentation about Ginninderra Creek states a catchment area of 320km^2. The authors have been unable to reproduce this number and their GIS team advise it is 224 km^2.

Table 11. Hydrological metrics for Ginninderra Creek.
Data sourced from the Bureau of Meteorology Water Data Online (http://www.bom.gov.au/waterdata/) and the ACT Government.

Station (period of record)	Annual Flow metrics Mean (ML/year)	Median (ML/year)	Max (year)	Min (year)
Ginninderra Creek upstream Charnwood Road (410750) (1979–2021)	14,865	13,718	39,106 (2021)	4,033 (1994)
Ginninderra Creek upstream Barton Highway (410751) (1980–2021)	7,104	5,172	35,153 (2021)	99 (1980)

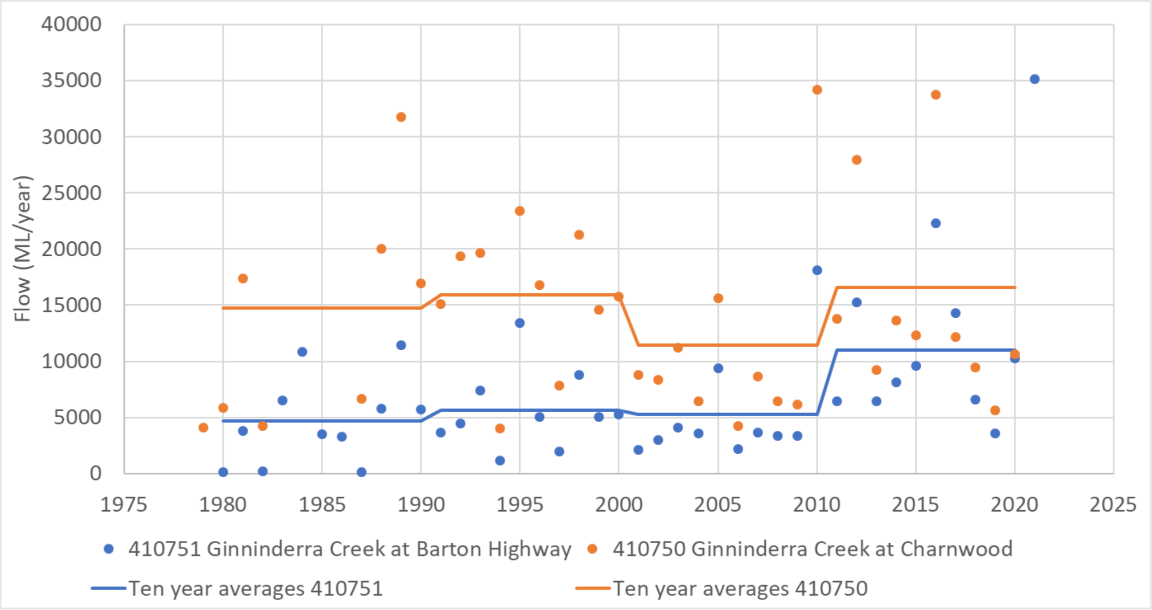

Figure 8. Annual flow in Ginninderra Creek between 1980 and 2020.
Data sourced from the Bureau of Meteorology Water Data Online (http://www.bom.gov.au/waterdata/) and the ACT Government.

There are several major impoundments in the Ginninderra Creek catchment. Gungahlin Pond and Lake Ginninderra are on the main stem of Ginninderra Creek. Yerrabi Pond is located on the eastern arm of Ginninderra Creek, and The Valley Pond and Mulligan's Flat Dam are located on smaller drainage lines. Except for Mulligan's Flat Dam, these impoundments were constructed as part of the Water Sensitive Urban Design (WSUD) infrastructure in the catchment and provide both recreational opportunities and potential water quality improvements in the creek.

Ginninderra Creek and its surrounds provide an important stream corridor through the northern and western suburbs of Canberra. The creek flows through numerous public parks, providing a focus for community recreation, and there are popular pedestrian and bike paths alongside significant portions of the creek. The last few kilometres of the creek become a series of falls through Ginninderra Gorge, a spectacular and reasonably well-preserved remnant natural area of substantial interest to some members of the community. Ginninderra Creek and its riparian areas are managed by the ACT Government.

5.1.1 The current state of Ginninderra Creek

Addressing the evaluation questions for Ginninderra Creek draws on supporting material included in Technical Appendices E and F.

Are the aquatic ecosystems and water quality of Ginninderra Creek suitable to support its recreational functions?

Ginninderra Creek provides a range of aesthetic and recreational values to Gungahlin and Belconnen. The negative impacts of human activities are often present, with high concentrations of suspended sediment and rubbish transported by the creek. These are typically deposited in the upstream sections of the lakes and ponds that have been built on the creek.

Increasing urban development across the catchment, particularly in Gungahlin over the past 15–20 years, has negatively impacted the creek. Sediment runoff from this urban development has been an issue, and more than 60% of the turbidity levels recorded in the creek over the past 10 years have been above the acceptable range. This appears to be slightly worse upstream of Lake Ginninderra, compared with the observations downstream of the lake. The turbid water of the creek is accompanied by low concentrations of dissolved oxygen, high nitrogen concentrations and high conductivity, making it challenging for a healthy aquatic ecosystem to flourish.

The banks of Ginninderra Creek comprise a mix of native and exotic vegetation and, like all urban areas, they are subject to the pressures of human activities that introduce rubbish and other pollutants, exotic and invasive plants, as well as create informal pathways among the riparian vegetation. The RARC assessment for the urban rivers and creeks identifies the riparian zone as *fair* to *degraded*, with very low scores across all aspects of the vegetation except for cover. In urban settings, the RARC may not be the most appropriate evaluation of the riparian condition as it is often managed in a manner that means it may never achieve a good score, but without specific guidance about the expected ecological condition or the targeted ecological condition and accompanying monitoring data, it is the only available information.

Is the water of sufficient quality to support the aquatic ecosystems of Ginninderra Creek?

While phosphorus concentrations and pH recorded in Ginninderra Creek are almost always (>99%) within the acceptable range, turbidity, electrical conductivity, dissolved oxygen and nitrogen concentrations in Ginninderra Creek are regularly outside the acceptable ranges specified in the *Environment Protection Regulation 2005*. Turbidity and electrical conductivity levels are more frequently above the acceptable range in the upstream Waterwatch sites, compared with the downstream sites. The higher levels of turbidity and conductivity in the upstream sites may be caused by runoff from the urban development that has been occurring in the upper catchment over the past 10 years. There have been improvements in the upstream turbidity levels since 2014 that may reflect changes in the location of urban development in relation to the sampling locations. However, without spatial data regarding development in the area that has been collected at an appropriate frequency, it is difficult to better understand these patterns. The downstream improvements in turbidity are likely to be in part caused by the trapping of sediment in Lake

Ginninderra (see Section 4.3). In contrast, dissolved oxygen and nitrogen concentrations are more frequently outside the acceptable range in the downstream sites.

ACT Government monitoring of the macroinvertebrate communities in Ginninderra Creek indicates that the instream biological community ranges between *significantly* and *severely impaired*. This is not dissimilar to other monitored creeks in the urban areas of Canberra and is most likely a function of the quality of the urban runoff and degraded in-stream habitat. In contrast, macroinvertebrate community data collected as part of the Waterwatch program suggest the macroinvertebrate community upstream of Lake Ginninderra is better, and more consistently better, than that recorded downstream. The two programs collect quite different data sets at different locations and use different approaches to data analysis. It is possible that the differences observed are the result of differences in site character but could also be methodological. It is recommended that to improve communication of the monitoring results, consideration be given to how the two programs could be better integrated to inform creek management.

5.1.2 Knowledge gaps: Ginninderra Creek

There are several Waterwatch monitoring sites on Ginninderra Creek that have provided valuable data, but these are limited in their temporal resolution due to a focus on low flow sampling. It is likely that these data tell a more positive story about the water quality conditions of the creek than would be told from monitoring a broader range of flow conditions. They are also limited to the creek downstream of Gungahlin Pond, meaning they miss the opportunity to detect the effects of urban runoff from the newer developments in the headwaters of the catchment. Given continued development in the headwaters of Ginninderra Creek, and the current state of Lake Ginninderra as one of the better urban lakes, investment in developing a better understanding of the water quality in the creek to inform management that enables maintenance of existing water quality is recommended.

There are two gauging stations in the Ginninderra catchment, both located on the main stem, making understanding the relative contributions of both flow and nutrient loads from the tributaries impossible. This has implications for future interpretation of water quality data, particularly pollutant loads.

5.2 The Molonglo River

The Molonglo River rises on the western side of the Great Dividing Range in Tallaganda National Park. It flows north then north-west through Captain's Flat and Queanbeyan before it enters the ACT at Oaks Estate and is joined by the Queanbeyan River. The river then flows west through Canberra, where it has been dammed to form Lake Burley Griffin, and on to join the Murrumbidgee River near Uriarra Crossing. It drains a catchment area of just under 2,000 km^2, approximately one third of which is the Queanbeyan River catchment. The entire Molonglo River catchment comprises a mix of urban (9%), rural (64%) and conservation/recreation landuses (27%) (Figure 9).

Several tributaries contribute flow to the Molonglo River, most being upstream of the ACT border (Figure 9). The greatest volume is contributed by the Queanbeyan River, providing between 10 and 80% of the flow in any one year at Oaks Estate (Table 12). The relative contribution from the Queanbeyan River is dependent on the prevailing weather conditions, combined with the operation of Googong Dam.

The Molonglo River also receives discharge from the two main wastewater treatments plants in the region. The Queanbeyan Sewerage Treatment Plant (STP), operated by Queanbeyan Palerang Regional Council (QPRC), discharges treated wastewater into the Molonglo River upstream of Lake Burley Griffin at Oaks Estate. The ACT's main wastewater treatment plant, the Lower Molonglo Water Quality Control Centre (LMWQCC) discharges treated wastewater into the Molonglo River just upstream of the confluence with the Murrumbidgee River at Uriarra Crossing.

The Molonglo River has played a pivotal role in the siting of Canberra. It is dammed to provide the National Capital with its major water feature, Lake Burley Griffin, and is therefore significant as the main source of water for this lake. Additionally, the river itself provides important visual and recreational amenity for the Canberra community and provides habitat for aquatic and riparian species. Until recently, the major recreational feature of the Molonglo River in the ACT was Lake Burley Griffin, but the urban development of Molonglo Valley has resulted in a focus on the river corridor between Scrivener Dam and the Murrumbidgee River. As the population increases in Molonglo Valley, this reach of the Molonglo River is likely to see increased pressure from both construction and local residents (see more on this in Section 8.3).

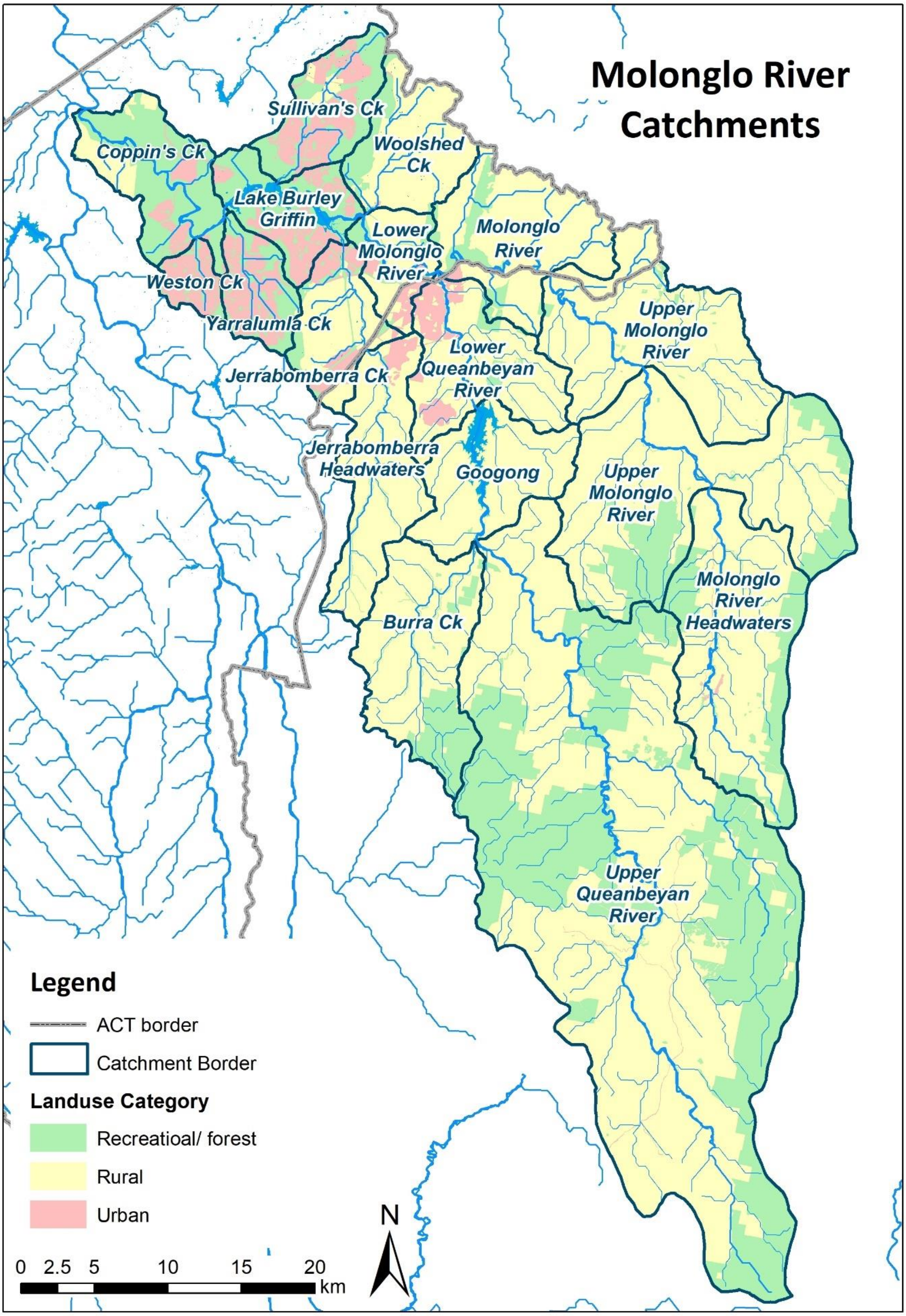

Figure 9. Map of the Molonglo River catchment showing the distribution of different landuse categories.

Table 12. Hydrological metrics for the gauging stations within the Molonglo River catchment. Data sourced from the Bureau of Meteorology Water Data Online (http://www.bom.gov.au/waterdata/).

Annual Flow metrics					
River	Station (period of record)	Mean (ML/year)	Median (ML/year)	Maximum (year)	Minimum (year)
Molonglo River	Oaks Estate 410729 (1964–2021)	118,225	73,957	617,518 (1974)	3,733 (2004)
Molonglo River	Coppins Crossing 410756 (1979–2021)	127,141	86,394	566,376 (1989)	8,160 (1982)
Queanbeyan River	ACT Border 410770 (1978–2019)	29,787	18,150	190,207 (1978)	2,266 (2009)

Within the ACT, the river is managed by the ACT Government, and the NCA is responsible for managing Lake Burley Griffin and its foreshores (see Section 4.1 for more on Lake Burley Griffin). There is a specific plan of management for the Molonglo River downstream of Scrivener Dam: The Molonglo River Reserve Management Plan (ACT Government 2019c). This document identifies the Molonglo River Reserve as a ‘substantial natural centrepiece running through the Molonglo Valley suburbs’ (ACT Government 2019c p. 13), and the river and its riparian areas are noted as providing important habitat for both aquatic species and a number of important plants and animals. While the scope of the management plan is quite broad, protecting the naturalness of the reserve and improving the ecological condition of the river and riparian zones are identified as some of its key objectives. Achieving these objectives relies on protecting the quality of water and the ecological character of the river and its riparian areas.

5.2.1 The current state of the Molonglo River

Addressing the evaluation questions for the Molonglo River draws on supporting material included in Technical Appendices E and G. Because there is a specific plan of management for the Molonglo River Corridor downstream of Lake Burley Griffin that sets out some broad management objectives, an additional evaluation question has been included to address the expected visual amenity of the river.

Is the water of acceptable quality to support the recreational functions of the Molonglo River?

The Molonglo River immediately upstream of Lake Burley Griffin is used for water skiing and, consequently, needs water of a quality suited to primary contact. Downstream of Lake Burley Griffin, the river is not expected to be used for primary contact activities. The ACT Government monitors cyanobacteria and Enterococci bacteria levels at the water ski area, as well as a site immediately upstream of the lake. The data sets analysed as part of the review have not included a record of these attributes as not all data were available during the preparation of the report and those that were available are from 2018 onwards.

The Molonglo River upstream of Lake Burley Griffin is affected by the negative impacts of human activities in the catchment, with regular high concentrations of sediment and rubbish present in the reach. Turbidity levels are frequently above the acceptable range, irrespective of the flow conditions. The rubbish accumulates and some of the sediment is deposited in the upper reaches of Lake Burley Griffin.

Do the aquatic ecosystems and water quality of the river provide the expected visual amenity?

Downstream of Lake Burley Griffin, turbidity levels have historically been high during wet periods where there are substantial releases from Lake Burley Griffin. However, since 2019, turbidity levels in the river have increased markedly. This is likely to be associated with urban development in the Molonglo Valley. More than 70% of the turbidity levels recorded in the river in 2020 and 2021 have been above the acceptable range compared with fewer than 40% in the preceding three years. Interestingly, prior to 2019, the turbidity downstream of Lake Burley Griffin was generally better than in the upstream reaches, suggesting that the lake was having a positive effect on water quality in the river. In the past two years, the turbidity downstream of the lake is worse than upstream, which suggests the local sediment contributions are negating the water quality benefits of the lake. This issue is explored further in Section 8.3 and highlights the need to better manage the runoff from the development occurring in the Molonglo Valley to protect the aquatic ecosystems and maintain the visual amenity of the water.

The banks of the Molonglo River comprise a mix of native and exotic vegetation and, like all urban areas, they are subject to the pressures of human activities that introduce rubbish and other pollutants, exotic and invasive plants, as well as create informal pathways among the riparian vegetation. Upstream of Lake Burley Griffin, the riparian areas are also fringed by exotic and invasive species. The RARC scores for this section of the river identifies the riparian zone as *poor*, with low scores across all aspects of the vegetation. Downstream of Lake Burley Griffin, the RARC scores are slightly better, with the riparian zone identified as being in *fair* to *poor* condition. The better scores for this reach of the river are because of the greater proportion of native vegetation in this reach. While in most urban settings the RARC may not be the most appropriate method of evaluating riparian condition, it provides a reasonable tool for the Molonglo River by offering potential improvements of the riparian areas to a more native and functional habitat and consequent visual amenity.

Is the water of sufficient quality to support the aquatic ecosystems of the creeks and rivers?

Concentrations of phosphorus and dissolved oxygen as well as pH and conductivity recorded in both the upstream and downstream reaches of the Molonglo River are commonly within the acceptable range, with between 70 and 100% of the readings falling within this range as specified in the *Environment Protection Regulation 2005*. In contrast, nitrate concentrations and turbidity are regularly outside of the acceptable range. These higher concentrations of nitrogen and turbidity are likely to have adverse effects on instream aquatic ecosystems. High turbidity levels and the incidences of extreme sediment inputs downstream of Lake Burley Griffin are of particular concern for the aquatic ecosystems of the creek (see Section 8.3). These have the potential to smother habitat and cause significant impairment of the aquatic ecosystems, reducing the conservation values of the Molonglo River corridor.

ACT Government monitoring of the macroinvertebrate communities in the Molonglo River occurs at a single site upstream of Lake Burley Griffin, at the Sutton Road Bridge. These data indicate that the instream biological community is typically significantly impaired, with the most recent scores suggesting severe impairment of the autumn macroinvertebrate community. The impaired instream biological community is most likely a function of both the water quality and degraded in-stream habitat. It is unclear what has caused the recent decline in AUSRIVAS scores, but it may be due to drier autumns experienced in the region rather than any specific local activities.

As part of the Waterwatch program, macroinvertebrate data are collected both upstream and downstream of Lake Burley Griffin. In contrast to the ACT Monitoring data, these data sets suggest the upstream macroinvertebrate community is typically considered *good*. The macroinvertebrate community at two sites downstream of Lake Burley Griffin is also generally considered *good*, except for the spring macroinvertebrate community recorded just upstream of the confluence with the Murrumbidgee River. This suggests that there may be some impact on the Molonglo River between Coppins Crossing and the Murrumbidgee confluence that may be attributable to the influence of the LMWQCC but would require further investigation.

5.3 Sullivans Creek

Sullivans Creek is situated in the inner north of Canberra and forms one of the eight main ACT catchments. Sullivans Creek commences in Goorooyarroo Nature Reserve near Old Joe Hill and flows through the rapidly-developing Gunghalin suburbs of Throsby and Harrison and the grasslands of Kenny. It then flows through the older suburbs of Canberra's inner north, the Australian National University (ANU) and finally into Lake Burley Griffin. The catchment is 52.4 km^2 and has a north-south length of 12 km and an east-west length of 4.5 km. The catchment comprises a mix of urban (43%), rural (10%) and conservation/recreation landuses (47%) (Figure 10).

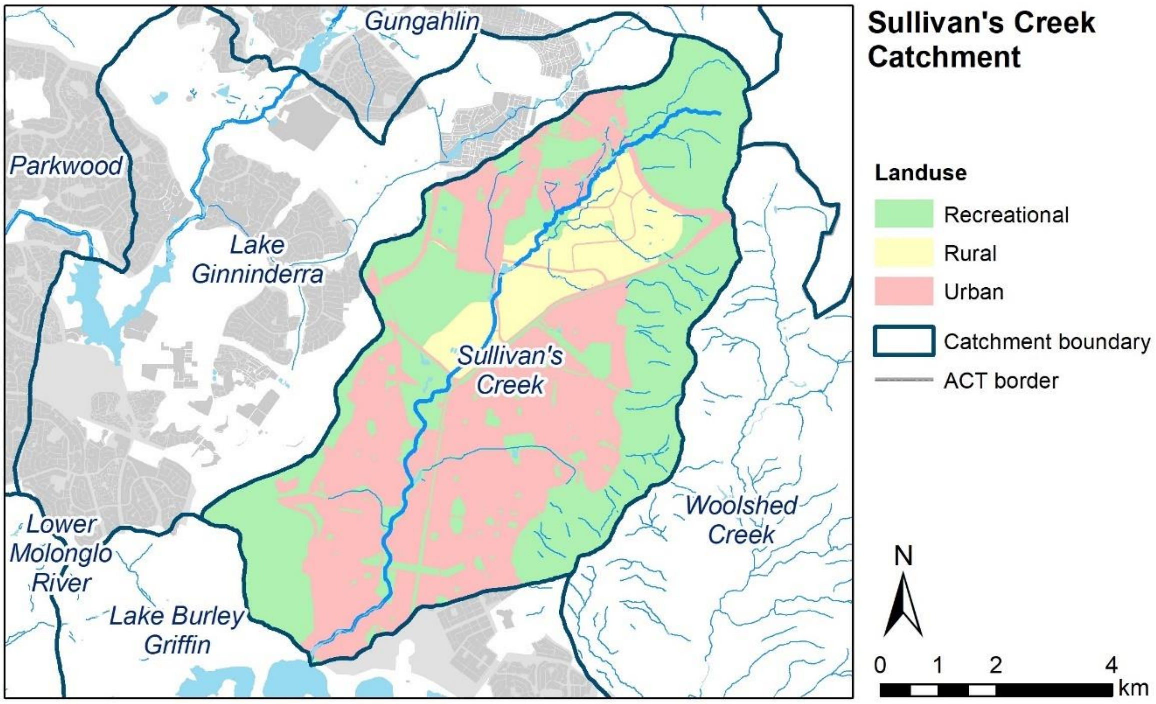

Figure 10. Map of Sullivans Creek catchment showing the distribution of different landuse categories.

Downstream of Flemington Road, the creek is a concrete lined channel, designed to transport stormwater more efficiently. The vegetation surrounding the creek comprises native grasses, reeds and scattered trees of various species. This vegetation was removed in the process of converting the creek to concrete channels and replaced with turf and a mixture of native, exotic and invasive trees. The concrete channels are devoid of aquatic life, presenting no framework or refuge for biological processes. As the creek flows through the ANU, it has been landscaped to be a series of ponds connected by grassed channels.

In more recent years, the ACT Government designed a system of 'retro-fitted' wetlands and ponds across the landscape to improve the water for the environment and the growing population. A portion of these have been installed in the Sullivans Creek catchment (ACT Government 2018b). These wetlands include the Flemington Road Ponds, Mitchell; David Street Wetland, O'Connor; Banksia Street Wetland, O'Connor; Howdon Street Wetland, Dickson; and Goodwin Street Wetland, Lyneham (ACT Government 2014). The wetlands and ponds have attracted frogs, macroinvertebrates and bird species, and more species have appeared as the associated planting has matured. The Inner North Reticulation System is a stormwater harvesting and managed aquifer recharge system (ACT

Government 2015) associated with the wetlands that was designed to use the water collected in the wetlands for the irrigation of public green spaces in the catchment. This improves the supply of water for local community assets (public green spaces), particularly during dry periods as well as providing focal points for the community through the constructed pond systems.

A series of urban drains contribute flow to Sullivans Creek, the largest of these being from the foothills of Mount Ainslie and collects runoff from the suburbs of Ainslie, Hackett and Dickson. None of the tributaries are gauged, meaning it is not possible to determine the relative contributions to the main creek. Mean annual flow in Sullivans Creek is between 2,000 ML/year at Southwell Park and slightly more than 5,000 ML/year at Barry Drive (Table 13). By flow, this makes it the smallest of the four urban creek systems evaluated. There has been a slight increase in the annual flow volumes in the creek from 2010 onwards, despite the stormwater harvesting program in the catchment (Figure 11). The increased flow in the creek may be a result of the urban development that has occurred in the upper catchment since 2010.

Table 13. Hydrological metrics for Sullivans Creek.
Data sourced from the Bureau of Meteorology Water Data Online (http://www.bom.gov.au/waterdata/).

Station (period of record)	Annual Flow metrics Mean (ML/yr)	Median (ML/yr)	Max (year)	Min (year)
Sullivans Creek at Barry Drive (1986–2021)	5,170	4,133	12,914	1,178
Sullivans Creek at Southwell Park (1980–2021)	2,000	1,372	6,358	551

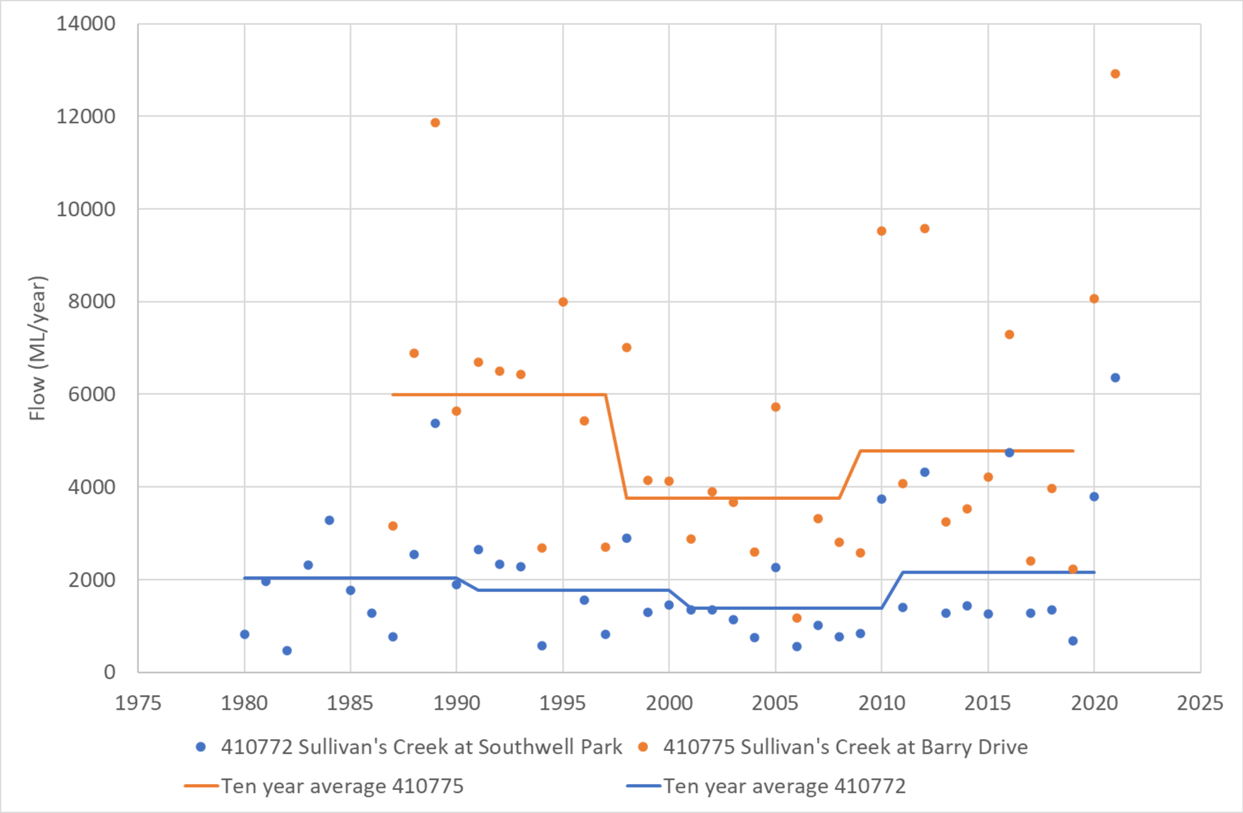

Figure 11. Annual flow in Sullivans Creek between 1980 and 2021.
Data sourced from the Bureau of Meteorology Water Data Online (http://www.bom.gov.au/waterdata/) and the ACT Government.

The upper half of Sullivans Creek flows through reserve and farmland and has eroded and incised, likely because of early land clearing. There are also small farm dams on the creek and tributaries that slow the flow of water. These upper reaches are vulnerable to further erosion and incision if flows were to increase as a result of urban development in the area. The Sullivans Creek corridor provides an important pathway through the northern suburbs of Canberra, with a key bike path travelling along the floodway of the creek from Mouat Street in Lyneham to the ANU and the city. Sections of the corridor provide ornamental and aesthetically pleasing scenery and the suite of wetlands that are located within the catchment are key recreational focal points. The creek is also a focal point through the ANU, and it has undergone some significant remodelling as part of the recent campus modifications. Sullivans Creek and its riparian areas are managed by the ACT Government and ANU Facilities and Services.

5.3.1 The current state of Sullivans Creek

Addressing the evaluation questions for Sullivans Creek draws on supporting material included in Technical Appendices E and H. Sullivans Creek can be considered in three parts: the reach that flows through reserve and farmland from the headwaters to Flemington Road (the upper reach); the highly urbanised reach that flows through the inner north suburbs to the ANU (the mid reach); and the section that flows through the ANU to Lake Burley Griffin (the lower reach). The features of these reaches are markedly different. The data available for the upper and mid reaches are either sparse and not suited to the evaluation or from wetlands along the creek system. The longest data set available is from several sites within the lower reach, meaning the assessment of the current state is focused on this reach, with some commentary provided around the mid reach.

Are the aquatic ecosystems and water quality of Sullivans Creek suitable to support the recreational functions and visual amenity of the creek?

Sullivans Creek provides a range of aesthetic and recreational values to the ANU and the inner northern suburbs of Canberra. As with other urban creek systems, the negative impacts of human activities are often present, with high concentrations of suspended sediment and rubbish transported by the creek. Typically, these are deposited in the upstream sections of the ponds built along the creek.

Generally, the quality of water in the lower reach of Sullivans Creek is poor, with low concentrations of oxygen, high turbidity and high nutrient concentrations — all regularly outside the acceptable range. These detract from the visual amenity of the creek and, despite the works implemented by the ANU Grounds Management, the creek water is often black (signifying a high organic content) or highly turbid.

Research in the late 1990s (Dyer 2000) implicated the sequence of the Gross Pollutant Trap (GPT) at Barry Drive and the pond at Toad Hall (an ANU student residence) in contributing to water quality problems in the lower reaches of the creek. The substantial amount of organic matter (primarily leaves) trapped in the GPT and Toad Pond were thought to be causing the release of dissolved nutrients as the organic matter broke down. Consequently, management of the GPT was changed to include cleaning out these locations more frequently, but the stockpiling of material from the GPT beside Sullivans Creek to enable dewatering is unlikely to have solved the problem.

The concrete-lined channels of the mid reaches of Sullivans Creek have no ecological value, with green filamentous algae and the occasional yabby the main biological attributes of the creek. The quality of water in these reaches is not regularly monitored, but the research of (Ubrihien et al. 2019a) suggests that concentrations of nitrogen and phosphorus are regularly well above the acceptable range.

The riparian areas of the mid and lower reaches of Sullivans Creek are highly managed, typically comprising mown grass and tree plantings, with a mix of native and exotic vegetation. The RARC assessment for the urban rivers and creeks identifies the riparian zone as *fair* to *poor*. As previously mentioned, in urban settings, the RARC may not be the most appropriate evaluation of the riparian condition as it is often managed in a manner that means it may never achieve a good score, but without specific guidance about the expected ecological condition or the targeted ecological condition and accompanying monitoring data, it is the only available information.

Is the water of sufficient quality to support the expected aquatic ecosystems of the creeks?

Sullivans Creek and its urban tributaries have been retrofitted with ponds designed to improve the quality of water in the creek, with three of these providing reticulated water for irrigation via a neighbourhood scale stormwater harvesting system. These ponds have resulted in improvement in the water quality of the creek, particularly under low flows, with reductions in nutrients observed across the ponds. While the water quality in the creek remains poor, without these interventions it is likely to be considerably worse.

In the lower reaches of Sullivans Creek, concentrations of nutrients and turbidity are high, and the concentrations of dissolved oxygen are low. This is likely to result in a highly modified aquatic ecosystem in the creek and contributes poor quality water to Lake Burley Griffin. Data from the mid-reaches of the creek suggest this is an issue for at least its highly urbanised reaches, but these reaches also lack the natural features that would enable an aquatic ecosystem to develop. Positively, despite the poor water quality in these reaches, the macroinvertebrate community is consistently identified as being good.

5.4 Tuggeranong Creek

Tuggeranong Creek is a partly perennial creek that begins near the ACT and NSW border east of the Monaro Highway and southeast of the suburb of Theodore. The creek flows north alongside the highway before turning west and travelling through the suburbs of Calwell, Richardson, Isabella Plains and Bonython, where it is impounded to form Isabella Pond and then Lake Tuggeranong (Figure 12). The creek is a concrete lined channel for most of its length, with only the small sections upstream of the Monaro Highway and downstream of Lake Tuggeranong retaining natural form. The catchment comprises a mix of urban (43%), rural (29%) and conservation/recreation landuses (28%).

Several tributaries contribute flow to Tuggeranong Creek, including unnamed tributaries through Fadden and Wanniassa that join upstream of Lake Tuggeranong. Kambah Creek and Village Creek also flow into Lake Tuggeranong. Additionally, a complex stormwater network runs throughout the Tuggeranong suburbs and channels urban runoff into the creeks and rivers. A single gauging station operates within the catchment, located on Tuggeranong Creek downstream of Lake Tuggeranong. Flows in this section of the creek are likely to be significantly influenced by the lake, and the lack of gauging stations throughout the catchment means the relative contributions from the tributaries and the influence of the lake on downstream flows are unable to be determined (see also Section 4.2). Mean annual flow in the lower reaches of the creek is around 10,000 ML/day (Table 14), which is less than either Ginninderra Creek or Sullivans Creek.

Tuggeranong Creek and its tributaries flow through urban corridors within the southern suburbs of Canberra. The concrete lining of a substantial portion of the creek and its tributaries upstream of Lake Tuggeranong means they offer little visual amenity to the community, and the recreational values of the creek reserve are not founded on the water quality or aquatic ecosystems of the creek. The main functionality of these areas is the capacity to move flows efficiently and effectively away from urban life and properties. Downstream of Lake Tuggeranong, the creek flows through the Urambi Hills Nature Reserve and private land before it joins the Murrumbidgee River. Tuggeranong Creek and its riparian areas are managed by the ACT Government.

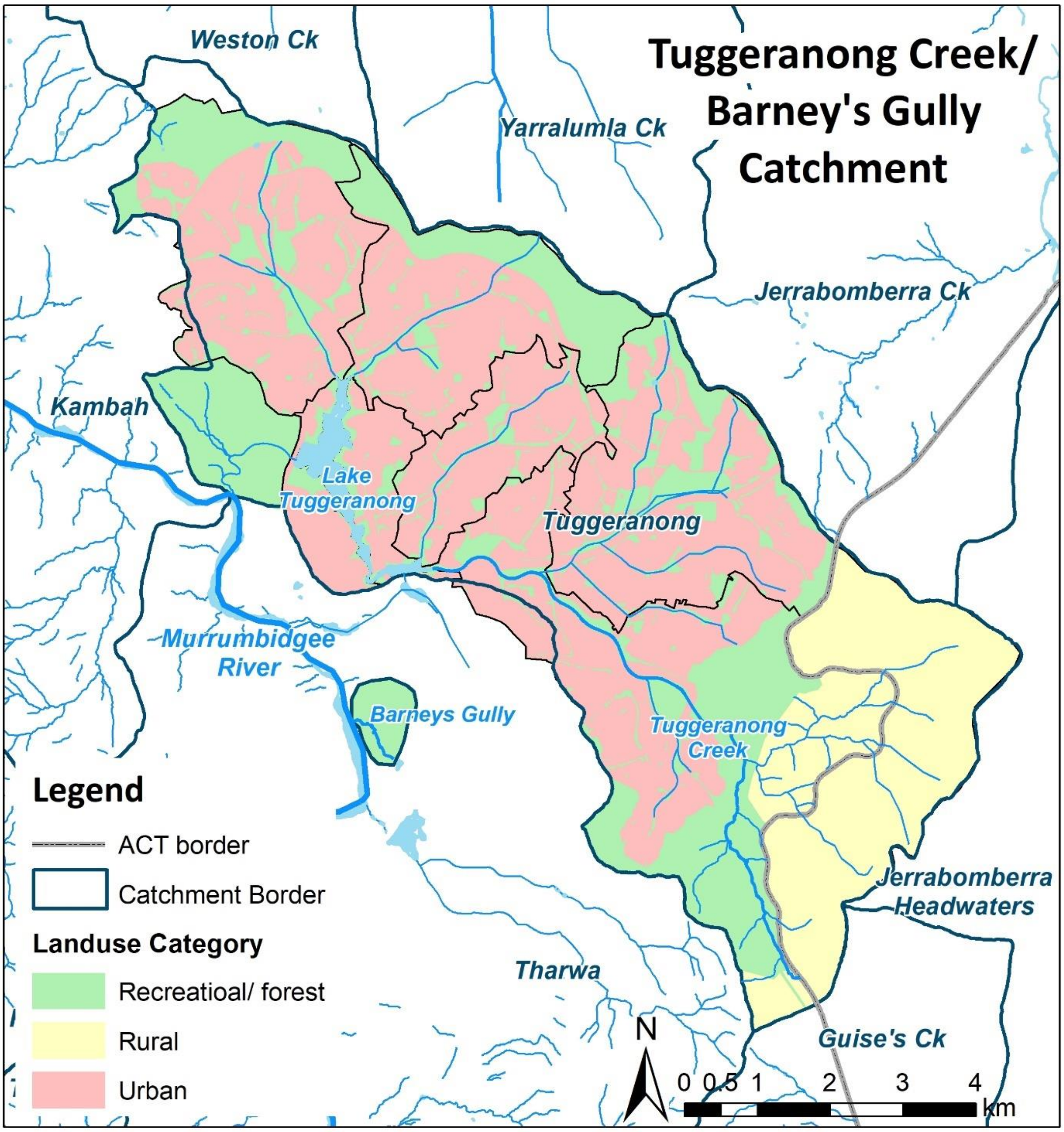

Figure 12. Map of Tuggeranong Creek catchment showing the distribution of different landuse categories.

Table 14. Hydrological metrics for Tuggeranong Creek.
Data sourced from the Bureau of Meteorology Water Data Online (http://www.bom.gov.au/waterdata/).

	Annual Flow metrics			
Station (period of record)	**Mean (ML/year)**	**Median (ML/year)**	**Maximum (year)**	**Minimum (year)**
Tuggeranong Creek (410779) (1986–2021)	10,546	10,142	24,903 (2010)	2,839 (2019)

5.4.1 The current state of Tuggeranong Creek

Addressing the evaluation questions for Tuggeranong Creek draws on supporting material included in Technical Appendices E and I.

Are the aquatic ecosystems and water quality of Tuggeranong Creek suitable to support the recreational functions and visual amenity of the creek?
Upstream of Lake Tuggeranong, the concrete lined Tuggeranong Creek and its major tributaries are almost entirely devoid of ecosystem value. Waterwatch reports include reference to the creek being full of rubbish which detracts from any possible visual amenity provided. The riparian vegetation is *poor* to *degraded*, being predominantly made up of invasive weed species and mown grass.

Downstream of Lake Tuggeranong, the creek has a more natural form and is fringed by reeds, grassed slopes and casuarina, with the riparian condition considered to be *fair* to *poor*. The current river and creek water quality issues that affect recreation and the aesthetic values of these areas are likely to be a result of highly turbid water and low dissolved oxygen concentrations. Turbidity is frequently high in this reach, but dissolved oxygen concentrations are rarely outside of the acceptable range.

Is the water of sufficient quality to support the aquatic ecosystems of Tuggeranong Creek?
The water in the upstream reaches of Tuggeranong Creek is regularly outside the acceptable range for one or more water quality parameters. The poorest water quality parameters are conductivity (EC), nitrates and turbidity, which is consistent with water in concrete lined drains. While phosphorus concentrations are generally within the acceptable range for urban streams, the concentrations are sufficiently high that they can readily support algal bloom problems in Lake Tuggeranong. The macroinvertebrate community in these upstream reaches are variable and frequently classed as *poor*. This may be attributed to both substandard habitat and water quality impacts.

The macroinvertebrate community in the reach below Lake Tuggeranong ranges from being similar to reference through to severely impaired depending on the season. This suggests the quality of water and/or habitat is also impaired, but that the effects are not consistent across seasons. There has been an improvement in the autumn macroinvertebrate communities over the past ten years, accompanied by an improvement in dissolved oxygen concentrations in the creek, but a decline in turbidity and nutrient concentrations has also been observed.

Downstream of Lake Tuggeranong, the conductivity improves markedly, and there is slight improvement in the dissolved oxygen concentrations, suggesting improvements in water quality caused by the lake. In contrast, the nitrate concentrations, turbidity and phosphorus concentrations are worse downstream of the lake than upstream, indicating the effect of the lake is parameter-specific. Nitrate and turbidity are frequently outside the acceptable range for aquatic ecosystems in urban creeks, which may explain some of the impairment in macroinvertebrate community observed in the creek.

5.5 Knowledge gaps and opportunities: urban creeks and rivers

Although all other waterbodies in the ACT are guided by planning and management documentation, there is no explicit documentation guiding the management of the ACT's urban creeks and rivers. As this makes it challenging to assess whether an expected condition or quality is being met, it is recommended that the urban creeks and rivers also be included in the ACT's water management plans.

Long term, consistent data sets are available for a small number of sites within the ACT monitoring network, and it has been an extensive job to compile a ten-year assessment of even just a few sites. Some of the best available data comes from the Waterwatch data sets, which are reported annually. There is an opportunity for Waterwatch to produce a regular (every five to 10 years) evaluation of trends and patterns in the data that would provide far more comprehensive coverage than the report provided here, but this would be a significant exercise and require substantial investment.

The ACT Water Reports(ACT Government 2022) provided a valuable synthesis of the management of water resources and water quality in the ACT. These brought together information from a range of sources and were a useful resource. They do not appear to have been produced since 2014–15 and much of the information included in them is now no longer available to the general public, including the river health assessments undertaken in the urban creeks of Canberra using the macroinvertebrate community data.

The macroinvertebrate community data collected as part of the ACT Water Quality monitoring program provides rare, comprehensive assessments of the aquatic ecosystem condition in the ACT's urban creeks and rivers. These data are not well integrated into the broader ACT Water Quality monitoring program, therefore opportunity exists to combine the traditional water quality monitoring undertaken by the ACT Government with the macroinvertebrate community monitoring to better understand patterns in the data and inform creek management.

In summary, there is a strategic body of work with the potential to combine the management of urban creeks and rivers, develop planning and management documents and build on existing programs and data sets to provide a more complete approach to managing the ACT's urban creeks and rivers.

6. The state of the ACT’s urban ponds and wetlands

Constructed ponds and wetlands found in the urban environment are established primarily to address human-induced water quality impacts and are regularly used as part of water sensitive urban design infrastructure (Kadlec et al. 2000; Wong 2006). The ACT’s urban ponds and wetlands are designed with the aim to improve water quality through pollution control, reducing flow, promoting settling of solids and removal of contaminants (Abbott et al. 2008; ACT Government 2019b; Ubrihien et al. 2019a), as well as delivering a multitude of ecosystem services including enhancing biodiversity, improving aesthetics, community involvement and recreational opportunities.

There are currently 198 constructed urban ponds and wetlands in the ACT with a combined surface area of more than 216 hectares (Figure 13) that are maintained by the ACT Government (ACT Government 2021a). This review covers the state of the Coombs A and B Ponds, Dickson Pond, Lyneham Pond, Jarramlee Pond and Yerrabi Pond, as well as an overall assessment of 15 ponds and wetlands with available long-term data sets (see Table 53). The technical analysis underpinning the assessments are included in Appendices K to Q, and the reader is encouraged to refer to the material in the appendix to better understand the interpretation provided here.

The main function of the ACT's constructed urban ponds and wetlands is to maintain and enhance the water quality of urban stormwater and runoff, which contributes to the ecological functioning of urban environments (Abbott et al. 2008; ACT Government 2019b; OCSE 2015). Ponds and wetlands remove nitrogen, phosphorus and suspended sediments from stormwater and urban runoff (ACT Government 2014b; ACT Government 2019a; ACT Government 2021a), providing downstream benefits to the ACT's lakes and the Molonglo and Murrumbidgee Rivers (ACT Government 2021b). These constructed areas also provide flood mitigation during storm and high flow events by capturing runoff from surrounding urban catchments (ACT Government 2014b; ACT Government 2019b). Sites such as Dickson Pond, Lyneham Pond and Flemington Road Ponds play a significant role in reducing peak flood flows which, in turn, provides flood protection for surrounding and downstream residents (ACT Government 2021a).

The ACT's urban ponds and wetlands are also a critical part of the region’s green infrastructure and contribute greatly to aesthetic values and recreational opportunities including the fitness, health and social wellbeing of the ACT's residents (Abbott et al. 2008; ACT Government 2019b; OCSE 2015; Schirmer et al. 2018). Although the majority of the ACT's urban ponds and wetlands are small in size, which limits the capacity for recreational activities within the water (Draft Canberra Urban Lakes and Ponds Land Management Plan 2019), the open spaces and outdoor settings allow for social gatherings and leisure activities (ACT Government 2019b; Schirmer et al. 2018). In addition, locations such as the Flemington Road Ponds, Dickson Pond and Lyneham Pond can provide a fit for purpose water storage source which benefits the maintenance of local racecourses, golf courses and irrigation for playing fields (Abbott et al. 2008; ACT Government 2014b; ACT Government 2019b; OCSE 2015).

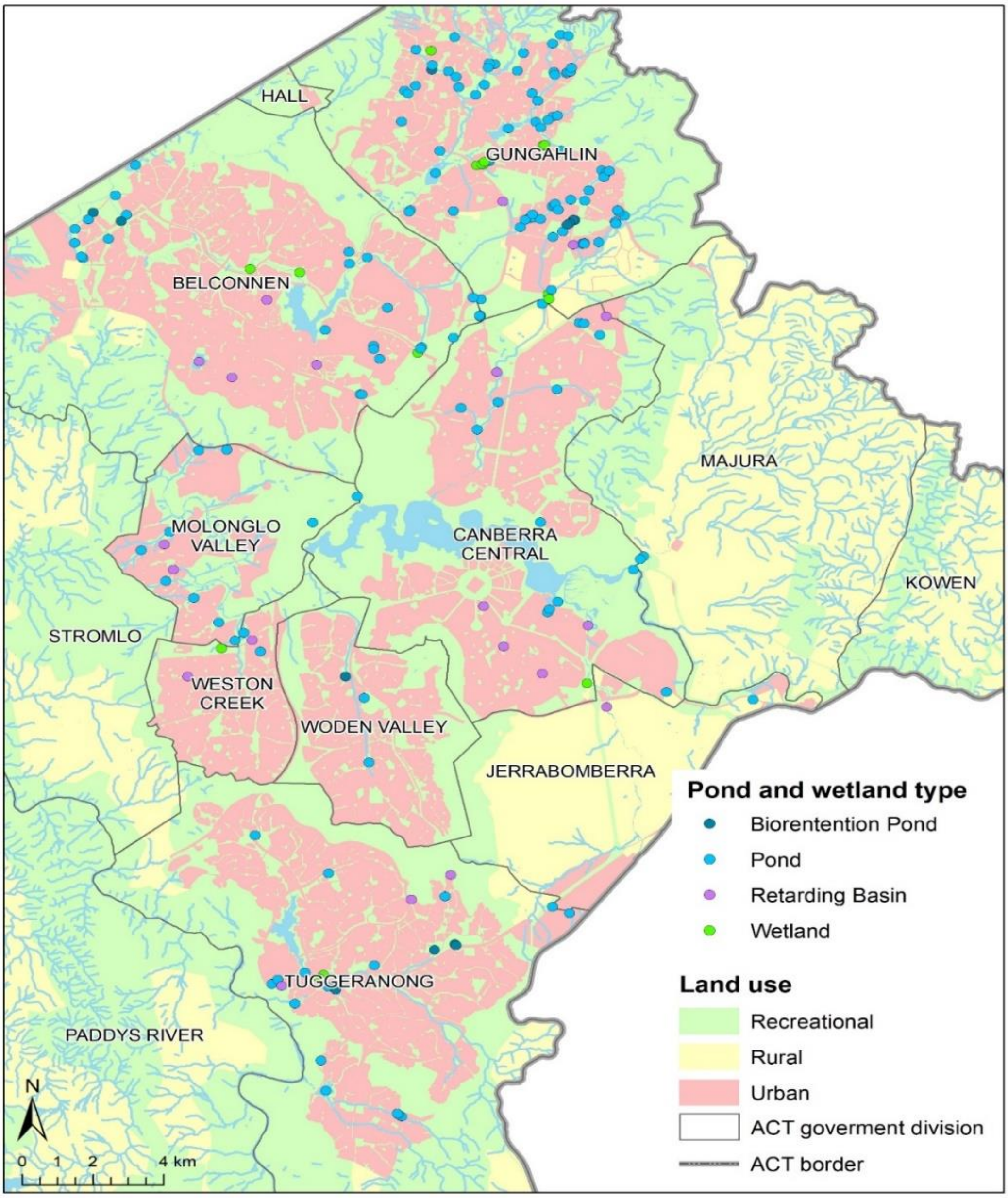

Figure 13. Map of the ACT's urban ponds and wetlands.

Outdoor spaces that incorporate waterways are highly valued by the local community as they provide an appreciation for and the opportunity to interact with the natural environment (ACT Government 2019b; OCSE 2015; Schirmer et al. 2018). The ACT's urban ponds and wetlands are designed to be attractive as well as functional community assets. The Mawson Pond has been identified as a location for an outdoor classroom, and many other urban ponds and wetlands within the ACT have created significant community engagement through volunteering and educational opportunities. Design of these areas which incorporate leisure areas, native macrophytes and nearby vegetation provide an attractive outdoor environment and reduce urban heat pollution, adding to the liveability of the city (ACT Government 2014b; ACT Government 2019b).

The ACT's urban ponds and wetlands create valuable habitats which, in turn, increases biodiversity of the area and provides both aquatic and terrestrial protection for a variety of native birds and other wildlife (Abbott et al. 2008; ACT Government 2014b; ACT Government 2019b; ACT Government

2021a; Cullen 1991). Ensuring the design of these areas incorporates a diverse array of native macrophytes and shrubs increases aesthetic values and habitat space and promotes conservation (Abbott et al. 2008; ACT Government 2018a). Maintaining good water quality in these areas is also essential for macrophyte establishment and the protection of riparian vegetation, which are both ecologically valuable for bank stability and pollution and nutrient capture and provide a buffer zone between urban areas and the waterways (Abbott et al. 2008). Ensuring a high level of water quality contributes to the protection of fish and waterbird populations as well as safeguarding the maintenance of community recreational venues and area aesthetics (Abbott et al. 2008).

The Draft Canberra Urban Lakes and Ponds Land Management Plan (ACT Government 2019b) is a document that ’presents the framework guiding the management of Canberra’s urban waterbodies in a manner responsive to a range of environmental and community values’. The report describes the vision for the urban lakes and ponds of the ACT, discusses management intentions and strategies and highlights performance indicators and measures. The management objectives raised in the Plan (ACT Government 2019b), are drawn from the *Planning and Development Act 2007* (Table 15).

Table 15. Management objectives for lakes and ponds, as stated in accordance with the Planning and Development Act 2007.

- Prevent and control floods by providing a reservoir to receive flows from rivers, creeks and urban run-off.
- Prevent and control pollution of waterways.
- Provide for public use of the lake or pond for recreation.
- Provide habitat for fauna and flora.

The state of the urban ponds and wetlands can be assessed using evaluation questions that address how well the ponds and wetlands meet the management objectives shown in Table 15:

- How effectively are the ACT’s urban ponds and wetlands acting as water quality control ponds to maintain downstream water quality and flow?
- Do the ACT’s urban ponds and wetlands provide the expected aesthetic and community recreational values?
- Do the aquatic ecosystems and water quality of the ACT’s urban ponds and wetlands support the expected habitat values?

These evaluation questions will be addressed in the following sections for the six selected ponds and wetlands, as well as the overall state of 15 ponds and wetlands with long-term data sets (see Table 53).

6.1 Coombs A and B Ponds

The Coombs A and Coombs B Ponds were built in 2011 and 2012, respectively, and are located in the Gunghalin suburb of Coombs. The ponds were constructed at the time of development of the suburb, and effectively acted as sediment basins collecting runoff during the construction phase, which is likely to account for the high rate of sediment accumulation in the pond (Alluvium 2016). They now act to retain and improve stormwater runoff and to meet the regional targets set in the ACT's water sensitive urban design (WSUD) code (Alluvium 2016).

The Coombs A Pond has a surface area of 1.73 hectares and a volume of 35.7 ML (Alluvium 2016). In addition, the Coombs A Pond area as a percentage of catchment area is 1.3%, with primary land use in the catchment as low density residential (Table 16). There are currently no documented catchment land use figures for the Coombs B Pond, but they can be considered to sit within the same catchment as the Coombs A Pond. There is limited further documented information on the background and objectives of either pond.

Table 16. Catchment land use for Coombs A Pond.
Data sourced from Alluvium (2016).

Land Use	Area (ha)	Area (%)
Residential high density	19	14%
Residential low density	71	52%
Commercial	7	5%
Urban open space	14	10%
Natural/Bushland	17	13%
Roads/Transport	7	6%
TOTAL	**135**	**100**

6.1.1 The current state of the Coombs A and B Ponds

Addressing the evaluation questions for the Coombs A and B Ponds draws on supporting material included in Technical Appendix L.

How effectively are the Coombs A and B Ponds acting as water quality control ponds to maintain downstream water quality and flow?

The ACT's urban ponds and wetlands are designed to improve water quality, removing nutrients and sediment before the water is discharged downstream into receiving waters. The water entering the ACT's urban ponds and wetlands from urban streams and drains is often high in nutrients and suspended solids (Dyer 2000; Ubrihien et al. 2019a) and the role of these sites is to provide an opportunity for sediment and nutrients to settle, resulting in improved water quality downstream.

Data collected by Ubrihien et al. (2019a) suggest that both the Coombs A and B Ponds are improving and maintaining downstream water quality, with the majority of data demonstrating lower concentrations of nutrients in the outflowing water compared with the inflowing water. It appears that both ponds are more effective at removing nitrogen than phosphorus from the system, and that improvements in phosphorus concentrations are inconsistent over the monitoring periods.

There are currently no long-term data available to assess how the Coombs A and B Ponds are performing in reducing suspended solids. However, data collected by Ubrihien et al. (2019a) suggests that in particular the Coombs B Pond demonstrated a lower concentration of suspended sediment in the downstream locations and is likely to be effectively reducing sediment in the urban system.

Do the Coombs A and B Ponds provide the expected aesthetic and community recreational values?
The aquatic ecosystems and water quality of the Coombs A and B Ponds provide a range of aesthetic and visual values, but the negative impacts of human activities, in particular development and construction activity within the catchment during the earlier years of this assessment, has been quite evident at this site, with approximately 46% of the catchment undergoing development (Alluvium 2016). Beyond urban development, the negative impacts of human activities are not recorded for either pond. Like all urban parklands, they are subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation, but the extent of these pressures and the performance of the pond are unknown.

Do the aquatic ecosystems and water quality of the Coombs A and B Ponds support the expected habitat values?
The annual average phosphorus concentrations from 2017–2019 within the Coombs A and B Ponds are within the acceptable range more than 90% of the time, with some elevated concentrations of phosphorus and nitrogen observed intermittently. This may be an indication of irregular contamination events rather than a persistent problem.

Total suspended solids (TSS) from 2017–2019 recorded at both ponds were within the acceptable range 86% of the time, which is a similar trend seen across the ACT's urban ponds and wetlands. Both ponds were within the range generally displayed for pH and performed well for dissolved oxygen, suggesting these systems are therefore likely to provide acceptable habitat for a range of aquatic species.

The condition and performance of vegetation and available habitat at both the Coombs A and Coombs B Ponds are not documented, nor are the state of macroinvertebrate communities within both ponds.

6.2 Dickson Pond

Dickson Pond is located within the Sullivans Creek catchment and is part of the Sullivans Creek and Inner North Reticulation Network completed in 2011. The pond receives urban stormwater runoff from a large concrete stormwater channel and has primary objectives to improve water quality, enhance urban habitat and to supply water for irrigation to local playing fields (see Table 53). The outflow from the pond continues downstream through the Dickson channel of Sullivans Creek to the Lyneham Pond.

6.2.1 The current state of Dickson Pond

Addressing the evaluation questions for Dickson Pond draws on supporting material included in Technical Appendix M.

How effectively is Dickson Pond acting as a water quality control pond to maintain downstream water quality and flow?

The ACT's urban ponds and wetlands are designed to improve water quality by removing nutrients and sediment before the water is discharged downstream into receiving waters. The water entering the ACT's urban ponds and wetlands from urban streams and drains is often high in nutrients and suspended solids (Dyer 2000; Ubrihien et al. 2019a), and the role of these sites is to provide an opportunity for sediment and nutrients to settle, resulting in improved water quality downstream.

The ACT’s urban ponds and wetlands are generally demonstrating an effective reduction in nutrients from the system, but the data suggest that Dickson Pond is much less effective. The pond recorded a reduction in phosphorus from inflow to outflow for fewer than half of all sampling years, and nitrate concentrations either increased or showed no reduction from across most sampling years. The reason for this was thought to be a water leak upstream that was permanently contributing high quality treated water (potable water) to the Dickson channel, therefore providing low nutrient water to Dickson Pond at the inflows. This has not been verified, but the information has been provided to the ACT Government.

There are currently no long-term data available to assess how the wetlands are performing in reducing suspended solids. Data collected by Ubrihien et al. (2019a) suggest that Dickson Pond demonstrated a higher concentration of suspended sediment in the open water and downstream locations than other ponds, and is therefore thought to be less effective at reducing sediment in the urban system. However, this is not a fair interpretation of the data. The concentrations of suspended solids are low in the inflow channel, the open water areas and the downstream channel compared with other similar locations in the area (e.g. Lyneham Pond). If there is an input of good quality water to the Dickson channel, this would likely also result in a low concentration of suspended solids in the inflows. Under these circumstances, the wetland would appear to be performing poorly, but there is little capacity for the wetland to improve water quality.

Does Dickson Pond provide the expected aesthetic and community recreational values?

The aquatic ecosystems and water quality of Dickson Pond provide a range of aesthetic and visual values. However, the negative impacts of human activities can be quite evident, with the entrance to the trash rack blocking easily, causing water to bypass Dickson Pond and limiting treatment of that water (Alluvium 2016). This reduces the ability of the pond to improve water quality, and it detracts from the aesthetic values of the pond. Local volunteers at Dickson Pond have collected many kilograms of rubbish per year from within the ponds, improving the visual amenity of the pond. The involvement of volunteers in maintaining and supporting the community values is particularly important as there are no government resources available to provide regular rubbish collection.

Visual commentary associated with Waterwatch data for several occasions indicate that during periods of no flow, the water within Dickson Pond appears turbid. This is likely to impact on the visual amenity of this waterway, but there seems to be no clear description of either cause or longevity of the issue.

Vegetation including macrophytes, native grasses and trees around and within Dickson Pond were planted by more than 200 people during a Community Planting Day in 2011 (ACT Government 2021c). Like all urban parklands, the surrounding areas of Dickson Pond have since been subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation. Active community engagement such as that at Dickson Pond contribute to far better maintained vegetation than seen at other ponds and providing resources to support community groups to maintain these areas is likely to be of significant benefit.

Do the aquatic ecosystems and water quality of Dickson Pond support the expected habitat values?

The quality of water in Dickson Pond over the past 10 years has been within the acceptable range for freshwater ecosystems no less than 70% of the time, with well performing results (>90%) for pH, conductivity, turbidity and dissolved oxygen suggesting the pond is providing acceptable habitat for a range of aquatic species.

The condition of vegetation around Dickson Pond between 2015 and 2021 was classed as being in poor condition 25% of the time and in fair condition 75% of the time, possibly indicating the pond is not performing to its full potential. The approach used to establish the riparian vegetation condition was designed for the riparian areas of rivers and is not designed for a constructed urban system where the vegetation has been planted and is maintained by local community groups and park managers.

Data collected from the Waterwatch Monitoring Program indicates that Dickson Pond has supported a consistently good condition for macroinvertebrate habitat and taxa richness.

6.3 Jarramlee Pond

Constructed in 1994, Jarramlee Pond is in the suburb of Dunlop, with a catchment area of 752,424 m^2. The pond receives inflow from urban stormwater runoff and sits on Ginninderra Creek, which then flows through Jarramlee-West MacGregor Grasslands Nature Reserve. There is limited further documented information on the background and objectives of Jarramlee Pond.

6.3.1 The current state of Jarramlee Pond

Addressing the evaluation questions for Jarramlee Pond draws on supporting material included in Technical Appendix N.

How effectively is Jarramlee Pond acting as a water quality control pond to maintain downstream water quality and flow?

The ACT's urban ponds and wetlands are designed to improve water quality by removing nutrients and sediment before the water is discharged downstream into receiving waters. The water entering the ACT's urban ponds and wetlands from urban streams and drains is often high in nutrients and suspended solids (Dyer 2000; Ubrihien et al. 2019a), and the role of these sites is to provide an opportunity for sediment and nutrients to settle, resulting in improved water quality downstream.

There are currently no long-term data available to assess how Jarramlee Pond is performing in reducing nutrients or suspended solids. However, data collected by Ubrihien et al. (2019a) indicate that Jarramlee Pond was effective at removing both nitrogen and phosphorus concentrations from the inflow to downstream sites, as well as eliciting a small reduction in TSS from inflow to downstream sites at the pond.

Does Jarramlee Pond provide the expected aesthetic and community recreational values?

Although the aquatic ecosystems and water quality of Jarramlee Pond provide a range of aesthetic and visual values, the negative impacts of human activities are not recorded. Like all urban parklands, they are subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation, but the extent of these pressures and the performance of the pond are unknown.

Visual commentary associated with Waterwatch data for Jarramlee Pond identifies occasional instances when the water within the pond was turbid with the presence of algae. This is likely to have an impact on the visual amenity of these waterways, but there seems to be no clear description of either cause or longevity of the issue.

Do the aquatic ecosystems and water quality of Jarramlee Pond support the expected habitat values?

The quality of water in Jarramlee Pond over the past 10 years has been within the acceptable range for freshwater ecosystems more than 90% of the time, with all water quality parameters performing well. This suggests the pond is providing acceptable habitat for a range of aquatic species.

The condition of the vegetation around Jarramlee Pond between 2015 and 2021 was classed as being in poor condition 100% of the time. The condition of the vegetation may indicate the pond is possibly not performing to its full potential. The approach used to establish the riparian vegetation condition was designed for the riparian areas of rivers and is not designed for a constructed urban system where the vegetation has been planted and is maintained by local community groups and park managers.

The state of macroinvertebrate communities within Jarramlee Pond is not documented.

6.4 Lyneham Pond

Lyneham Pond is located within the Sullivans Creek catchment area and is part of the Sullivans Creek and Inner North Reticulation Network completed in 2012. The pond is located immediately upstream of the Sullivans Creek confluence and receives urban stormwater runoff from a stormwater network of concrete pipes and channels. The primary objectives of Lyneham Pond are to improve water quality, enhance urban habitat and to supply water for irrigation to local playing fields (see Table 53). URS (2010) has estimated water quality performance for Lyneham Pond as a 54% reduction in total suspended solids, a 44% reduction in total phosphorus and a 34% reduction in total nitrogen, but it is unclear whether the pond has met these estimates since the date of construction. The outflow from the pond continues downstream through Sullivans Creek, eventually discharging into Lake Burley Griffin.

6.4.1 The current state of Lyneham Pond

Addressing the evaluation questions for Lyneham Pond draws on supporting material included in Technical Appendix O.

How effectively is Lyneham Pond acting as a water quality control pond to maintain downstream water quality and flow?

The ACT's urban ponds and wetlands are designed to improve water quality by removing nutrients and sediment before the water is discharged downstream into receiving waters. The water entering the ACT's urban ponds and wetlands from urban streams and drains is often high in nutrients and suspended solids (Dyer 2000; Ubrihien et al. 2019a), and the role of these sites is to provide an opportunity for sediment and nutrients to settle, resulting in improved water quality downstream.

There are currently no long-term data available to assess how the Lyneham Pond is performing in reducing nutrients or suspended solids. However, data collected by Ubrihien et al. (2019a) indicate Lyneham Pond was effective at removing both nitrogen and phosphorus concentrations from the inflow to downstream site, but there was no significant reduction in suspended solids from inflow to downstream sites. While the Ubrihien et al. (2019a) data set indicates some removal of phosphorus and nitrogen, the proportion of phosphorus removed would appear to be considerably less than the URS (2010) estimate. but similar to the estimates of nitrogen removal.

Does Lyneham Pond provide the expected aesthetic and community recreational values?

The aquatic ecosystems and water quality of Lyneham Pond provide a range of aesthetic and visual values, but the negative impacts of human activities can be quite evident, with the upstream Gross Pollutant Trap likely to be too small for the catchment and becoming blocked after high flow events (Alluvium 2016). This reduces the ability of the pond to improve water quality and detracts from the pond’s aesthetic values.

During a Community Planting Day in 2011, volunteers planted 1,200 native grasses and shrubs at Lyneham Pond (ACT Government 2021c). Like all urban parklands, the surrounding areas of Lyneham Pond have since been subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation. Due to high flow areas and frequent disturbance at the Lyneham Pond spillway, there have been a number of historical issues with establishing vegetation in this area (Alluvium 2016). In addition, there have been challenges within establishing shrub beds around the banks of the pond, which are relatively steep and often inundated with water (Alluvium 2016).

Visual commentary associated with Waterwatch data for Lyneham Pond identifies that, on a significant number of occasions, the water within the pond has appeared turbid and surface scum or oil slicks, litter and odour have been present. This is likely to have a large impact on the visual amenity of this waterway, but there seems to be no clear description of either cause or longevity of the issue. During dry conditions, which are a common occurrence at Lyneham Pond, strong smells may be associated with decaying organic matter.

Community activities at Lyneham Pond have included significant community involvement, including school visits and community education sessions, with interpretive signage at the site helping to raise wider awareness (Alluvium 2016). Considering this, it is likely that Lyneham Pond is performing well in providing the expected community recreational values.

Do the aquatic ecosystems and water quality of Lyneham Pond support the expected habitat values?

The quality of water in Lyneham Pond from 2014 to 2021 has demonstrated a range of performances between water quality parameters, with some areas such as pH, turbidity and conductivity all within the acceptable range for more than 90% of the time. However, phosphorus, TSS and dissolved oxygen were underperforming, with some years recording data outside the acceptable range for more than 70% of the time. This suggests the pond is performing better at some water quality parameters than others but is still likely to be providing acceptable habitat for a range of aquatic species most of the time.

The condition of the vegetation around the Lyneham Pond between 2015 and 2021 was classed as being in poor condition 75% of the time and in fair condition 25% of the time. The condition of the vegetation may indicate the pond is possibly not performing to its full potential. The approach used to establish the riparian vegetation condition was designed for the riparian areas of rivers and is not designed for a constructed urban system where the vegetation has been planted and is maintained by local community groups and park managers.

The condition of the macroinvertebrate communities at Lyneham Pond is for the majority categorised as *poor*, indicating the pond is not supporting a healthy functioning macroinvertebrate community. Visual commentary associated with Waterwatch data for several sampling occasions indicates there are often low water levels and rubbish within the pond, which is likely to have an impact on the availability of suitable habitat and taxa richness of macroinvertebrate communities. There are no clear descriptions of either cause or longevity of the issues.

6.5 Yerrabi Pond

Yerrabi Pond is located within the Ginninderra Creek catchment area and was constructed in 1994 as part of the Gungahlin Stormwater Pollution Control and Belconnen Flood Protection Strategy. The pond receives urban stormwater runoff from surrounding suburbs and the outflow from the pond continues downstream through Ginninderra Creek, Ginninderra Pond and eventually discharges into Lake Ginninderra. The primary objectives of the pond are to limit pollution downstream at Lake Ginninderra, as well as to provide aesthetic and recreational values (see Table 53).

6.5.1 The current state of Yerrabi Pond

Addressing the evaluation questions for Yerrabi Pond draws on supporting material included in Technical Appendix P.

How effectively is Yerrabi Pond acting as a water quality control pond to maintain downstream water quality and flow?

The ACT's urban ponds and wetlands are designed to improve water quality by removing nutrients and sediment before the water is discharged downstream into receiving waters. The water entering the ACT's urban ponds and wetlands from urban streams and drains is often high in nutrients and suspended solids (Dyer 2000; Ubrihien et al. 2019a), and the role of these sites is to provide an opportunity for sediment and nutrients to settle, resulting in improved water quality downstream.

As a general assessment, the data suggest Yerrabi Pond performs effectively as a water quality control pond to improve and maintain downstream water quality, with most nutrient concentrations demonstrating lower concentrations in outflowing water compared to inflowing water. There are currently no long-term data available to assess how Yerrabi Pond is performing in reducing suspended solids.

Does Yerrabi Pond provide the expected aesthetic and community recreational values?

The aquatic ecosystems and water quality of Yerrabi Pond provide a range of aesthetic and visual values, but the negative impacts of human activities (particularly development and construction activity within the catchment during the earlier years of this assessment) has been quite evident at this site, with a number of high turbidity events detracting from these values (Alluvium 2016). Alluvium (2016) has also identified there are inherent design limitations at Yerrabi Pond, with minimal macrophyte coverage at the water’s edge. Like all urban parklands, Yerrabi Pond is subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation.

Some of the ACT's urban ponds and wetlands experience regular cyanobacterial blooms that detract from the ornamental and visual values, but these are confined to summer periods and are consistent with the water quality control features of the ACT's urban ponds and wetlands. Visual commentary associated with Waterwatch data for Yerrabi Pond identifies frequent occasions when algae has been present, and Alluvium (2016) noted during their study the pond was closed to contact activities due to algae. This is likely to have an impact on the visual amenity of these waterways, but there seems to be no clear descriptions of either cause or longevity of the issue.

Do the aquatic ecosystems and water quality of Yerrabi Pond support the expected habitat values?

The quality of water in Yerrabi Pond over the past 10 years has been within the acceptable range for freshwater ecosystems no less than 80% of the time, with well performing results (>90%) for pH, phosphorus, turbidity, total suspended solids and dissolved oxygen suggesting that the pond is providing acceptable habitat for a range of aquatic species.

While the water quality has generally been within the acceptable range, the 2014 fish kill at Yerrabi Pond is the type of adverse outcome that can arise from short periods of very poor water quality. Reports of this fish kill state a large number of Murray Cod were killed over a 25-day period (ACT Government 2014c). Investigations failed to determine the reasons for the event, but it was considered likely that short-term warm temperatures and low dissolved oxygen conditions may have been contributing factors.

The condition of the vegetation around Yerrabi Pond between 2015 and 2021 was classed as being in poor condition 86% of the time and degraded condition 14% of the time. The condition of the vegetation may indicate the pond is possibly not performing to its full potential. The approach used to establish the riparian vegetation condition was designed for the riparian areas of rivers and is not designed for a constructed urban system where the vegetation has been planted and is maintained by local community groups and park managers.

The condition of the macroinvertebrate communities at Yerrabi Pond may suggest that, in the earlier sampling years, the pond was not performing to its full potential. However, from 2017 onwards it appears Yerrabi Pond has supported a consistently good condition for macroinvertebrate habitat and taxa richness.

6.6 Other ACT urban ponds and wetlands

How effectively are the ACT’s urban ponds and wetlands acting as water quality control ponds to maintain downstream water quality and flow?

The ACT's urban ponds and wetlands are designed to improve water quality by removing nutrients and sediment before the water is discharged downstream into receiving waters. The water entering the ACT's urban ponds and wetlands from urban streams and drains is often high in nutrients and suspended solids (Dyer 2000; Ubrihien et al. 2019a), and the role of these sites is to provide an opportunity for sediment and nutrients to settle, resulting in improved water quality downstream.

As a general assessment, the long-term data suggest that, collectively, the urban ponds and wetlands are performing effectively as water quality control ponds to significantly improve and maintain downstream water quality. This has also been suggested in a more detailed study by (Ubrihien et al. 2019a), who undertook weekly sampling to demonstrate the urban ponds and wetlands across a range of catchments and ages were providing a valuable service in the stormwater network by reducing concentrations of nutrients and suspended solids moving through the system.

Analysis of data from 15 of the ACT's urban ponds and wetlands for this report suggests the urban ponds and wetlands are consistently reducing nutrient concentrations, with lower concentrations in outflowing water compared to inflowing water. This supports the more detailed study of Ubrihien et al. (2019a). The nutrient removal performance of the wetlands varies with time and between wetlands. Ponds such as Flemington Pond and Yerrabi Pond consistently remove a significant proportion of the nutrients, whereas Dickson Pond and David Street Wetlands are less effective.

The author’s current data review suggests that, across a variety of ponds and wetlands, the removal of phosphorus has been more effective than the removal of nitrogen. This is contrary to the more detailed study of (Ubrihien et al. 2019a), who reported the ponds were less effective at removing phosphorus than they were at removing nitrogen. There are currently no long-term data available to assess how the wetlands are performing in reducing suspended solids.

Do the ACT’s urban ponds and wetlands provide the expected aesthetic and community recreational values?

The aquatic ecosystems and water quality of the ACT's ponds and wetlands provide a range of aesthetic and visual values, but the negative impacts of human activities can be quite evident in some areas, with rubbish collecting in inlet zones. As the wetlands collect stormwater flows from urban drains, they also collect rubbish that is then deposited within the pond or wetland environment. While this forms part of the water quality improvement character of the wetlands, it detracts from the aesthetic values of the ponds. Local volunteers at Dickson Pond have collected many kilograms of rubbish per year from within the ponds, improving the visual amenity of the pond. The involvement of volunteers in maintaining and supporting the community values is particularly important as there are no government resources available to provide regular rubbish collection.

Some of the ACT's urban ponds and wetlands experience regular cyanobacterial blooms that detract from the ornamental and visual values, but these are confined to summer periods and are consistent with the water quality control features of the ACT's urban ponds and wetlands. While an improvement to the inflowing water quality would be beneficial to the aesthetic and recreational amenity of the ACT's urban ponds and wetlands, one of their main purposes is to treat and manage inflows. At times, the expectations of these urban waterways are not well aligned.

The vegetation around and within the ACT's urban ponds and wetlands has been planted and is maintained through regular mowing and management, consistent with the management of the urban park estate. There are limited resources to actively manage weeds and undertake routine maintenance other than mowing. The regions surrounding the ACT's urban ponds and wetlands comprise a mix of native and exotic vegetation, the condition of which is defined by the level of management effort. Like all urban parklands, they are subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation. Ponds and wetlands where there are active community groups (such as Banksia Street Wetland) have far better maintained vegetation associated with them than do other ponds. Providing resources to support community groups to maintain these areas is likely to be of significant benefit.

Visual commentary associated with Waterwatch data for several sites identifies frequent occasions when water within the ACT's urban ponds and wetlands is turbid with a slight odour. This is likely to have an impact on the visual amenity of these waterways, but there seems to be no clear descriptions of either cause or longevity of the issue. During dry conditions, or drawdown of some ponds, there are strong smells associated with decaying organic matter, but these rarely persist for more than a few weeks once the pond or wetland refills.

Do the aquatic ecosystems and water quality of the ACT’s urban ponds and wetlands support the expected habitat values?

The quality of water in the urban wetlands over the past 10 years has been within the acceptable range for freshwater ecosystems more than 75% of the time, suggesting they are providing acceptable habitat for a range of aquatic species. No noticeable trends in water quality were evident, with considerable temporal and spatial variability reflecting variation in the concentrations from inflowing streams rather than longer-term trends.

The phosphorus concentrations within the urban wetlands and ponds of the ACT were within the acceptable range more than 90% of the time, and nitrogen concentrations were within the acceptable range 75% of the time. High concentrations of nitrogen were observed intermittently, but these were not persistent and may be more indicative of irregular contamination events rather than a persistent problem. (Ubrihien et al. 2019a) detected similar high concentration contamination events in a detailed study of six urban wetlands.

TSS within the urban ponds and wetlands were within the acceptable range 86% of the time. As found with nutrients, there is variation in the concentrations of TSS between individual sites, with some such as Dickson Wetlands, Point Hut Pond in Gordon and Yerrabi Pond consistently within the acceptable range more than 90% of the time, and others such as Lyneham Pond within the acceptable range less than 60% of the time.

The average of the combined data for all urban ponds and wetlands across all sampling years records pH values within guideline thresholds of 6–9 more than 90% of the time. Banksia Street Wetland had pH levels within guideline values 85% of the time, and Stranger Pond in Bonython performed exceptionally well and was below threshold values 100% of the time. All urban ponds and wetlands were within the range generally displayed for pH, and these systems are therefore likely to provide acceptable habitat for a range of aquatic species.

The condition of the vegetation around the urban ponds and wetlands between 2015 and 2021 was classed as being in poor to fair condition and was very rarely classed as in good condition. Both the David Street and Dickson Wetlands performed best, with a classification of *fair* more than 80% of the time. The approach used to establish the riparian vegetation condition was designed for the riparian areas of rivers and is not designed for a constructed urban system where the vegetation has been planted and is maintained by local community groups and park managers.

Macrophyte condition was also regarded as being very poor in most wetlands (Alluvium 2016), suggesting that the wetlands were possibly not performing to their full potential.

6.7 Knowledge gaps: ACT’s urban ponds and wetlands

The ACT has invested significantly in lakes, ponds and wetlands as key elements of the water quality infrastructure of urban developments. There are limited data collected to evaluate the effectiveness or long-term performance of these assets, meaning the capacity to learn from existing investment and improve over time is limited. Waterwatch data are useful, but are constrained by relatively low sampling frequency, which biases them toward low flows. Targeted studies such as Ubrihien et al. (2019a) are invaluable, and it would be worthwhile undertaking regular targeted studies to monitor and understand performance.

7. Management of the ACT’s urban waterways

Management of urban waterways in the ACT is predominantly the responsibility of the ACT Government, with the NCA responsible for Lake Burley Griffin. Within the ACT Government, numerous government agencies are delegated differing responsibilities. ACT Government areas with roles that directly influence the management of urban waterways include the Environment, Planning and Sustainable Development Directorate (EPSDD), ACT Planning and Land Authority (ACTPLA), the Environmental Protection Authority (EPA), ACT Health Directorate and Transport Canberra and City Services (TCCS). These stakeholders manage Canberra’s urban waterways based on a range of legislation, regulations, strategic planning and policy documents that have been prepared with differing objectives and goals in mind.

In addition to ACT government stakeholders that have direct responsibility and influence over the management of Canberra waterways, there are numerous community stakeholders that include, but are not limited to, community organisations, not-for-profit groups, private landholders and federal Government departments.

A systematic approach to management entails a planning phase, an implementation phase, ongoing monitoring of implementation, a review phase and identification of continual improvement needs. In addition, comprehensive identification of relevant stakeholders, their roles and how engagement between stakeholders occurs is key for effective communication outcomes. Across the ACT, the range of agencies responsible for various aspects of urban water quality and condition appear to lack an overarching systematic approach to water quality and urban waterway management. The multiple strategy documents outline high level policy objectives, but the demonstration of achievement through target setting, auditing and systematic review of achievement of objectives is patchy. Improvements to urban water quality management outcomes may be achieved by detailing a systematic management ’roadmap’ that also includes documentation of key stakeholders and communication strategies. This can also assist in determining how identified knowledge gaps can be filled, and by which government agency.

As an example, the approach to managing Canberra’s urban lakes and ponds is documented in Canberra’s Urban Lakes and Ponds Plan of Management (ACT Government 2001), an update of which was published in draft form in 2019 (ACT Government 2019). The most recent draft reflects the substantial increase in the number of lakes and ponds in the ACT over the past 20 years and has been used as the guiding document for this assessment. It is noted that the Draft Plan was published in 2019 and, at the time of writing, is still expected to be finalised ‘soon’. This plan of management provides expected uses for the different lakes and ponds, a set of standards for water quality and attributes of aquatic ecosystems and the approach to managing the sites as a community resource. It does not provide information about the data required to inform the effectiveness (or otherwise) of management actions. For most lakes and ponds, there are limited data collected that could inform the effectiveness of management actions for meeting the specified standards.

Similar documentation does not exist for the urban creeks and rivers of the ACT. The ACT Aquatic and Riparian Conservation Strategy (ACT Government 2018a), which generally deals with the rivers and streams of the ACT, does not cover urban waterways, and this is a notable gap in planning and management.

Similarly, limited management framework and responsibility around the collection of water samples and data on algal blooms and lake closures were identified in this review. This management gap has serious implications for both water quality management and public health outcomes.

7.1 Indicators, targets and threshold values

The multiple agencies that have responsibility for urban waters means that where information exists about indicators, targets and threshold values, it is distributed across multiple documents and managed by different agencies. At times, this leads to a lack of clarity around the specific targets and thresholds that are in place, and there is the risk that inconsistencies will arise. Notably, the Draft Urban Lake and Ponds Report (ACT Government 2019b) has slightly different thresholds from the ACT Guidelines for Recreational Water Quality, the *Environment Protection Regulation 2005* values for urban lakes and ponds (AQUA/3) and the *Environment Protection Regulation 2005* values for urban wetlands (AQUA/5) (EPA 2005). While it is important that indicators, targets and thresholds are regularly reviewed, it would be beneficial to establish a clear central point of documentation to guide management.

Additionally, there is little specific guidance about the expected ecological condition or the targeted ecological condition for most urban waterways. The *Environment Protection Regulation 2005* establishes water quality targets and environmental standards for different types of waterbodies within the ACT. This includes recreational and aesthetic values of waterways and, in some instances, incorporates ecosystem indicators. However, while standards for water quality parameters (e.g. total phosphorus concentrations) and some ecosystem attributes (cyanobacterial cell counts) are clearly defined numerically and easy to apply, others are less clear. For example, the standards specified for aquatic macrophytes (both floating and rooted) and colour are that they are 'not objectionable'. How 'objectionable' is determined is open to interpretation.

The Draft Urban Lake and Ponds Report (ACT Government 2019b) provides targets for some indicators of ecological condition for a range of zones within urban lakes and ponds, but similar targets and indicators are not available for other types of urban waterways. This has made it difficult to evaluate the extent to which the urban waterways are performing in relation to their desired state. It would be valuable to establish a set of indicators of ecological condition for all types of urban waterways to guide management activities.

7.1.1 Nitrogen

The ACT does not specify threshold values or standards for total nitrogen concentrations in either recreational waters or for the protection of aquatic ecosystems. Standards are established for nitrate and nitrite in drinking water because of the public health risks associated with drinking water that is high in these compounds. For recreational waters and aquatic ecosystems, the nitrogen to phosphorus (N:P) ratio of >12:1 is recommended, based on the belief that nitrogen is not a limiting nutrient for algal growth. This belief arose from studies that have shown that N:P ratios are key determinants of algal populations (Biggs 2000; Guildford and Hecky 2000). While such published studies have always suggested high variability in the stoichiometric thresholds for nutrient limitation of algal growth in freshwaters, general 'rules of thumb' have tended to find their way into management approaches, e.g. blue-green algae dominance when ratios are below 30N:1P (Smith 1983); DIN:TP[3] ratio should be maintained at a level of at least above 10, but preferably above 50 (Li et al. 2018).

There has not been a systematic review of the literature to provide widely accepted guidance to water managers. Recent literature continues to suggest there is substantial variability in the stoichiometric thresholds for cyanobacterial growth in lakes, and that the response of cyanobacteria is complex, with a recent paper demonstrating that high N:P ratios enhanced the physiological processes of phosphate uptake by cyanobacteria, rather than shifting species composition (Aubriot and Bonilla 2018). The belief that 'the potential threat from nutrients in forming algae growth is ameliorated in the effluent discharged due to its low phosphorus and high nitrate concentrations' (Commissioner for Sustainability and Environment, 2012, p. v,) is risky and no longer supported by most involved in the management of algal blooms (Chorus and Spijkerman 2021; Dolman et al. 2012; Dolman and Wiedner 2015; Hamilton et al. 2016; Harris et al. 2014; Maberly et al. 2020; NCA 2011; Paerl 2017). Fundamentally, it implies that an unlimited nitrogen concentration is acceptable, which is unlikely to have been the intent of the regulation.

It is recommended that the specified standard for a 12N:1P ratio is revisited to determine the relevance to Canberra lakes and that threshold values for nitrogen are established for the region. These should be based on limiting factors to primary production rather than nutrient ratios. The ANZECC guidelines offer default threshold values for nitrogen for the protection of freshwater ecosystems, and these would seem to be a good starting point for the establishment of standards.

7.1.2 Phosphorus

The acceptable range of concentrations for total phosphorus in Lake Burley Griffin, which is based on the historically recorded range of concentrations in the lake, lacks biological relevance to lake processes. Phosphorus is recognised as the limiting nutrient for cyanobacterial blooms in lake systems (Håkanson et al. 2007). There is some thought that concentrations below 0.025 mg/L are limiting to cyanobacterial blooms (see, for example, data in Dolman et al. 2012), and it may be worth developing total phosphorus targets for the lake in conjunction with targets for the inflowing streams as part of a broader strategy to reduce the incidence of cyanobacterial blooms.

7.2 Data

This report has drawn on data from a wide range of sources to assess the state of the ACT's waterways. While the data are limited in spatial and temporal resolution, in combination they provide reasonable coverage of the region. It is notable that this research has relied heavily on the Waterwatch data set for spatial coverage, and these data continue to make an important contribution to understanding and management of the region's waterways.

There are important gaps in the data set that have limited the author's understanding. Flow data from the urban stormwater network is sparse at best and non-existent in many cases. It is

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[3] DIN: dissolved inorganic nitrogen; TP: total phosphorus

challenging to gauge the stormwater network, but the relative contributions from urban runoff are currently very poorly understood. Given the notable contributions of (particularly dissolved) nutrients to the urban lakes, ponds and wetlands, which are largely flow driven, there would be value in gaining some understanding of the flows in the urban stormwater network.

One of the challenges of the ACT’s water quality data sets is the limited temporal resolution of the data. While Waterwatch provides valuable regular monitoring of the ACT’s urban waterways, it is limited to monthly sampling and is biased towards low flows. Given that a large portion of nutrients and other urban pollutants are transported in high flow events, the assessment conducted here likely misses important information that would be obtained from more frequent sampling. It is generally cost prohibitive to undertake continuous monitoring of water quality, and event sampling is particularly challenging. Studies such as those of Ubrihien et al. (2019a); Ubrihien et al. (2019b) and Ubrihien et al. (2020), along with targeted monitoring of Telopea Creek conducted by the ACT Government, are invaluable for understanding the concentrations of nutrients and other pollutants being transported during a range of flow conditions. Importantly, the more frequent monitoring has a greater probability of capturing contamination events.

The state of information on historical lake closures of the swimming locations at Lake Ginninderra and Lake Tuggeranong is particularly poor. The available data have not been consistently recorded, records prior to 2015 are not available and there are generally poor links to water quality data sets (cyanobacterial counts or Enterococci), personal observations or weather conditions. As this is a key indicator of the recreational amenity of the lakes, it would be valuable to be able to track closures (and the reasons for closure) over time.

Ecological data for the ACT’s waterways are particularly rare, with the only data with reasonable coverage available from the Waterwatch and Frogwatch programs for riparian vegetation or aquatic and amphibious fauna. Long term macroinvertebrate data sets are available for selected sites within the urban stream network, and these data provide some insight as to the water quality conditions. The authors have used the data collected by Waterwatch relating to riparian condition to comment on the riparian areas of the urban creeks, but this is not fit for purpose in areas of managed parklands. A stronger understanding of the expected riparian character of Canberra’s urban waterways should be developed to guide management effort and enable clear evaluation of performance.

7.3 Management responses

The lack of an overarching systematic approach to water quality and urban waterway management means that the capacity to manage adaptively and make use of the data that are collected is limited.

Copious amounts of water quality data have been collected, but these are not necessarily the data needed to evaluate management objectives. This means the capacity to manage adaptively is limited. Processes for managing and recording data are constrained by agency resourcing, meaning the data sets are not always clean nor easily used. It has been an intense process to review, analyse and interpret the data for use in this report. There are not clear processes for reviewing and responding to the information in the water quality data, therefore a number of instances where the water quality readings have been implausible or should have raised substantial concerns have been noted.

There is a lack of reporting of urban waterway condition that includes an evaluation of the effectiveness of management actions and recommendations for improvement. The ACT Government previously produced a series of annual ‘Water Reports’ (ACT Government 2022) that summarised water resource management and water quality in the ACT. These reports synthesised data and other information and provided a series of recommendations and management responses. These reports have not been produced since 2015. It would also be beneficial for the ACT Government and the NCA to report on recreational water quality, but this would require considerable improvement in the ACT Government data sets (see above section).

8. Current and future threats for ACT lakes and waterways

8.1 Climate change

As Canberra's climate warms, the region is expected to experience longer and more severe droughts, more intense rainfall events, decreases in spring rainfall and increases in summer and autumn rainfall (NSW Government 2014). This poses significant challenges for the management of water quality. Changes in temperature and rainfall will affect runoff patterns and stream flows, changing the way in which pollutants and contaminants are generated and transported through the stream network.

Longer and more severe droughts will reduce groundcover vegetation, leaving areas of bare ground susceptible to erosion. Such long dry spells will also result in an accumulation of organic matter, pollutants and contaminants on impervious surfaces. Drought-breaking rains are likely to result in significant erosion, increasing turbidity and contribute an increased load of nutrients and other pollutants into urban waterways. Accumulated pollutants and contaminants will be delivered in a pulsed fashion to the urban stormwater network, placing additional pressure on the existing stormwater infrastructure on which the ACT relies for water quality improvements.

The combination of higher nutrient loads and longer warm periods means cyanobacterial blooms are likely to increase in magnitude and frequency as the climate warms. Cyanobacteria can grow more rapidly at higher temperatures, and waterbodies are more inclined to stratify at higher temperatures (Håkanson et al. 2007; O'Neil et al. 2012). The additional risk of cyanobacterial blooms is likely to occur concurrently with an increased recreational demand for the urban lakes, resulting in an increase in public pressure to better manage the quality of water in the urban lakes.

8.2 Urban development

Increases in population, urban development and urban densification in the ACT lead to greater pressures on the urban waterways. This has implications for both water quality and the aquatic ecosystems of urban areas.

Urbanisation leads to increased turbidity and higher concentrations of nutrients and other pollutants in urban waterways. In Canberra, these are somewhat attenuated under low flows by urban wetlands and under higher flows by urban lakes. Developments on the western edge of Canberra that drain directly into the Molonglo and Murrumbidgee Rivers have the potential to contribute sediment, nutrients and other pollutants directly to the rivers below the major impoundments which can trap sediment. Effective water quality management in these areas is frequently constrained by the landscape, which is steep, with little room for effective WSUD features. This is a significant planning and design challenge.

Increased contributions of sediment, nutrients and other pollutants to the lower Molonglo and Murrumbidgee Rivers as suburbs develop pose a risk to the aquatic ecosystems of the rivers, as well as water quality risks to some of the popular recreational sites along the river (see Section 8.3). They also make it harder for the ACT to meet its 2002 Legislative Assembly commitments; that water leaving the ACT is no worse than is entering the ACT. Further, it is likely that, as Canberra's population grows and a higher density of living is promoted, there will be increased pressure on existing recreational areas. If this occurs as the water quality and aquatic ecosystems degrade, there will be increasing political pressure to better manage the urban waterways. This is a challenge that needs a strong planning approach, based on clear objectives and novel solutions to managing urban runoff.

The Molonglo River is considered a non-urban system in most ACT Government documentation. However, the increasing expansion of urban development that drains into the Molonglo River catchment downstream of Lake Burley Griffin suggests it should be reclassified as an urban waterway.

The urban development occurring on the shores of Lake Burley Griffin and Lake Tuggeranong mean the management of water quality in the lakes becomes particularly important. Cyanobacteria produce toxins that pose significant risks to human and animal health. Most concerns relate to ingestion of the toxins, which can result in illness (Lippy and Erb 1976; Texeira et al. 1993) and, in extreme cases, death (Jochimsen et al. 1998), hence the closure of lakes to primary contact when cyanobacterial concentrations are high. There are also increasing concerns about the links between neurodegenerative disorders and prolonged exposure to cyanotoxins simply from living near waterbodies (Fiore et al. 2020). Such risks are unlikely to be realised for tens of years, making developments on the shores of lakes that suffer regular cyanobacterial blooms an uncomfortable public health experiment. This should be a major concern for waterbody managers.

8.3 Sedimentation

Alterations to the sediment regimes of waterways is a common outcome of urbanisation, with increased sediment loads a common feature of the 'urban stream syndrome' (Russell et al. 2017; Walsh et al. 2005). Increases in sediment loads affect aquatic ecosystems both physically and chemically. Physically, a reduction in light associated with increased sediment loads affects primary production and feeding behaviours of aquatic animals, the smothering of habitat reduces the availability of breeding and feeding sites, the abrasion effects of increased amounts of sediment in the water column makes streams less habitable which, in combination, leads to a substantially altered biological community (Wood and Armitage 1997). The association of nutrients and other contaminants with fine sediments implicates increased sedimentation in eutrophication processes and can have long term effects on water quality.

Soil eroded during urban construction is a major source of sediment to urban waterways, and a range of mitigation measures are implemented in Canberra with varying degrees of effectiveness. Aerial imagery of the detention ponds associated with urban construction activities attests to the sediment leaving construction sites in the ACT (Figure 14). Most of the erosion of sediment from construction sites occurs during rainfall events, therefore associated failures of mitigation measures occur when it is raining and are rarely detected in the ACT's monitoring programs that are based on monthly data collection. Community members and Waterwatch volunteers are key in identifying problems and raising concerns.

Figure 14. Aerial images of urban constructions areas in Taylor (upper image) and Denman Prospect (lower image). Note the colour of the water in the ponds downstream of the construction areas.

Targeted monitoring of Deep Creek, which drains the developing suburb of Whitlam, has been undertaken as part of the ACT Healthy Waterways monitoring program. This provides a valuable case study that highlights the challenges of urban development in the ACT.

Deep Creek is a short ephemeral creek that drains directly into the Molonglo River downstream of Lake Burley Griffin. A significant portion of the Deep Creek catchment is being developed to create the suburb or Whitlam. Standard sediment and erosion control measures have been implemented within the development area. These include silt fences and temporary sediment basins, and further sediment detention ponds have been constructed across Deep Creek.

Despite the implementation of erosion control measures, high levels of sedimentation have been observed in Deep Creek since construction. Concentrations of suspended solids in Deep Creek are rarely within the acceptable range for ACT waterways (Figure 15) and often reach extremes of sediment concentrations. Sediment control infrastructure has been observed to be of very limited effectiveness (Figure 16) and the sediment detention ponds on Deep Creek have failed multiple times (Figure 17 and Figure 18), leading to high suspended sediment loads being delivered directly into the Molonglo River downstream of Lake Burley Griffin (Figure 19). While the Deep Creek catchment is a particularly challenging site in which to control sediment runoff, failures of sediment control measures associated with construction in the ACT are not uncommon (e.g. Figure 20) and images of sediment laden urban waterways are not unusual (Figure 21).

There is a substantial need to improve the erosion and sediment control activities associated with urban development in Canberra to protect the urban waterways, as well as the surrounding waterways which are becoming increasingly urbanised. This requires attention across the planning and regulatory systems within the ACT. Future developments need to better consider the impacts of sedimentation and be held accountable for minimising the downstream impacts. This will be more costly for the developments but failing to address these issues fails to fully account for the true cost of developing new suburbs.

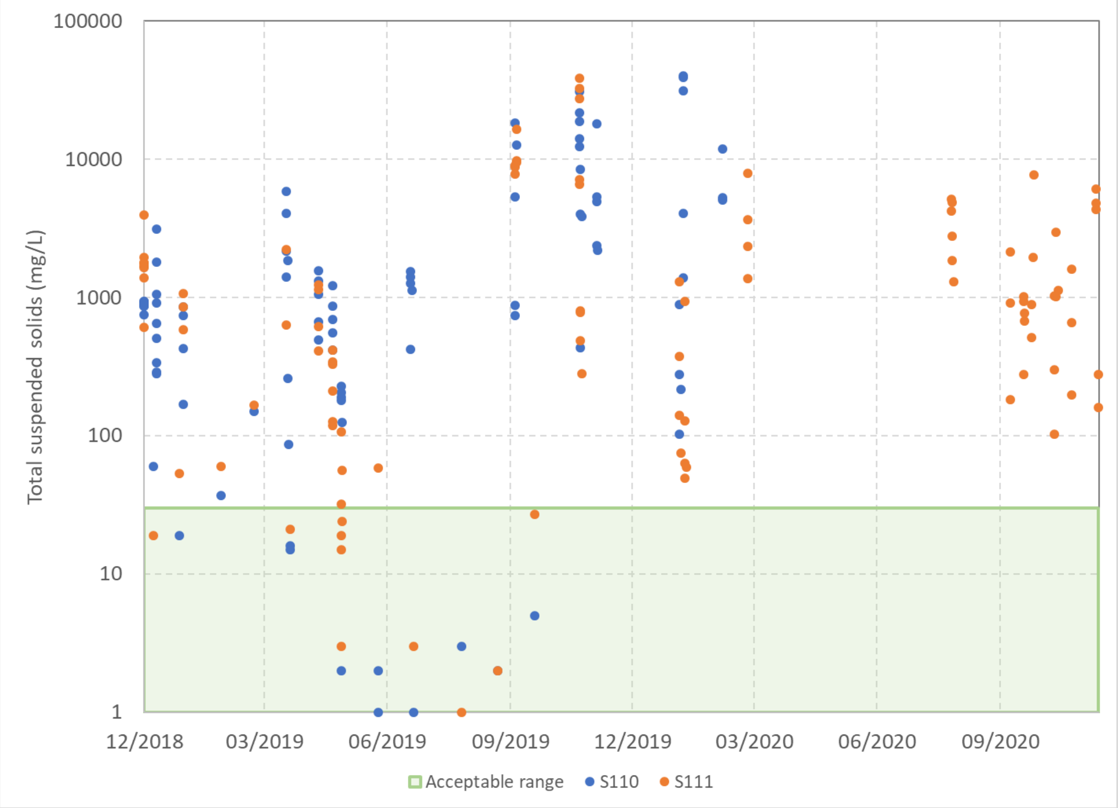

Figure 15. Suspended sediment concentrations recorded at two stations (S110 and S111) on Deep Creek in 2019 and 2020.

Data from the ACT Healthy Waterways Program. The green band shows the acceptable range for aquatic ecosystems in the ACT.

Figure 16. Sediment entering Deep Creek from construction areas, illustrating the failure of silt fencing to contain the mobilized sediment, February 2020. Source: ACT Waterwatch.

Figure 17. Deep Creek sediment detention pond illustrating the failure of the pond to trap fine sediments, June 2020. Source: ACT Waterwatch.

Figure 18. Failure of the Deep Creek sediment detention pond wall, February 2020. Source: ACT Waterwatch.

Figure 19. Deep Creek confluence with the Molonglo River. Source: ACT Waterwatch.

Figure 20. Poorly maintained silt fencing associated with urban development in the ACT. Source: ACT Waterwatch.

Figure 21. Sediment-laden water in Giralang Pond in June 2016 (left) and around the Casey Development in June 2013 (right). Source: ACT Waterwatch.

8.4 Queanbeyan Sewerage Treatment Plant Upgrade

The planned upgrade of the Queanbeyan Sewerage Treatment Plant (STP) directly affects water quality in Lake Burley Griffin. Historically, discharges from the Queanbeyan STP have played a significant role in water quality and the eutrophic state of Lake Burley Griffin. The potential for this to continue to be significant is ongoing, with around one third of the inflows to Lake Burley Griffin in 2019 being from the outflows from the Queanbeyan STP. The current proposed upgrade is necessary as the existing plant has exceeded its life expectancy and there are non-zero risks of failure with potentially catastrophic consequences. Information about the design of the new plant and its environmental impacts have been made publicly available through a Draft Environmental Impact Statement (EIS) (ACT Government 2021d).

Numerous concerns have been raised about the downstream water quality consequences associated with the upgraded STP. These have included a submission from CAWS at UC that raises concerns that the new STP will not provide any improvement in water quality and that there are substantial risks to the downstream receiving waters (including Lake Burley Griffin) because of potential reductions in water quality (ACT Government 2021d). The submission indicated there has been insufficient data analysis and predictive modelling undertaken to adequately assess the environmental impacts of the upgraded STP, and this should be undertaken so that the implications of the plant are fully understood. Given the importance of Lake Burley Griffin as a centrepiece for Canberra and the recreational value placed upon the lake, it is well worth additional investment to better understand the effects of the STP.

8.5 Limitations associated with WSUD approaches

Research by Ubrihien et al. (2019b) highlighted that a significant (up to 50%) proportion of nutrients being transported through the stormwater network draining into Lake Tuggeranong is in dissolved form. This is consistent with the data of Dyer (2000) from storm events monitored in Sullivans Creek, but is counter to the accepted paradigm that most nutrients transported in storm events are transported in particulate form. WSUD approaches and modelling tools are based on trapping particle-bound nutrients and do not account for a load in which up to 50% of the nutrients may be in dissolved form. This requires some rethinking around the way urban runoff is managed, and likely means that some of the WSUD approaches being implemented in Canberra are unlikely to perform as designed. This needs urgent attention, as planning decisions for new developments made now will have long term ramifications for water quality.

8.6 Contamination events

Research conducted by UC in the Tuggeranong catchment (Ubrihien et al. 2019b; Ubrihien et al. 2020) and at eight of Canberra's urban ponds (Ubrihien et al. 2019a) highlights the occurrence of infrequent contamination events. These events comprise very high concentrations of available nutrients in the urban stormwater network, and they have been detected across Canberra, from Tuggeranong Creek to the inflows to Fassifern Pond in Dunlop. The source of these contamination events is almost impossible to determine; regular monitoring picks them up occasionally, but by the time samples are processed, the event has passed. They often occur at low flows and suggest that people are dumping or washing something into the waterways.

The spatial and temporal variability in these contamination events makes targeting them via management action very difficult. Their relative contribution to the overall nutrient load in the system is very low, meaning investment in addressing them is not justified. However, they highlight two important points:

1. The importance of very regular monitoring of the stormwater network to identify unusual events that have the potential to be problematic.
2. The need for ongoing community education to encourage behaviours that are not detrimental to water quality outcomes.

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STATE OF THE ACT'S LAKES AND WATERWAYS 2011–2021: A TECHNICAL REVIEW

TECHNICAL APPENDICES

A. Technical Appendix — Water quality indicators and threshold indicators

Water quality management in Australia is guided by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000). The Guidelines set out a framework for establishing locally specific threshold values for water quality parameters in fresh and marine waters. This approach has been used by the NCA to establish threshold values for Lake Burley Griffin, and by the ACT Government to establish threshold values for lakes, wetlands and streams within the ACT. ACT Health has established the threshold levels for water quality in recreational waterways. The following describes each of the indicators of waterway condition and the guideline levels that are used in this assessment. Where possible, locally specific thresholds have been used, but where these have not been established, default values for slightly disturbed ecosystems (ANZECC 2000) have been used, but recognise that most urban waterways are more akin to highly disturbed ecosystems.

A.1 Cyanobacteria

Cyanobacteria (also known as blue-green algae) are a microscopic algae-like bacteria commonly found in freshwater systems. There are many types of cyanobacteria, some of which produce toxins that are harmful to humans and animals. Under the right conditions, cyanobacteria can multiply to excessive levels, forming unsightly 'blooms' that pose risks to animal and human health. Large amounts of decaying algae can reduce dissolved oxygen levels in the water that can lead to fish deaths (Table 17).

Table 17. Cyanobacteria thresholds for urban waterbodies in the ACT, as defined by regulatory authorities.

Waterbody	Acceptable range	Source
Lake Burley Griffin	<20,000 cells/mL	Lake Burley Griffin Water Quality Management Plan (NCA 2011)
Recreational waters	<20,000 cells/mL (Increased health risks: 20,000–50,000 cells/mL and lakes closed to recreation at >50,000 cells/mL)	ACT Guidelines for Recreational Water Quality (ACT Government 2014a)
Other urban lakes	≤5,000 cells/mL	*Environment Protection Regulation 2005* values for urban lakes and ponds (AQUA/3)
Urban ponds and wetlands	≤5,000 cells/mL	*Environment Protection Regulation 2005* values for urban wetlands (AQUA/5)
Urban streams	≤5,000 cells/mL	*Environment Protection Regulation 2005* values for urban drains and streams (AQUA/4)

A.2 Enterococci bacteria

Bacteria are found across all aquatic environments and comprise a mix of species that are harmful (pathogenic) to humans and those that are benign (non-pathogenic). The presence of pathogenic bacteria renders water unsuitable for recreational uses, particularly swimming. While a large number of potential pathogenic bacteria are found in freshwaters, the accepted indicator of risk is the intestinal Enterococci bacteria.

Threshold values for acceptable concentrations of Enterococci bacteria are determined based on water body type and likely human use of the water body (Table 18).

Table 18. Acceptable ranges of Enterococci bacteria across different urban water bodies within the Canberra region, as defined by relevant documentation.

Waterbody	Acceptable range	Source
Lake Burley Griffin	< 200 CFU/100mL	Lake Burley Griffin Water Quality Management Plan (NCA 2011)
Other urban lakes	< 200 CFU/100mL < 150 CFU/100mL < 1,000 CFU/100mL	ACT Guidelines for recreational water quality (ACT Government 2014a) Draft Urban Lakes and Ponds Report (Swimming) Draft Urban Lakes and Ponds Report (Boating) (ACT Government 2019b)
Urban ponds and wetlands	< 230 CFU/100mL < 150 CFU/100mL < 1,000 CFU/100mL	ANZECC & ARMCANZ (2000) default guideline values for secondary contact recreational waters (ANZECC 2000) Draft Urban Lakes and Ponds Report (Swimming) Draft Urban Lakes and Ponds Report (Boating) (ACT Government 2019b)
Urban streams	< 230 CFU/100mL	ANZECC & ARMCANZ, 2000 default guideline values for secondary contact recreational waters (ANZECC 2000)

A.3 Phosphorus

Phosphorus is an essential element for plant life. However an overabundance in waterways can result in excess algal growth and reduced dissolved oxygen, potentially resulting in reduced ecological diversity, poor habitat availability and low water quality. Sources of phosphorus include fertilisers, soil erosion and manure. Phosphorus can be both attached to particulate matter and dissolved in the water. It is the dissolved form that is most readily available to support plant and algal growth. Phosphorus is typically reported as either total phosphorus (TP) or dissolved (filterable) reactive phosphorus (FRP). Phosphorus threshold values for Canberra urban waterways are identified based on the water body classification (Table 19).

Table 19. Threshold values for phosphorus concentrations in urban waterways in the Canberra area.

Waterbody	Acceptable range	Source
Lake Burley Griffin	TP < 0.06 mg/L	Lake Burley Griffin Water Quality Management Plan (NCA 2011)
Other urban lakes	TP ≤ 0.1 mg/L	*Environment Protection Regulation 2005* values for urban lakes and ponds (AQUA/3) (EPA 2005)

Waterbody	Acceptable range	Source
	TP < 0.2 mg/L	Draft Urban Lakes and Ponds Report (Swimming, Boating and Visual amenity) Draft Urban Lakes and Ponds Report (Moderate and deep water zones) Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones) (ACT Government 2019b)
Urban ponds and wetlands	TP ≤ 0.1 mg/L TP < 0.2 mg/L	*Environment Protection Regulation 2005* values for urban wetlands (AQUA/5) Draft Urban Lakes and Ponds Report (Moderate and deep water zones) Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones) (ACT Government 2019b)
Urban streams	TP ≤ 0.1 mg/L	*Environment Protection Regulation 2005* values for urban drains and streams (AQUA/4) (EPA 2005)

In addition, it is noted that the ACT *Environment Protection Regulation 2005* specifies standards for phosphorus loads leaving three major lakes — Lake Burley Griffin, Lake Ginninderra and Lake Tuggeranong — as well as the Murrumbidgee River at the ACT border (Table 20).

Table 20. Allowable phosphorus loads for water draining from the three major urban lakes in Canberra, as defined by the ACT Environmental Protection Regulation (2005).

Waterbody	Acceptable load
Lake Burley Griffin	< 8,600 kg/year
Lake Ginninderra	< 300 kg/year
Lake Tuggeranong	< 600 kg/year
Murrumbidgee River at ACT border	< 83,200 kg/year

A.4 Nitrogen

Nitrogen is an essential element for plant growth, but excess nitrogen in the environment can cause overstimulation of algal and plant development. Sources of nitrogen in water ways may include sewage and fertiliser or animal waste. Nitrogen can be dissolved in the water and attached to particulate matter in the water. Nitrogen can be present in many forms in waterways and is typically reported as either Total nitrogen (TN), oxides of nitrogen (NOx) or as ammonium (NH4+).

There are differences in the way in which nitrogen is measured depending on the program: Waterwatch teams measure nitrate (NO_3^-) and monitoring programs that undertake laboratory based analysis measure TN. In this report we graph:

- Nitrate – where we are only comparing nitrate measurements

- Total nitrogen – where total nitrogen is the only measurement used
- Nitrogen – where we are using a mix of both nitrate and total nitrogen and have judged that the comparison is appropriate (if not strictly valid).

The discussion of the results refers to nitrogen and we encourage the reader to refer to the detailed supporting figures in the Appendices for the form of nitrogen that is relevant.

Acceptable ranges for nitrogen have been identified for Lake Burley Griffin, but it is noted that the ACT Government has not established default threshold values for nitrogen and, as such, the authors have applied the lower of the values established for Lake Burley Griffin to other urban lakes and urban wetlands (Table 21). This is a notable omission, and it is recommended the ACT Government establish threshold values for nitrogen to support the management of the urban waterways.

Table 21. Threshold values for total nitrogen and ammonia concentrations in ACT urban water bodies.

Waterbody	Acceptable range	Source
Lake Burley Griffin	TN < 1.4 mg/mL (East Basin) TN < 1.0 mg/L (West Lake) Ammonia <0.1 mg/L	Lake Burley Griffin Water Quality Management Plan (NCA 2011)
Other urban lakes	TN < 1.0 mg/L (West Lake) Ammonia <0.1 mg/L	
Urban ponds and wetlands	TN < 1.0 mg/L (West Lake) Ammonia <0.1 mg/L	
Urban streams	TN < 0.25 mg/L NOx < 0.015 mg/L NH4+ < 0.013 mg/L Ammonia depends on temperature and pH	ANZECC & ARMCANZ (2000) default guideline values for slightly disturbed upland rivers (ANZECC 2000) *Environment Protection Regulation 2005* values for urban drains and streams (AQUA/4) (EPA 2005)

A.5 pH

Measures of acidity and alkalinity (pH) provide an indicator of water quality and have environmental implications on ecological quality and habitat availability. Runoff can negatively affect pH, potentially changing it to a level that will reduce water quality to unacceptable levels. Acceptable ranges of pH values are defined based on water body type and water zones (Table 22).

Table 22. Acceptable ranges of pH in Canberra's urban waterways, as defined by water body type.

Waterbody	Acceptable range	Source
Lake Burley Griffin	6.5–8.5	Lake Burley Griffin Water Quality Management Plan (NCA 2011)
Other urban lakes	6–9	*Environment Protection Regulation 2005* values for urban lakes and ponds (AQUA/3) (EPA 2005)

Waterbody	Acceptable range	Source
	6.5–9	Draft Urban Lakes and Ponds Report (Moderate and deep water zones) (ACT Government 2019b)
	6.5–8.5	Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones; Swimming) (ACT Government 2019b)
Urban ponds and wetlands	6–9	*Environment Protection Regulation 2005* values for urban wetlands (AQUA/5) (EPA 2005)
	6.5–9	Draft Urban Lakes and Ponds Report (Moderate and deep water zones) (ACT Government 2019b)
	6.5–8.5	Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones) (ACT Government 2019b)
Urban streams	6–9	*Environment Protection Regulation 2005* values for urban drains and streams (AQUA/4) (EPA 2005)

A.6 Turbidity/suspended sediment

Turbidity provides a measure of water clarity within a waterway and is important for aesthetics and aquatic ecosystems. High turbidity indicates increased volumes of suspended material in the water. This may be sediment or organic material, and high concentrations can impact on habitat availability, ecological values and visual and recreational amenity. Threshold values for measures of turbidity indicated in nephelometric turbidity units (NTU) and suspended solids as mg/L are defined for different classifications of water bodies within the Canberra urban area (Table 23).

Table 23. Acceptable ranges for turbidity and suspended solids in Canberra urban water bodies.

Waterbody	Acceptable range	Source
Lake Burley Griffin	Suspended solids: 40 mg/L (East Basin) 20 mg/L (West Lake) Turbidity 40 NTU (East Basin); 20 NTU (West Lake)	Lake Burley Griffin Water Quality Management Plan (NCA 2011)
Other urban lakes	Turbidity < 30 NTU Suspended solids ≤ 25mg/L	*Environment Protection Regulation 2005* values for urban lakes and ponds (AQUA/3) (EPA 2005)
	Turbidity < 30 NTU Suspended solids ≤ 20mg/L	Draft Urban Lake and Ponds Report (Deep water zones) (ACT Government 2019b)
	Turbidity < 30 NTU Suspended solids ≤ 40mg/L	Draft Urban Lakes and Ponds Report (Moderately deep water zones) (ACT Government 2019b)
	Suspended solids ≤ 6mg/L	

Waterbody	Acceptable range	Source
		Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones) (ACT Government 2019b)
Urban ponds and wetlands	Turbidity < 30 NTU Suspended solids ≤ 25mg/L	*Environment Protection Regulation 2005* values for urban wetlands (AQUA/5) (EPA 2005)
	Turbidity < 30 NTU Suspended solids ≤ 20mg/L	Draft Urban Lake and Ponds Report (Deep water zones) (ACT Government 2019b)
	Turbidity < 30 NTU Suspended solids ≤ 40mg/L	Draft Urban Lakes and Ponds Report (Moderately deep water zones) (ACT Government 2019b)
	Suspended solids ≤ 6mg/L	Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones) (ACT Government 2019b)
Urban streams	Turbidity < 10 NTU Suspended solids ≤ 25 mg/L	ANZECC & ARMCANZ (2000) default guideline values for slightly disturbed upland rivers (ANZECC 2000) *Environment Protection Regulation 2005* values for urban drains and streams (AQUA/4) (EPA 2005)

A.7 Conductivity

Conductivity is used as a measure for determining the concentration of ions within the water. Conductivity in water is affected by the presence of inorganic dissolved material. Increasing conductivity indicates increasing salinity, which will negatively affect water quality and aquatic ecosystems in freshwater environment. It is noted the ACT Government has not established default threshold values for conductivity and, as such, the authors have applied ANZECC and ARMCANZ (2000) Guidelines for urban streams (Table 24).

Table 24. Threshold values used to assess conductivity trends in Canberra's urban water landscape.

Waterbody	Acceptable range	Source
Lake Burley Griffin	< 400 mS/cm	Lake Burley Griffin Water Quality Management Plan (NCA 2011)
Other urban lakes	< 350 µS/cm	ANZECC & ARMCANZ (2000) default guideline values for slightly disturbed upland rivers (ANZECC 2000)
Urban ponds and wetlands	< 350 mS/cm	ANZECC & ARMCANZ (2000) default guideline values for slightly disturbed upland rivers (ANZECC 2000)

Urban streams	< 350 µS/cm	ANZECC & ARMCANZ (2000) default guideline values for slightly disturbed upland rivers (ANZECC 2000)

A.8 Dissolved oxygen

Dissolved oxygen is essential to aquatic life and many aquatic organisms require concentrations of greater than 4 mg/L to survive. Concentrations of less than 4 mg/L are considered low and below 2 mg/L are hypoxic. The effect of low and hypoxic concentrations of dissolved oxygen varies with species, life stage and the duration of the low concentrations. Low dissolved oxygen concentrations in bottom waters can also result in the release of nutrients and metals into the overlying water column. The release of nutrients has been linked to increased growth of cyanobacteria.

Table 25. Dissolved oxygen threshold values for assessing water quality of Canberra urban water bodies.

Waterbody	Acceptable range	Source
Lake Burley Griffin	≥4 mg/L	Not specified for Lake Burley Griffin. Acceptable range based on *Environment Protection Regulation 2005* values for urban lakes and ponds (AQUA/3) (EPA 2005)
Other urban lakes	≥4 mg/L	*Environment Protection Regulation 2005* values for urban wetlands (AQUA/5) (EPA 2005) Draft Urban Lake and Ponds Report (Deep water zones) (ACT Government 2019b) Draft Urban Lakes and Ponds Report (Moderately deep water zones) (ACT Government 2019b) Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones) (ACT Government 2019b)
Urban ponds and wetlands	≥4 mg/L	*Environment Protection Regulation 2005* values for urban lakes and ponds (AQUA/3) (EPA 2005) Draft Urban Lake and Ponds Report (Deep water zones) (ACT Government 2019b) Draft Urban Lakes and Ponds Report (Moderately deep water zones) (ACT Government 2019b) Draft Urban Lakes and Ponds Report (Shallow water zones — emergent macrophyte zones) (ACT Govermment 2019b)
Urban streams	≥6 mg/L	*Environment Protection Regulation 2005* values for urban drains and streams (AQUA/4) (EPA 2005)

A.9 Indicators of ecological condition

The Draft Urban Lake and Ponds Report (ACT Government 2019b) provides targets for some indicators of ecological condition for a range of zones within urban lakes and ponds (Table 26) . Similar targets and indicators are not available for other types of urban waterways. There are limited data available to use to report against the indicators and targets. Some information about the freshwater ecosystems of Canberra's urban waterways is collected as part of the Waterwatch program, the ACT Water Quality Monitoring Program and the Frogwatch program. These programs provide information about the macroinvertebrate communities, riparian condition, platypus numbers and frog populations. Where specific targets or thresholds for the indicators of ecological condition do not exist, this document review and data analyses focus on trends over the past 10 years.

Table 26. Indicators of macrophyte community condition for assessing ecological conditions in Canberra urban waterbodies.

Indicators	Shallow water — emergent macrophyte zone	Moderate water depth — submerged macrophyte zone	Deep water — algal and grazing zone
Emergent macrophyte cover (%)	> 30	> 10	> 5
Submerged macrophyte cover (%)	–	> 30	–
Emergent macrophytes • **Diversity** • **Appropriate species**	Dominant species < 70% and free of exotics	Dominant species < 60% and free of exotics	Dominant species < 50% and free of exotics
Submerged macrophyte diversity	–	Dominant species < 80%	–
Number of waterfowl, fish and mammals	4 frog species 10 bird species	5 bird species and juvenile and adult stocked native fish species*	> 5 bird species and juvenile and adult stocked native fish species*

*Managed fisheries only

A.10 Riparian condition

The riparian zone of a waterway is the land adjacent to streams, rivers, lakes and wetlands that are directly influenced by the waterway. It is where interactions between aquatic and terrestrial ecosystems occur and, as a result, supports a diverse and dynamic range of species, as well as providing important ecological functions (Ewel et al. 2001). In urban areas, the riparian zone is often where the human-waterway interaction occurs, and a healthy riparian zone is valued for providing a recreational resource in conjunction with being aesthetically pleasing.

The ACT Waterwatch program undertakes a rapid appraisal of riparian condition at sites across the region every two years using the Rapid Appraisal of Riparian Condition (RARC) (Jansen et al. 2005; Jansen and Robertson 2001). The RARC assesses the ecological condition of riparian habitats using five indices that relate to the habitat and functioning of the riparian zone and is predominantly based on metrics of riparian vegetation.

A.11 Macroinvertebrate communities

Aquatic macroinvertebrates are small animals that lack an internal skeleton and live for part or all their lives in water. Examples include water beetles, snails, dragonfly larvae, mosquito larvae and water fleas. They are an essential part of freshwater food webs, processing organic matter and algae and providing food for birds, fish and other animals. Aquatic macroinvertebrates are widely recognised as good indicators of stream health because they vary in their tolerance to pollution or disturbances.

The ACT Waterwatch program collects macroinvertebrate data annually in spring, with some sites also sampled in autumn. This program involves identifying animals to order level. These data are used to report a condition rating that is based on the number of taxa present, the sensitivity of that taxa (using the SIGNAL 2.0 score, as per Chessman (2001); Chessman (2003)) and the presence of three sensitive orders of *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies) and *Trichoptera* (caddisflies). For the purposes of this report, a scoring system has been developed that converts the combined signal score and number of taxa present to match the condition rating. This is specific to each site, and there is more value in interpreting the condition rating than the numerical score.

The ACT Government, through their ACT Water Quality Monitoring Program, collects macroinvertebrate data annually in spring and autumn identifying animals to family level. These data are used to report a condition rating using the Australian Rivers Assessment (AUSRIVAS) approach (Davies 2000), which is based on a comparison of the animals present as the assessed site with a reference site.

A.12 Frog populations

The Frogwatch program in the ACT conducts an annual survey of frogs in October each year, identifying the species present at a range of sites across Canberra. Expected numbers of species have been specified for the urban lakes and ponds, but not for other waterbodies.

B. Lake Burley Griffin Technical Appendices

B.1 Defining catchment areas and landuse calculations

Defining catchment areas and component landuses was undertaken in 2004 by Neil (2012) (Table 27), and it was considered likely that some of the landuse areas had changed between 2004 and 2021. As the authors were unable to find details of how the original calculations were obtained, the approach used to establish 2021 landuse and catchment areas for this report are provided in this Appendix.

Table 27. Definitions of the sub-catchment areas and landuse, as undertaken by Neil (2012).

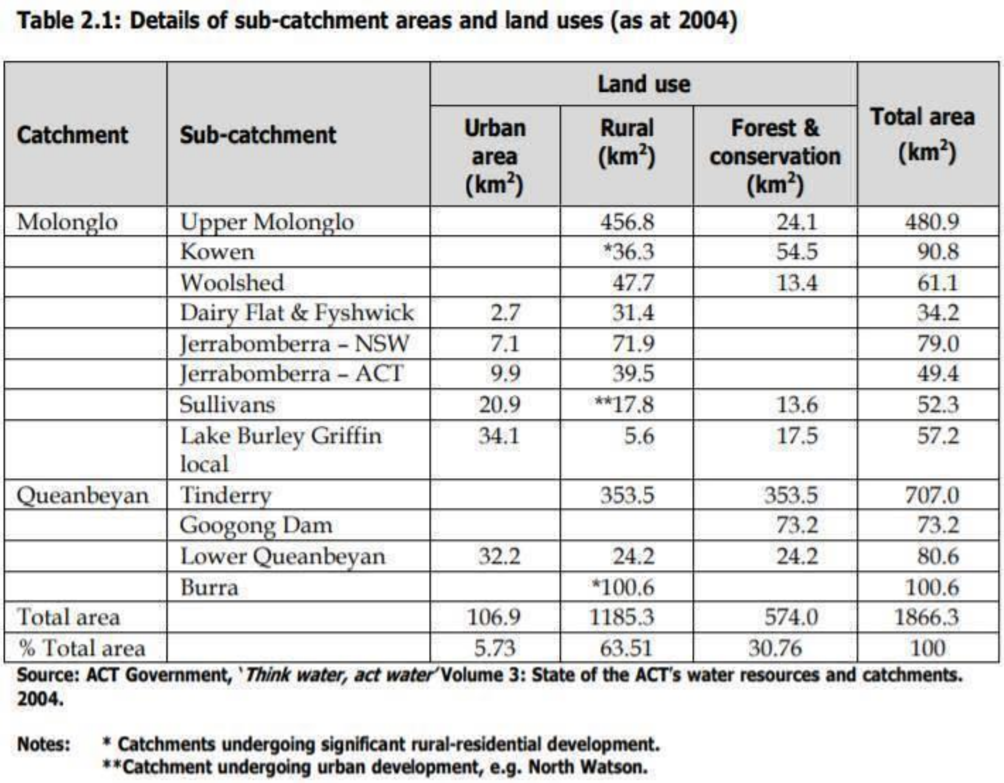

Table 2.1: Details of sub-catchment areas and land uses (as at 2004)

Catchment	Sub-catchment	Land use			Total area (km^2)
		Urban area (km^2)	Rural (km^2)	Forest & conservation (km^2)	
Molonglo	Upper Molonglo		456.8	24.1	480.9
	Kowen		*36.3	54.5	90.8
	Woolshed		47.7	13.4	61.1
	Dairy Flat & Fyshwick	2.7	31.4		34.2
	Jerrabomberra – NSW	7.1	71.9		79.0
	Jerrabomberra – ACT	9.9	39.5		49.4
	Sullivans	20.9	**17.8	13.6	52.3
	Lake Burley Griffin local	34.1	5.6	17.5	57.2
Queanbeyan	Tinderry		353.5	353.5	707.0
	Googong Dam			73.2	73.2
	Lower Queanbeyan	32.2	24.2	24.2	80.6
	Burra		*100.6		100.6
Total area		106.9	1185.3	574.0	1866.3
% Total area		5.73	63.51	30.76	100

Source: ACT Government, '*Think water, act water*' Volume 3: State of the ACT's water resources and catchments. 2004.

Notes: * Catchments undergoing significant rural-residential development.
**Catchment undergoing urban development, e.g. North Watson.

Data for the ACT and NSW were downloaded separately. ACT land use data were sourced from the ACT Government Online Maps and Apps server (https://actmapi-actgov.opendata.arcgis.com/), and the 'Territory Plan[4] Land Use Zones — polygon' layer was used.

In Table 28, the three main landuse categories (Urban, Recreational and Rural) are assigned to each landuse zone (see Zoning code and Description columns). The unspecified landuse zone labelled 'DES' (Designated) are assigned to category 'Recreational'. To examine it in greater detail, a layer combining the government agency building and roads (work by a UC student) was used to remove urban area from the data.

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[4] 'The Territory Plan is the key statutory planning document in the ACT, providing the policy framework for the administration of planning in the ACT. The purpose of the Territory Plan is to manage land use change and development in a manner consistent with strategic directions set by the ACT Government, Legislative Assembly and the community.' The Plan was most recently updated on 28 June 2021 ({ACT Government, 2021 #143}).

Table 28. Landuse zones converted to three main categories for the ACT.

Zoning code	Description	Category
CZ1	Commercial core	Urban
CZ2	Commercial — business	Urban
CZ3	Commercial — services	Urban
CZ4	Commercial — local centre	Urban
CZ5	Commercial mixed use	Urban
CZ6	Leisure and accommodation	Urban
IZ1	Industrial — general industrial	Urban
IZ2	Industrial — Industrial mixed use	Urban
RZ1	Residential suburban	Urban
RZ2	Residential suburban core	Urban
RZ3	Residential — urban residential	Urban
RZ4	Residential — medium density	Urban
RZ5	Residential — high density residential	Urban
TSZ1	Transport and services — transport	Urban
TSZ2	Transport and services — services	Urban
NUZ1	Non-urban — broad acre	Rural
NUZ2	Non-urban — rural	Rural
NUZ3	Non-urban — hills ridges and buffers	Recreational
NUZ4	Non-urban — River corridor	Recreational
NUZ5	Non-urban mountains and bushland	Recreational
PRZ1	Open urban spaces	Recreational
PRZ2	Urban parks and Recreation	Recreational
DES	Designated	Recreational
	Government Agencies*	Urban
	Roads reserves*	Urban

*Removed from zone 'Designated' and assigned to category 'Urban'

The 2017 NSW landuse layer was downloaded from the NSW government data server, SEED: The Central Resource for Sharing and Enabling Environmental Data[5] in NSW (https://datasets.seed.nsw.gov.au/dataset/nsw-landuse-2017-v1p2-f0ed). To create a landuse layer similar to that used for the ACT, the three main categories were assigned to the secondary and, in some instances, to tertiary land use zones (Table 29). For the Urban category, the 'Residential and farm infrastructure' layer was divided from 'Urban residential' to 'Urban' and 'Rural residential with/without farming' to 'Rural'.

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[5] 'The 2017 Landuse captures how the landscape in NSW is being used for food production, forestry, nature conservation, infrastructure and urban development. It can be used to monitor changes in the landscape and identify impacts on biodiversity values and individual ecosystems. The NSW 2017 Landuse mapping is dated September 2017.' It incorporates tenure-based information for National Parks and State Forests in NSW, at the time of mapping (NSW Government 2020).

Table 29. Landuse zones converted to three main categories for NSW.

Secondary zone	Tertiary zone	Category
5.3.0 Manufacturing and industrial		Urban
5.4.0 Residential and farm infrastructure	5.4.1 Urban residential	Urban
5.5.0 Services	5.5.1 Commercial services	Urban
5.5.0 Services	5.5.2 Public services	Urban
5.7.0 Transport and communication		Urban
5.8.0 Mining		Urban
5.9.0 Waste treatment and disposal		Urban
2.1.0 Grazing native vegetation*		Urban
3.2.0 Grazing modified pastures*		Urban
2.1.0 Grazing native vegetation		Rural
3.2.0 Grazing modified pastures		Rural
3.3.0 Cropping		Rural
3.4.0 Perennial horticulture		Rural
5.1.0 Intensive horticulture		Rural
5.2.0 Intensive animal production		Rural
5.4.0 Residential and farm infrastructure	5.4.2 Rural residential with agriculture	Rural
5.4.0 Residential and farm infrastructure	5.4.3 Rural residential without agriculture	Rural
5.4.0 Residential and farm infrastructure	5.4.5 Farm buildings/infrastructure	Rural
5.6.0 Utilities		Rural
1.1.0 Nature conservation		Recreational
1.2.0 Managed resource protection		Recreational
1.3.0 Other minimal use		Recreational
2.2.0 Production native forestry		Recreational
3.1.0 Plantation forests		Recreational
5.5.0 Services	5.5.3 Recreation and culture	Recreational
6.1.0 Lake		Recreational
6.2.0 Reservoir/dam		Recreational
6.3.0 River		Recreational
6.5.0 Marsh/wetland		Recreational

*New urban and industrial development since 2017 (including Googong Foreshore, Queanbeyan East and Hume).

To create the catchment layer, we used the ‘ACT Water Management Areas’ and a sub-catchment layer from the Catchment Health Indicator Program (CHIP). The land use and catchment layers were combined and used to calculate the area of each sub-catchment that flows into Lake Burley Griffin, as well as the area of each main land use category (Table 30).

Table 30. Land use per sub-catchment for the Molonglo and Queanbeyan Rivers within the three main categories per km².

		Land use in km²			
Catchment	**Sub-catchment**	**Urban**	**Rural**	**Recreational**	**Total (km²)**
Molonglo River	Lake Burley Griffin*	20.9	–	30.0	50.9
	Sullivans Creek	24.3	3.0	25.1	52.4
	Woolshed Creek	1.3	49.0	10.6	60.9
	Lower Molonglo River	7.0	20.5	6.6	34.1
	Molonglo River	1.6	75.0	14.2	90.8
	Upper Molonglo River	1.7	392.4	86.8	480.9
	Jerrabomberra Creek	13.1	30.1	6.1	49.3
	Jerrabomberra Headwaters	3.7	73.4	2.0	79.0
Queanbeyan River	Lower Queanbeyan River	12.8	61.4	6.3	80.5
	Googong**	–	65.4	7.8	73.2
	Upper Queanbeyan River	1.4	427.6	278.0	707.0
	Burra Creek	–	76.4	24.2	100.6
	Total Area	87.9	1,274.1	497.7	1,859.7
	% Total Area	4.7	68.5	26.8	100.0

* including 'Lake Burley Griffin' with 6.3 km² as recreational ** including 'Googong Dam' with 6.4 km² as recreational

B.2 Document review: Lake Burley Griffin water quality history

Since filling in 1964, Lake Burley Griffin has had periods of poor water quality that have adversely affected the aesthetic and recreational use of the lake. Most notably, the lake has suffered from periods of toxic cyanobacteria growth, particularly during periods of low inflows (1977/78, 1982/83 and during the drought over the period 1999–2009 (Lawrence (2012). While toxic cyanobacterial growth attracts some of the greatest publicity for water quality in Lake Burley Griffin, the lake has also experienced heavy metal pollution from waste from the Lake George Mine at Captains Flat (Maher et al. 1992; Stinton et al. 2020), faecal pollution from sewerage overflows, treated sewerage effluent from the Queanbeyan City Council Sewage Treatment Plant and suspended sediment from agricultural runoff (Wallbrink and Fogarty 1998).

Over the years, Lake Burley Griffin has been the subject of numerous studies that have investigated various aspects of lake water quality, including nuisance plant and algal growth (Caitcheon et al. 1988; Cullen et al. 1978; Maher et al. 1992; Rosich and Cullen 1981; Wallbrink and Fogarty 1998). A considerable number of reports have been produced that summarise the water quality monitoring programs and research activities, reflecting an ongoing focus on water quality management in the lake.

In the early years, the lake was reported to have suffered from excessive aquatic plant growth that was considered to have been promoted by nutrient input from storm runoff (Rosich and Cullen 1981). By the late 1970s, the lake was characterised by significant aquatic plant growth, high algal concentrations and low oxygen water levels. By 1979, the phosphorus concentrations and algal population meant that the lake was considered eutrophic (Cullen 1991), and the area of submerged aquatic plants was observed to decrease throughout the 1980s, thought to be the result of light limitation caused by increased suspended sediment or through harvesting 'to minimize conflicts with recreational activities' (Lawrence 2012; Neil 2012).

In developing the Water Quality Management Plan for Lake Burley Griffin (NCA 2011), Central Queensland University reviewed NCA data from 1981 to 2009 and concluded that the overall environmental health of the lake was generally good, but the basis for the evaluation is unclear . Their analysis of the long-term water quality data set showed that phosphorus concentrations had declined over time, with a marked change in concentrations observed in the early to mid-1990s, attributed to the upgrade of the Queanbeyan Sewage Treatment Plant (STP) during the mid-1980s and improvements in catchment management practices. Other water quality parameters (dissolved oxygen concentrations, nitrogen concentrations, turbidity, chlorophyll a, metal concentrations and pH) had remained relatively unchanged over the time period, with a slight decline in turbidity, chlorophyll a and nitrogen concentrations. Conductivity had increased during the millennium drought and bacterial counts were highly variable, with instances of significantly high counts that were unable to be attributed to a particular cause.

A water quality assessment was undertaken by Ian Lawrence as part of the Report on the State of the Watercourses and Catchment for Lake Burley Griffin (Neil 2012). Drawing on data over the period 1978–2011 and partitioning it into data sets for wet years (where inflows were greater than 1.5 times the lake volume) and dry years (where inflows were less than 1.5 times the lake volume), the assessment showed significant variation in water quality reflecting annual and seasonal weather conditions, as well as changes in land and water management within the catchment. Between 1978 and 1983, high concentrations of phosphorus (between 0.1 and 0.6 mg/L) were commonly recorded in Molonglo Reach as a result of sewage discharge from the Queanbeyan STP. Following the upgrade to the treatment plant in the mid-1980s, phosphorus concentrations in Molonglo Reach reduced markedly (to typically less than 0.1 mg/L). A similar pattern in ammonia was observed, with high concentrations from the treatment plant in the late 1970s and early 1980s declining notably following the upgrade to the treatment plant. While less marked, these patterns in phosphorus concentrations were observed through to the east basin of the lake. It is interesting to note that there appears to be an increase in phosphorus and nitrogen concentrations in the lake during a period of the Millenium drought (between 2004 and 2009), which was not mentioned in the assessment.

The assessment presented in (Neil 2012) focused on a comparison of two very dry periods (1982–83 and 2007–09), where inflows to the lake were low. Key to note from the assessment were significant reductions in both total nitrogen and total phosphorus concentrations with flow through the lake (from Molonglo Reach to Yarramundi Reach) in 2007–2009. This suggested that de-nitrification and sedimentation processes were effectively removing nutrients from the water column, and phosphorus in particular was continuing to be trapped within the lake sediments. Interestingly, dissolved oxygen concentrations in the lake were considered to have reduced significantly between the two time periods. This was hypothesised to be a consequence of increased internal loading of organic material in the lake, the breakdown of which was causing a decrease in dissolved oxygen concentrations. It should be recognised that the comparison of two data points does not constitute a trend, and further data are required to verify the existence of a trend in dissolved oxygen concentrations in the bottom waters.

The conclusion drawn from (Neil 2012) was , as an urban inland lake, Lake Burley Griffin is subject to high summer temperatures and solar radiation and mild wind speeds in late summer and autumn. In combination with high nutrient concentrations, this provides ideal conditions for algal blooms to occur during the hot summer months. Under extended dry periods, this combination will continue to favour cyanobacteria and disadvantage green algae, and the algal problems were considered likely to persist. The report postulated that during low inflows, urban runoff was a trigger for cyanobacteria blooms. Urban runoff was also considered to be the dominant source of organic matter to the lake, which subsequently drove the release of sediment-bound phosphorus.

Subsequent to the Report on the State of the Watercourses and Catchment for Lake Burley Griffin (Neil 2012), a Lake Burley Griffin Task Force was established to identify actions that could be undertaken to improve the overall lake water quality and outline a program of works. The Task Force developed an Action Plan (ACT Government 2012). While many of recommended actions do not appear to have been implemented, some have obviously informed the activities of the ACT Government in recent years.

In 2020, Dyer (2020) undertook a review of NCA cyanobacteria and nutrient data to assist in identifying options to mitigate cyanobacterial blooms in Lake Burley Griffin. This built on detailed research by CAWS into water quality in Lake Tuggeranong between 2017 and 2020 and, in part, aimed to determine if the two lakes had sufficiently similar behaviour of the drivers of cyanobacterial blooms to transfer learnings. The review identified that while both lakes experienced significant cyanobacterial blooms, the blooms and their likely drivers were sufficiently different to be able to directly transfer learnings and management recommendations.

In undertaking their review, Dyer (2020) identified strong seasonal patterns in cyanobacterial composition and concentrations in Lake Burley Griffin. Between 2010 and 2019, peak blooms were more prevalent in late summer and early autumn, with increased cyanobacterial cell counts over summer attributed to increased water temperature, longer days and stratification of the lake. Blooms that occurred at the end of summer and in autumn were considered likely to be the result of water column mixing providing an increase in nutrients to the surface waters of the lake. Further, cyanobacteria concentrations in Lake Burley Griffin appeared to be lower during and following wet years and, as the duration of dry years increases, the concentrations of algae increased. This suggested that during dry periods, internal lake processes become increasingly important for driving algal blooms.

Interestingly, Dyer (2020) noted the nutrient concentrations in both the surface and bottom waters of Lake Burley Griffin had declined between 2010 and 2019, yet this did not appear to have led to reductions in cyanobacteria presence in the lake. The reason for the decline in phosphorus concentrations was not clear, but concentrations were considered to be approaching levels at which they could be the limiting factor for the phytoplankton community, and further targeted reductions in phosphorus concentrations appeared to be the best option for managing cyanobacteria blooms in Lake Burley Griffin.

Recently, Stinton et al. (2020) assessed the legacy of the Lake George Mine at Captains Flat for mercury contamination in the Molonglo River and Lake Burley Griffin. In doing so, the authors investigated the spatial patterns of mercury contamination in Lake Burley Griffin using a set of sediment cores from within the lake. The investigation detected mercury contamination from the mine in the sediments from Lake Burley Griffin, with peak concentrations corresponding to the Molonglo River sediment from the early 1960s. Concentrations in more recently deposited sediments were lower, suggesting that mine rehabilitation activities had reduced the contribution of mercury to the lake. Concentrations of mercury in the sediments were noted to be below the thresholds of concern.

B.3 Water quality data analysis: Lake Burley Griffin 2010–2021

Published studies on Lake Burley Griffin include data to the end of 2019. As part of the current review, these analyses were updated to include data from 2020 and part of 2021. The data used were from the NCA monitoring data set (2010–2021) and comprised time series water quality data from all sites within the lake.

Sites 529, 511, 514, 517 and 507 (Figure 22) spanned the longest time period and were the focus of analyses (consistent with the analyses undertaken by Dyer et al. (2020)), but for some water quality attributes, the entire data set was used. The water quality data were augmented with meteorological and stream discharge data (Bureau of Meteorology 2021). In addition, lake closure information from the NCA for the period 2011–2021 were compiled and reported.

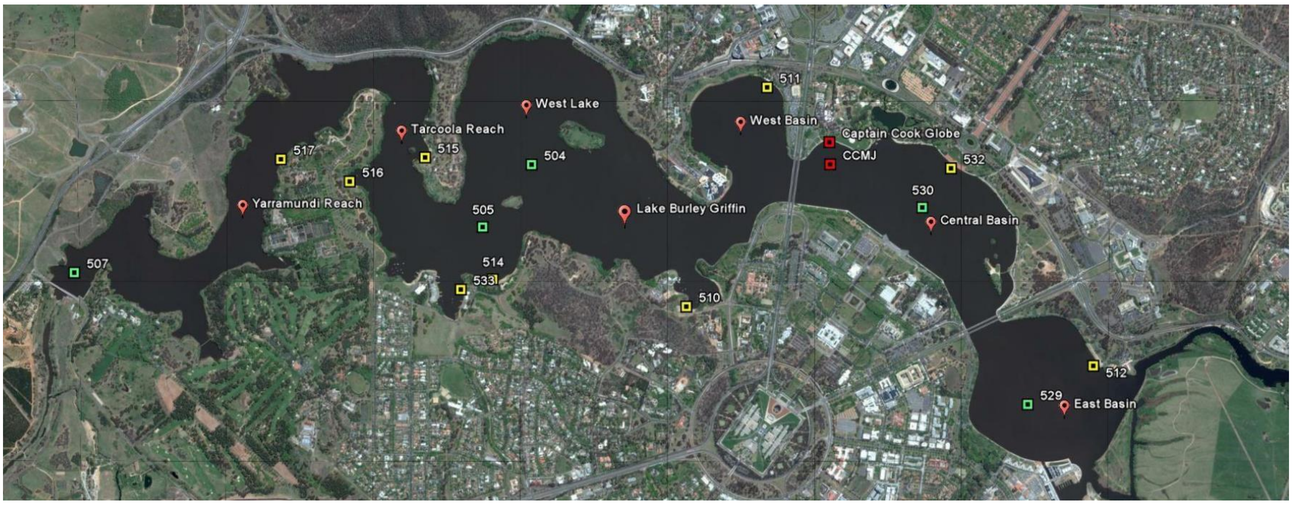

Figure 22. Sampling sites map taken from Lake Burley Griffin Water Quality Sampling and Analysis 2017–2020: Attachment 1 — Specifications Report (unpublished report from the National Capital Authority).

B.4 Inflows

Major inflows to Lake Burley Griffin include the Molonglo River (which receives water from the Queanbeyan River and Woolshed Creek), Sullivans Creek and Jerrabomberra Creek (Figure 3).

Over the past 10 years, inflows have ranged from approximately 10,000 ML in 2019 to more than 470,000 ML for 2021 (Figure 23). Flows from the Queanbeyan STP enter the Molonglo River downstream of the Oaks Estate gauging station and are not incorporated in these data sets. Input from the Queanbeyan STP is reported to range between 3.5 and 89.7 ML/day, with an average of 9.7 ML/day (Queanbeyan-Palerang Regional Council (QPRC) 2020) This suggests an annual average contribution of around 3,540 ML/year, which is a substantial contribution in dry years. For example, this would have represented a quarter of the inflows to the lake in 2019.

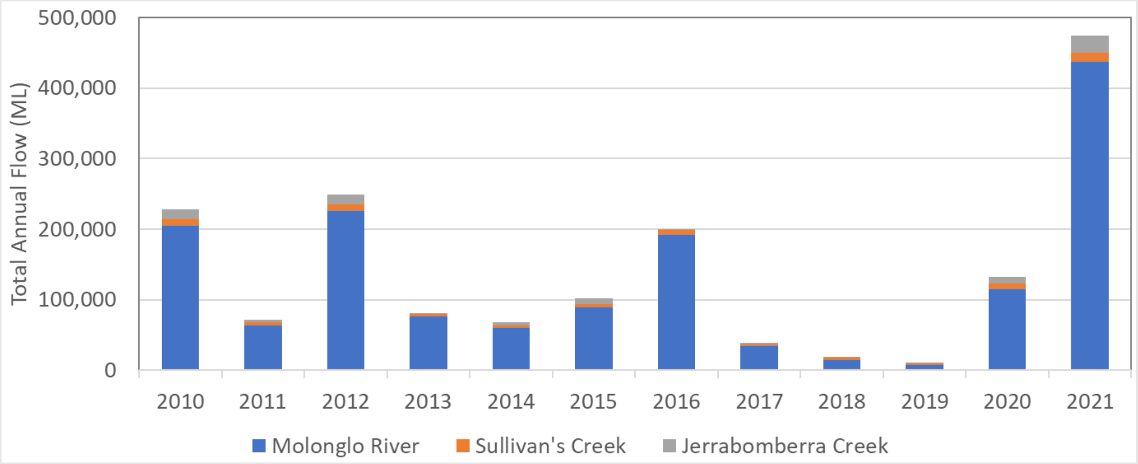

Figure 23. Annual inflows to Lake Burley Griffin from the Molonglo River, Sullivans Creek and Jerrabomberra Creek from 2010 to 2021.

Data sourced from the Bureau of Meteorology. Data for Jerrabomberra Creek between 2010 and 2013 have been estimated based on a relationship between 2014–2020 data from Sullivans Creek and Jerrabomberra Creek.

There are also a range of smaller urban streams and stormwater drains that deliver water to the lake, however long-term flow records are only available for the Molonglo River, Sullivans Creek and Jerrabomberra Creek. Analysis of these data indicates that the majority of flow into the lake in most years overwhelmingly comes from the Molonglo River (Figure 24). During dry years, the proportional contribution to inflows from the urban catchments increases notably, with estimated contributions approaching 30%.

The many small urban streams and stormwater drains that deliver water to the lake are typically ungauged. As part of the Health Waterways project, monitoring of Telopea Creek in Bowen Park was undertaken that included measurements of flow into the lake. The total flow into the lake from Telopea Creek in 2019 was 22 ML, which is negligible compared with approximately 10,000 ML from the three main tributaries. Even the combined stormwater network is unlikely to make a substantial proportional contribution to the lake inflows.

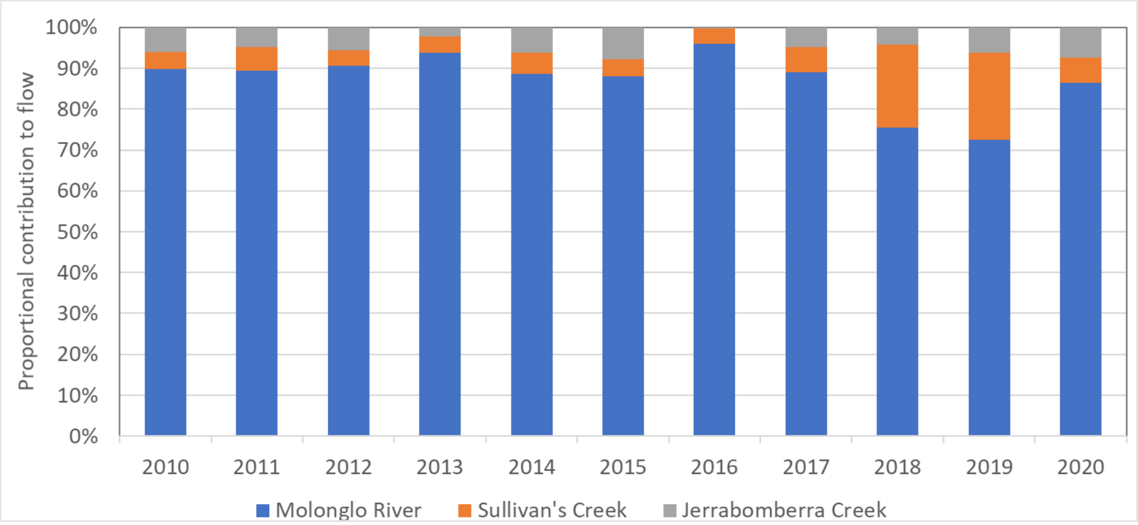

Figure 24. Annual proportional contribution to inflows to Lake Burley Griffin from the Molonglo River, Sullivans Creek and Jerrabomberra Creek from 2010 to 2020.

Data sourced from the Bureau of Meteorology. Data for Jerrabomberra Creek between 2010 and 2013 have been estimated based on a moderate relationship between 2014–2020 data from Sullivans Creek and Jerrabomberra Creek.

B.5 Lake closures

Lake Burley Griffin water quality is monitored during the main recreational season (mid-October to mid-April) and the lake closed to recreational use if either cyanobacteria or Enterococci concentrations exceed thresholds of concern. The lake is generally open to recreation for more than 70% of the recreational season and, in five of the last 10 years, the lake was open to recreation for more than 90% of the recreational season (Figure 25). There are no clear trends in the proportion of the recreational season that the lake is open; the lake was closed most frequently in the summer of 2011–12 and between 2017 and 2021 (Figure 25). The summer of 2020–21 was one of the worst for closures, with the lake closed more than 30% of the time.

Over the past four summers (2017–18 onwards), the main reason for lake closures was the presence of high concentrations of cyanobacteria. Prior to the summer of 2017–18, the main reason for lake closures was high concentrations of Enterococci. There are no clear reasons for the differences, and it is also noted that the closure data doesn’t match the expected closures from the cyanobacteria data (see Section B.6).

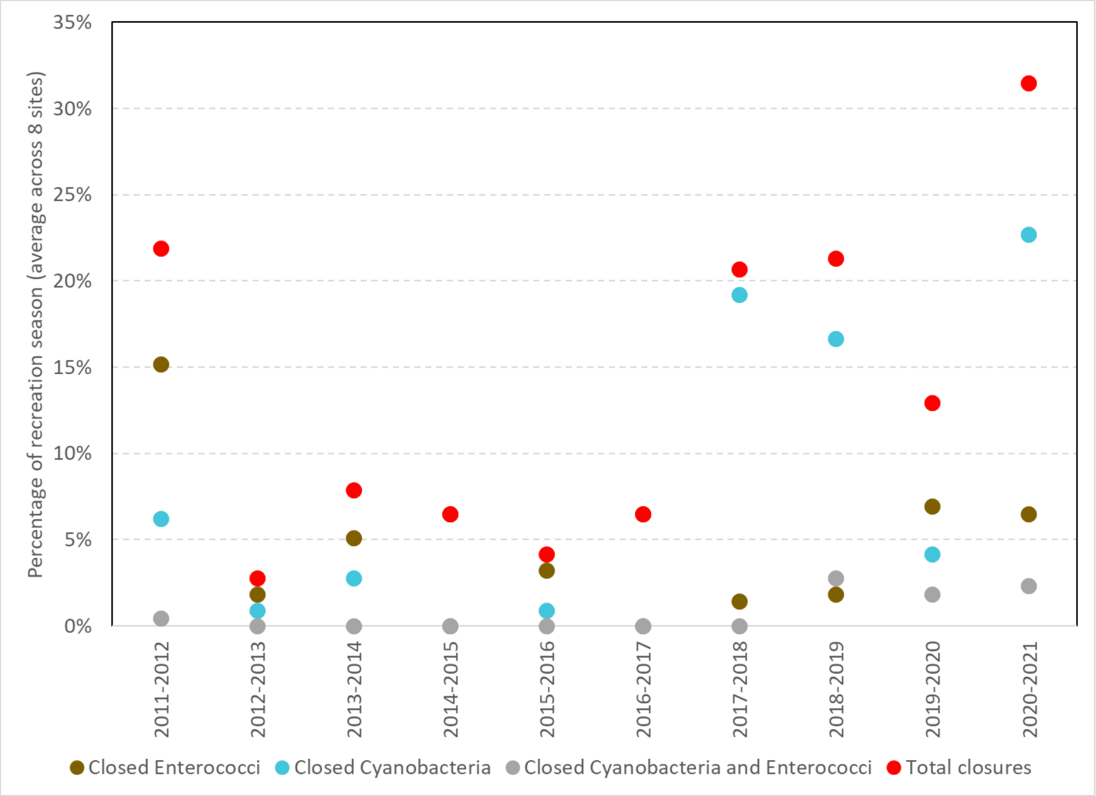

Figure 25. Proportion of the recreational season that Lake Burley Griffin was closed to recreational activities. Data show the average closures across eight monitored sites during the recreation season (October to April). Data sourced from the NCA.

B.6 Cyanobacteria

The concentrations of cyanobacteria cells in Lake Burley Griffin varies seasonally, with higher concentrations recorded in late summer and early autumn. Three distinctly different time periods were evident in the data (Figure 26). In the periods 2010 to June 2012 and 2018 to 2021, cell counts regularly reached the extreme alert level over the summer and autumn seasons. In the intervening period from July 2012 until 2018, there was only one occurrence where the cyanobacteria cell counts reached extreme alert levels. In this intervening period, the cell counts were substantially lower than the years before or after. There does not appear to be a link between inflows to the lake and cell counts, with the wet years of 2010 to 2012 displaying similar extreme concentrations of cyanobacteria to the drier years between 2017 and 2019 (Figure 26).

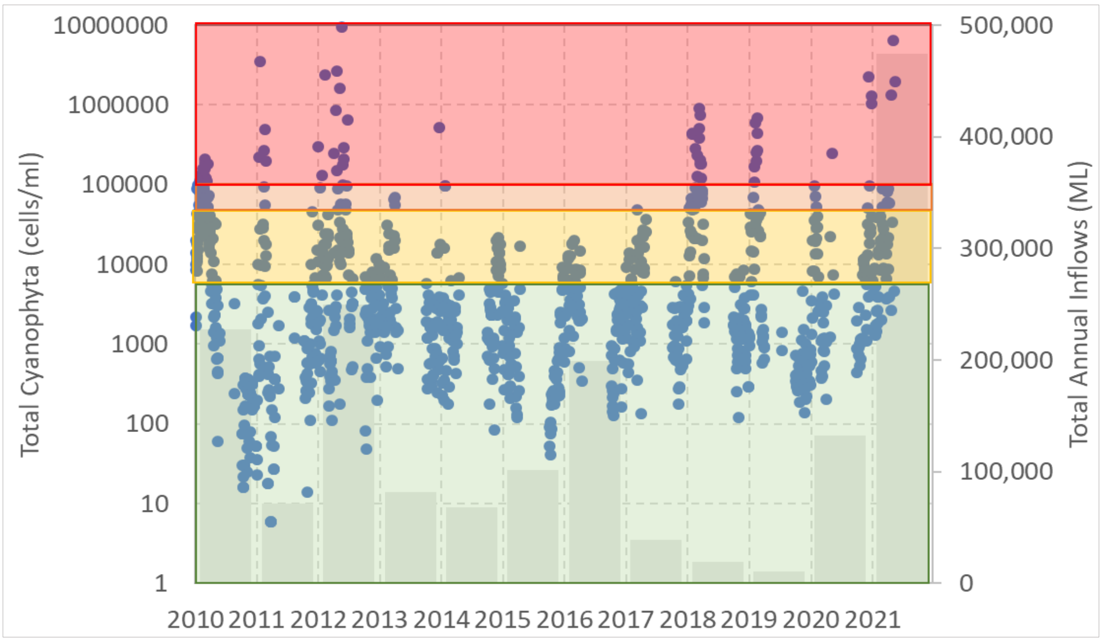

Figure 26. Cyanophyta cell counts in Lake Burley Griffin for the period January 2010 to May 2021 (blue dots) and estimated annual inflows (calendar year) to the lake (grey bars).

Coloured bands indicate the alert level categories (ACT Government 2014a), red = extreme, orange = high, yellow = medium, green = low.

Extreme cyanobacteria levels have occurred in six of the past 10 summers compared with four of the preceding 10. Estimates from Neil (2012) suggest the incidence of extreme concentrations may be increasing.

B.7 Nutrients

Between 25 and 30% of nutrient concentrations results have been above the acceptable range of concentrations for Lake Burley Griffin during the past 10 years (Figure 27 and Figure 28), with regular records of very high concentrations. The concentrations of nutrients in the surface waters of the lake are broadly similar to those in the inflows from the Molonglo River (Technical Appendix G), reflecting the Molonglo River as the major source of water to the lake. While the patterns over the past 10 years in the mean annual nutrient concentrations in the inflows from the Molonglo River match those in Lake Burley Griffin (Figure 29), the mean annual phosphorus concentration in the inflowing Molonglo River water in 2016 was markedly higher than the concentrations in the lake in the same year. It is not clear why this might have been the case.

Average concentrations of total phosphorus and total nitrogen in the surface waters of Lake Burley Griffin had been observed to have declined consistently between 2011 and 2019 (Dyer et al. 2020). It was not clear why this decline occurred, as it occurred across both wet and dry periods. Unfortunately, this decline did not continue through 2020 and 2021 (Figure 29 and Figure 30), with notable increases in the concentrations of both nutrients.

The drivers of the changes in surface water nutrients concentrations are not clear, although it does appear that there is a weak positive relationship between annual inflows and average annual nutrients concentrations (Figure 31).

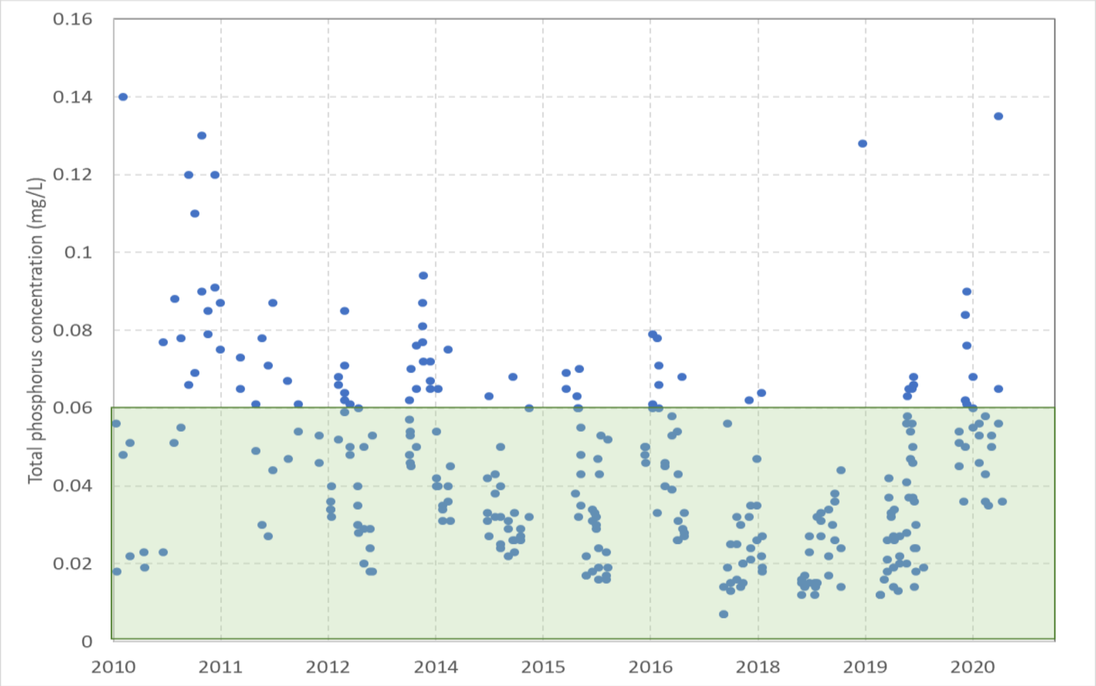

Figure 27. Total phosphorus (TP) concentrations in the surface waters of Lake Burley Griffin from 2010 to 2021. Data are from five sites (529, 511, 514, 517 and 507) for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for total phosphorus specified in the Lake Burley Griffin Water Quality Management Plan.

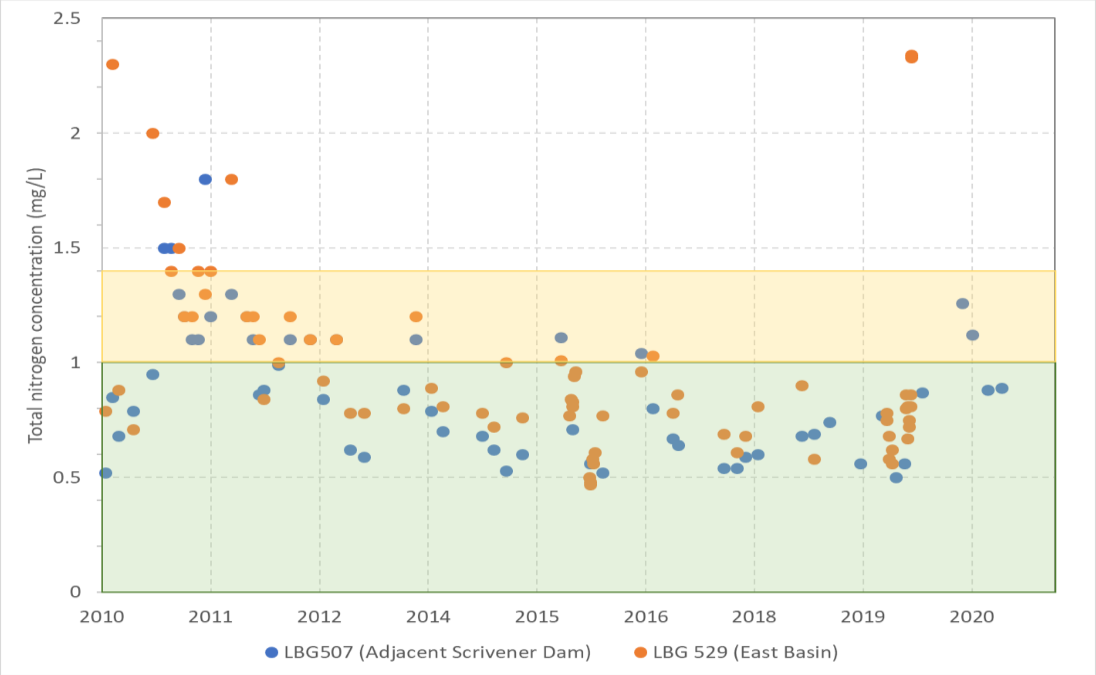

Figure 28. Total nitrogen (TN) concentrations in the surface waters of Lake Burley Griffin from 2010 to 2021. Data are averages for two sites (507 adjacent Scrivener Dam and 529 mid-east basin). The data from 2021 are incomplete at the time of writing. The green shading shows the acceptable concentrations for the western lake and the yellow shading shows the acceptable concentrations for the east basin as specified in the specified in the Lake Burley Griffin Water Quality Management Plan.

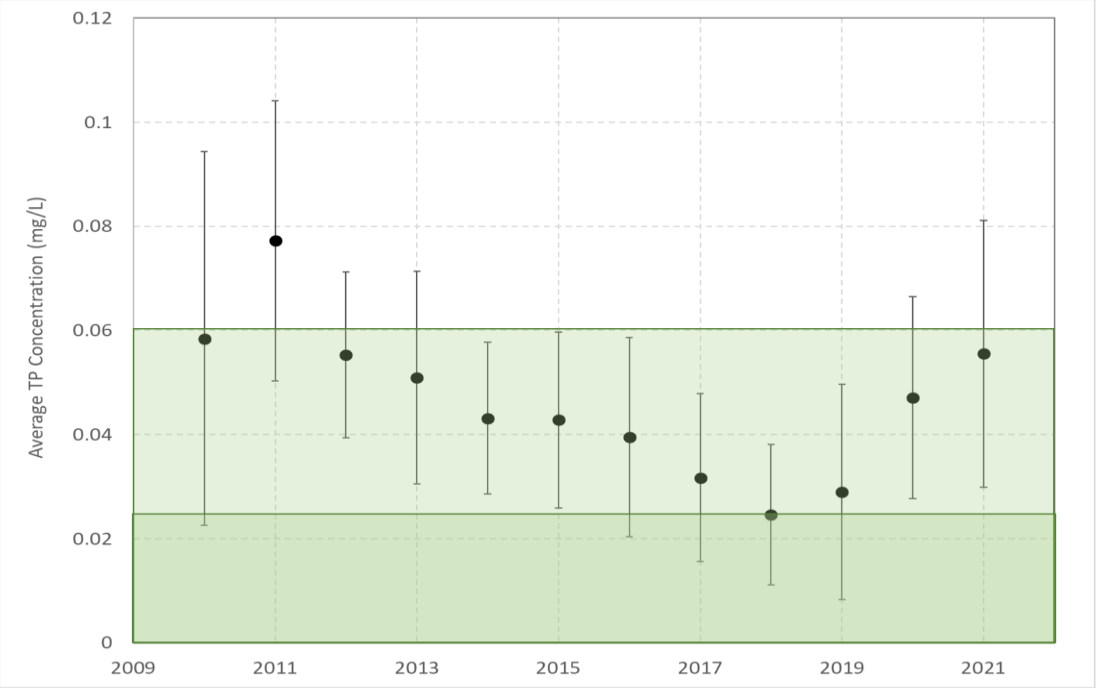

Figure 29. Annual mean total phosphorus (TP) concentrations in the surface water of Lake Burley Griffin from 2010 to 2021.

Data are averages from five sites (529, 511, 514, 517 and 507) for each calendar year, noting that the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for total phosphorus specified in the Lake Burley Griffin Water Quality Management Plan. The darker green shading shows the concentrations that are expected to limit the formation of cyanobacterial blooms. Error bars represent the standard deviation.

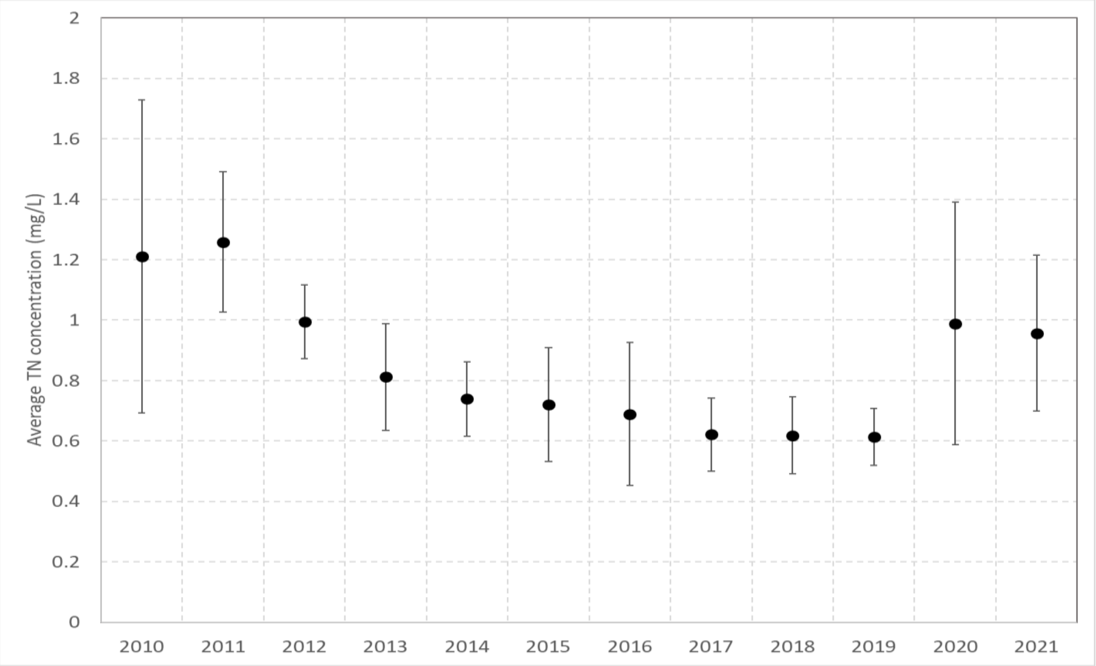

Figure 30. Annual mean total nitrogen (TN) concentrations in the surface water of Lake Burley Griffin from 2010 to 2021.

Data are averages from five sites (529, 511, 514, 517 and 507) for each calendar year, noting that the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

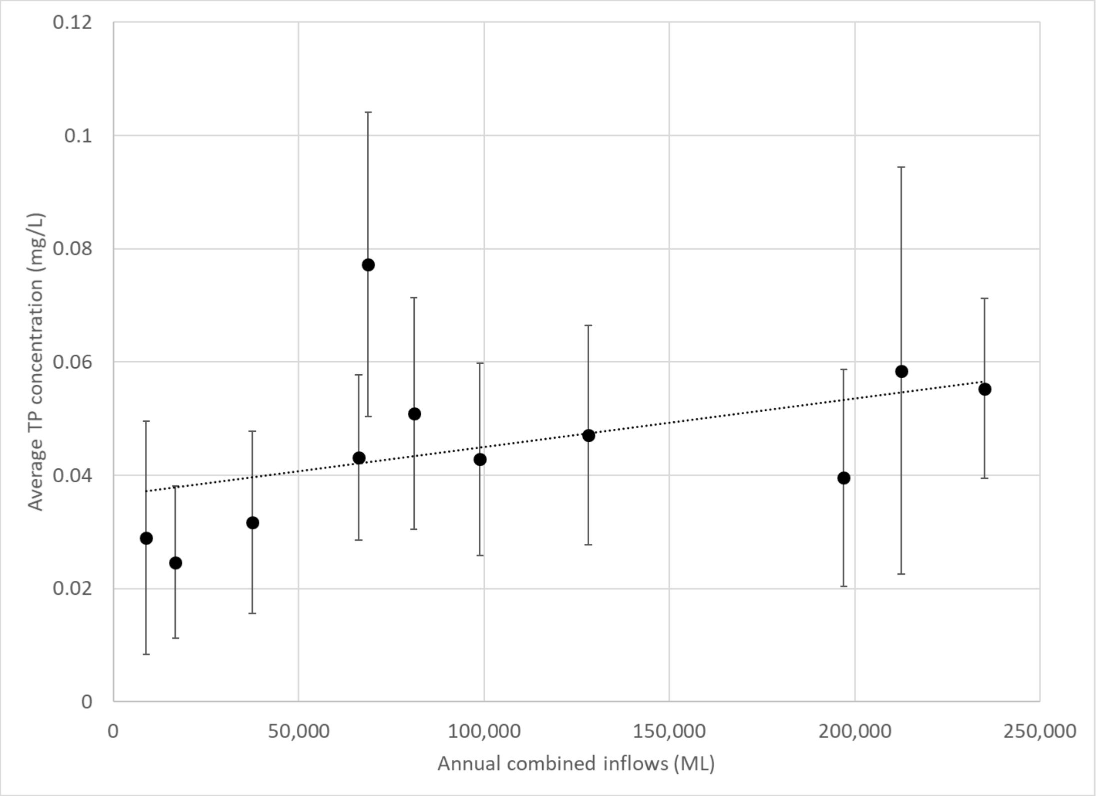

Figure 31. Relationship between annual combined inflows (from the Molonglo River, Sullivans Creek and Jerrabomberra Creek) and total phosphorus concentrations in the surface water of Lake Burley Griffin. Error bars represent the standard deviation.

It is noted that the acceptable range of concentrations for total phosphorus in Lake Burley Griffin, which is based on the historically recorded range of concentrations in the lake, lacks biological relevance to lake processes. Phosphorus is recognised as the limiting nutrient for cyanobacterial blooms in lake systems (Håkanson et al. 2007). There is some thought that concentrations below 0.025 mg/L are limiting to cyanobacterial blooms (see for example data in Dolman et al. 2012), and it may be worth developing total phosphorus targets for the lake in conjunction with targets for the inflowing streams as part of a broader strategy to reduce the incidence of cyanobacterial blooms.

B.8 Dissolved oxygen

Dissolved oxygen concentrations in the surface waters are generally well above levels of concern, ranging between 7 and 9 mg/L (Figure 32) with very rare (< 0.5% of readings), isolated instances where concentrations were below acceptable levels. Concentrations in the bottom waters are lower and are consistent with those of lakes that stratify over summer (data not shown).

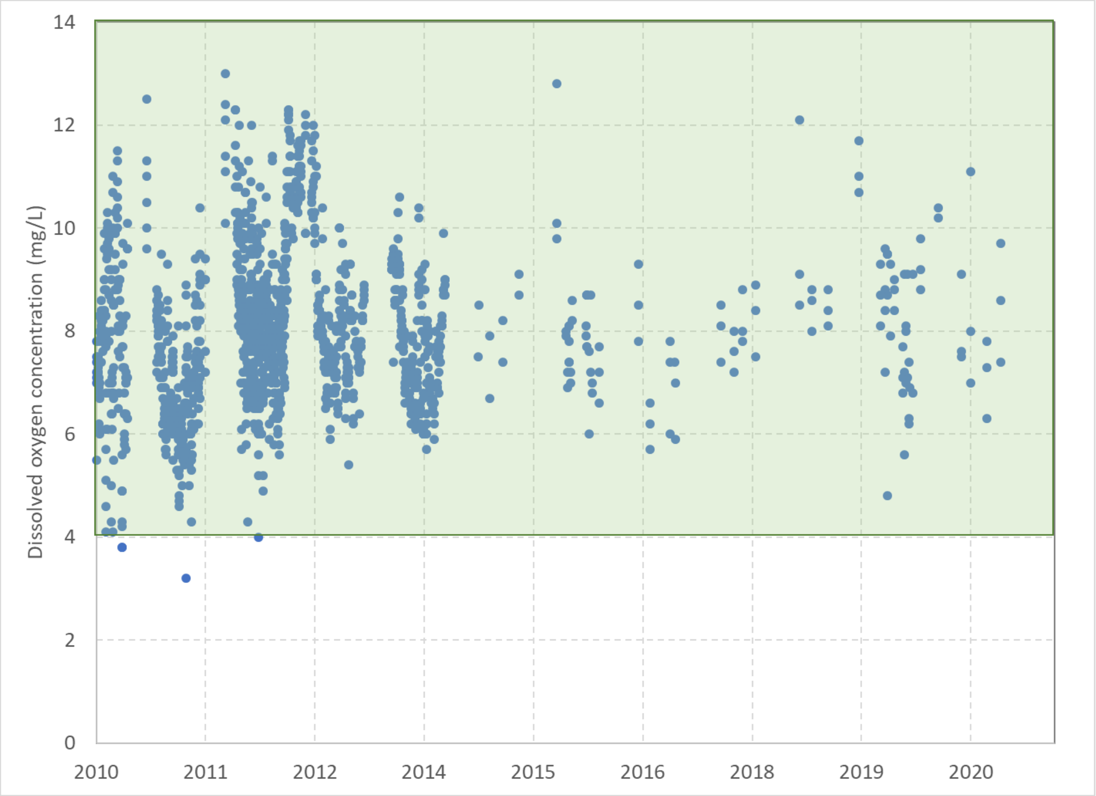

Figure 32. Dissolved oxygen concentrations (mg/L) in the surface waters of Lake Burley Griffin from 2010 to 2021.
Data are averages for each calendar year, noting that the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen specified in the Lake Burley Griffin Water Quality Management Plan.

B.9 Turbidity

Turbidity varies across the lake, and it is expected the turbidity will reduce along the length of the lake as fine sediment settles. This is reflected in the differences in the turbidity levels that are considered to be acceptable for the east basin (< 40 NTU) and the west lake (< 20 NTU).

Turbidity in the east basin between 2010 and 2021 has been below 40 NTU in 95% of readings (Figure 33), with few instances of high turbidity corresponding to very high rainfall events (e.g. turbidity of > 60 NTU on 26 February 2018 corresponded to 60 mm rainfall being recorded in the preceding 24 hours).

Turbidity in the west lake is rarely above 40 NTU, but has been above the acceptable levels for this part of the lake (20 NTU) for nearly 15% of readings (Figure 34), most frequently in wetter years. It should be noted that the lack of data for the wetter years of 2010 and 2011 for the west lake sites means that this is likely an underestimate. A similar pattern is noted at the site near to Scrivener Dam (Figure 35), which is expected to have the lowest turbidity in the lake.

While there is notable improvement in turbidity along the lake (Figure 36), the data suggest the improvement in turbidity desired from the lake is not being achieved in wetter years. There has been little change in turbidity in the past 10 years within the east basin, and comparison with published data prior to 2010 (NCA 2011) suggests the long term turbidity has been consistent in this part of the lake since the mid-1980s. Turbidity within the west basin was observed to be consistently below 20 NTU in the Millenium drought years of 2000–2010 and it is similarly low in 2015, 2016, 2018 and 2019. In wetter years, the turbidity in the west basin, while still lower than the east basin, is higher.

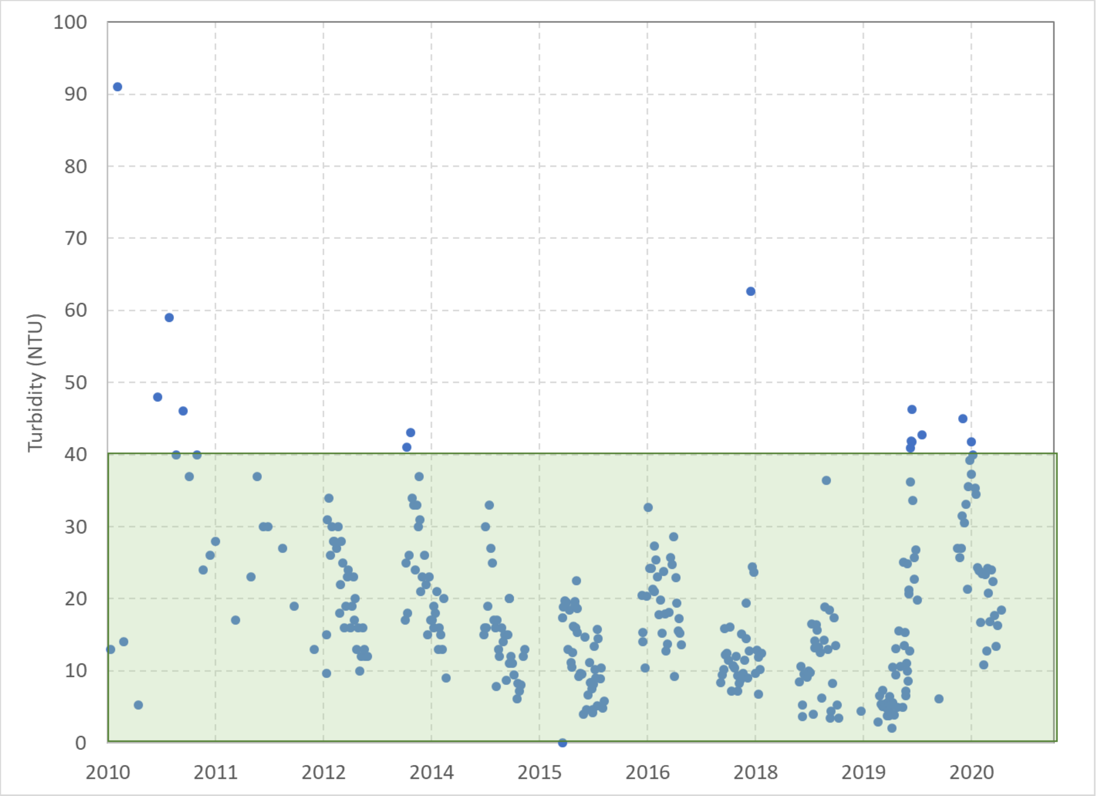

Figure 33. Turbidity in the surface waters of the east basin of Lake Burley Griffin from 2010 to 2021. Data are from sites 529 and 512 for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity as specified in the Lake Burley Griffin Water Quality Management Plan.

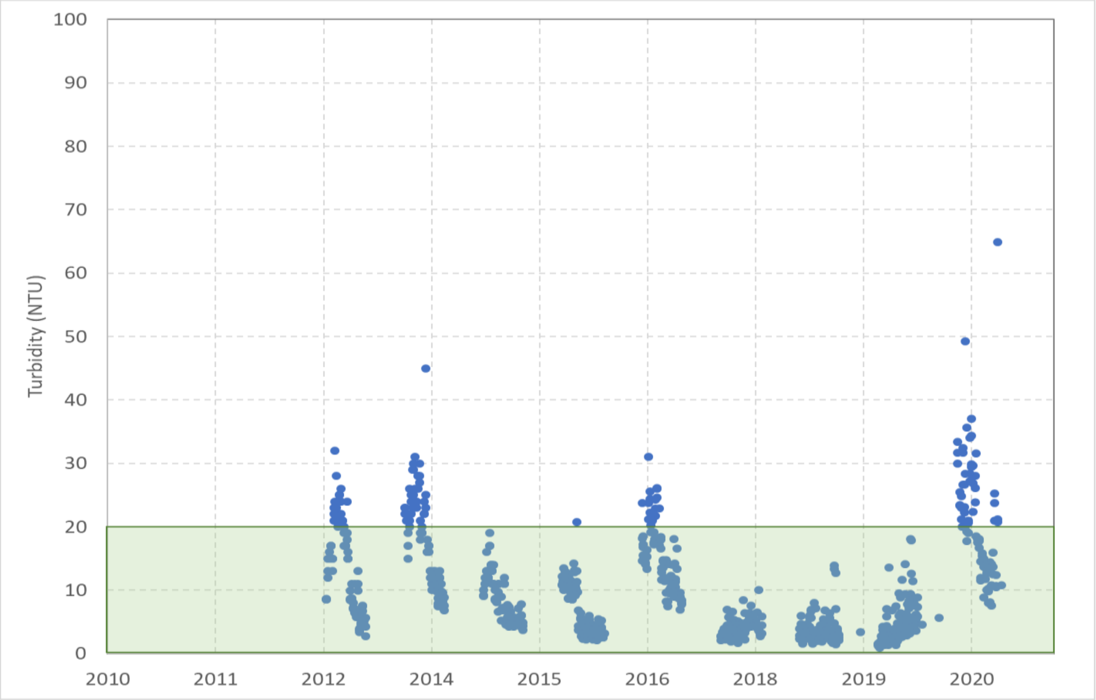

Figure 34. Turbidity in the surface waters of the west basin of Lake Burley Griffin from 2010 to 2021 (excluding the sampling site adjacent Scrivener Dam).

Data are from sites 504, 505, 514, 515 and 516 for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity as specified in the Lake Burley Griffin Water Quality Management Plan.

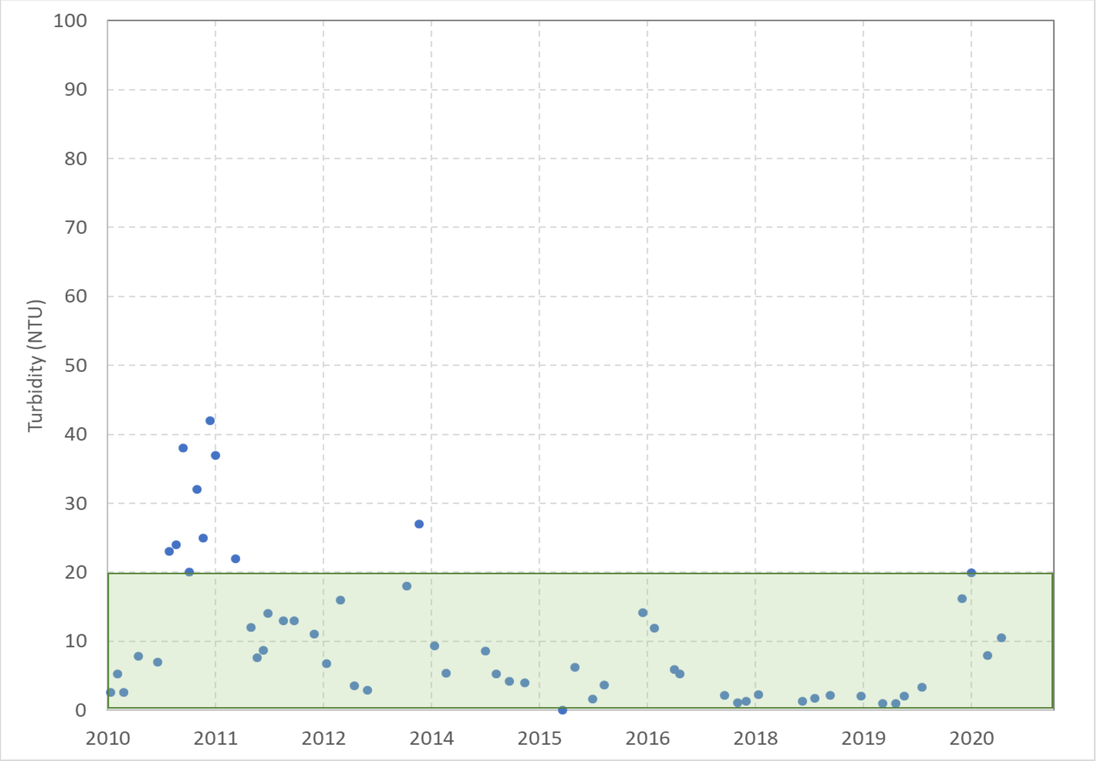

Figure 35. Turbidity in the surface waters of Lake Burley Griffin near Scrivener Dam from 2010 to 2021.

Data are from site 507 for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity as specified in the Lake Burley Griffin Water Quality Management Plan.

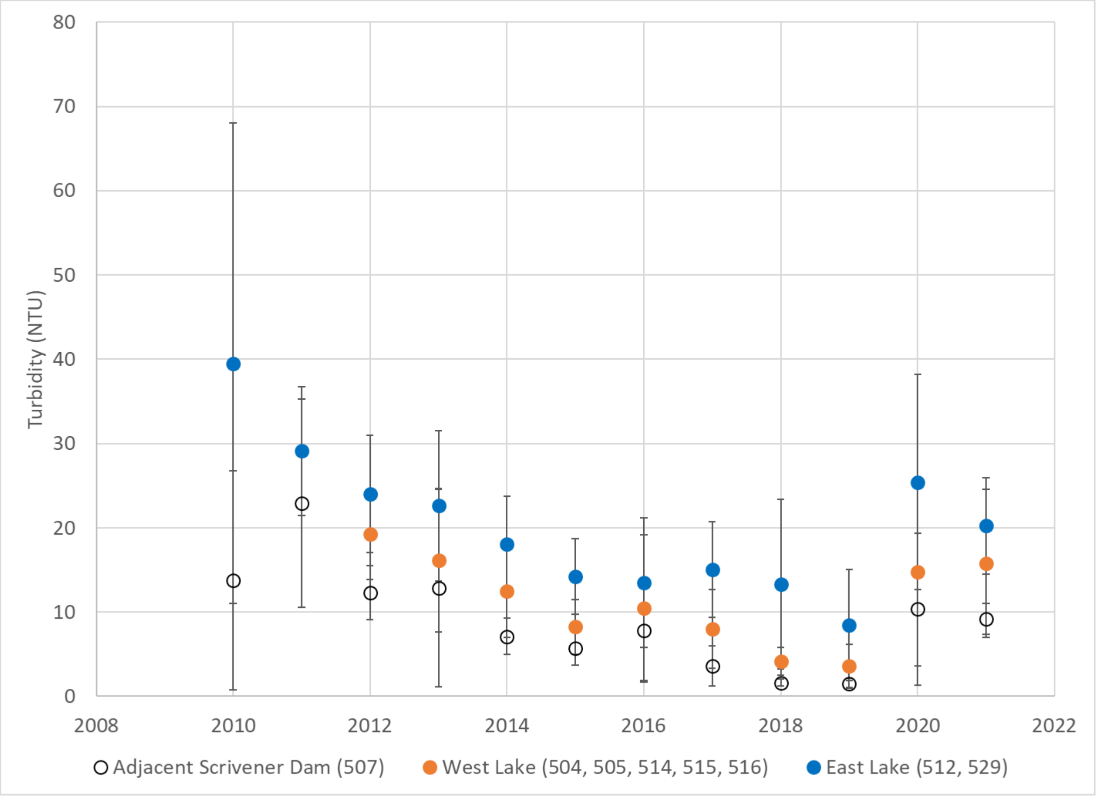

Figure 36. Annual mean turbidity (NTU) in the surface waters of Lake Burley Griffin from 2010 to 2021. Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

B.10 pH

The lake pH has consistently been within the acceptable range (Figure 37), with only 3% of pH readings above the upper limit of 8.5 and none below the lower limit of 6.5. There is a slight increase in pH between 2016 and 2019, which is likely a result of the source of water to the lake. Typically, pH in Lake Burley Griffin is slightly higher in the drier months (data not shown), reflecting a dominance of input from baseflows (with a higher groundwater contribution) and stormwater inputs (delivered via concrete drains). During very dry years, these types of flows will dominate throughout the year and the pH in the lake will be higher.

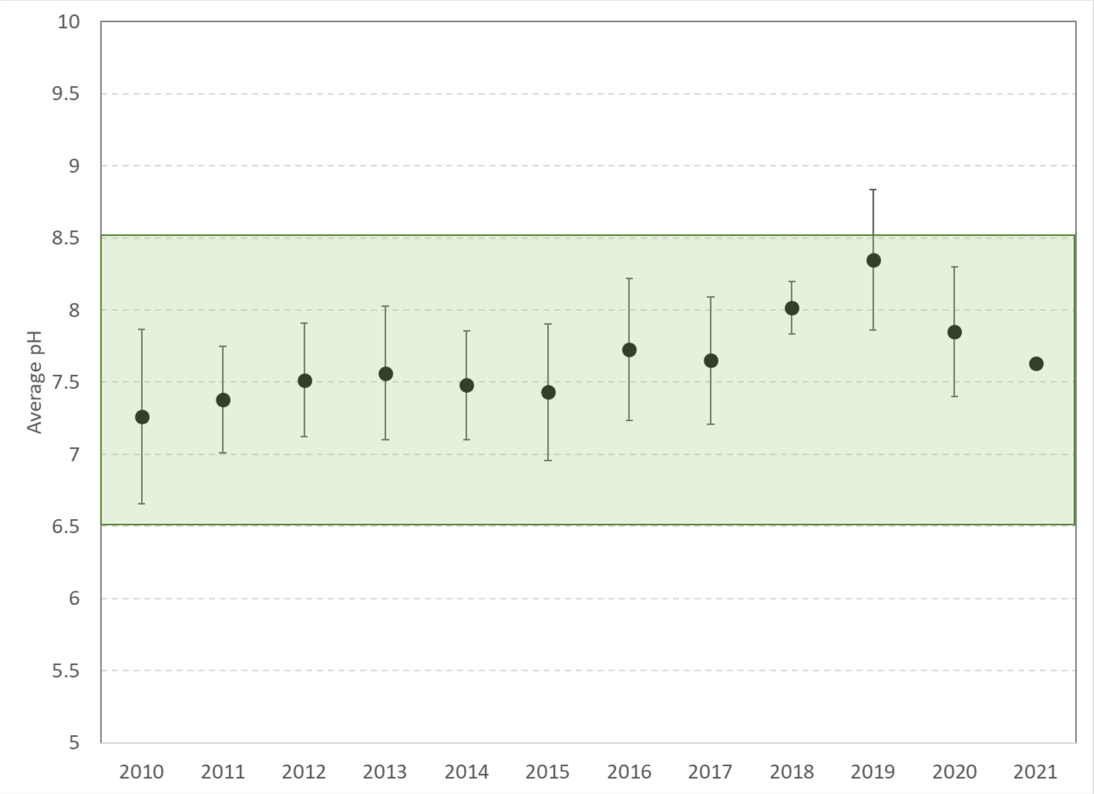

Figure 37. Annual mean pH in the surface waters of Lake Burley Griffin from 2010 to 2021.
Data are averages from all sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH as specified in the Lake Burley Griffin Water Quality Management Plan. Error bars represent the standard deviation.

B.11 Conductivity

Conductivity within the surface waters of the lake is almost always within the acceptable range, with extremely rare instances of values exceeding 400 µS/cm (Figure 38). The conductivity of the lake water increased between 2013 and 2019, possibly because of drier conditions, and the return of wetter conditions in 2020 and 2021 has seen values declining again.

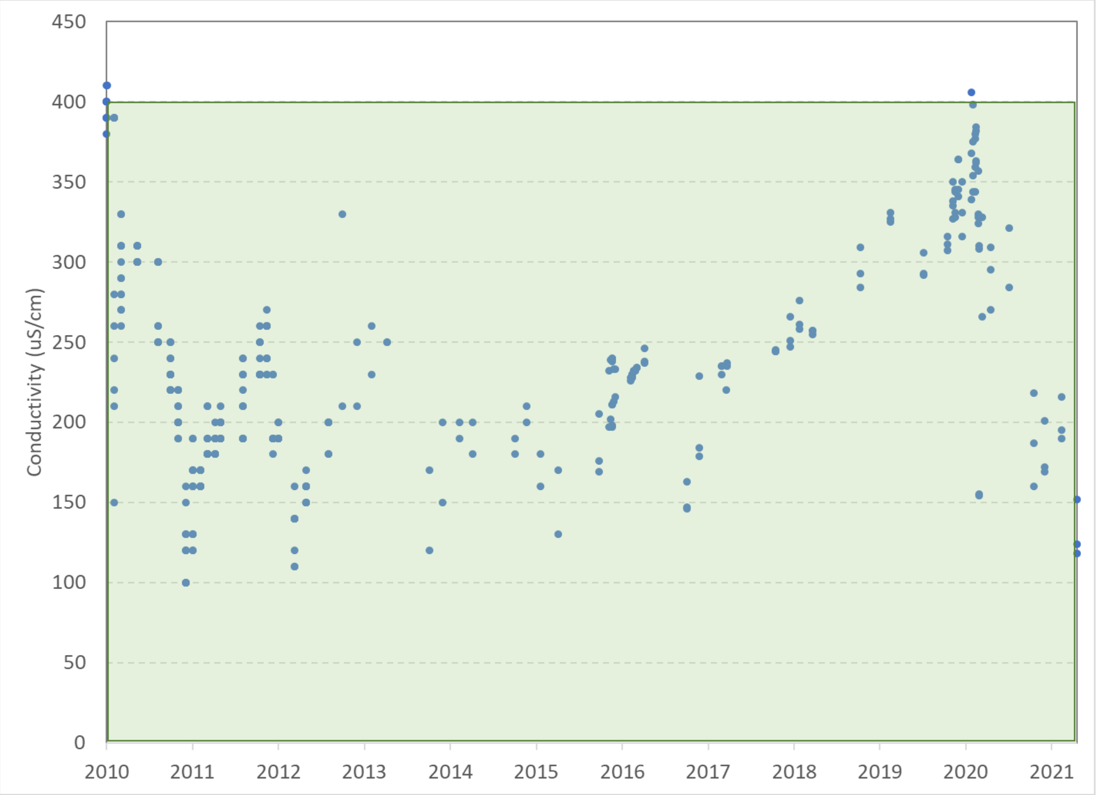

Figure 38. Conductivity of the surface waters of Lake Burley Griffin from 2010 to 2021.

Data are from sites 504, 507, 529 and 530 for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for conductivity as specified in the Lake Burley Griffin Water Quality Management Plan. Note the data prior to 2015 were recorded to the nearest 10 µS/cm.

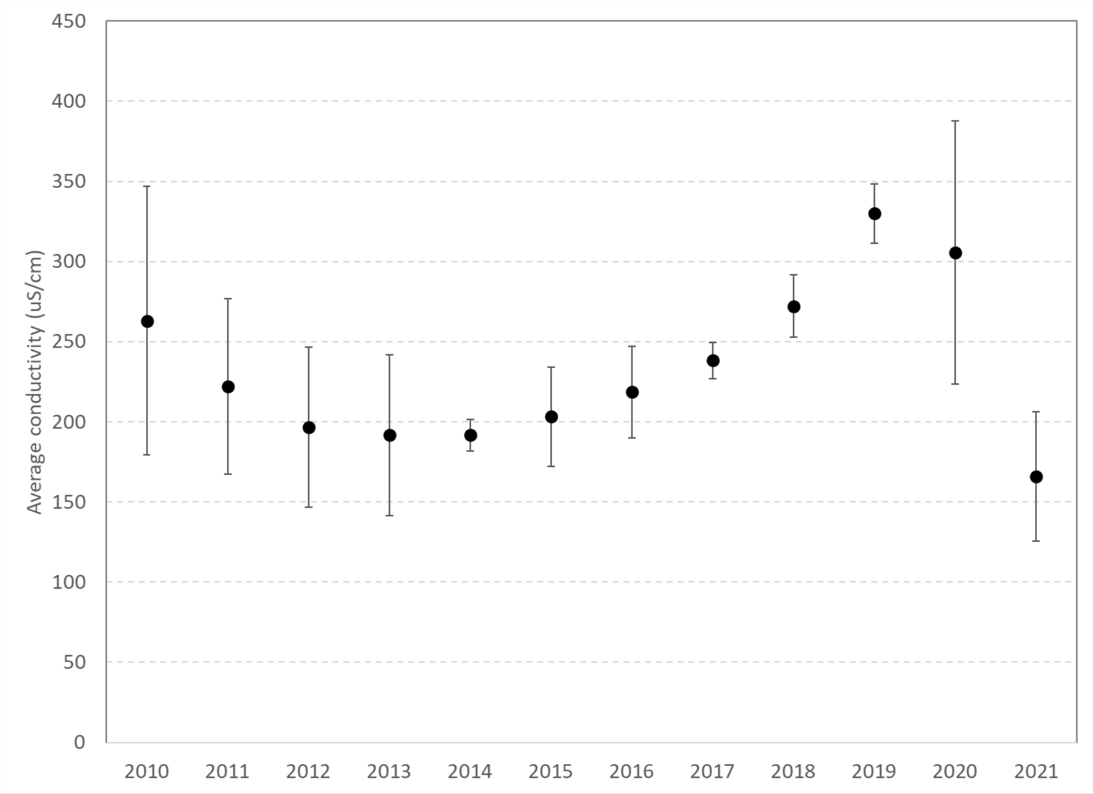

Figure 39. Annual mean conductivity of the surface waters of Lake Burley Griffin from 2010 to 2021. Data are averages from all sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. Note all values are within the acceptable range for conductivity defined in the Lake Burley Griffin Water Quality Management Plan. Error bars represent the standard deviation.

B.12 Water quality data analyses: inflows to and outflows from Lake Burley Griffin

The concentrations of phosphorus in the water flowing into the lake from the Molonglo River are substantially lower than those from either Sullivans Creek or Telopea Creek (Figure 40). The concentrations of phosphorus downstream of Lake Burley Griffin are similar to those in the Molonglo River, indicating the lake is acting to effectively trap the phosphorus from the urban runoff, thus protecting the water quality in the downstream reaches of the Molonglo River.

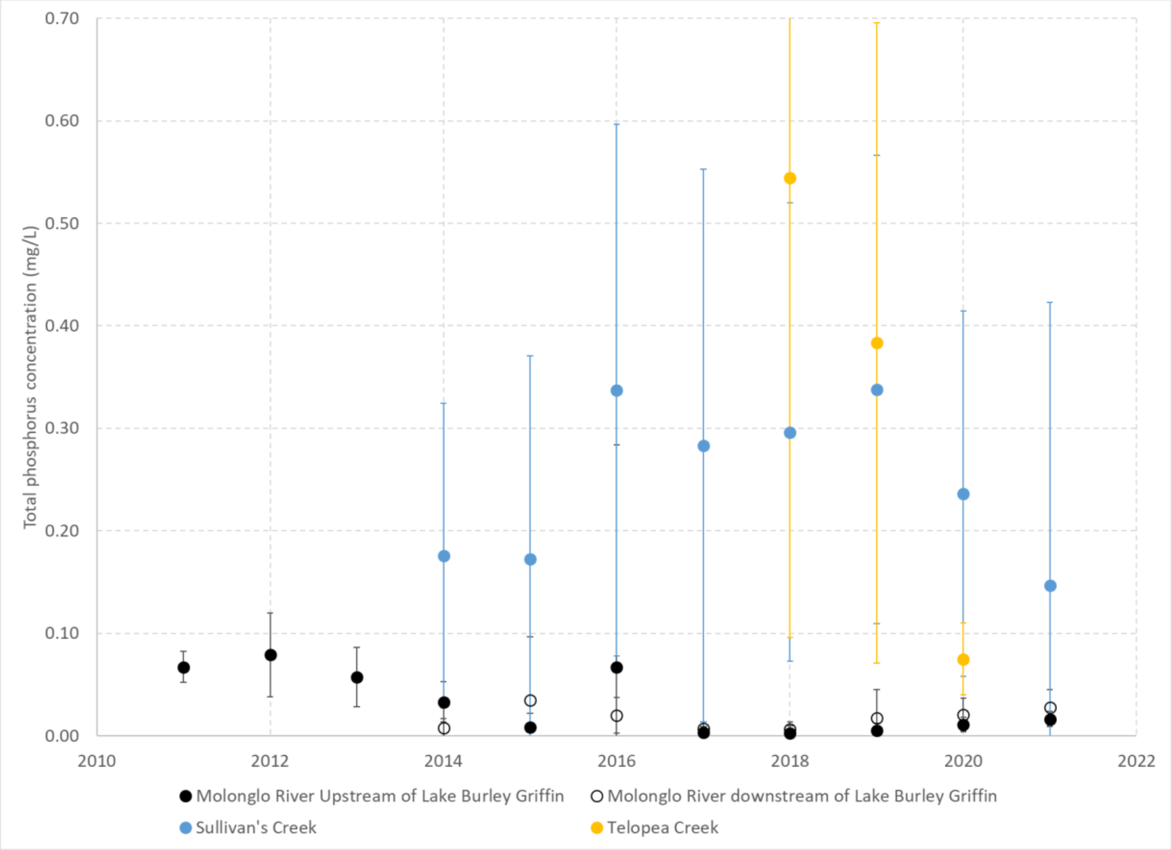

Figure 40. Annual mean total phosphorus (TP) concentrations in the inflows to Lake Burley Griffin from the Molonglo River, Sullivans Creek and Telopea Creek, as well as the mean annual total phosphorus concentration in the Molonglo River below the lake from 2010 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

The data available for nitrogen concentrations in the inflowing creek are not ideal for comparisons. For the Molonglo River and Sullivans Creek, the data include nitrate concentrations, but for Telopea Creek, total nitrogen concentrations are available. The comparisons provided only include the Molonglo River and Sullivans Creek. Nitrate concentrations have typically been higher upstream of Lake Burley Griffin compared with those recorded downstream (Figure 41), and these have been notably higher from 2017 until present. The nitrate concentrations in Sullivans Creek are similar to those recorded in the Molonglo River downstream of Lake Burley Griffin.

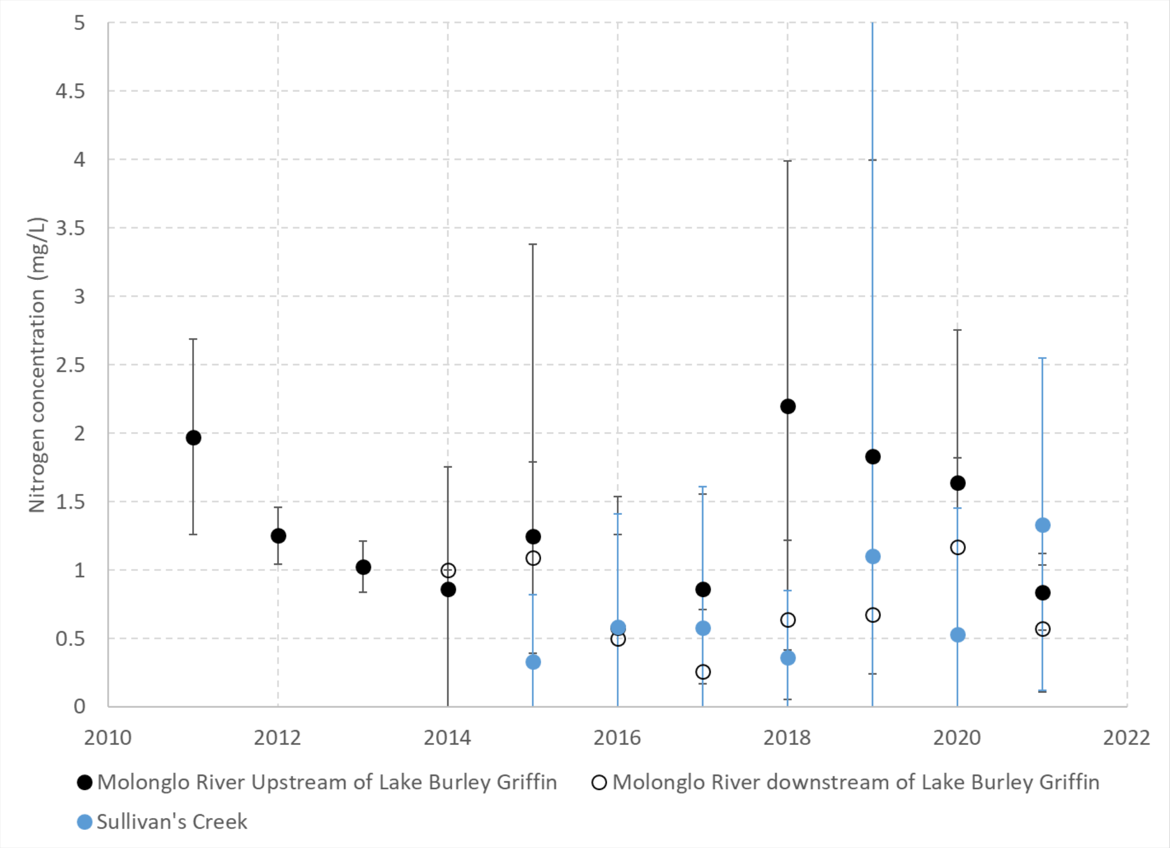

Figure 41. Annual mean nitrate (as N) concentrations in the inflows to Lake Burley Griffin from the Molonglo River and Sullivans Creek, as well as the Molonglo River below the lake from 2010 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

Turbidity in the inflows to Lake Burley Griffin from the Molonglo River and Sullivans Creek over the past 10 years have been similar to those recorded downstream of the lake, with the notable exception of 2020 (Figure 42). In 2020, the turbidity recorded in the Molonglo River downstream of Lake Burley Griffin was markedly higher than that recorded in the upstream Molonglo River sites and was similar to the concentrations recorded in Sullivans Creek. The high average annual values are caused by some very high turbidity that occurred in January, June and August of 2020. While the high concentrations were associated with rainfall days, the rain was not atypical and there is not an obvious reason for the high concentrations.

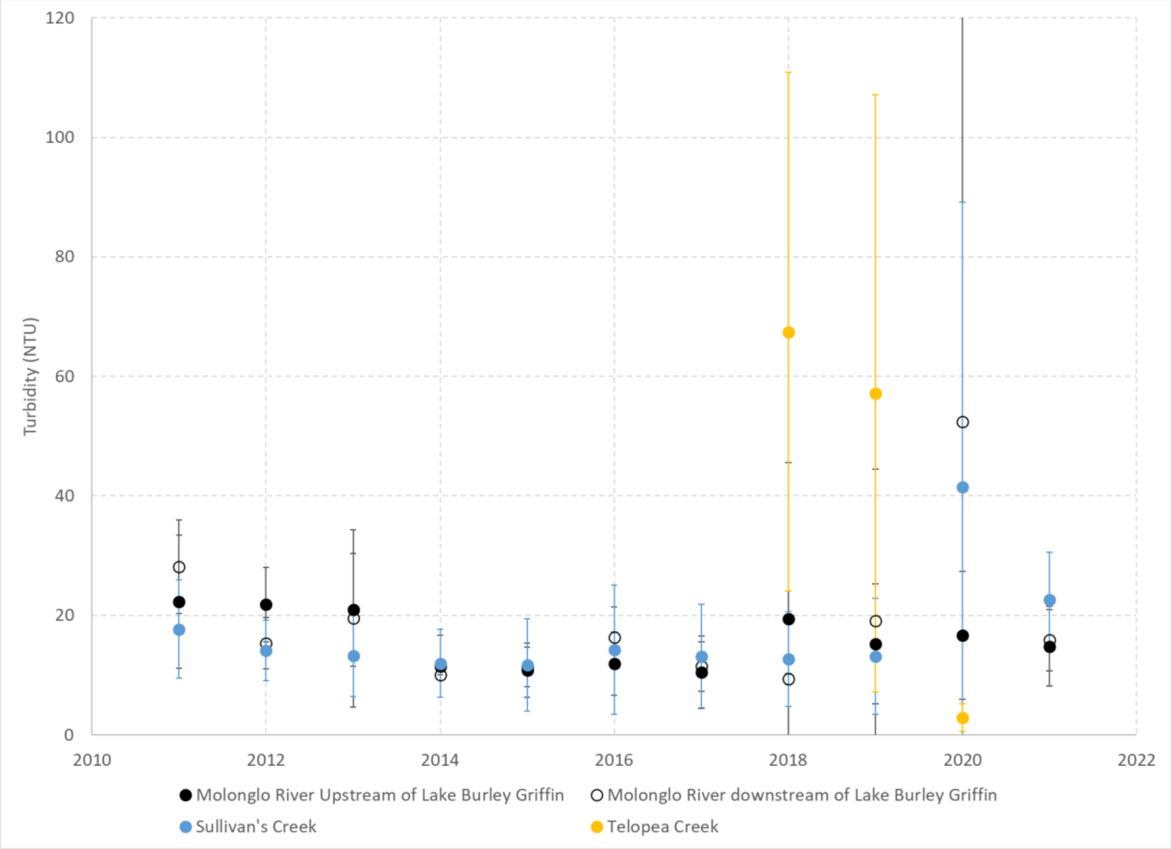

Figure 42. Annual mean turbidity (NTU) concentrations in the inflows to Lake Burley Griffin from the Molonglo River, Sullivans Creek and Telopea Creek, as well as the annual mean turbidity (NTU) concentrations in the Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

The electrical conductivity recorded in the reaches of the Molonglo River upstream of Lake Burley Griffin are generally the same as those recorded downstream (Figure 43). The electrical conductivity recorded from Sullivans Creek is slightly higher than those from the Molonglo River, and the electrical conductivity from Telopea Creek is generally lower.

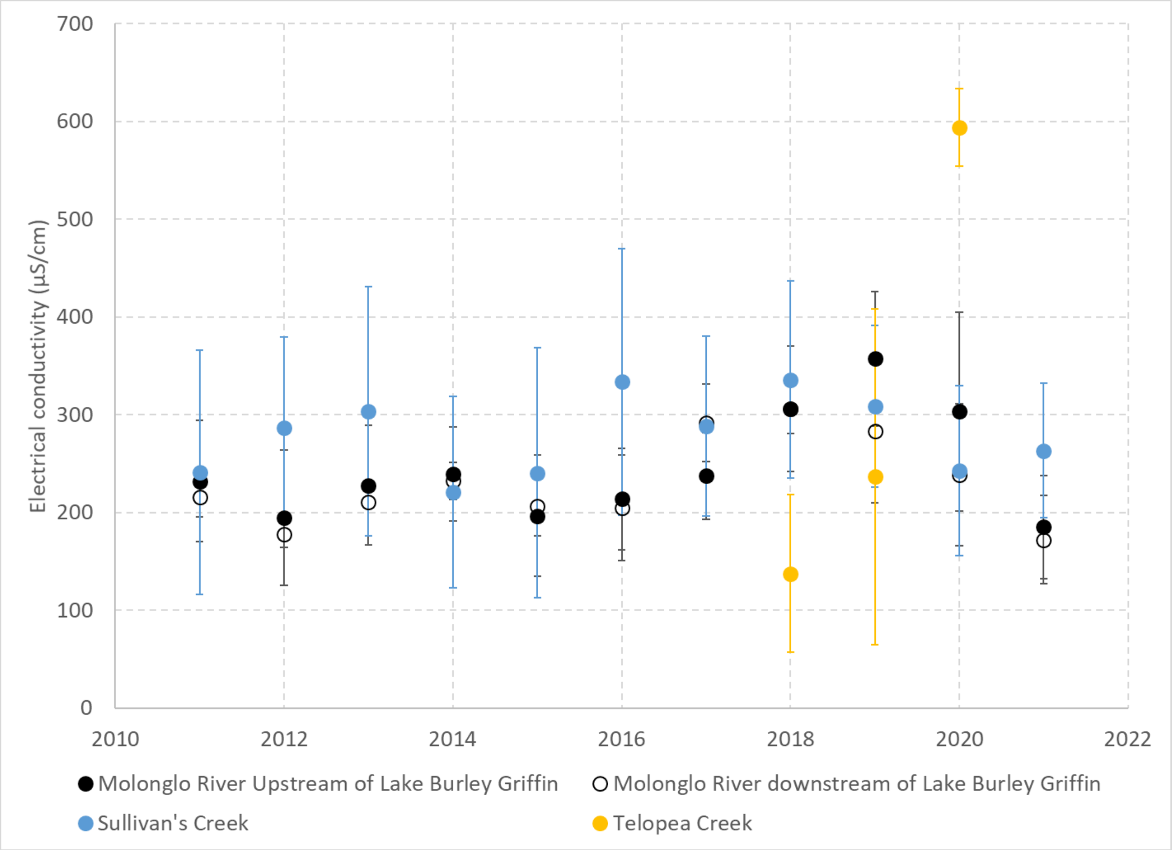

Figure 43. Annual mean electrical conductivity in the inflows to Lake Burley Griffin from the Molonglo River, Sullivans Creek and Telopea Creek, as well as the annual mean electrical conductivity in the Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

B.13 Ecological values

There are limited data available that would allow trends in the broader ecological values of Lake Burley Griffin to be determined.

B.14 Riparian condition

The shores of Lake Burley Griffin range from the paved and manicured foregrounds of Canberra's landmark buildings in the central basin to the urban parklands and beaches of the east and west basins. The parklands comprise a mix of native and exotic vegetation, the condition of which is defined by the level of management effort. Like all urban parklands, they are subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation.

B.15 Macrophyte condition

The previous Commissioner's report (Neil 2012) expressed concerns about the substantial loss of macrophyte beds in or adjacent to inlet zones (east basin and Sullivans Creek). While the authors lack macrophyte surveys for the lake, observations would suggest that these areas remain devoid of macrophyte beds. This suggests the lake has reached an alternate stable state that is dominated by phytoplankton rather than macrophytes. The reasons for this are unclear and the authors are unaware of any systematic investigation of the change. Opinions vary as to the possible reasons; similar changes described in the literature (e.g. Scheffer and Nes (2007); van Nes et al. (2007)) are attributed to changes in nutrient status, changes in turbidity and hydrological changes. It is likely this is not caused by a single factor, with some postulating that it may be partly attributable to high numbers of carp, which are known to adversely affect macrophyte growth (Miller and Crowl 2006; Vilizzi et al. 2014).

B.16 Fish, frogs and other animals

The fish community of the lake is highly managed, with regular stocking part of the ACT Government Fish Stocking Plan (ACT Government 2015). Focus is on stocking the lake with charismatic native recreational species (golden perch and Murray cod), with fingerlings introduced to the lake toward the end of each calendar year. Stocking is required to maintain populations of native fish species because the lakes do not seem to provide the appropriate conditions for breeding.

The lake supports self-sustaining populations of European carp and redfin perch, both introduced species that have negative effects on water quality and other fish species. European carp feed by disturbing the bottom sediments of waterbodies (Huser et al. 2016), which causes sediment resuspension and disturbance of aquatic vegetation. The resulting increased turbidity and loss of aquatic plants can have substantial effects of lake ecosystems (Breukelaar et al. 1994; Chumchal et al. 2005; Crivelli 1983; Roberts et al. 1995). Redfin perch are an aggressive predatory species that target smaller fish species and invertebrates. They also carry the EHN (epizootic haematopoietic necrosis) virus, which is detrimental to native fish species.

The lake is also home to rakali (or the Australian water-rat), with frequent observations from citizen science programs across the lake (Williams 2019). There is at least one resident rakali frequenting the waters near Claire Holland House (personal communication, Fred Anchell, Claire Holland House visitor, February to August 2019). Rakali are top predators and scavengers and appear to thrive on introduced fish species such as the carp and redfin perch that are prevalent in Lake Burley Griffin. They appear relatively oblivious to poor water quality and seem to be most frequently associated with areas where there are stable banks covered in low growing vegetation or emergent aquatic vegetation (Smart et al. 2011; Speldewinde et al. 2013).

C. Lake Tuggeranong Technical Appendices

C.1 Document review: Lake Tuggeranong water quality history

Early water quality research associated with options for the development of the suburb of Tuggeranong by the Centre for Resource and Environmental Studies at the ANU (Beer et al. 1982) highlighted the water quality challenges of Tuggeranong Creek and its catchment. The study noted large stormflows were transporting high concentrations of sediment and nutrients downstream to the Murrumbidgee River. The research team also identified high concentrations of coliform bacteria, particularly during high flows. They identified the construction of Lake Tuggeranong would likely improve the quality of water downstream of the lake but predicted the lake would likely be eutrophic and experience regular nuisance phytoplankton blooms. They also predicted bacterial contamination would increase with catchment development. These predictions appear to have been correct, and Lake Tuggeranong has a reputation for poor water quality.

Recent research from CAWS, as part of the ACT Healthy Waterways program (Ubrihien et al. 2019b; Ubrihien et al. 2020), has been directed at understanding the drivers of the nuisance cyanobacterial blooms that occur regularly in Lake Tuggeranong to inform management actions that would reduce the frequency and severity of the blooms. Temperature, stratification and nutrient concentrations are the key determinants of the algal blooms and were the primary focus of the research. The research involved a targeted catchment scale investigation into the spatial and temporal variability in nutrient loading from the catchment, assessing internal and external nutrient sources from lake sediment and the catchment, particularly in higher stormflows, and conducting mesocosm experiment to assess the potential of in-lake treatments of cyanobacterial blooms.

The findings of the study indicated that external nutrient sources from the catchment were the major contributors of nutrients to the lake. Large nutrient loads were seen to enter the lake during higher rainfall periods in January and February of 2020, with this loading containing a high proportion of nutrient in dissolved form, which are readily available for uptake by phytoplankton (Ubrihien et al. 2020). There was also evidence of increased dissolved nutrient loading from the lakebed sediments after rainfall events, potentially caused by increased organic matter input causing increased respiration in the lakebed sediments, creating anoxic conditions and facilitating dissolved nutrient release. These discoveries highlighted the importance of external nutrient sources in the developing conditions conducive to cyanobacterial blooms.

The external sources of nutrients under baseflow conditions were identified to come mainly from Village Creek and Wanniassa stormwater, as these inflows are draining areas with mainly concreted channels and underground pipes, giving very little opportunity for infiltration or nutrient attenuation in these catchments. The main management actions for these nutrient inputs, and to minimise contamination events, are WSUD infrastructure on the lower sections of Village Creek and increasing education about the appropriate use of the stormwater system and the application of fertilisers and watering in maintained ovals.

The total nutrient loads moving through Lake Tuggeranong under event flow conditions are much greater than the baseflow nutrient inputs. There is also evidence of high diffuse nutrient inputs from throughout the urban areas of the catchments during rainfall events. The high proportion of impervious surfaces, concreted channels and piped stormwater systems create high peak flows and allow little infiltration or retention in the catchments. Any intervention that facilitates infiltration, reduces flow rates and safely increases water retention in the catchment would help reduce the high nutrient inputs to the lake during events. This would have flow-on effects for the cyanobacterial communities in the lake as bloom-positive conditions often develop after rain events. These are often caused by the nutrients delivered in rainfall runoff supporting the rapid increase in cyanobacterial populations. This can lead to nuisance blooms, and further highlights the importance of external nutrient sources to the phytoplankton community in Lake Tuggeranong.

Other studies undertaken in Lake Tuggeranong as part of the ACT Healthy Waterways Program focused on the efficacy of Gross Pollutant Traps (GPTs) and sediment transport dynamics in the lake (HydroNumerics 2016). The study on GPTs found they did supply some functionality in increasing the visual amenity of lake, and therefore community recreation, and protecting downstream assets that are more sensitive to pollutant loads. However, the report found that GPTs should not be a priority option for improving water quality and reducing algal bloom frequency at Lake Tuggeranong. This is because they provide only moderate reductions in nutrient loading and algal community reduction (< 10% in all cases). The GPTs at Lake Tuggeranong primarily trap leaf litter and settle larger suspended solids that have a small potential to increase nutrient loads, and its capture and removal by GPTs has little effect on downstream quality. The efficacy of GPTs at Lake Tuggeranong could be improved by increasing the frequency of dredging and the introduction of macrophytes within or surrounding the traps to provide some biological treatment of the nutrient loads sourced from the surrounding catchments.

The study on the transport and fate of suspended sediments in Lake Tuggeranong found that fine sediment is being transported through the lake and downstream, the heavier, coarser sediment is being impounded in the GPTs at the inflows or being deposited in the initial reaches of the lake near the inflows and the very fine to medium sediment (100 to 512 µm) is being deposited in the highest concentrations in the lake. These deeper, more central areas of the lake are more susceptible to stratification, so this highest concentration of 100 to 512 µm sediment may have implications on nutrient release for the lakebed over the warmer periods of the year (HydroNumerics 2016).

C.2 Water quality data analysis: Lake Tuggeranong 2010–2021

Data from the ACT Government Lakes and Rivers Water quality monitoring program and Waterwatch data for Lake Tuggeranong from 2011–2021 was used to develop time series water quality data for this period. EPA cyanobacteria data was used to develop time series biological data for the same period. The CAWS Lake Tuggeranong Urban Stormwater Project data from 2017-2021 was also used to augment the longer time series data. Lake closure information from TCCS for 2015–2021 were compiled and reported.

C.3 Lake closures

Lake Tuggeranong water quality is monitored across the year, and the lake closed to recreational use if either cyanobacteria or Enterococci bacteria concentrations exceed thresholds of concern. Over the past six recreational seasons, Lake Tuggeranong has been frequently closed to recreational use over the recreational period of mid-October to mid-April (Figure 44). In four of those years, the lake was closed for more than 60% of the recreational season, and in 2016–17 and 2020–21, the lake was closed for around 80% of the recreational season. The main reason for the closures has been high concentrations of cyanobacteria in the lake. It should be noted that the closure data used has some limitations, particularly prior to 2018, meaning the data may not be well matched to the cyanobacteria or Enterococci data. However, the authors consider they provide a clear indication of the pattern of closures at Lake Tuggeranong, highlighting the frequent closures and failure to meet the expectations for recreational amenity for the lake.

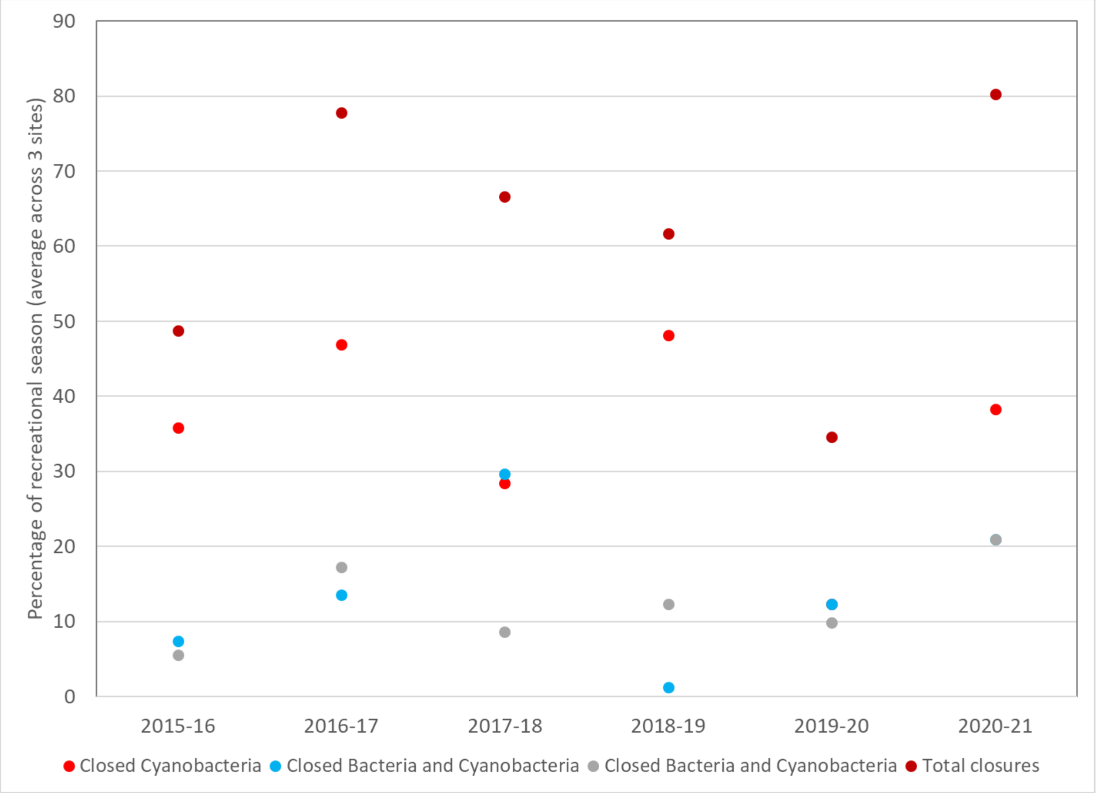

Figure 44. Proportion of the year Lake Tuggeranong was closed to recreational activities.
Data show the average closures across five monitored sites during the recreation season (October to April). Data sourced from the ACT Government.

C.4 Cyanobacteria

The concentrations of cyanobacteria in Lake Tuggeranong vary seasonally, with high concentrations occurring over the summer period (Figure 45). These data show regular extreme concentrations of cyanobacteria over the summer period, with peak concentrations occurring from mid-summer onwards, and is reflective of regular lake closures (Figure 44). The peak concentrations occur slightly earlier in the recreational season than has been observed in Lake Burley Griffin (see Figure 26). Dyer et al. 2020 noted the differences in seasonal patterns in the two lakes, suggesting this indicates there are different processes driving the algal blooms in the two lakes.

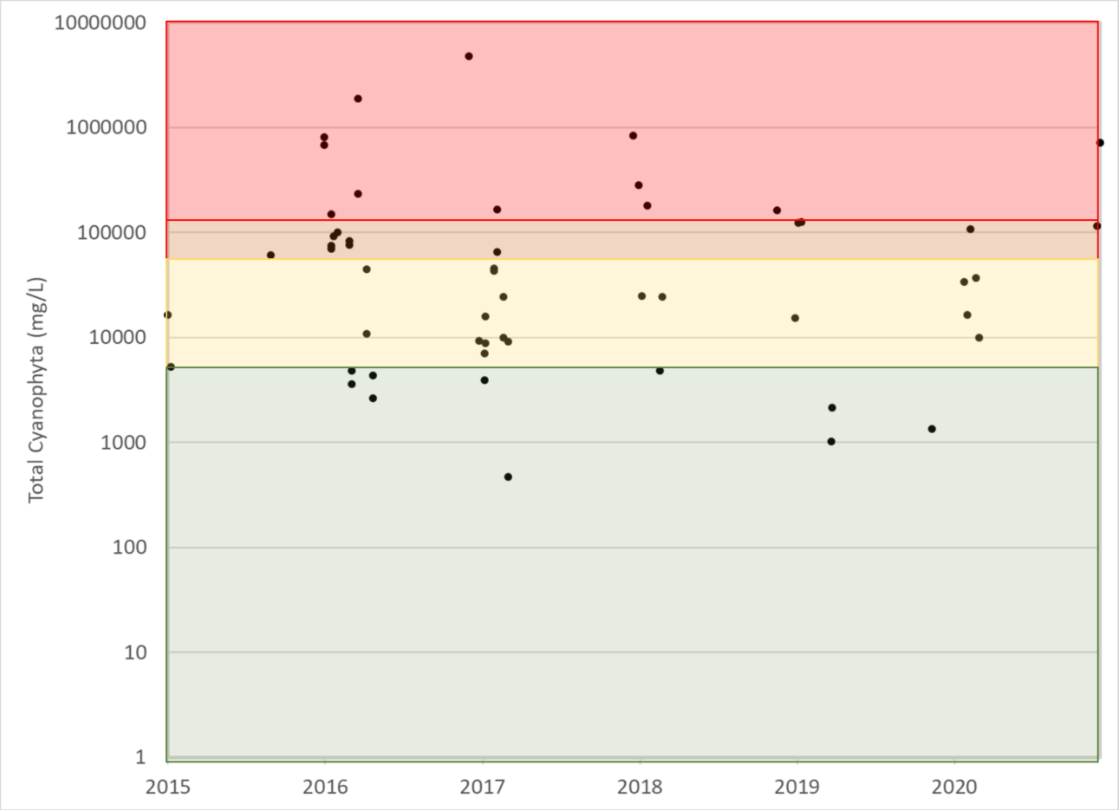

Figure 45. Cyanophyta cell counts in Lake Tuggeranong for the period January 2015 to December 2020. Data sourced from the EPA. Coloured bands behind the cell count data indicate the alert level categories (ACT Government 2014a), red = extreme, orange = high, yellow = medium, green = low.

C.5 Nutrients

ALS and Waterwatch data indicate that, during the past 10 years, slightly more than 10% of the recorded total phosphorus concentrations have been above the acceptable range of < 0.1 mg/L in the surface waters of Lake Tuggeranong (Figure 46). These concentrations are reasonably consistent with the concentrations recorded by Ubrihien et al. (2019b) between 2017 and 2019, where concentrations of total phosphorus ranged between 0.042 mg/L and 0.2 mg/L (mean TP = 0.5 mg/L).

Around 75% of the total nitrogen concentrations in the surface waters of the lake recorded by the ALS and Waterwatch have been above the acceptable range of concentrations, with some quite high concentrations recorded in the data set (Figure 47). Ubrihien et al. (2019b) recorded total nitrogen concentrations between 0.55 mg/L and 1.72 mg/L between 2017 and 2019 (mean TN = 1 mg/L), suggesting the combined ALS and Waterwatch dataset may be overestimating nitrogen concentrations.

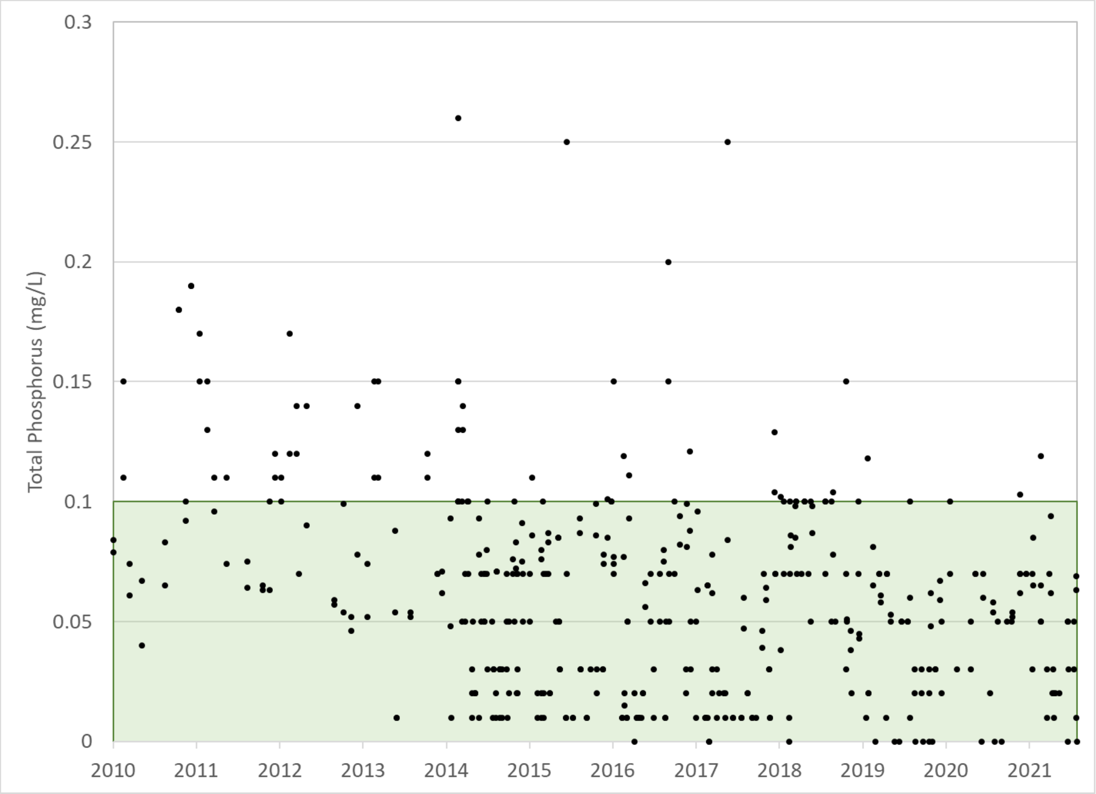

Figure 46. Total phosphorus (TP) concentrations in the surface waters of Lake Tuggeranong from 2010 to 2021. Data are combined from ALS and Waterwatch, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable concentrations of total phosphorus for urban lakes.

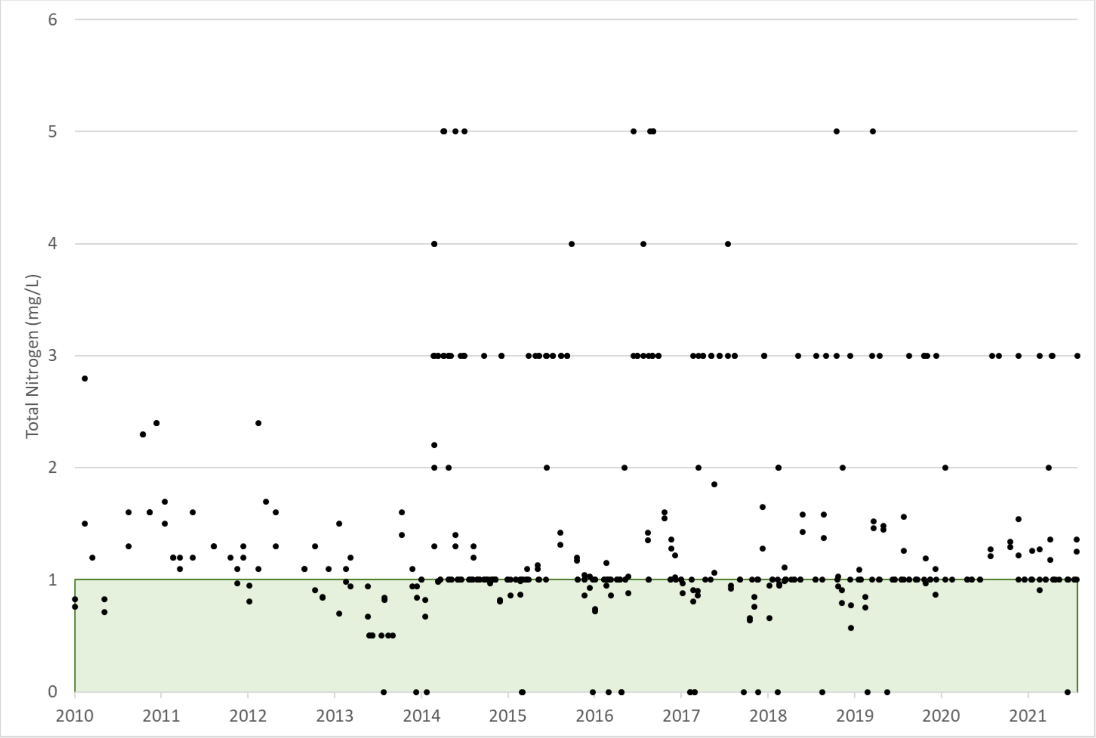

Figure 47. Nitrogen (TN) concentrations in the surface waters of Lake Tuggeranong from 2010 to 2021. Data are combined from ALS and Waterwatch, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable concentrations of total nitrogen for urban lakes.

The full data set is not suited to long term analyses because of the different data involved (data prior to 2014 does not include the Waterwatch data due to a change in sampling kits used). Average total phosphorus and total nitrogen concentrations in the surface waters of Lake Tuggeranong have been reasonably consistent since 2014 (Figure 48 and Figure 49).

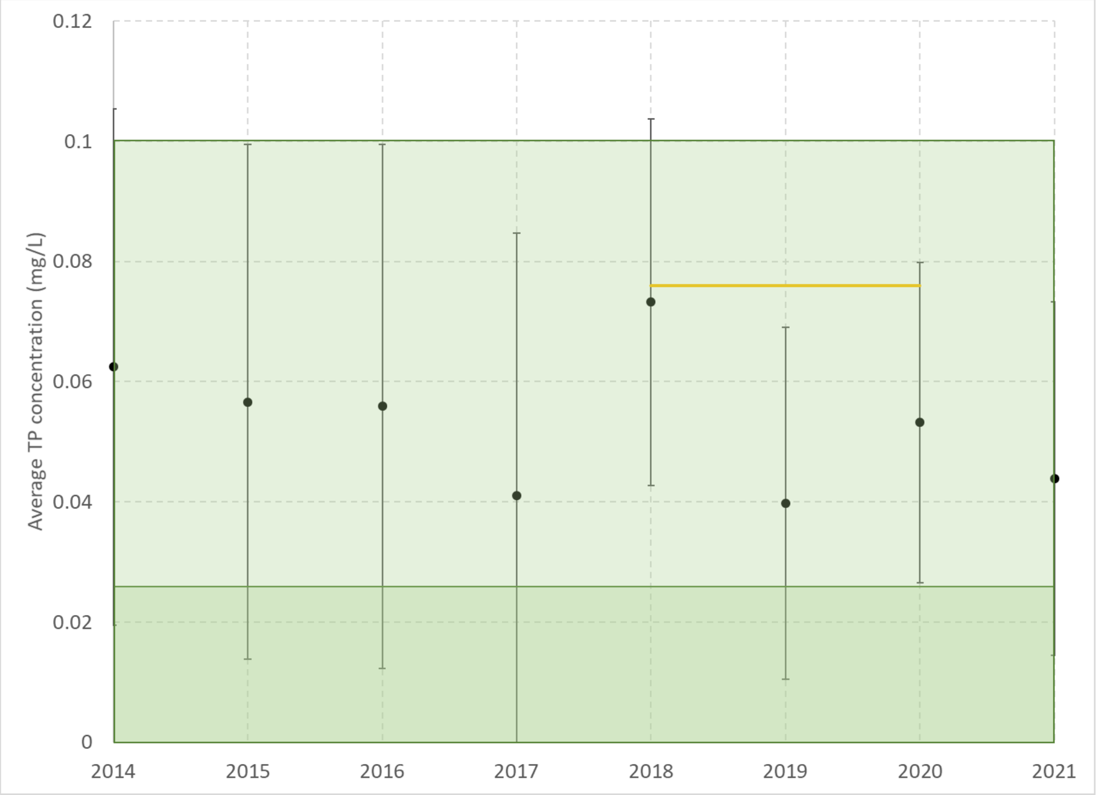

Figure 48. Annual mean total phosphorus (TP) concentrations in the surface waters of Lake Tuggeranong from 2010 to 2021.

Data are averages of ALS and Waterwatch data, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for total phosphorus. The darker green shading shows the concentrations that are expected to limit the formation of cyanobacterial blooms. The yellow bar represents the mean total phosphorus concentrations in the surface water of the lake recorded between 2018 and 2020 by Ubrihien et al. (2020). Error bars represent the standard deviation.

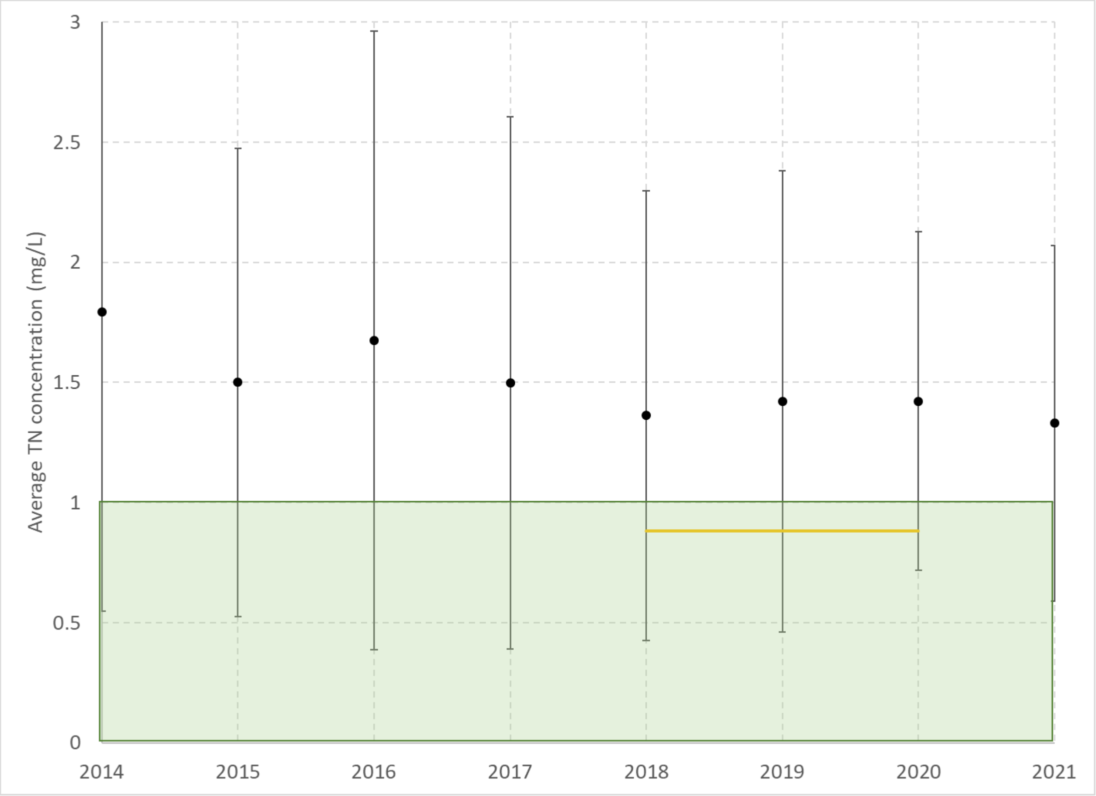

Figure 49. Annual mean total nitrogen (TN) concentrations in the surface waters of Lake Tuggeranong from 2010 to 2021.

Data are averages of ALS and Waterwatch, noting the data from 2021 are incomplete at the time of writing. The yellow bar represents the mean total nitrogen concentrations in the surface water of the lake recorded between 2018 and 2020 by Ubrihien et al. (2020). Error bars represent the standard deviation.

C.6 Dissolved oxygen

Dissolved oxygen concentrations in the surface waters are generally well above levels of concern, ranging between 7 and 9 mg/L (Figure 50), with around 5% of readings where concentrations were below acceptable levels (4mg/L). Concentrations in the bottom waters are lower and are consistent with those of lakes that stratify over summer (data not shown).

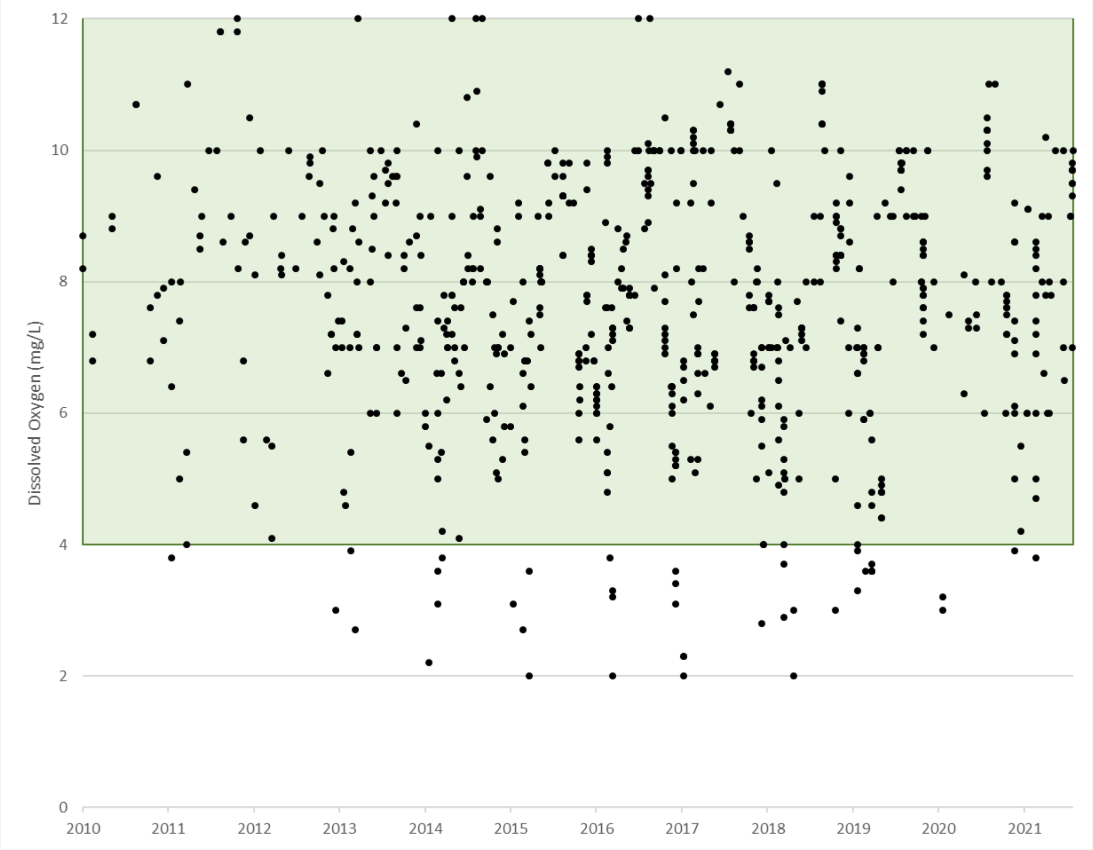

Figure 50. Dissolved oxygen concentrations (mg/L) in the surface waters of Lake Tuggeranong (0–2m) from 2010 to 2021.

Data are combined from ALS and Waterwatch. The green band shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005.

C.7 Turbidity

Turbidity levels are generally within the acceptable range, with only 13% of records above the acceptable range for ACT lakes (Figure 51 and Figure 52). The data are not suited to detecting if there is an improvement along the lake.

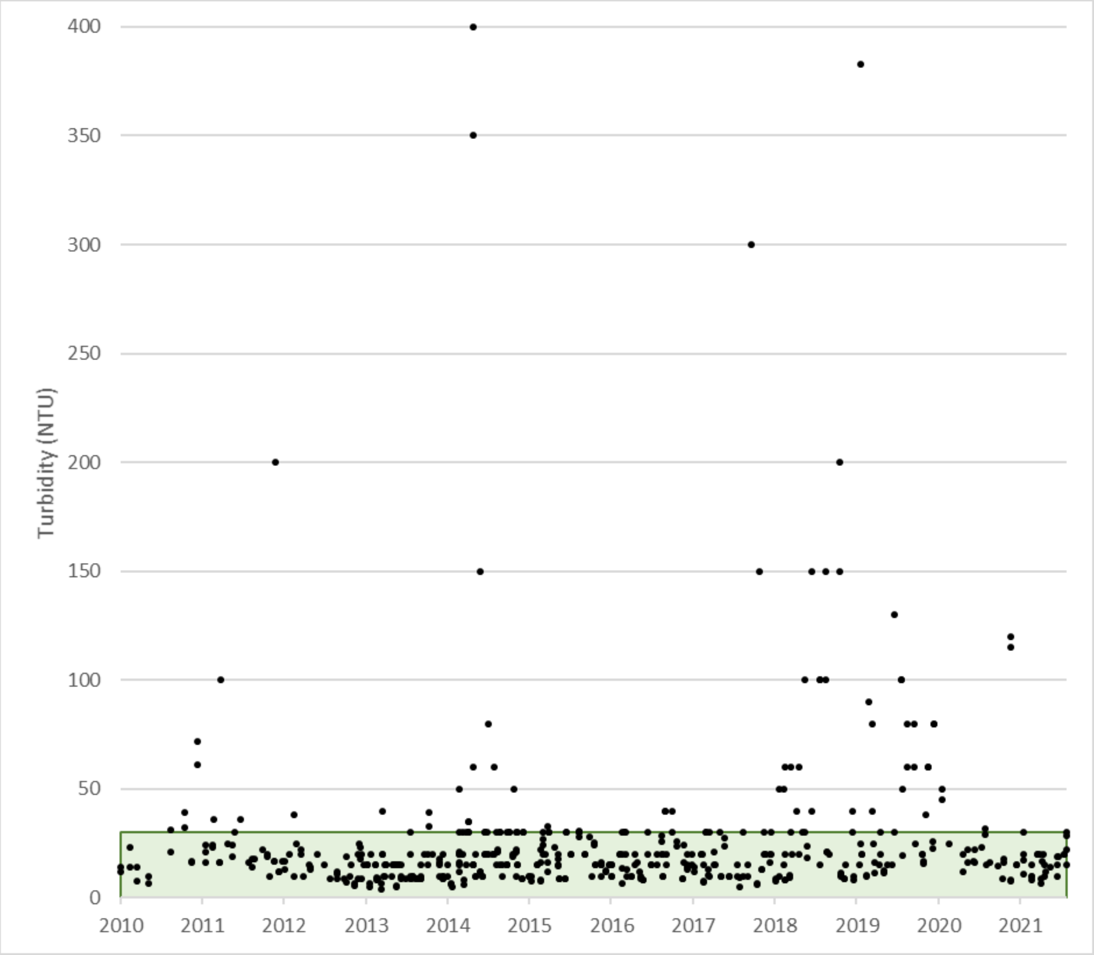

Figure 51. Turbidity in the surface waters of Lake Tuggeranong from 2010 to 2021.
Data are combined from ALS and Waterwatch, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity as specified in the Environment Protection Regulation 2005.

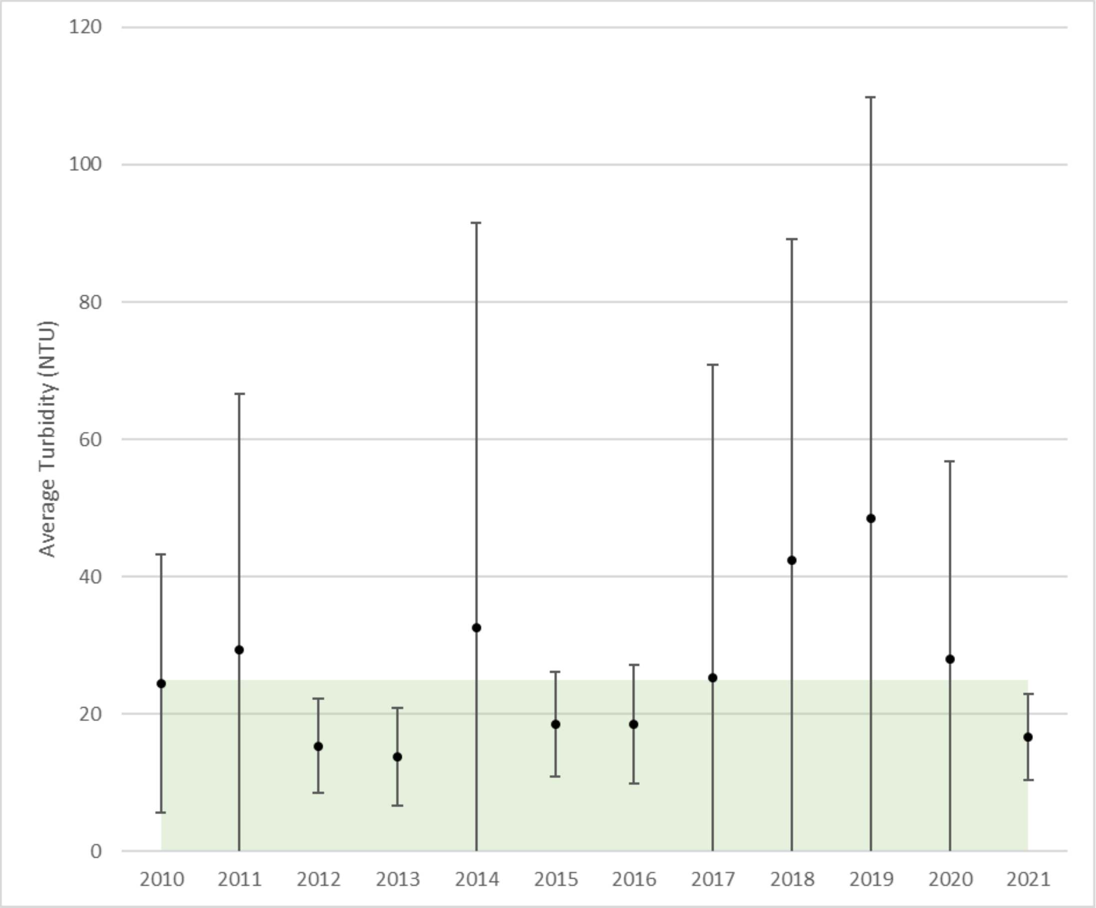

Figure 52. Annual mean turbidity (NTU) in the surface waters of Lake Tuggeranong from 2010 to 2021. Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity as specified in the Environment Protection Regulation 2005. Error bars represent the standard deviation.

C.8 pH

The lake pH is consistently within the acceptable range (Figure 53), with only 4% of data above the upper limit of 8.5 and 1%of data below 6.

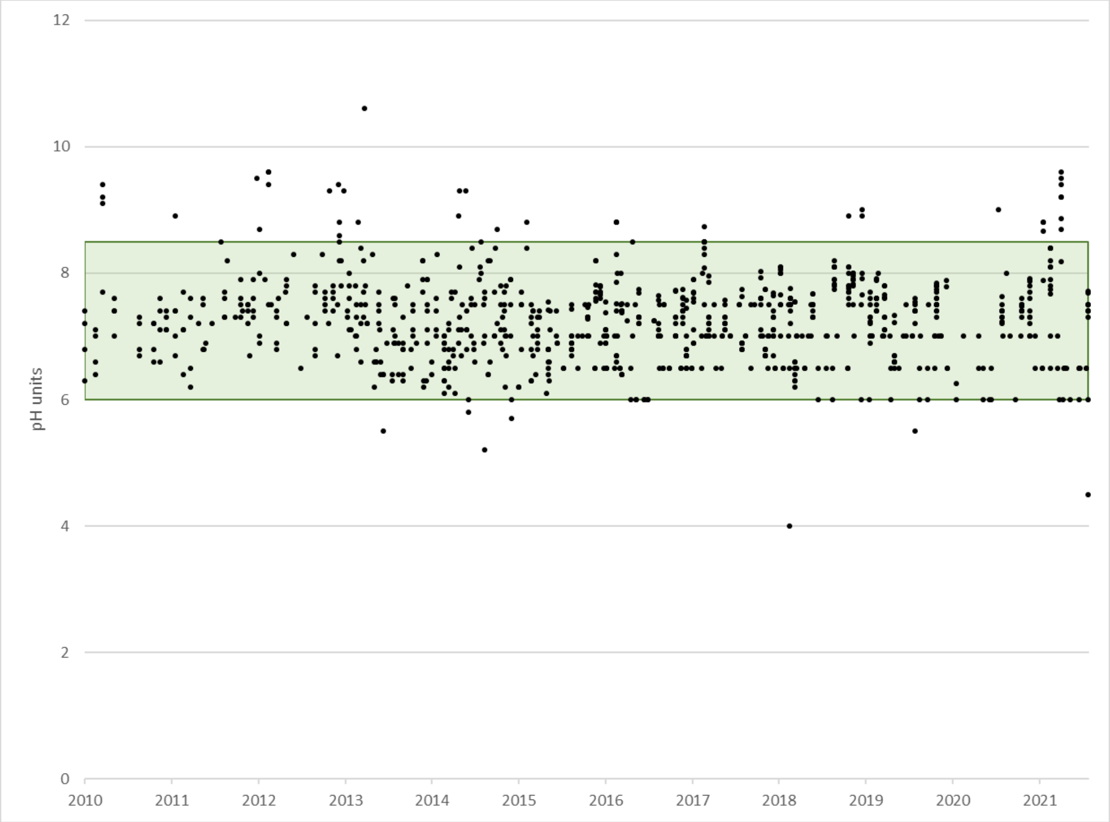

Figure 53. The pH in the surface waters of Lake Tuggeranong from 2010 to 2021.
Data are combined from ALS and Waterwatch, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH as specified in the Environment Protection Regulation 2005.

C.9 Conductivity

Conductivity within the surface waters of the lake is almost always within the acceptable range, with extremely rare instances of values exceeding 350 µS/cm (Figure 54 and Figure 55).

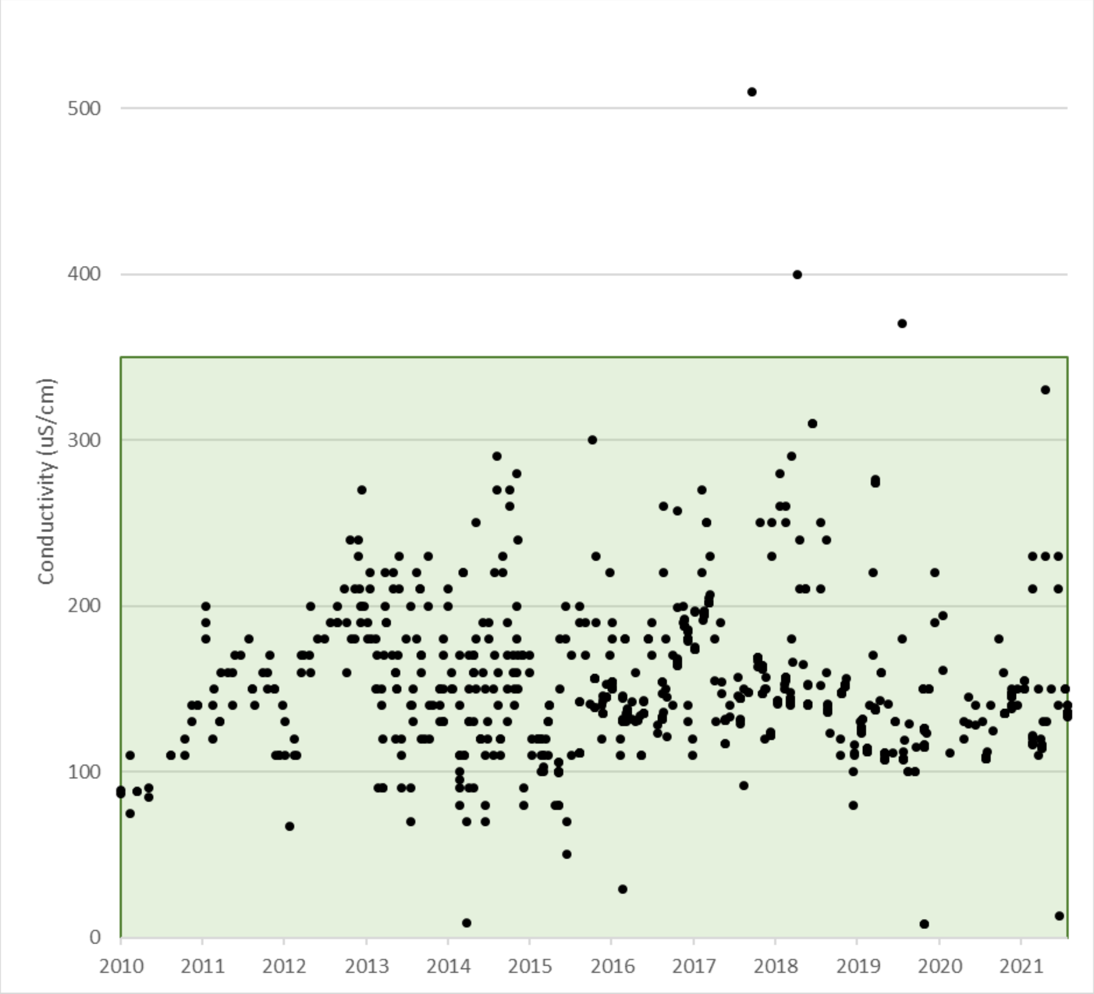

Figure 54. Conductivity of the surface waters of Lake Tuggeranong from 2010 to 2021.
Data are combined from ALS and Waterwatch, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for conductivity as specified ANZECC & ARMCANZ (2000) default guidelines.

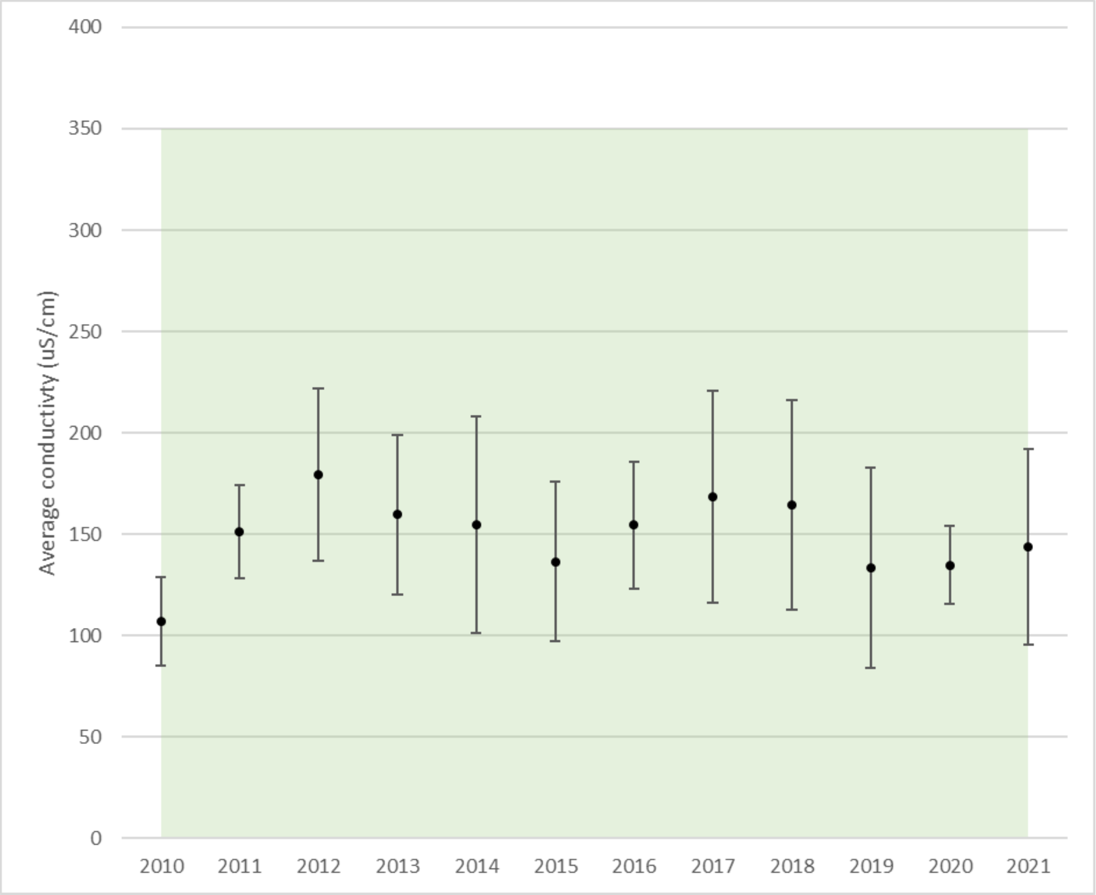

Figure 55. Annual mean conductivity of the surface waters of Lake Tuggeranong from 2010 to 2021. Data are averages from all sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for conductivity as specified ANZECC & ARMCANZ (2000) default guidelines. Error bars represent the standard deviation.

C.10 Water quality analyses: inflows to and outflows from Lake Tuggeranong

Waterwatch nutrient concentrations suggest concentrations of phosphorus and nitrogen are often higher at the downstream Tuggeranong Creek monitoring site and within the lake, compared with those recorded in the upstream Tuggeranong Creek sites (Figure 56 and Figure 57). The total phosphorus concentrations recorded in Tuggeranong Creek by Waterwatch are similar to the baseflow concentrations recorded in the more detailed study of Ubrihien et al. (2020) (Figure 56), whereas the nitrate concentrations differ (Figure 57). It is worth noting Ubrihien et al. (2020) found that concentrations of nutrients from the Tuggeranong Creek inflows were lower than those from most other inflows to the lake and substantially lower than those recorded in storm events (for further commentary, refer to Appendix I).

Turbidity data would suggest the turbidity in the lake is often greater than that recorded in the upstream and downstream sites in Tuggeranong Creek (Figure 58). This is not surprising given the data from Tuggeranong Creek is biased toward low flows, when the water is generally clear.

As such, the data are not well suited to evaluating the water quality mitigation performance of Lake Tuggeranong over the past 10 years.

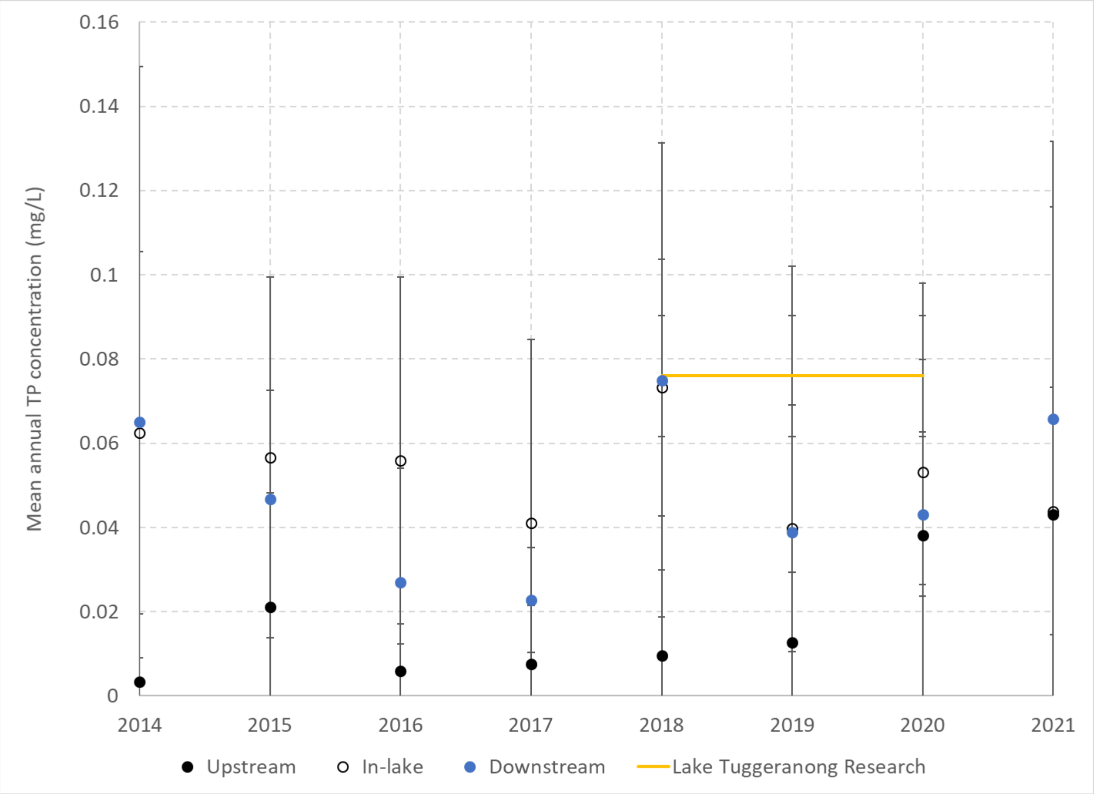

Figure 56. Annual mean total phosphorus (TP) concentrations in the inflows to and outflows from Lake Tuggeranong from Tuggeranong Creek, as well as the mean annual total phosphorus concentration in the lake from 2014 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. The yellow bar represents the mean total phosphorus concentrations in the surface water of the lake recorded between 2018 and 2020 by Ubrihien et al. (2020). Error bars represent the standard deviation.

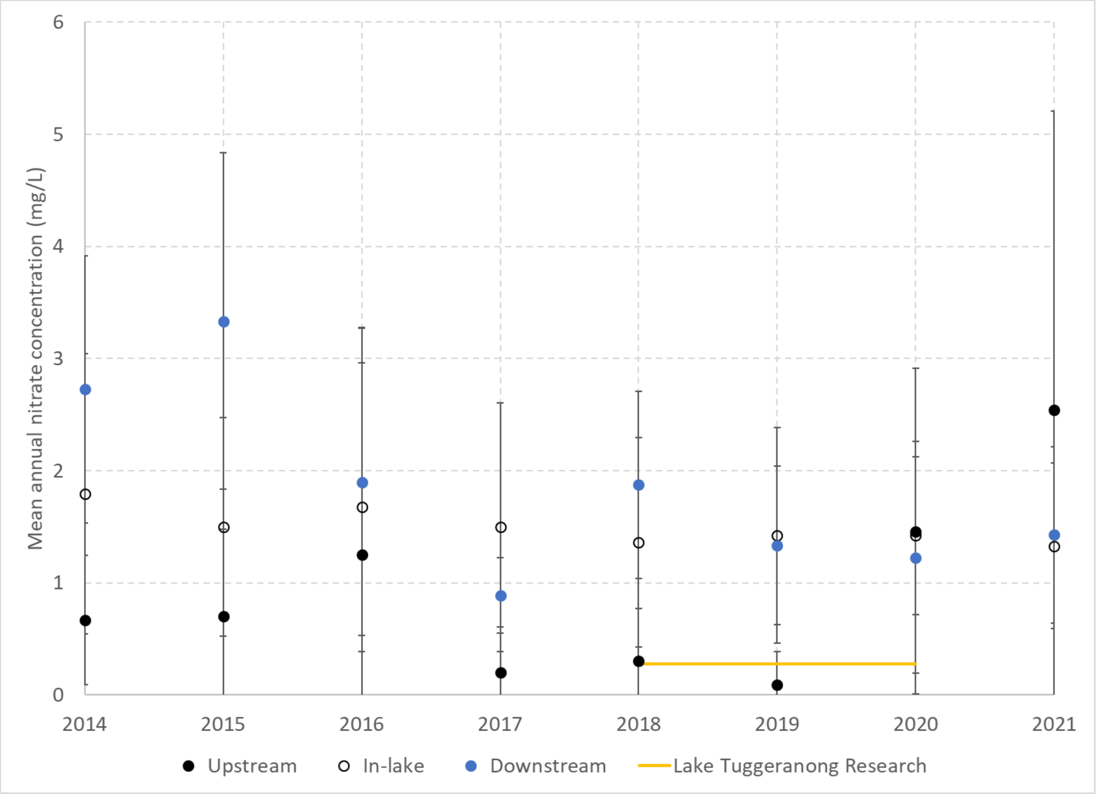

Figure 57. Annual mean nitrate concentrations in the inflows to and outflows from Lake Tuggeranong from Tuggeranong Creek, as well as the mean annual nitrate concentration in the lake from 2014 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. The yellow bar represents the mean total phosphorus concentrations in the surface water of the lake recorded between 2018 and 2020 by Ubrihien et al. (2020). Error bars represent the standard deviation.

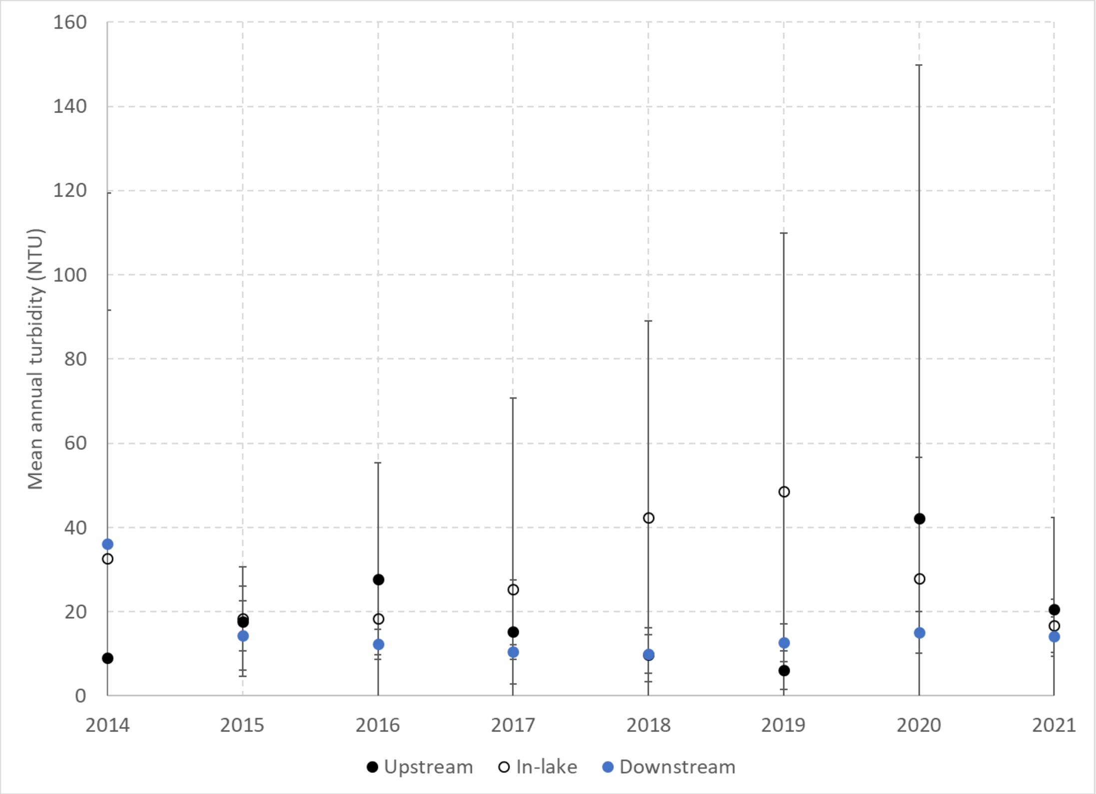

Figure 58. Annual mean turbidity in the inflows to and outflows from Lake Tuggeranong from Tuggeranong Creek, as well as the mean annual turbidity in the lake.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

C.11 Ecological values

There are little data available that would allow trends in the broader ecological values of Lake Tuggeranong to be determined.

C.12 Riparian condition

The shoreline of Lake Tuggeranong is managed urban parklands with mown grass to the edge of much of the lake. There are few riparian trees, and the condition of the area is defined by the level of management effort. Like the parklands surrounding other lakes, the lake shore zone is subject to the pressures of human activities that introduce rubbish and other pollutants and exotic and invasive plants, as well as create informal pathways among the riparian vegetation. The Rapid Appraisal of the Riparian Condition (RARC) score used by Waterwatch has identified the condition of the vegetation was considered *poor* to *degraded*. However, this is not a fair evaluation of the riparian vegetation in such managed environments, and to better understand the shores of Lake Tuggeranong requires the development of a set of clear expectations.

D. Lake Ginninderra Technical Appendices

D.1 Document review: Lake Ginninderra water quality history

Lake Ginninderra has received far less attention than the other major lakes in Canberra and publications that are related to the lake are in short supply. Not long after the lake filled, Cullen et al. (1978) provided a report to the National Capital Development Commission on the lake's water quality. At that stage, only 17% of the catchment was urbanised (it is now 46%), but the lake was considered to be eutrophic on the basis of algal species and phosphorus concentrations. The lake displayed excess algal and macrophyte growth, litter and high levels of faecal coliform bacteria that were contributing to the lake failing to meet specific performance standards at certain times of the year.

D.2 Water quality data analysis: Lake Ginninderra 2010–2021

ALS and Waterwatch data for Lake Ginninderra from 2011–2021 was used to develop time series water quality data for this period. EPA cyanobacteria data was used to develop time series biological data for the same period. Lake closure information from Transport Canberra and City Services (TCCS) for 2015–2021 were compiled and reported.

D.3 Lake closures

Lake Ginninderra water quality is monitored over the duration of the year and the lake closed to recreational use if either cyanobacteria or Enterococci concentrations exceed thresholds of concern (Figure 59). The lake is typically open to recreation for more than 70% of the recreational season, with exceptions in 2016–17 and 2017–18 when it was closed for around 60% of the recreational season. High Enterococci bacteria and high cyanobacteria concentrations have contributed almost equally to the closures of Lake Ginninderra, which contrasts with the closures at Lake Tuggeranong, which are predominantly caused by high cyanobacteria concentrations. Anecdotally, the beaches that are sampled as part of the water quality monitoring at Lake Ginninderra are known to be key congregation points for ducks and other waterbirds and this has been implicated in the high Enterococci levels. To the author's knowledge there has been no investigation into this.

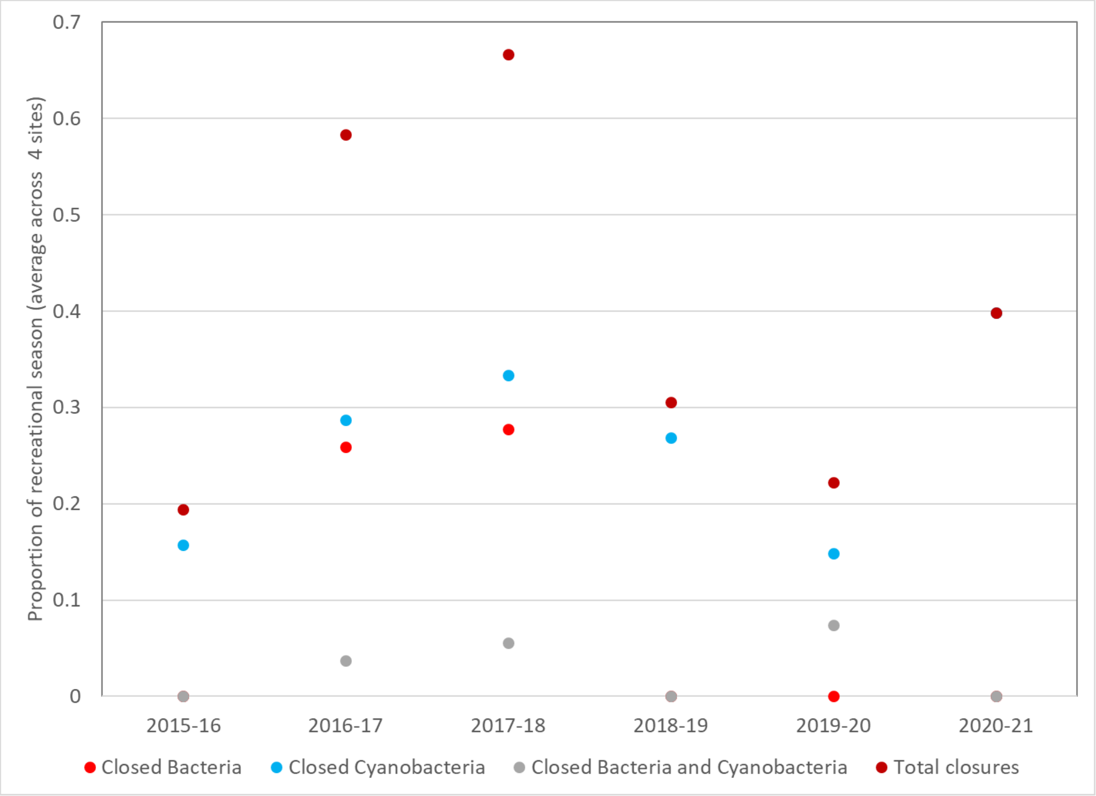

Figure 59. Proportion of the recreation season that Lake Ginninderra was closed to recreational activities. Data show the average closures across four monitored sites during the recreational season (October to April). Data sourced from the ACT Government.

D.4 Cyanobacteria

The concentrations of cyanobacteria cells in Lake Ginninderra are generally low, but they do vary seasonally with higher concentrations recorded in late summer and into autumn. The cell counts generally remain under < 20,000 cells/mL, with extreme values recorded in 2017 (Figure 60). Data are missing for 2015.

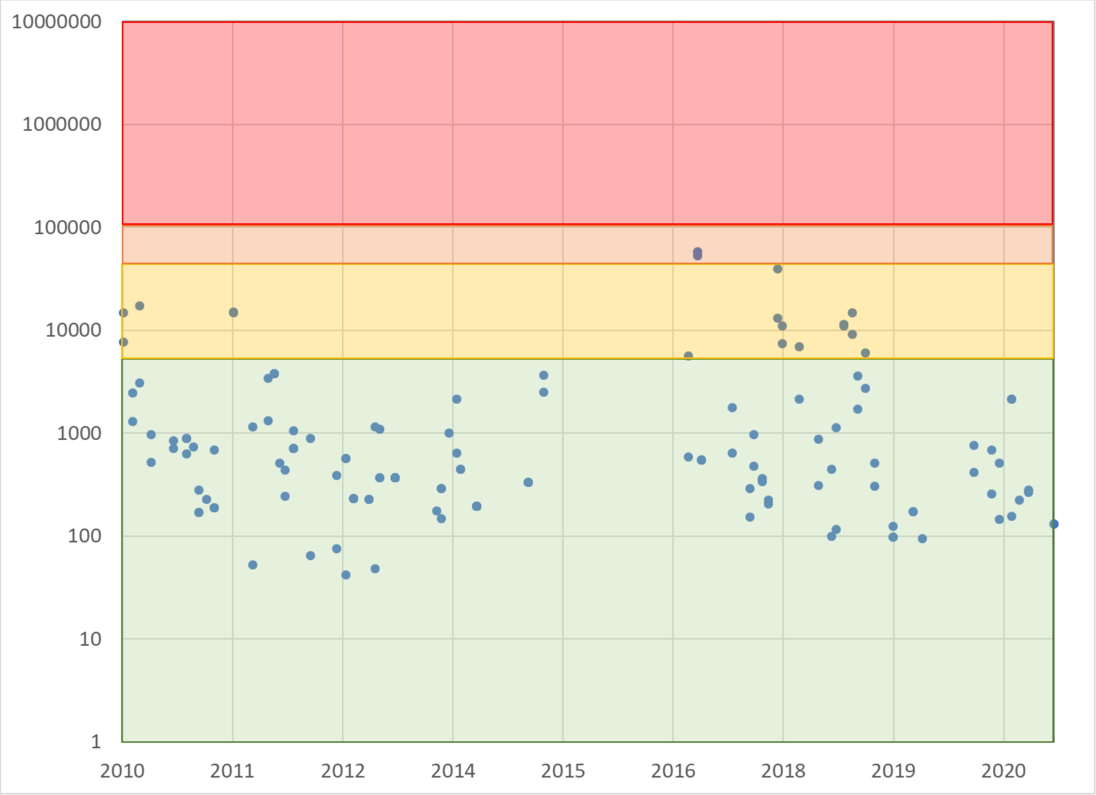

Figure 60. Cyanophyta cell counts in Lake Ginninderra for the period January 2010 to May 2021 (black dots) and estimated annual inflows (calendar year) into the lake (grey bars).

Coloured bands behind the cell count data indicate the alert level categories (ACT Government 2014a), red = extreme, orange = high, yellow = medium, green = low. No data exists for the 2015 calendar year.

D.5 Nutrients

Almost all recorded total nutrient concentrations for Lake Ginninderra during the past 10 years have been within the acceptable range of concentrations (Figure 61 and Figure 62), with a single data point recorded in 2014 giving a rare high concentration of total phosphorus and occasional high concentrations of total nitrogen evident throughout the record. Only 23% of total phosphorus records have been above 0.025 mg/L. Concentrations below 0.025 mg/L are thought to limit the growth of cyanobacteria, and this is likely to be the reason for the lower incidence of algal blooms in Lake Ginninderra compared with the other urban lakes in Canberra.

Average concentrations of total phosphorus and nitrogen in the surface waters of Lake Ginninderra have been relatively consistent over time (Figure 63 and Figure 64). Notably, the concentrations of phosphorus are generally below the levels at which algal blooms are expected to occur, and this is consistent with fewer incidences of algal blooms on Lake Ginninderra compared with the other Canberra lakes. Protection of these low phosphorus concentrations in Lake Ginninderra should be an imperative.

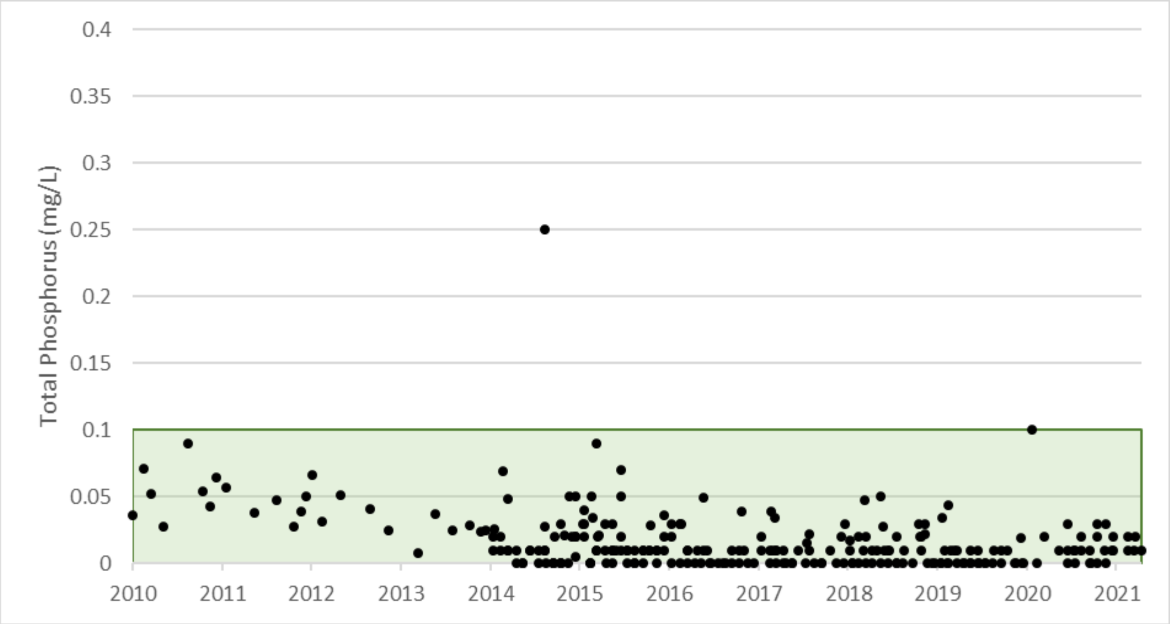

Figure 61. Total phosphorus (TP) concentrations in the surface waters of Lake Ginninderra from 2010 to 2021. Data are from two sites (LGN318 and LGN321) for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for total phosphorus specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3).

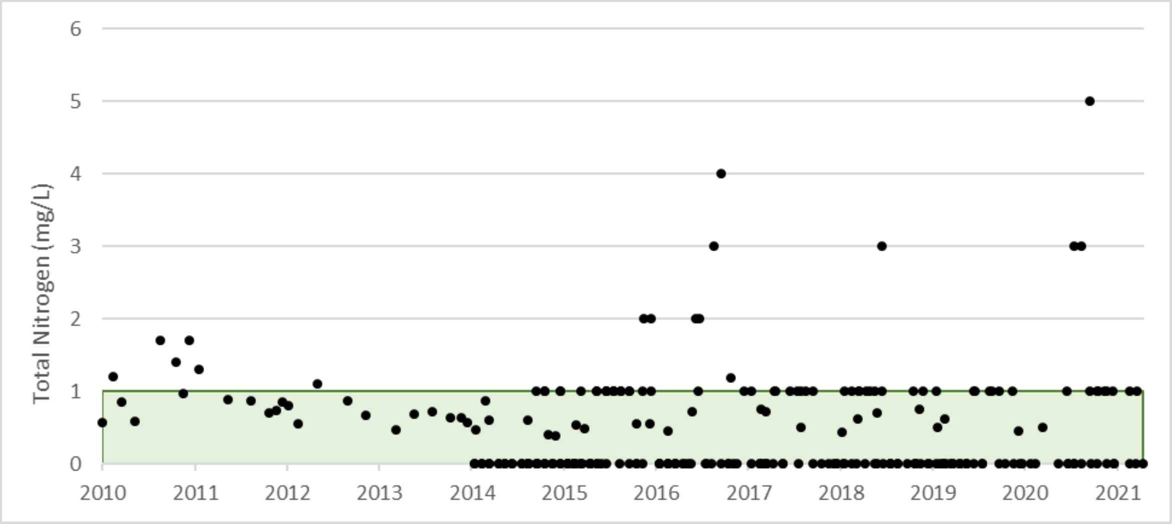

Figure 62. Total nitrogen (TN) concentrations in the surface waters of Lake Ginninderra from 2010 to 2021. Data are averages of two sites (LGN318 at the dam wall and LGN321 at the naval station), noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable concentrations as specified in the specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3).

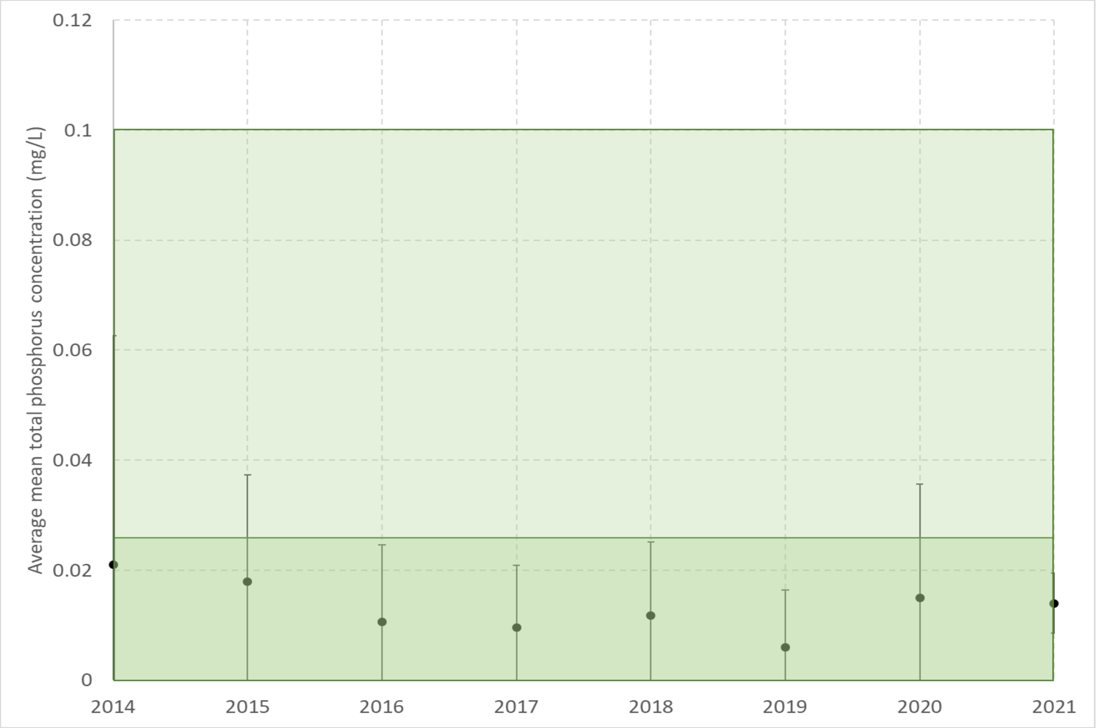

Figure 63. Annual mean total phosphorus (TP) concentrations in the surface waters of Lake Ginninderra from 2010 to 2021.

Data are averages from two sites (LGN318 at the dam wall and LGN321 at the naval station) for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for total phosphorus specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3). The darker green shading shows the concentrations that are expected to limit the formation of cyanobacterial blooms. Error bars represent the standard deviation.

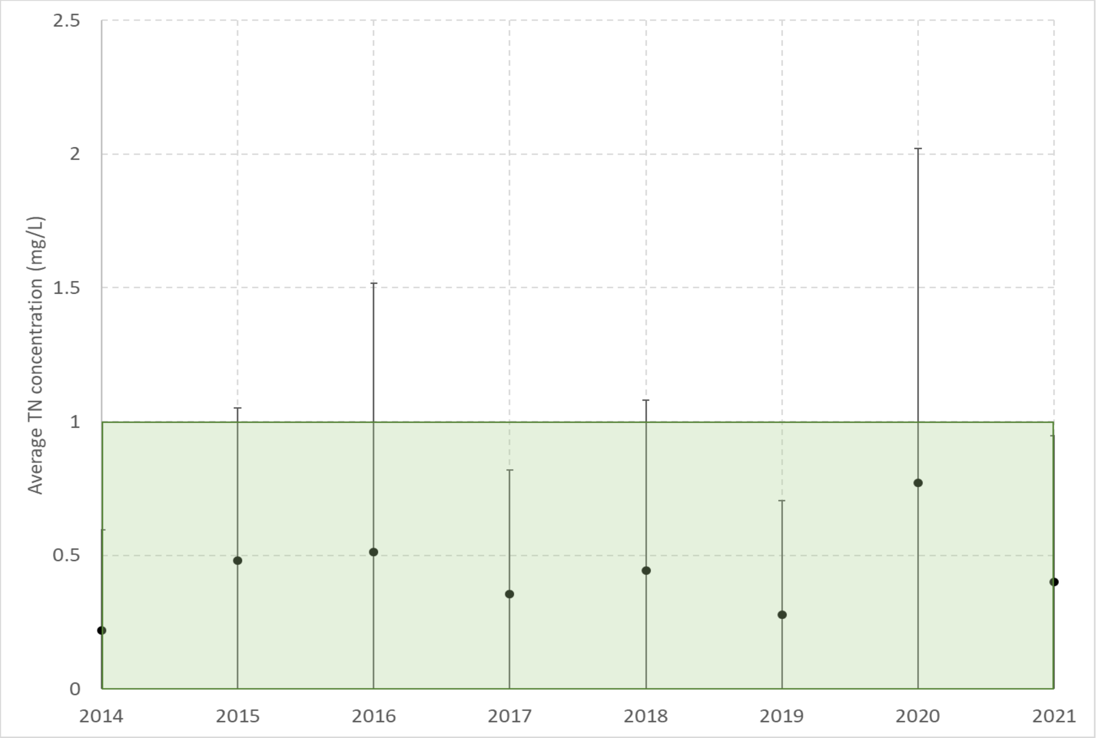

Figure 64. Annual mean total nitrogen (TN) concentrations in the surface waters of Lake Ginninderra from 2010 to 2021.

Data are averages from two sites (LGN318 at the dam wall and LGN321 at the naval station) for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

D.6 Dissolved oxygen

Dissolved oxygen concentrations in the surface waters are generally well above 4 mg/L (Figure 65), with very rare (< 1% of readings), isolated instances where concentrations were below acceptable levels. Concentrations in the bottom waters are consistent with those of lakes that stratify over summer (Figure 66).

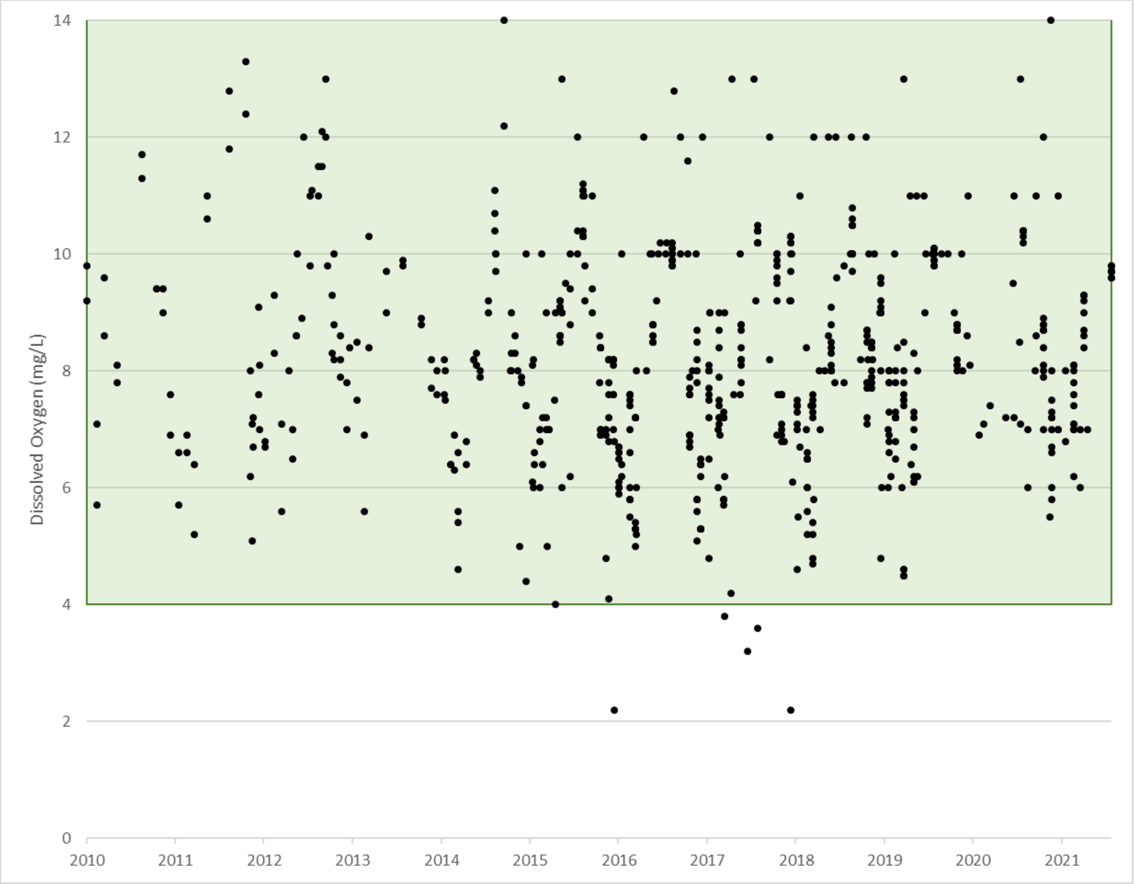

Figure 65. Dissolved oxygen concentrations (mg/L) in the surface waters (above 2m) of Lake Ginninderra from 2010 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3).

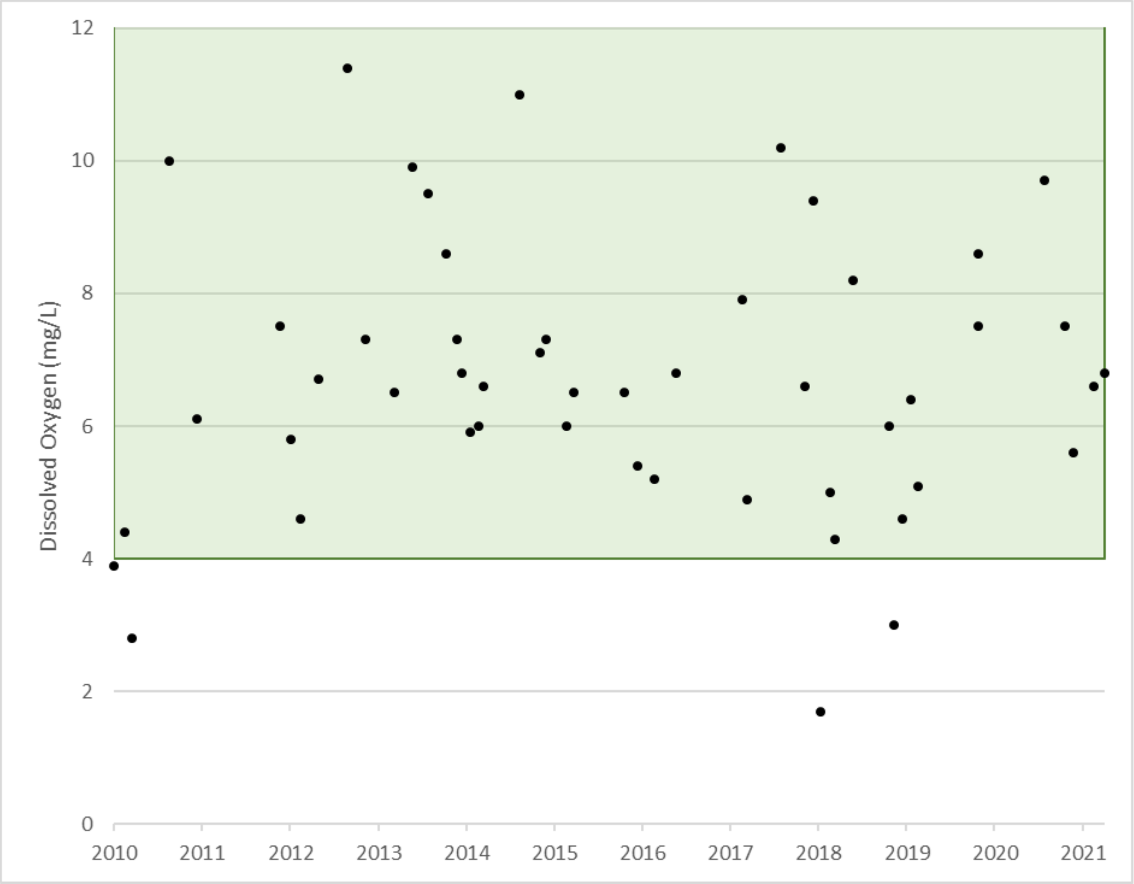

Figure 66. Dissolved oxygen concentrations (mg/L) in the bottom waters (below 2m) of Lake Ginninderra from 2010 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3).

D.7 Turbidity

Turbidity levels are within the acceptable range, with only 4% of records above the acceptable range for ACT lakes (Figure 67), and average annual turbidity levels have been consistent between 2013 and 2021 (Figure 68). The data set are not suited to detecting if there is an improvement along the lake.

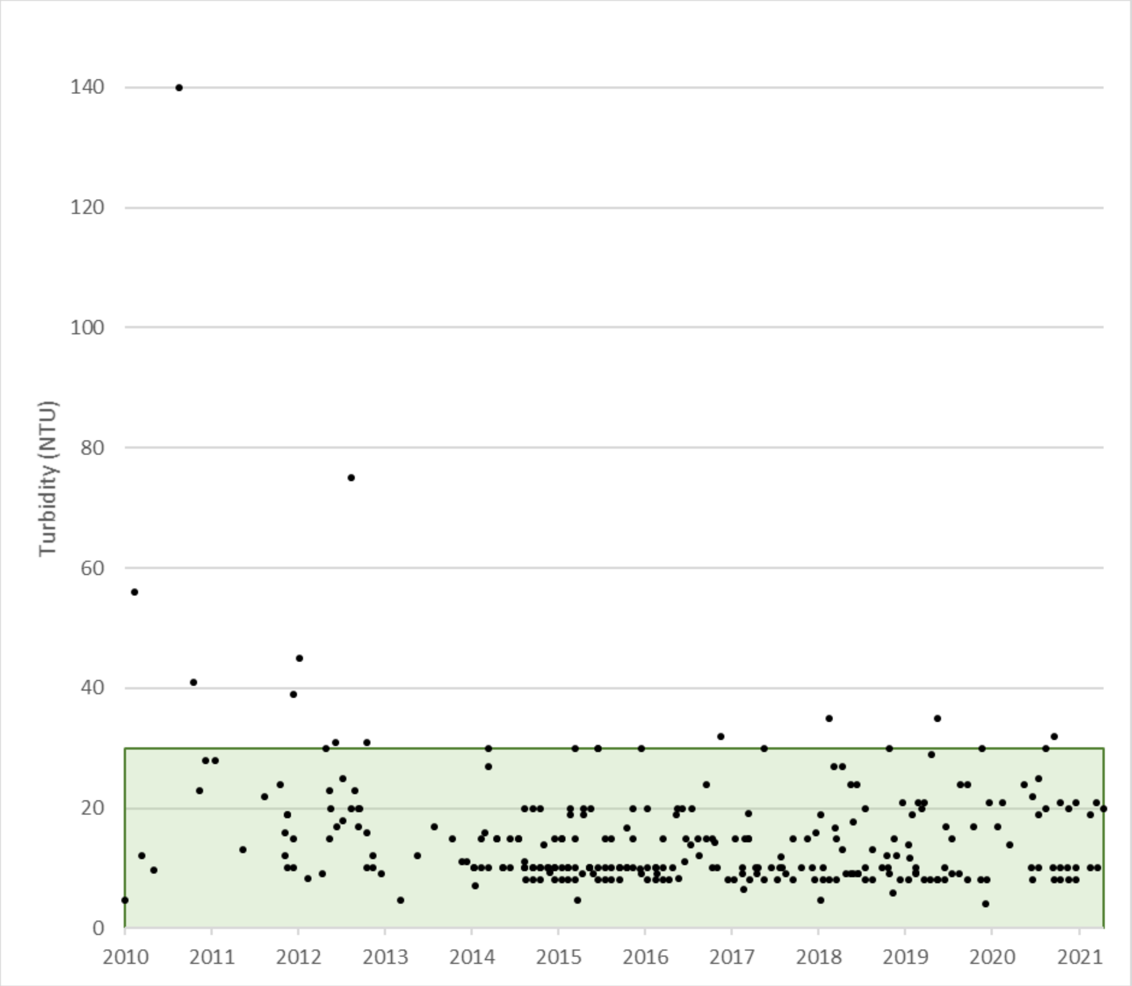

Figure 67. Turbidity in the surface waters of the Lake Ginninderra from 2010 to 2021.
Data are from two sites (LGN318 at the dam wall and LGN321 at the naval station) for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity as specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3).

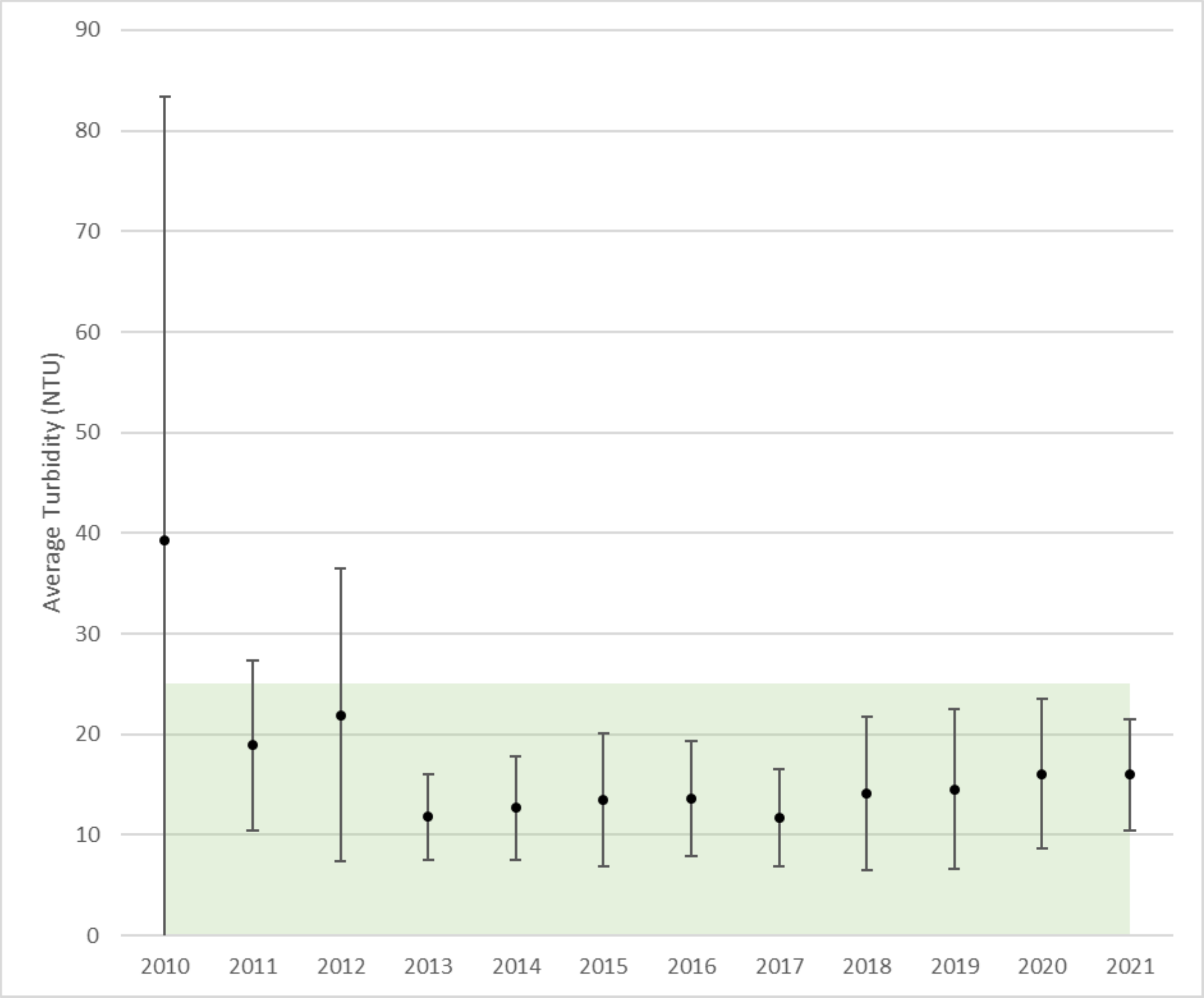

Figure 68. Annual mean turbidity (NTU) in the surface waters of Lake Ginninderra from 2010 to 2021. Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

D.8 pH

The lake pH is consistently within the acceptable range (Figure 69), with only a single data point above the upper limit of 8.5.

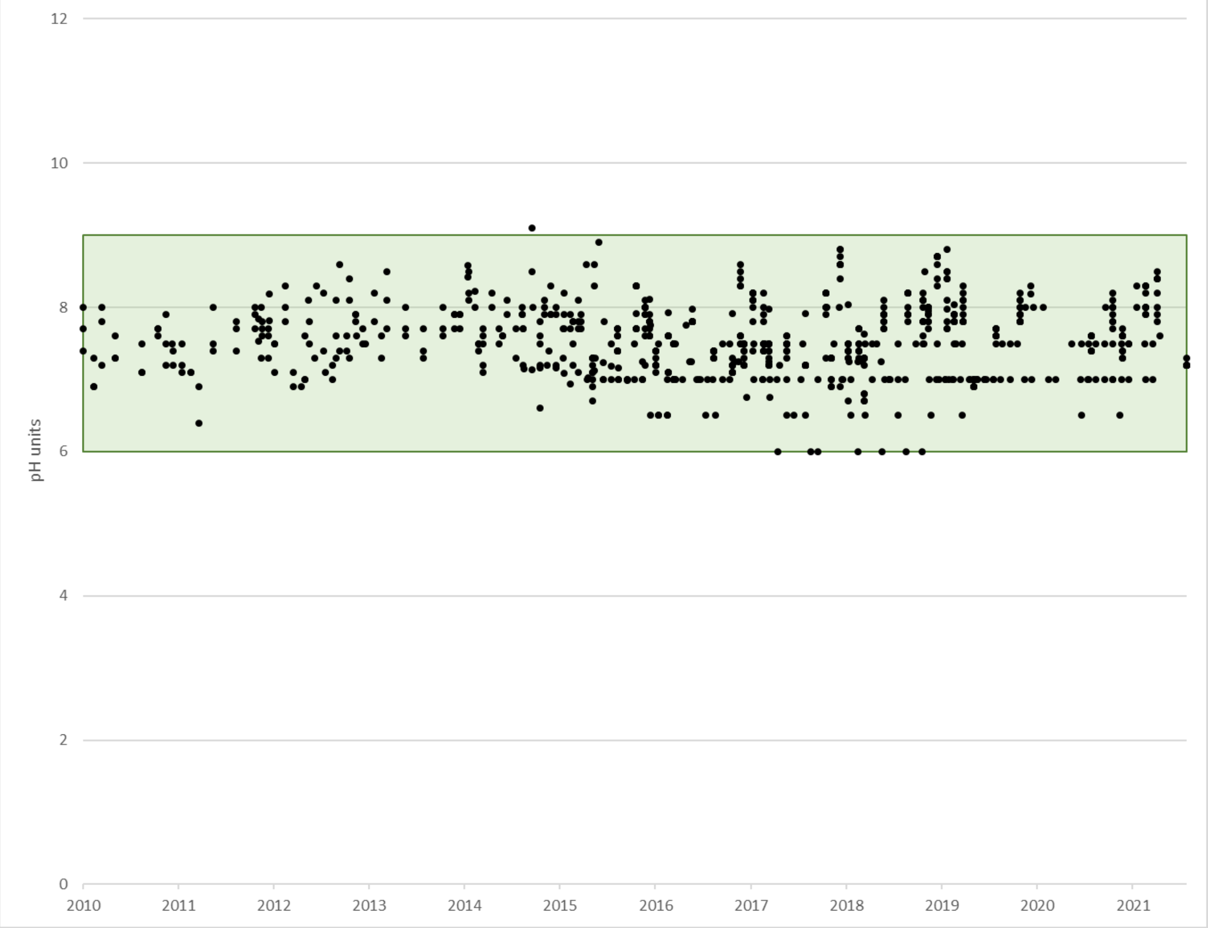

Figure 69. Annual mean pH in the surface waters of Lake Ginninderra from 2010 to 2021.

Data are averages from all sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity as specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3).

D.9 Conductivity

Conductivity within the surface waters of the lake is consistently within the acceptable range, with infrequent instances of values exceeding the acceptable range of 350 μS/cm (Figure 70 and Figure 71). The conductivity of the lake water increased slightly between 2012 and 2019, possibly because of drier conditions or possibly because of increased urban development in the upper catchment. Some quite high conductivity values were recorded in 2020, but it is not clear what may have caused this.

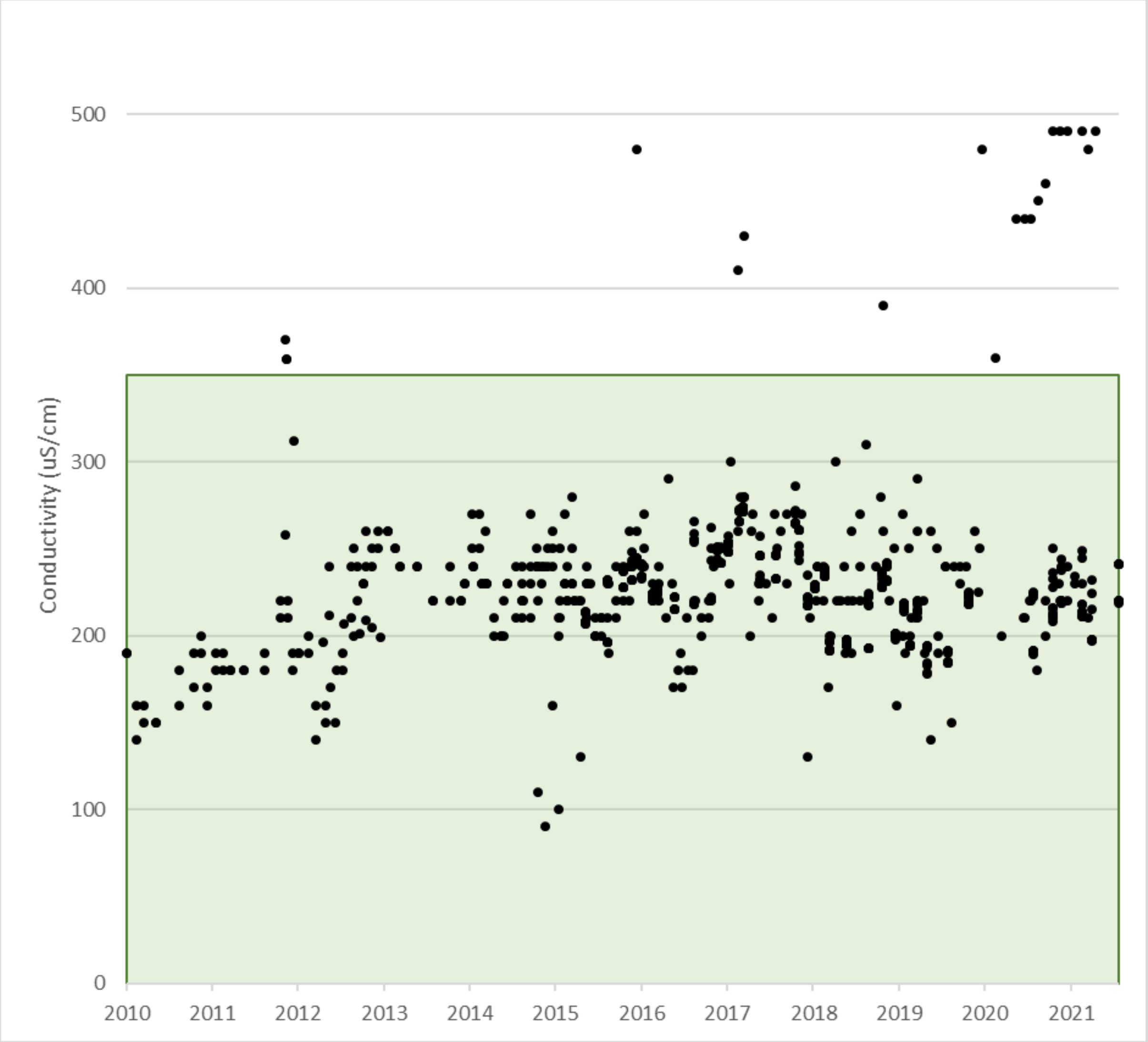

Figure 70. Conductivity of the surface waters of Lake Ginninderra from 2010 to 2021.
Data are averages from two sites (LGN318 at the dam wall and LGN321 at the naval station) for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for conductivity as specified in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3).

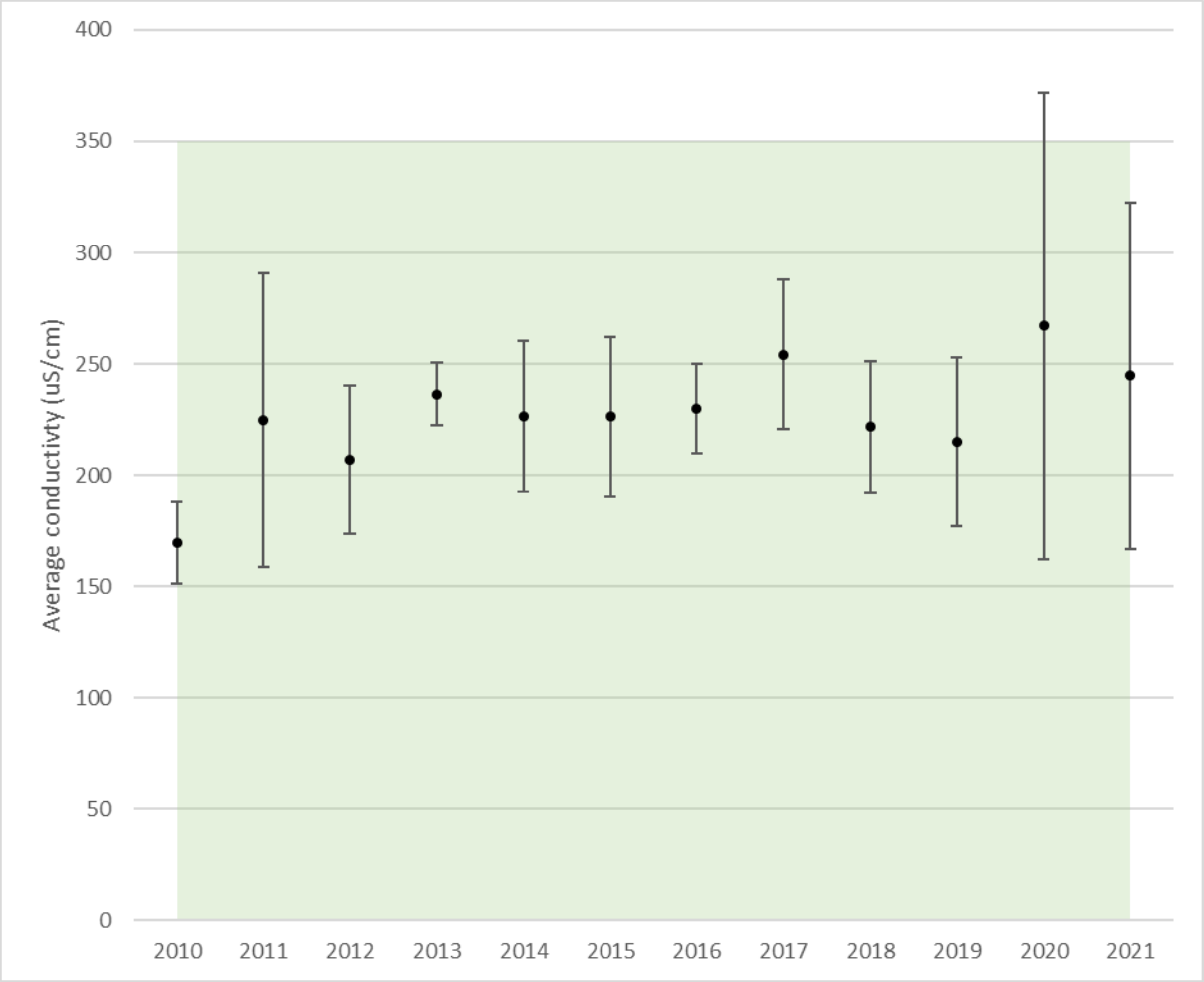

Figure 71. Mean annual conductivity of the surface waters of Lake Ginninderra from 2010 to 2021.

Data are averages from all sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. Note that all values are within the acceptable range for conductivity defined in the Environment Protection Regulation 2005 values for urban lakes and ponds (AQUA/3). Error bars represent the standard deviation.

D.10 Water quality analyses: inflows to and outflows from Lake Ginninderra

The concentrations of nutrients and the turbidity in Lake Ginninderra are similar to those recorded in Ginninderra Creek, both upstream and downstream of the lake (Figure 72, Figure 73 and Figure 74). This suggests the lake is not affecting nutrient concentrations or turbidity in Ginninderra Creek. This is not a fair evaluation of the lake's water quality mitigation performance. The samples recorded in Ginninderra Creek are typically collected under low flow conditions. From the research on Lake Tuggeranong inflows (Ubrihien et al. 2019b), it is known that the concentrations in event flows is considerably higher than during baseflows.

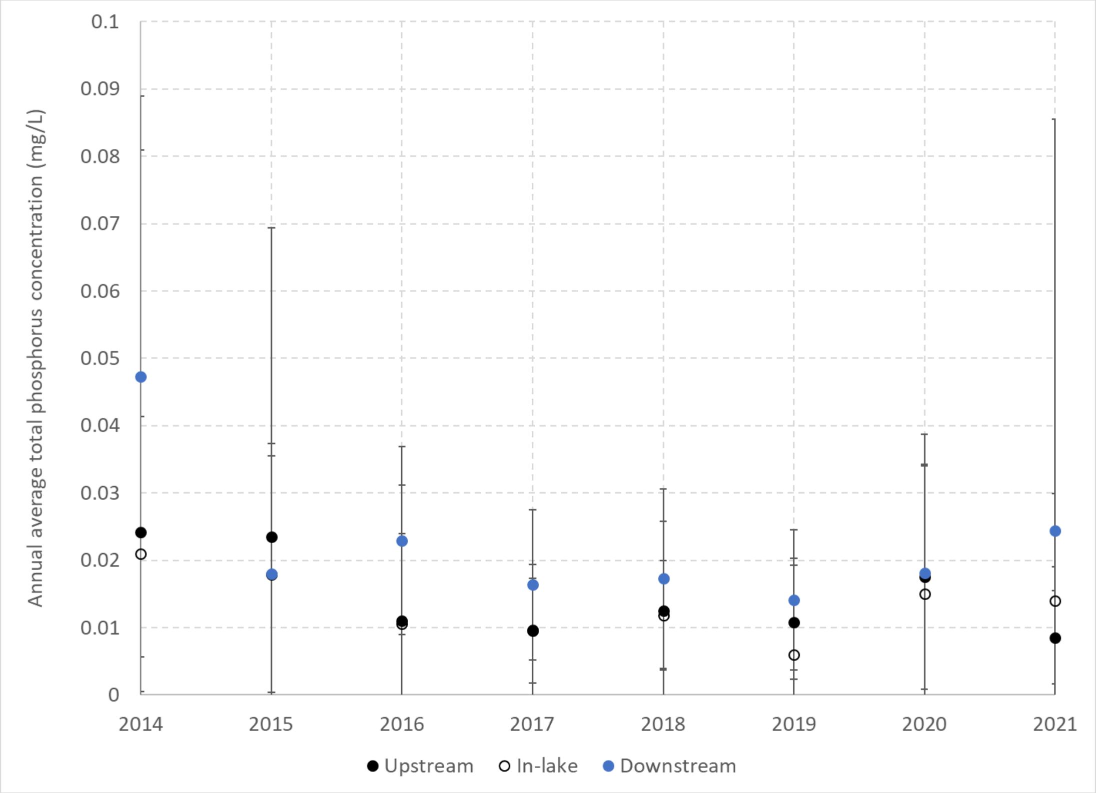

Figure 72. Annual mean total phosphorus (TP) concentrations in Ginninderra Creek upstream and downstream of Lake Ginninderra, as well as the concentrations recorded in-lake from 2014 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

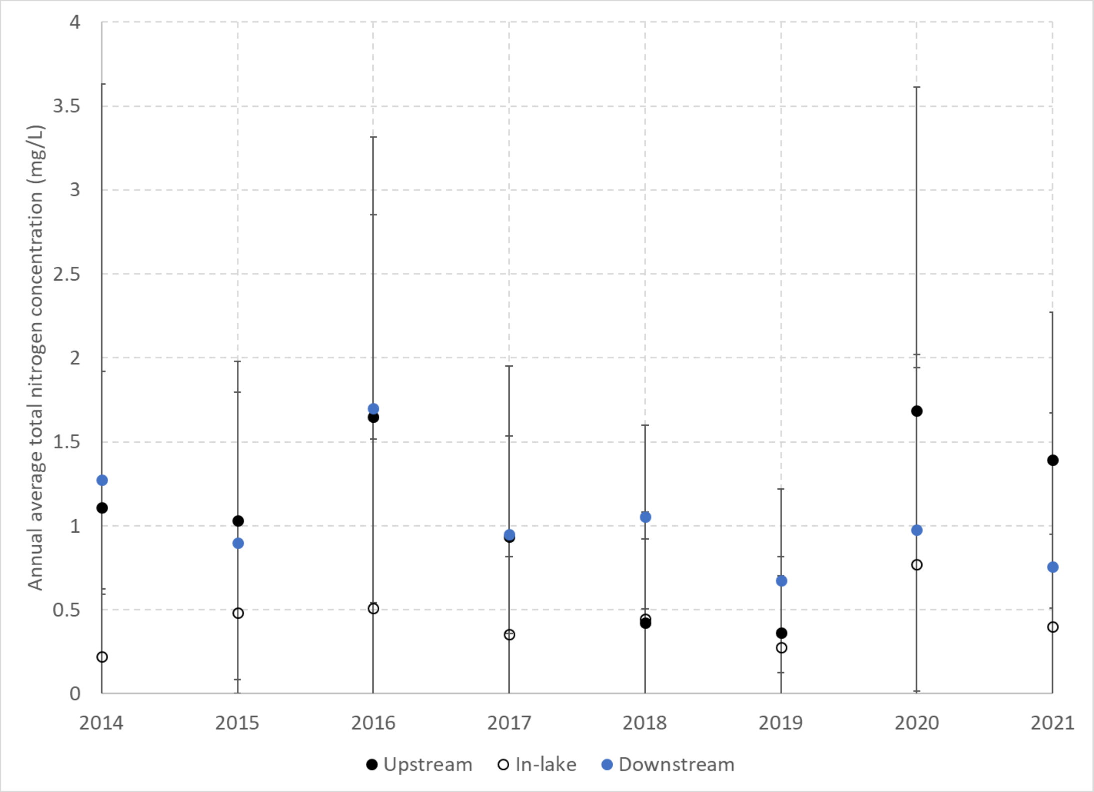

Figure 73. Annual mean total nitrogen (TN) concentrations in Ginninderra Creek upstream and downstream of Lake Ginninderra, as well as the concentrations recorded in-lake from 2014 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

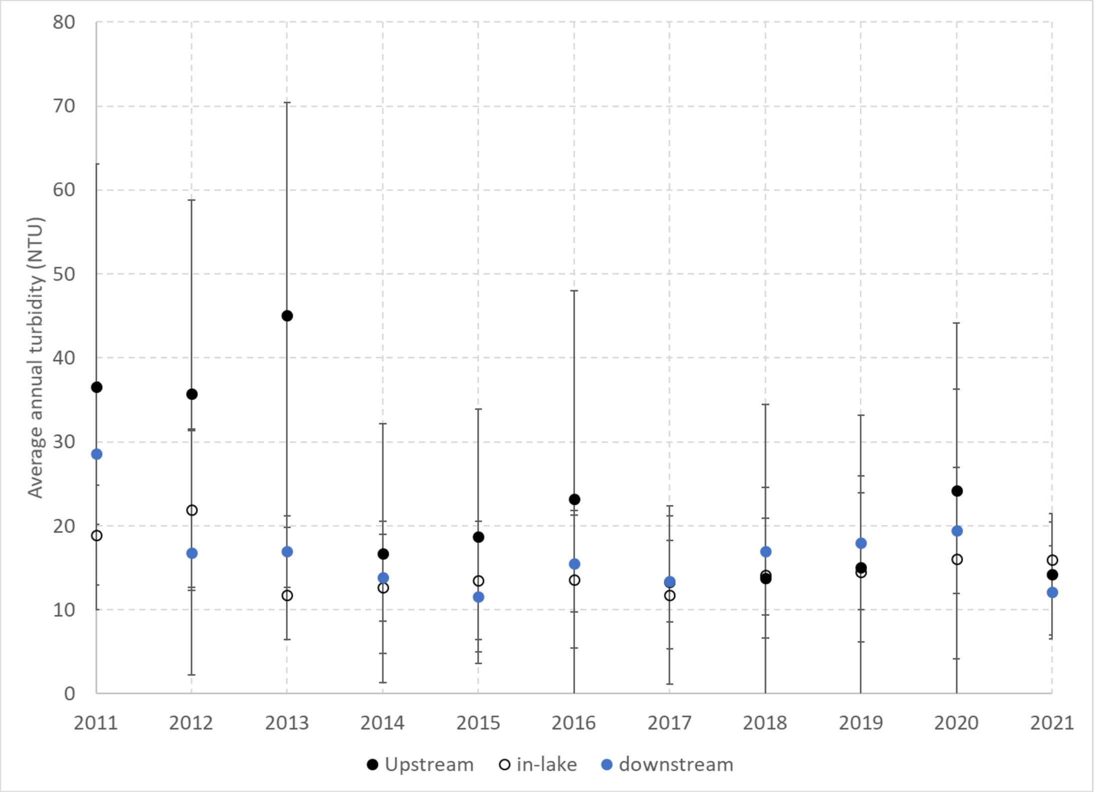

Figure 74. Annual mean turbidity in Ginninderra Creek upstream and downstream of Lake Ginninderra, as well as the concentrations recorded in-lake from 2011 to 2021.

Data are averages for each calendar year, noting the data from 2021 are incomplete at the time of writing. Error bars represent the standard deviation.

D.11 Ecological values

There are limited data available that would allow trends in the broader ecological values of Lake Ginninderra to be determined.

D.12 Riparian condition

The Rapid Appraisal of the Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent, good, fair, poor*or *degraded* conditions. The appraisal occurs every two years, and the lake was assessed in the years 2015, 2017, 2019 and 2021. In these years, the overall condition of the vegetation was considered *poor*.

D.13 Macrophyte condition

A thesis was published in 1992 (Moore 1992) on the growth of *Vallisneria gigantea* in Lake Ginninderra, and at the time, this was the only submerged macrophyte in the lake. There is no current information or long-term data collection on the macrophyte condition of the lake.

D.14 Fish, frogs, and other animals

The lake is also home to rakali (or the Australian water-rat), with frequent observations from citizen science programs across the lake (Williams et al. 2014). Between the years 2010 to mid-1019, there have been 48 reports of rakali sightings at Lake Ginninderra, with the species appearing relatively abundant in all parts of the lake. They appear relatively oblivious to poor water quality and seem to be most frequently associated with areas where there are stable banks covered in low growing vegetation or emergent aquatic vegetation (Smart et al. 2011; Speldewinde et al. 2013).

E. ACT's Urban Rivers and Creeks Technical Appendices

E.1 Document review: ACT's urban rivers and creeks water quality history

There are eight major urban creeks and rivers in the ACT that traverse the major catchment areas. These include the Molonglo River (upstream and downstream of Lake Burley Griffin) and Sullivans, Weston, Yarralumla, Ginninderra, Tuggeranong and Kippax Creeks. These urban creeks and rivers are a mix of natural and modified managed aquatic environments known to be subject to water quality issues such as high nutrient concentrations, heavy metal contamination and high salinity. There has been little research conducted on the urban creeks and rivers, with water quality research tending to be confined to understanding urban nutrients in specific creeks and rivers, and heavy metal contamination in the Molonglo River downstream of the Lake George Mine at Captains Flat.

Like many urban settings, the concentration of nutrients in Canberra's urban creeks often exceed guideline levels and occur at concentrations that result in problems in receiving waters. High concentrations of nutrients in Canberra's urban creeks were identified during rapid development of the suburbs (e.g. Beer at al. 1982 for Tuggeranong Creek and Cullen et al. 1978 for the Ginninderra Catchment), but research over the past 20 years indicates high concentrations of nutrients have persisted and are not just associated with the construction phase of the suburbs (Dyer 2000; Ubrihien et al. 2019a; Ubrihien et al. 2019b; Ubrihien et al. 2020).

While high concentrations of nutrients in urban creeks are not unusual, the proportion of the nutrients being transported in dissolved form in Canberra's urban creeks and rivers is surprising. In the late 1990s, total phosphorus concentrations in Sullivans Creek were observed to be consistently higher than in other ACT streams, and between 40 and 80% of the phosphorus transported in the creek was in dissolved form (Dyer 2000). The proportion of dissolved phosphorus were noted at the time as being unusually high compared with other Australian inland streams. More recently, work by (Ubrihien et al. 2019b) has also highlighted that up to 50% of the phosphorus transported in the creeks draining into Lake Tuggeranong were in dissolved form, even in high flow events. The high proportion of dissolved nutrients poses considerable challenges for the management of urban water quality, as much of the WSUD planning tools are not designed to handle a significant proportion of dissolved nutrients.

The management of the urban riparian zones has affected both the water quality and visual amenity of the urban creeks. Ginninderra Creek has had a history of poor water quality and low biodiversity, partly attributable to the prevalence of willows that had invaded along sections of the creek line. In the early 2000s, more than 9 km of willows were removed from the riparian areas of the creek with the support of National Heritage Trust funding (Department of Agriculture Water and Environment 2003). Like many such programs, there is limited information about the long-term water quality changes that have occurred with the removal of the willows and subsequent revegetation of the areas. Short term outcomes that increased erosion issues for the creek are described in Zukowski and Gawne (2006), and were caused, in part, because revegetation was hampered by the Millennium drought.

Urban creeks and rivers are commonly affected by heavy metal runoff (Birch and Rochford 2010; Li et al. 2012; Race et al. 2015), with industrial activity, degradation of asphalt and other material, vehicle emissions and the wear of brakes and tyres some of the key sources of metals (Revitt et al. 1990; Sansalone et al. 1996). While there has been limited heavy industrial activity in Canberra that would result in significant contamination of urban creeks and rivers, historical mining activities at Captains Flat have contaminated the Molonglo River through to Lake Burley Griffin with heavy metals (Brooks 1980; Maher et al. 1992; Nicholas and Thomas 1978; Wadige et al. 2016). The most recent study of mercury contamination between Captains Flat and Lake Burley Griffin (Stinton et al. 2020) suggests the contamination is most severe around Captains Flat, but the concentrations decrease downstream, and Lake Burley Griffin appears to be relatively unaffected. On this basis, it is expected the contamination would be negligible in the downstream reaches of the Molonglo River.

Regular monitoring of the aquatic ecosystems of Yarralumla Creek, Ginninderra Creek, Tuggeranong Creek, the Molonglo River and Jerrabomberra Creek is conducted through the ACT Water Quality Monitoring Program. This monitoring uses aquatic macroinvertebrate data to provide information about the water quality and ecological health of the creek systems. These data indicate the ecological health of the urban creeks and rivers are significantly to severely impaired, with rare instances when they are classed as similar to reference sites. Until 2015, these data were combined with a broad range of information on the ACT's water resources and made public through the ACT Water Reports (ACT Government 2022). They are no longer publicly available documents.

F. Water quality data analysis: Ginninderra Creek 2011–2021

The current assessment of Ginninderra Creek incorporates four sampling locations upstream of Lake Ginninderra and seven sampling locations downstream of the lake. These sites are located on the main stem of the creek and the most upstream site is below Gungahlin Pond and Yerrabi Pond. This means data provide an understanding of the creek downstream of major impoundments. There are no data to inform an understanding of the quality of water and the ecosystems in the headwaters. In this Appendix, the data analyses are presented for the sites upstream and downstream of Lake Ginninderra.

Summary data (Table 31 and Table 32) shows that concentrations of phosphorus, as well as pH and electrical conductivity recorded in both the upstream and downstream reaches of Ginninderra Creek are commonly (between 70 and 100% of readings) within the acceptable range of values for urban streams. Dissolved oxygen concentrations are also commonly within the acceptable range in the upstream sites but are more frequently outside of the acceptable range downstream of the lake. Conversely, electrical conductivity in the downstream sites is more frequently within the acceptable range than those upstream.

Turbidity and the concentrations of nitrate are regularly outside of the acceptable ranges (Table 31 and Table 32). For nitrate, this is particularly apparent in the downstream sites and for turbidity, this manifests in the upstream sites.

Table 31. Annual average of the percentage of data points recorded within Ginninderra Creek upstream of Lake Ginninderra that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4). Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range.

	Dissolved oxygen	pH	Total phosphorus	Nitrate	Electrical conductivity	Turbidity
2011	81	100	-	-	92	19
2012	96	100	-	-	67	13
2013	100	100	-	-	75	8
2014	80	100	95	61	68	45
2015	94	100	97	26	77	39
2016	71	100	100	45	90	19
2017	79	100	100	38	71	70
2018	84	100	100	58	67	61
2019	86	100	100	58	72	53
2020	83	100	100	20	91	40
2021	79	100	100	7	86	43

Table 32. Annual average of the percentage of data points recorded within Ginninderra Creek downstream of Lake Ginninderra that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

	Dissolved oxygen	pH	Total phosphorus	Nitrate	Electrical conductivity	Turbidity
2011	100	100	-	-	100	0
2012	76	100	-	-	97	36
2013	47	100	-	-	93	20
2014	64	100	100	0	100	55
2015	82	100	100	33	77	61
2016	64	100	100	10	88	39
2017	72	100	100	16	78	63
2018	51	100	100	7	86	46
2019	76	100	100	29	91	54
2020	69	100	98	23	97	58
2021	82	100	97	26	87	63

F.1 Nutrients

The concentrations of phosphorus in Ginninderra Creek upstream and downstream of Lake Ginninderra are consistently within the acceptable range for 99% of the time (Figure 75 and Figure 76). Nitrate concentrations are higher in the Ginninderra Creek downstream of Lake Ginninderra, with < 20% of records within acceptable range (Figure 77) compared with < 40% of sampling occasions recorded in the upstream reaches of Ginninderra Creek (Figure 78). It is not clear what would be driving the high nitrate concentrations downstream of Lake Ginninderra, but it is noted that nitrate concentrations are frequently outside of the acceptable range for most of the urban creek monitoring locations. Urban areas are known to display high concentrations of nitrate in the waterways, and the major culprits are thought to be sewerage, accumulation of atmospheric deposition on hard surfaces and the subsequent wash off, as well as fertilisers and groundwater inputs (Divers et al. 2014; Duncan et al. 2017; Kaushal et al. 2011; Silva et al. 2002). Given the possible causes of high nitrate concentrations in urban waters, it is unlikely to be caused by Lake Ginninderra. Detailed investigations are rare and the causes of high concentrations in the ACT waterways are unclear.

No clear relationship between flow and nutrient concentrations are observable in the data (not shown), which is possibly because the sampling has not captured a sufficient range of flows but may also be because there is not a strong relationship between the concentration of nutrients in the creek water and flow.

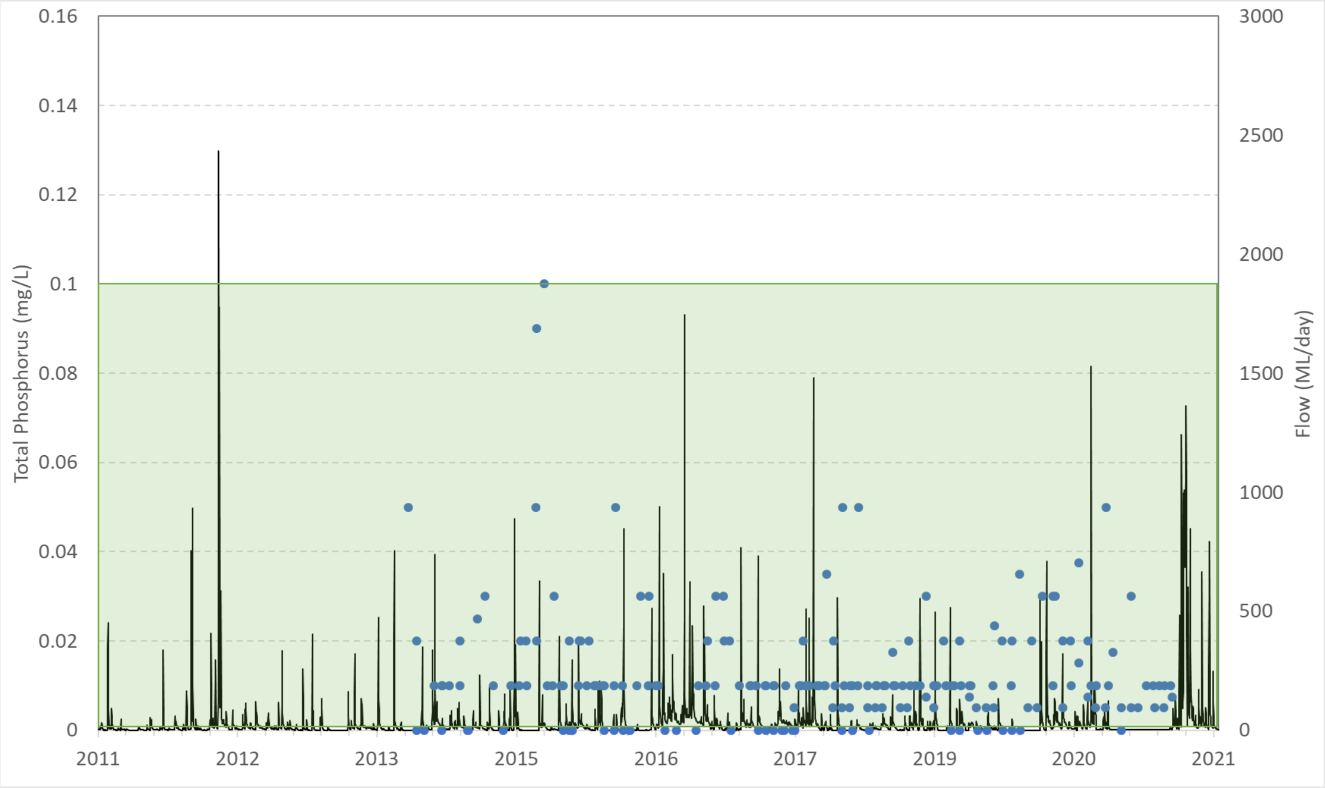

Figure 75. Phosphorus concentrations (mg/L) and flow (ML/day) within Ginninderra Creek between Lake Ginninderra and Gungahlin Pond from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for phosphorus concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

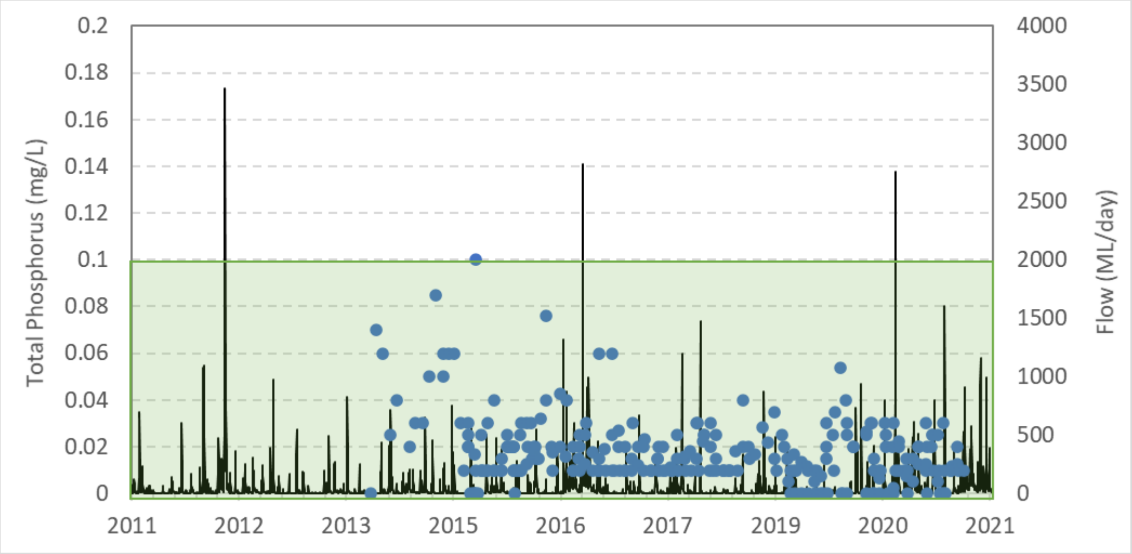

Figure 76. Phosphorus concentrations (mg/L) and flow (ML/day) within Ginninderra Creek downstream of Lake Ginninderra from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for phosphorus concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

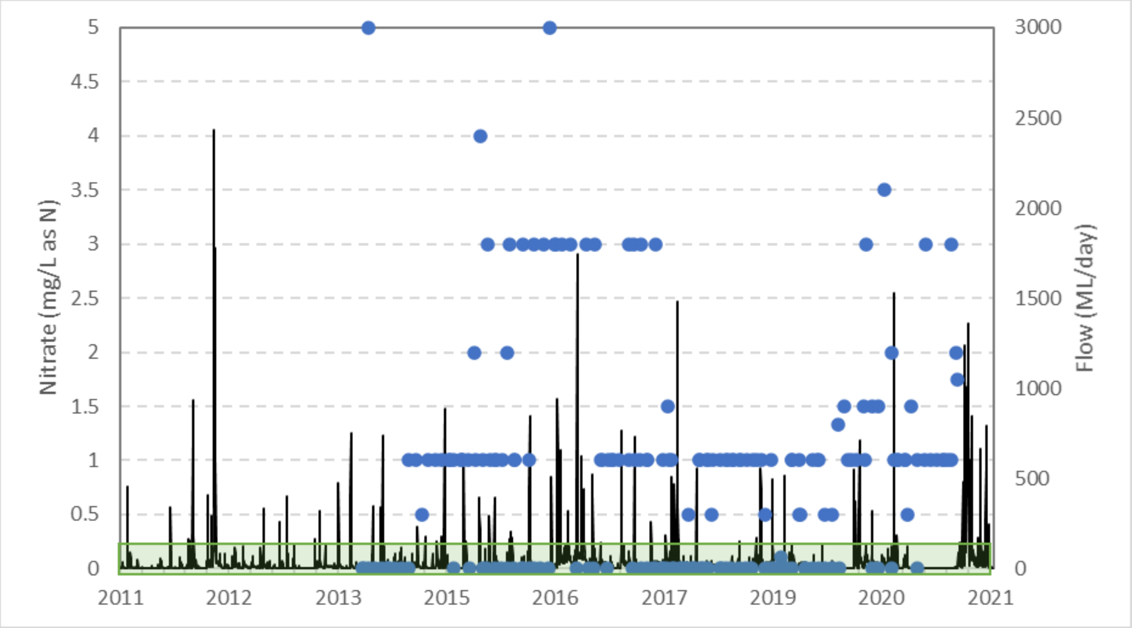

Figure 77. Nitrate concentrations (mg/L) and flow (ML/day) within Ginninderra Creek upstream of Lake Ginninderra from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for nitrogen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

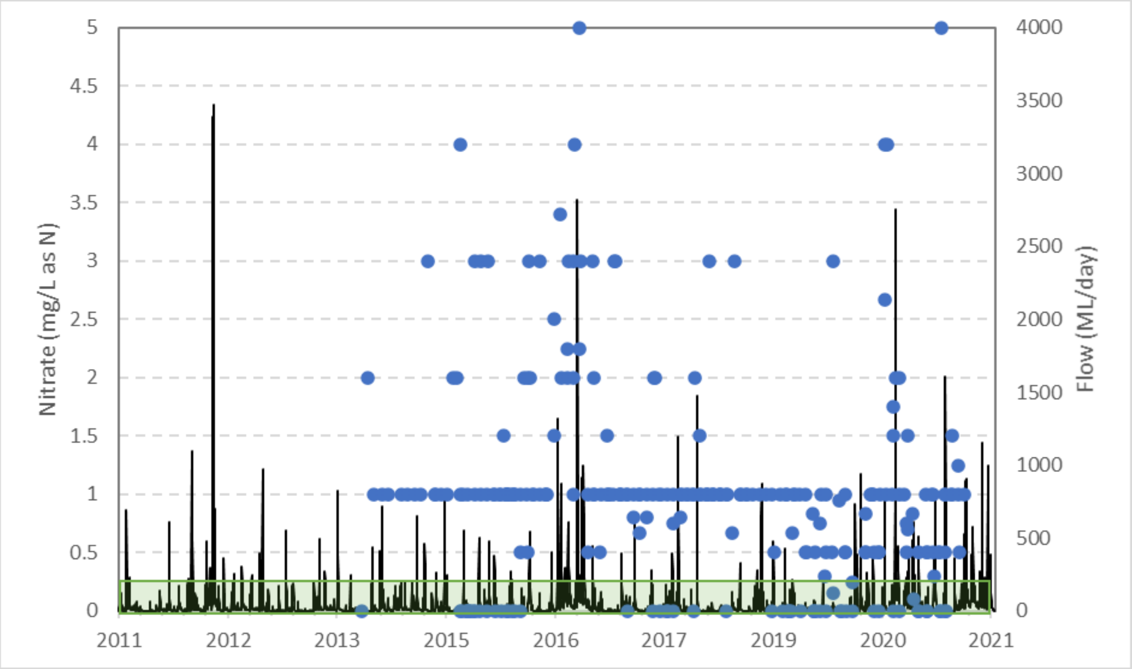

Figure 78. Nitrate concentrations (mg/L) and flow (ML/day) within Ginninderra Creek downstream of Lake Ginninderra from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for nitrogen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

F.2 pH

Ginninderra Creek both upstream and downstream of Lake Ginninderra has recorded pH consistently within the acceptable range over the past 10 years (Figure 79 and Figure 80).

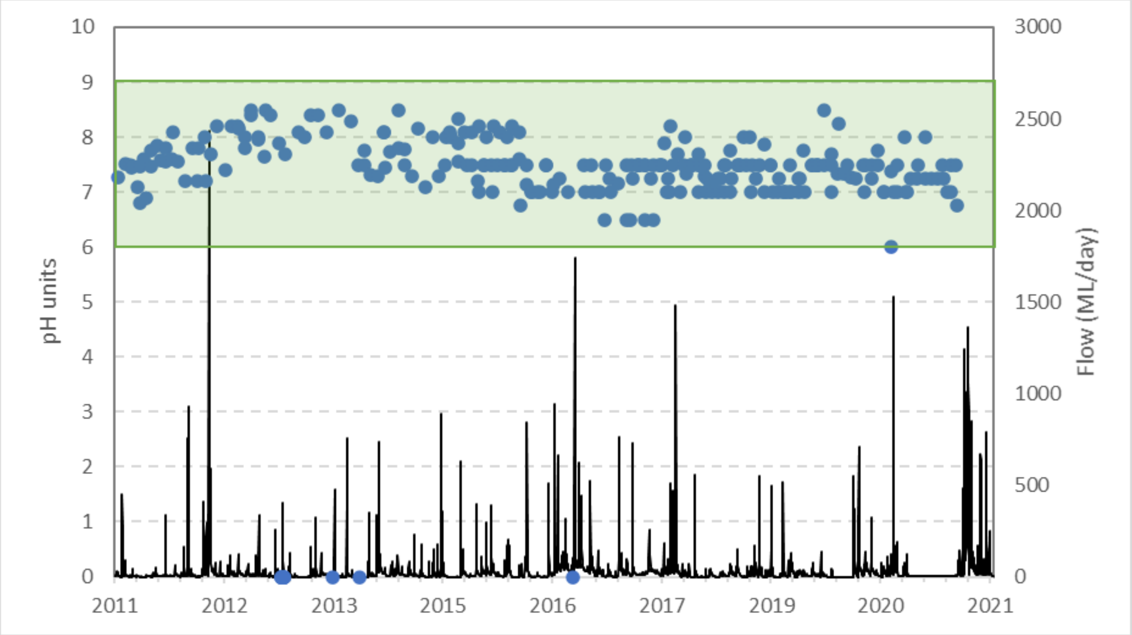

Figure 79. pH and flow (ML/day) within Ginninderra Creek upstream of Lake Ginninderra from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

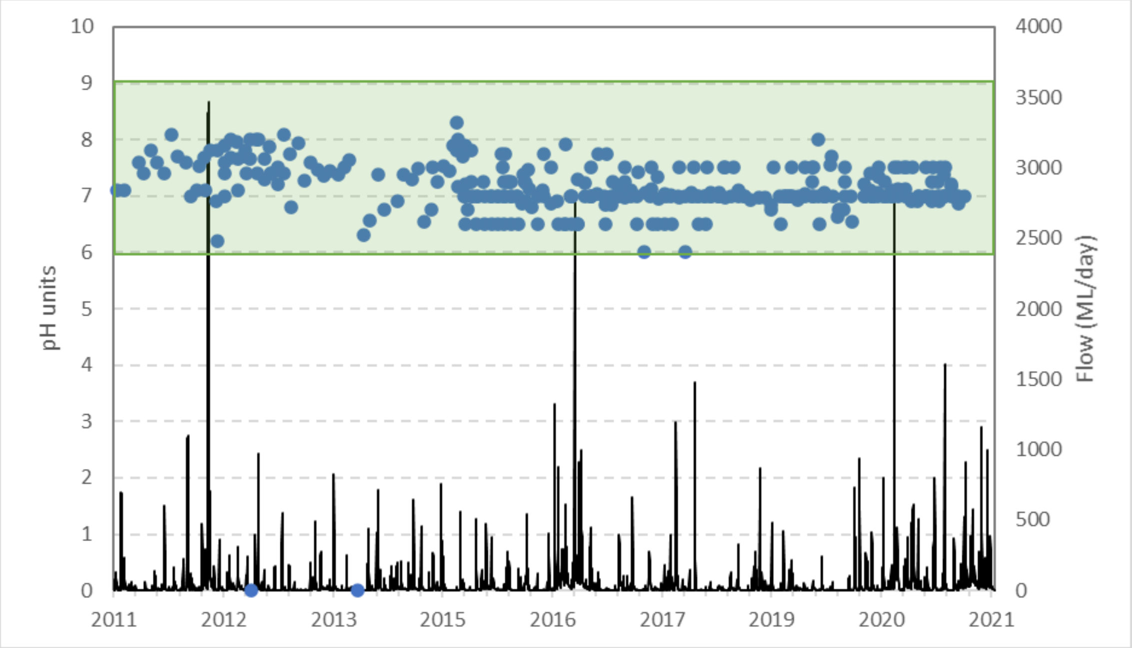

Figure 80. pH and flow (ML/day) within Ginninderra Creek downstream of Lake Ginninderra from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

F.3 Turbidity

Turbidity in Ginninderra Creek upstream of Lake Ginninderra is outside of acceptable levels for more than 60% of the time (Figure 81). There appears to be a slight improvement downstream of the lake, with turbidity readings outside of acceptable levels for 50% of the time (Figure 82). Interestingly, there is no relationship between turbidity and flow for either upstream or downstream sites (not shown). It would generally be expected that higher flows would be more turbid. The lack of a relationship in the data could be a function of not capturing a sufficient range of flows in the sampling, or it could be that there is not a strong relationship between flow and turbidity in these systems.

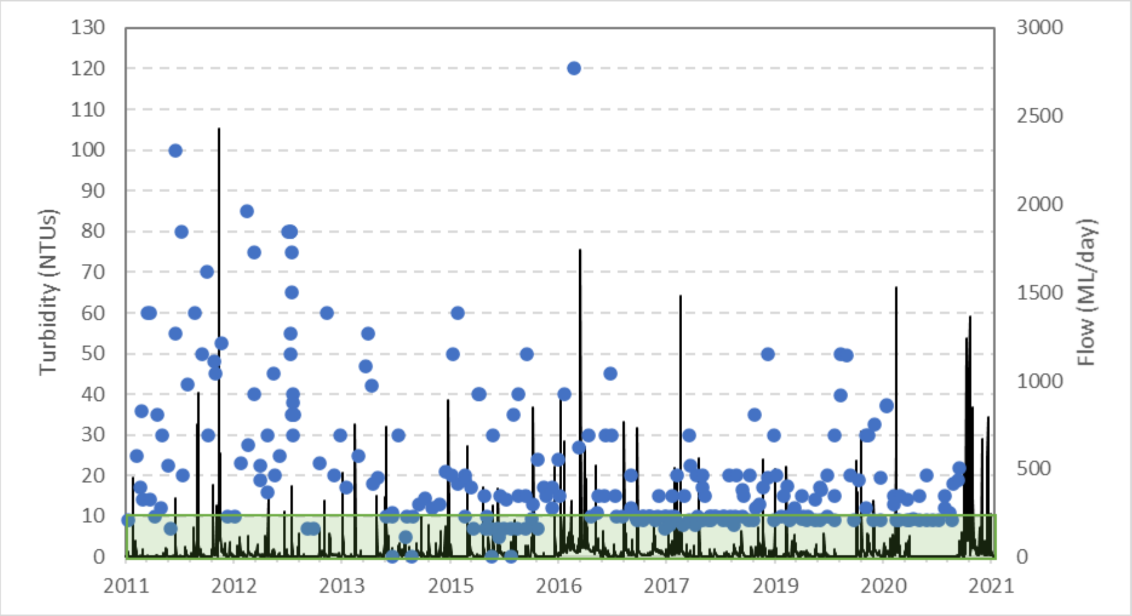

Figure 81. Turbidity (NTU) and flow (ML/day) within Ginninderra Creek upstream of Lake Ginninderra from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

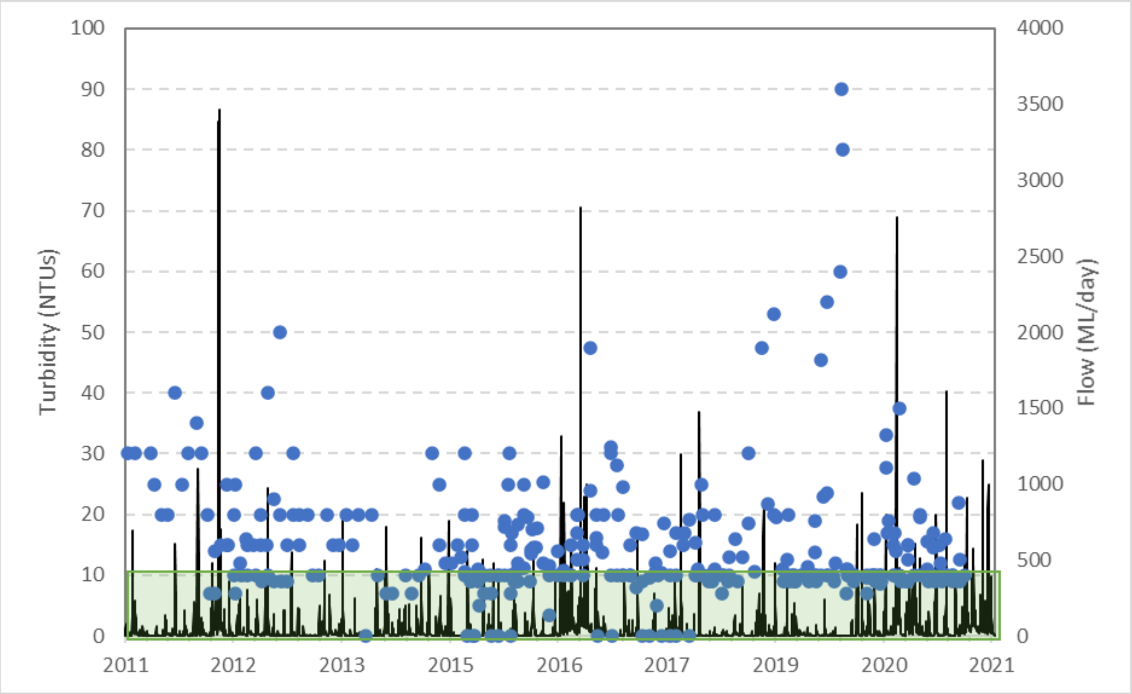

Figure 82. Turbidity (NTU) and flow (ML/day) within Ginninderra Creek downstream of Lake Ginninderra from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

F.4 Electrical conductivity

Electrical conductivity (EC) recorded in Ginninderra Creek upstream of Lake Ginninderra is within the acceptable range for 78% of the time, with an improvement to 87% of the time in the downstream reaches of Ginninderra Creek (Figure 83 and Figure 84). It is likely these differences are the result of differences in the character of the runoff from the local areas (perhaps relating to the proportion of concrete) rather than any effect of the dam. Both the upstream and downstream reaches have seen an increase in the number of high EC readings in the past five years, but the reasons for this are not clear. It is possible that very dry conditions may have contributed to high EC values between 2017 and 2019, but this would not explain the higher values in 2015–16. It is also possible the changes in catchment urbanisation have been sufficient to result in an increase in high EC readings, but the more noticeable change has been downstream of Lake Ginninderra, which has had less urban development over this time period.

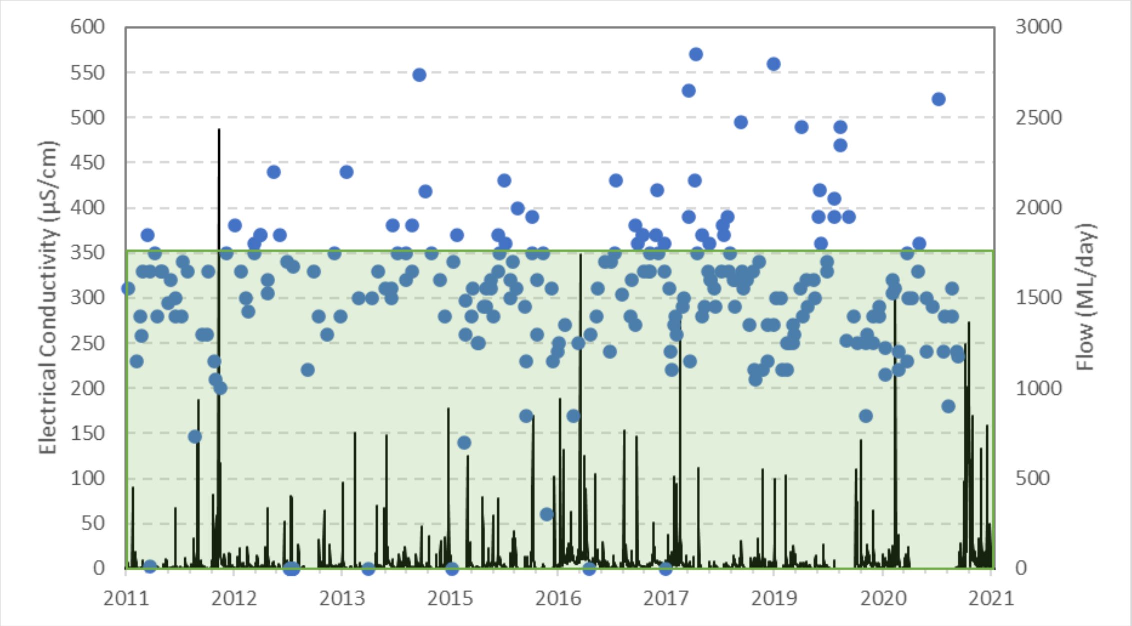

Figure 83. Electrical conductivity and flow (ML/day) within Ginninderra Creek upstream of Lake Ginninderra from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for electrical conductivity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

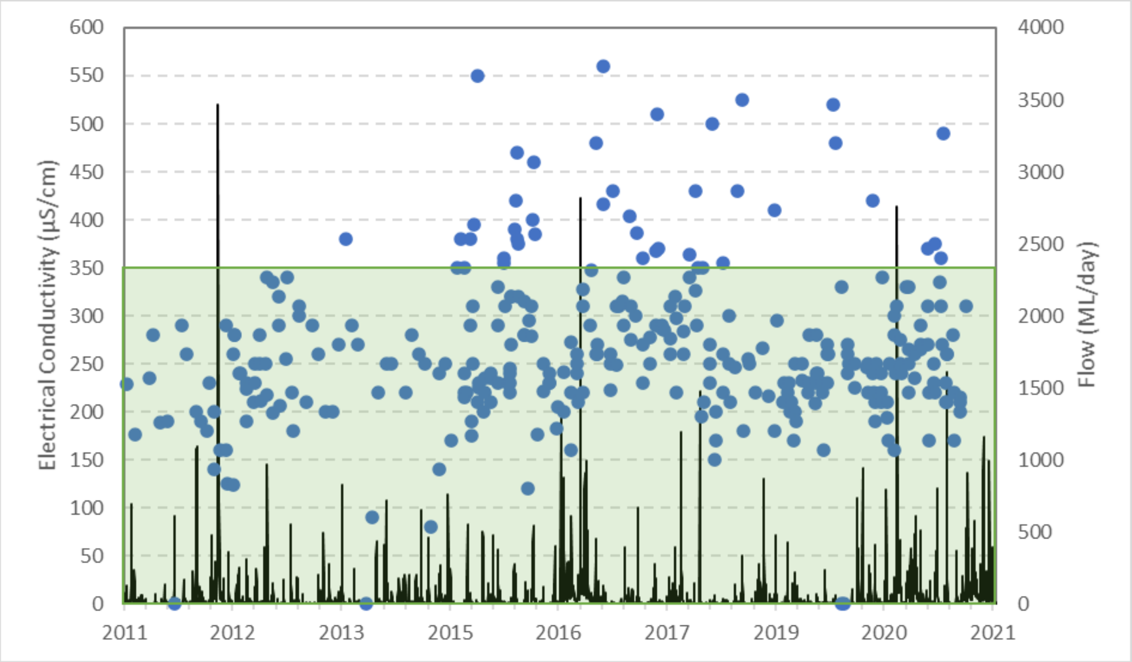

Figure 84. Electrical conductivity and flow (ML/day) within Ginninderra Creek downstream of Lake Ginninderra from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for electrical conductivity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

The higher electrical conductivity and turbidity observed in the upstream Ginninderra Creek sites may be a function of the urban development that has been occurring in the upper catchment over the past 10 years. These sites are downstream of Gungahlin Pond and Yerrabi Pond, so it is expected that development effects (that are mostly upstream of these ponds) would likely be attenuated. Without the corresponding spatial data that shows the development in the area at an annual timestep, it is difficult to provide a stronger interpretation of these data.

F.5 Dissolved oxygen

Dissolved oxygen concentrations in the Ginninderra Creek upstream of Lake Ginninderra are generally within acceptable levels, with only 15% of readings below acceptable levels ranging between 2 and 6 mg/L (Figure 85). In the reaches downstream of Lake Ginninderra, dissolved oxygen concentrations are within acceptable limits for 70% of the time, with the remaining readings ranging between 0.1 and 6 mg/L (Figure 86). Low concentrations of dissolved oxygen downstream of Lake Ginninderra may, in part, be caused by a high organic load in the creek (possibly from the leaf fall of deciduous trees that line the creek in sections), which increases the biological oxygen demand and reduces the dissolved oxygen in the creek waters.

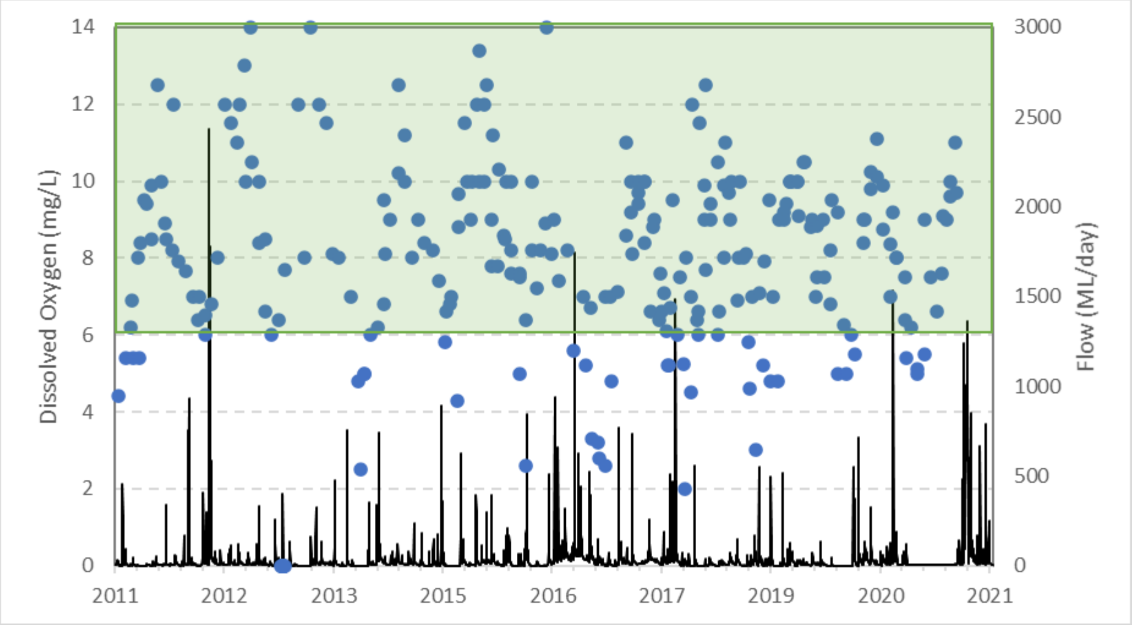

Figure 85. Dissolved oxygen and flow (ML/day) within Ginninderra Creek upstream of Lake Ginninderra from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

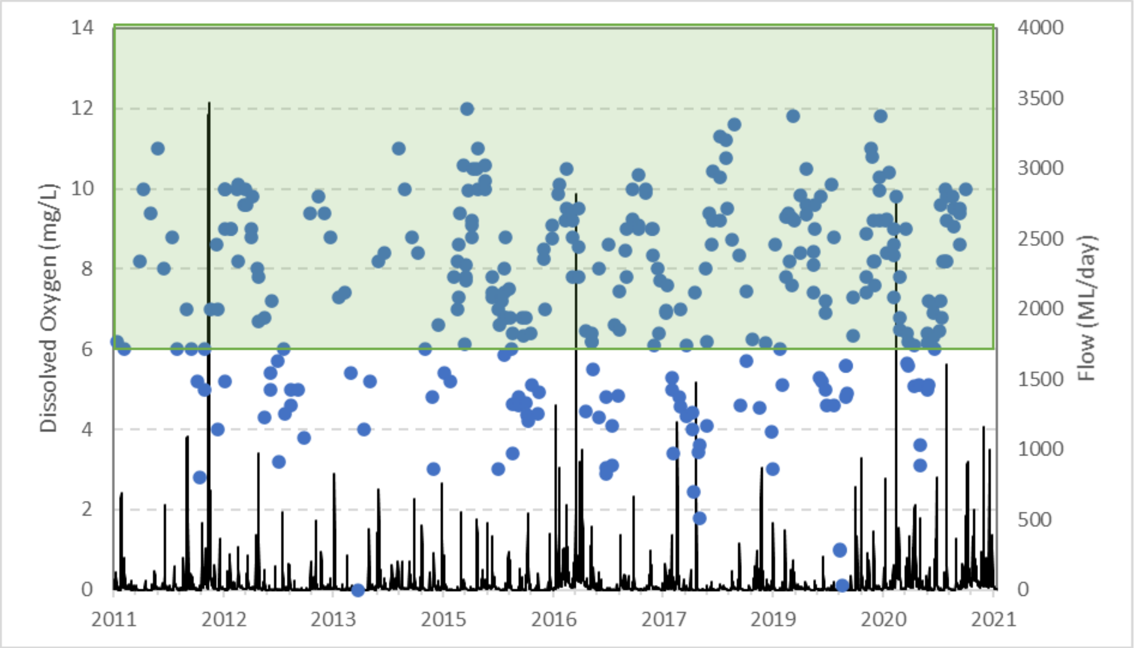

Figure 86. Dissolved oxygen and flow (ML/day) within Ginninderra Creek downstream of Lake Ginninderra from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

F.6 Ecological condition

Data collected in spring and autumn each year as part of the ACT Water Quality Monitoring Program indicate the macroinvertebrate communities of Ginninderra Creek are significantly to severely impaired (Figure 87 and Figure 88). The spring macroinvertebrate community seems to be more affected than the autumn community, which may be a function of the expected occurrence of more sensitive taxa in spring than in autumn.

As part of the Waterwatch program, macroinvertebrate data are collected from both upstream and downstream of Lake Ginninderra. These data indicate the macroinvertebrate community upstream of Lake Ginninderra is typically considered *good* (Figure 89), but downstream of the lake the community is far more variable, with almost half the records classed as *poor* (Figure 90). The poorer condition of the macroinvertebrate community varies with sampling site and season and there are not clear patterns in the data that are readily attributable to a cause.

The data collected from the ACT Monitoring Program and the Waterwatch program are not entirely consistent, which may be a function of site-specific differences or simply differences in sampling and analysis approaches. The two programs collect quite different data sets at different locations and use different approaches to analysing the data. This introduces variability that does not communicate well, and it would be beneficial to consider how the two programs could be better integrated to inform the management of the waterways.

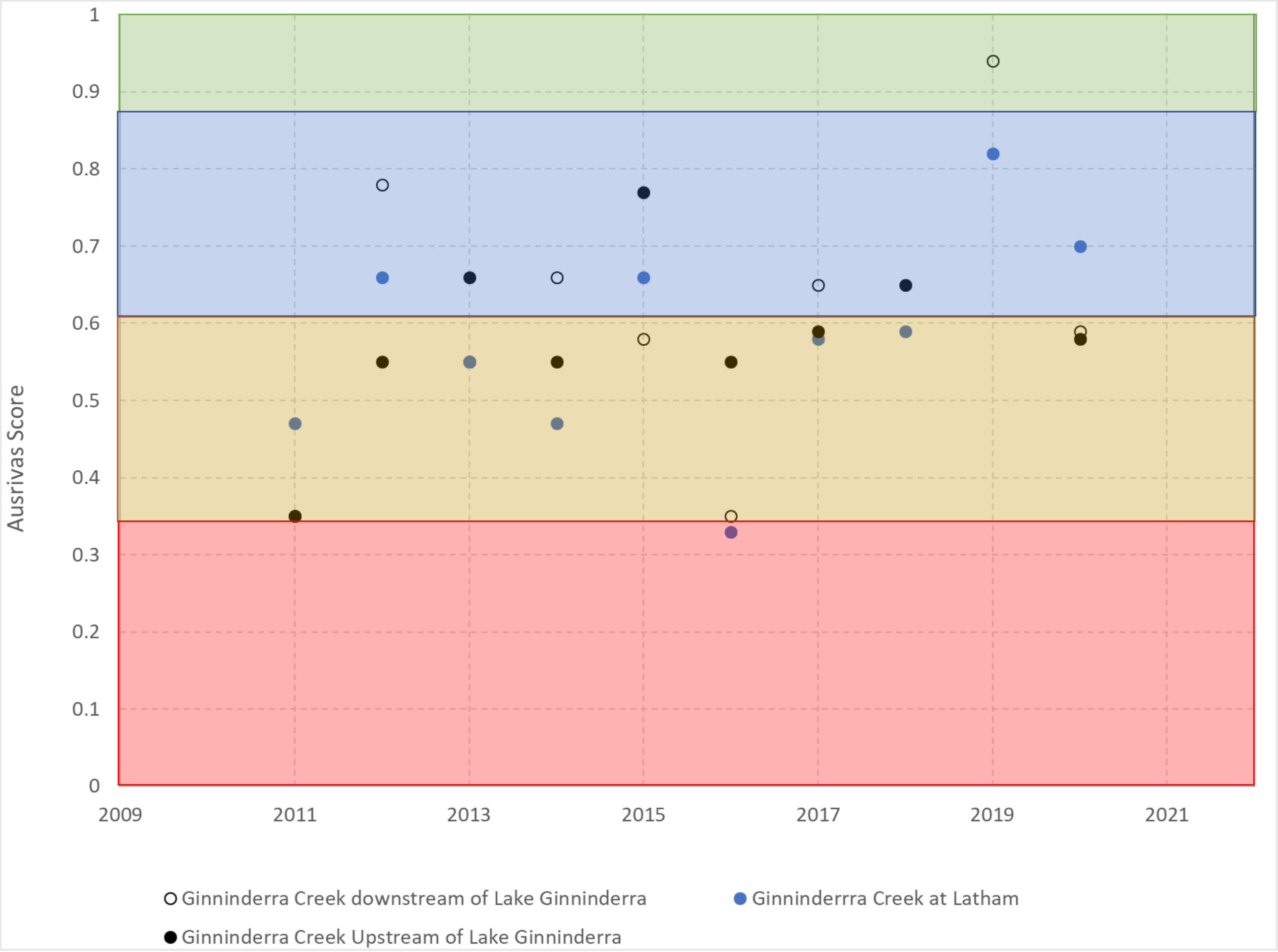

Figure 87. Spring AUSRIVAS scores for Ginninderra Creek sites from 2011 to 2020.

Data from the ACT Monitoring Program. Coloured bands represent the AUSRIVAS O/E biological condition classes, where green is similar to reference (Band A), blue is significantly impaired (Band B), orange is severely impaired (Band C) and red is extremely impaired (Band D).

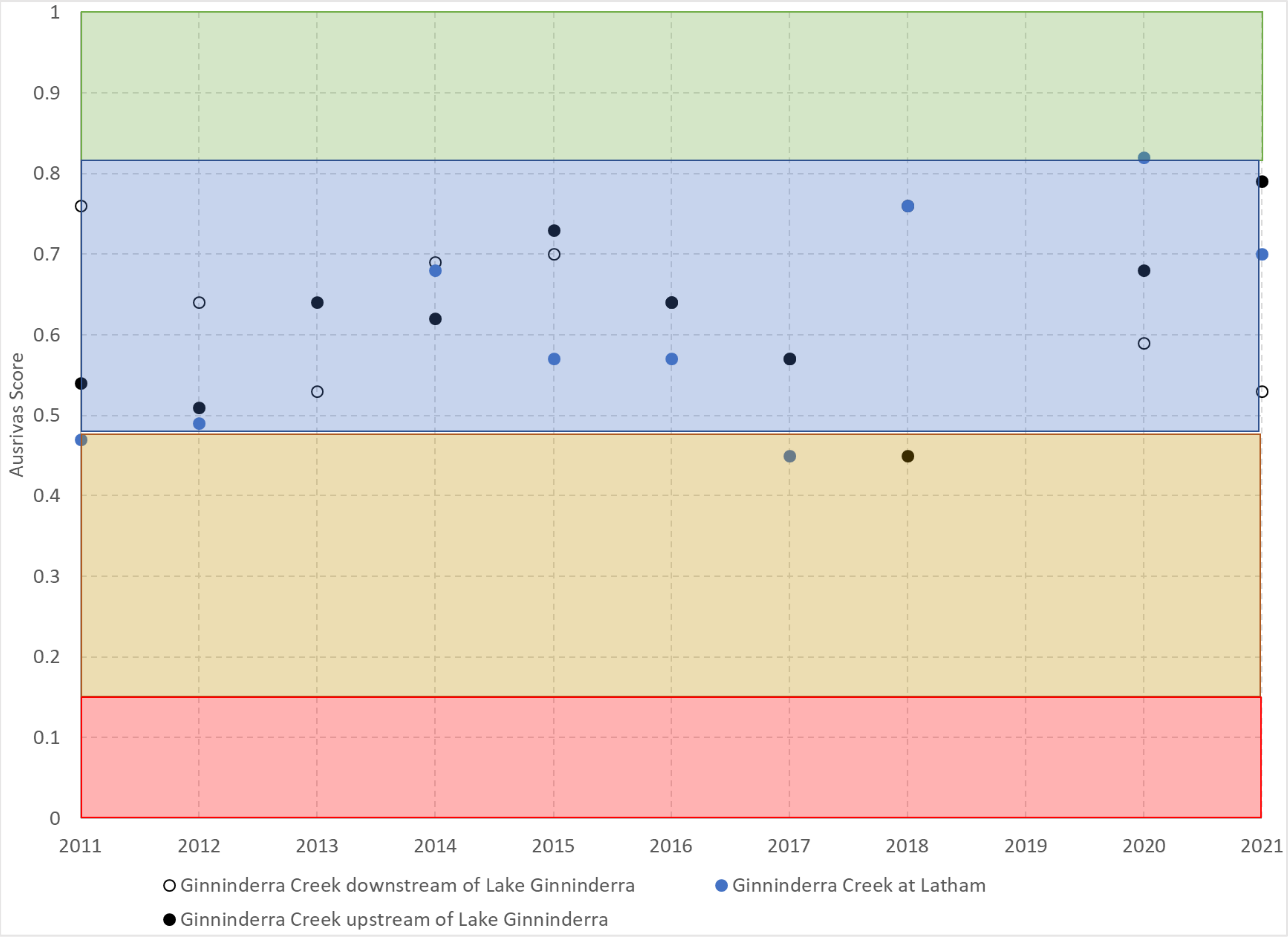

Figure 88. Autumn AUSRIVAS scores for Ginninderra Creek sites from 2011 to 2020.

Data from the ACT Monitoring Program. Coloured bands represent the AUSRIVAS O/E biological condition classes, where green is similar to reference (Band A), blue is significantly impaired (Band B), orange is severely impaired (Band C) and red is extremely impaired (Band D).

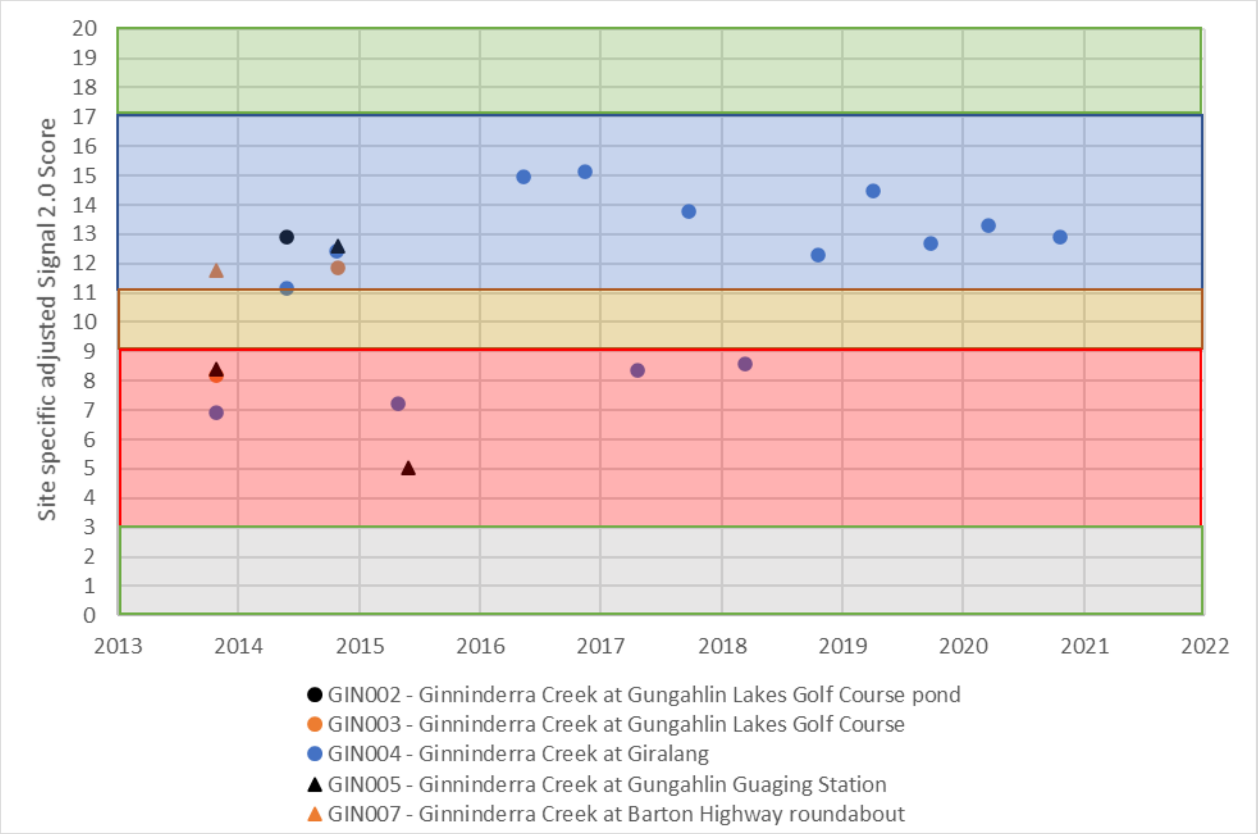

Figure 89. Adjusted SIGNAL 2.0 scores for Ginninderra Creek upstream of Lake Ginninderra from 2014 to 2021.

Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

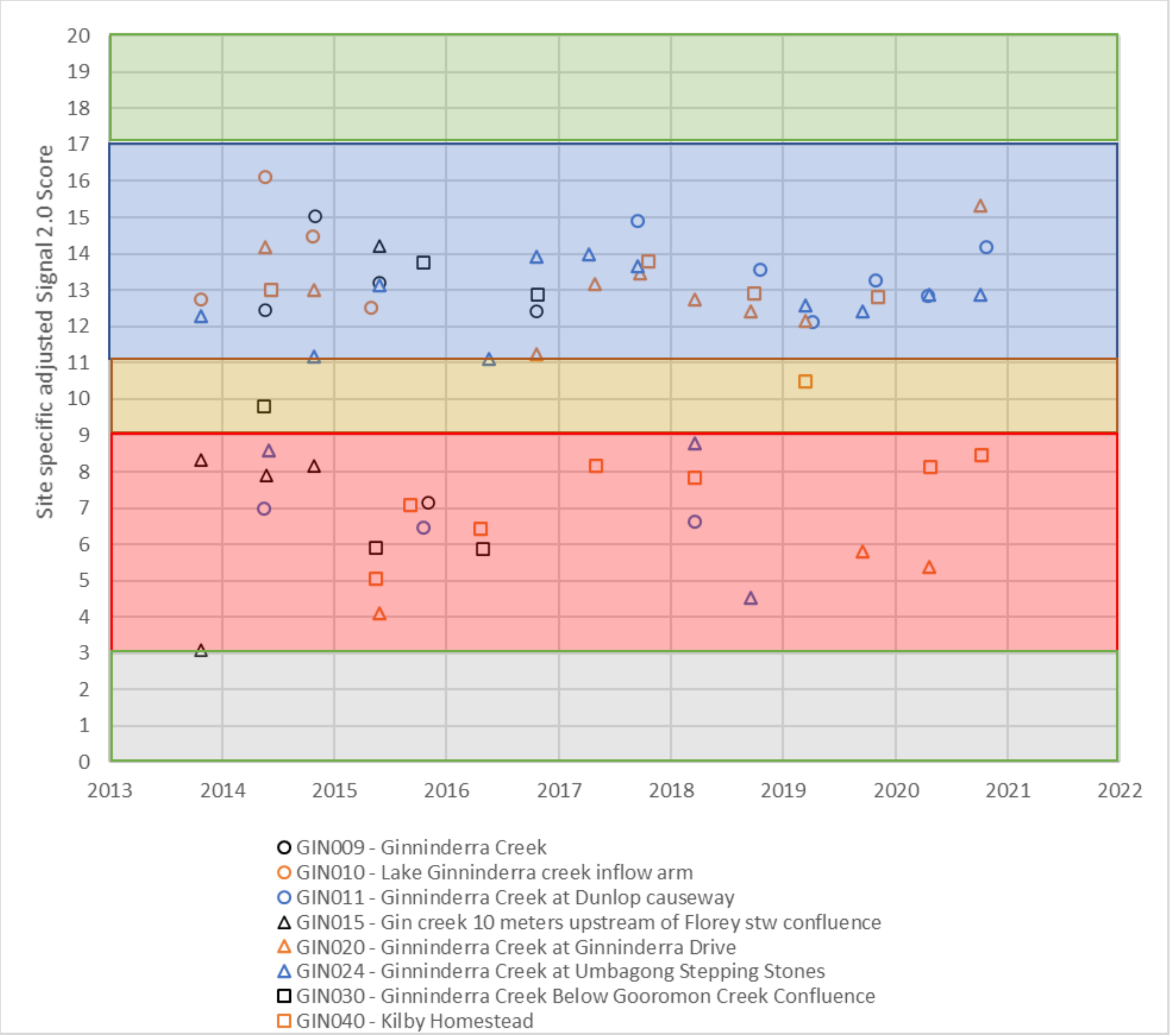

Figure 90. Adjusted SIGNAL 2.0 scores for Ginninderra Creek Downstream of Lake Ginninderra from 2014 to 2021.

Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

G. Water quality data analysis: Molonglo River 2011–2021

The current assessment of the Molonglo River incorporates four sampling locations upstream of Lake Burley Griffin and three sampling locations downstream of the lake. The data analyses are presented for the sites upstream and downstream of Lake Burley Griffin.

Summary data (Table 33 and Table 34) show the concentrations of phosphorus and dissolved oxygen, as well as pH and conductivity, recorded in both the upstream and downstream reaches of the Molonglo River are commonly within the acceptable range of values for urban streams, with between 70 and 100% of the readings within the acceptable range specified in the *Environment Protection Regulation 2005*. In contrast, nitrate concentrations and turbidity are regularly outside of the acceptable range. Until recently, the quality of water downstream of Lake Burley Griffin was generally better than that recorded in the upstream reaches. In the past two years, the proportion of downstream readings outside of the acceptable range for turbidity has increased notably and may be linked to the development that drains directly into the Molonglo River downstream of Lake Burley Griffin (see Section 8.3).

Table 33. Annual average of the percentage of data points recorded within Molonglo River upstream of Lake Burley Griffin that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4). Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range.

	Dissolved oxygen	pH	Total phosphorus	Nitrate	Electrical conductivity	Turbidity
2011	82	94	-	-	100	18
2012	68	100	-	-	93	0
2013	88	100	-	-	100	20
2014	94	94	100	38	100	53
2015	93	100	100	35	100	61
2016	81	100	92	54	100	62
2017	81	100	100	23	100	65
2018	68	100	100	9	68	64
2019	86	100	100	33	55	35
2020	84	100	100	0	67	37
2021	85	100	92	8	100	31

Table 34. Annual average of the percentage of data points recorded within Molonglo River downstream of Lake Burley Griffin that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

	Dissolved oxygen	pH	Total phosphorus	Nitrate	Electrical conductivity	Turbidity
2011	80	100	-	-	100	0
2012	50	100	-	-	100	33
2013	50	100	-	-	50	50
2014	75	100	100	0	100	100
2015	82	100	91	9	100	64
2016	95	100	100	65	100	15
2017	96	100	100	74	91	65
2018	86	100	100	41	95	91
2019	100	100	100	25	90	58
2020	89	100	100	5	95	25
2021	100	100	100	36	100	23

G.1 Nutrients

The concentrations of phosphorus in the Molonglo River upstream of Lake Burley Griffin are within acceptable range for 95% of the time (Figure 91), and concentrations downstream of Lake Burley Griffin are within acceptable range for > 99% of the time (Figure 92), suggesting the lake is actively trapping the phosphorus from the urban runoff and protecting the water quality in the downstream reaches of the Molonglo River.

Nitrogen concentrations are higher in the Molonglo River upstream of Lake Burley Griffin, with < 25% of records within acceptable range (Figure 93) compared with < 40% of sampling occasions recorded in the downstream reaches of the Molonglo River (Figure 94). The improvement is likely to be the result of nutrients being trapped by Lake Burley Griffin, thus the concentrations in the outflow are lower.

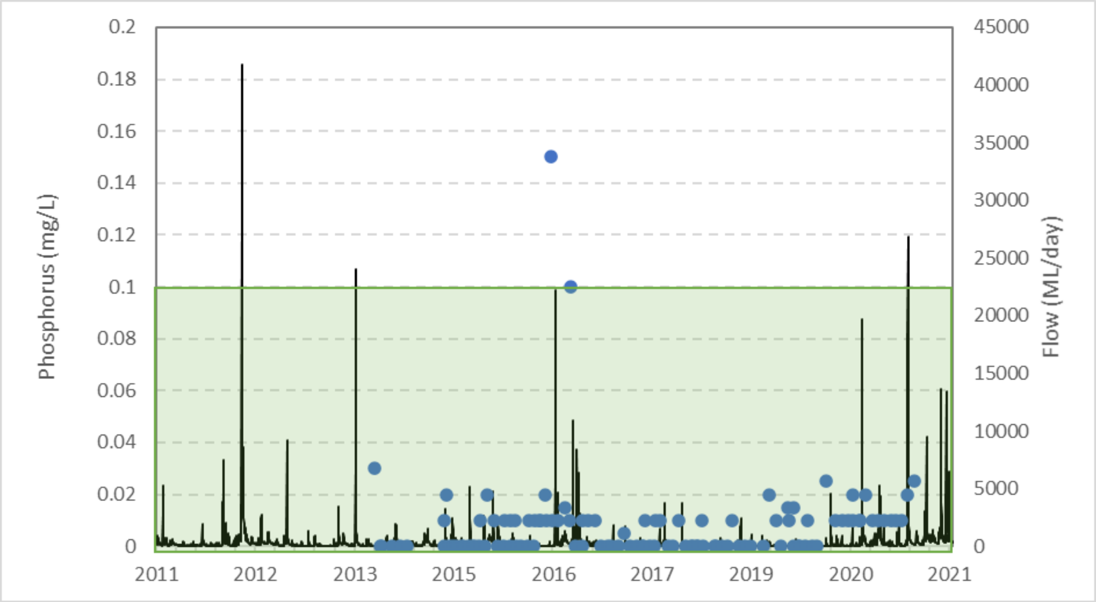

Figure 91. Phosphorus concentrations (mg/L) and flow (ML/day) within Molonglo River upstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for phosphorus concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

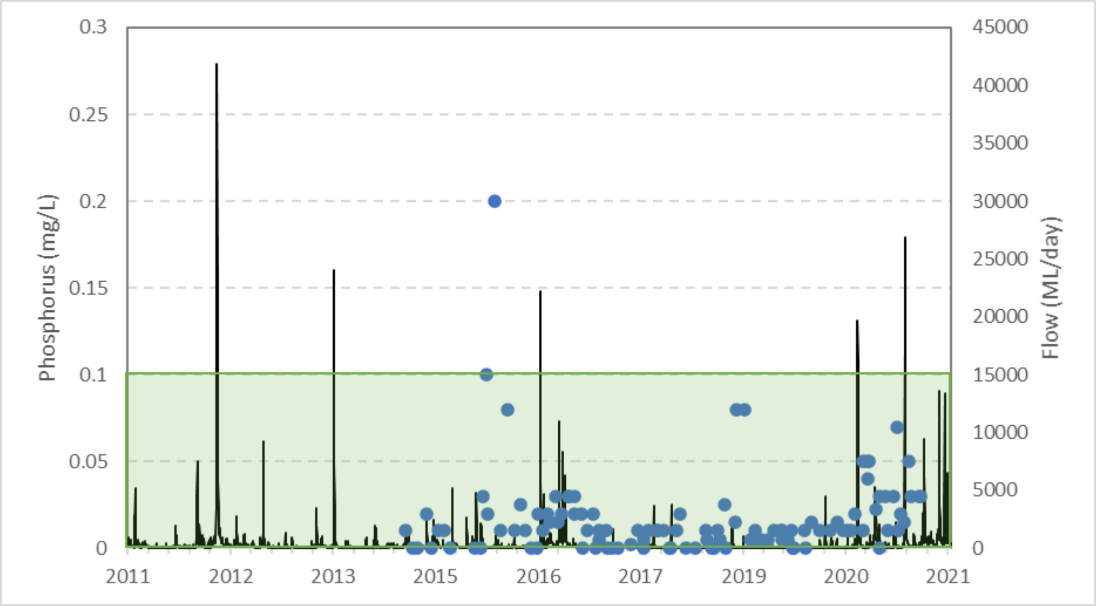

Figure 92. Phosphorus concentrations (mg/L) and flow (ML/day) within Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for phosphorus concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

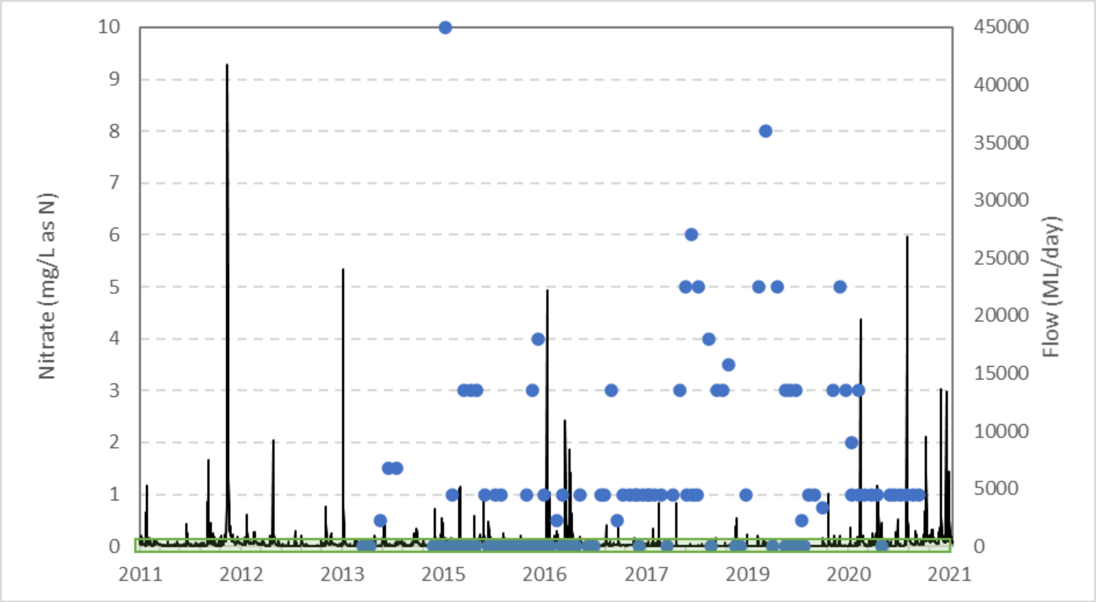

Figure 93. Nitrogen concentrations (mg/L) and flow (ML/day) within Molonglo River upstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for nitrogen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

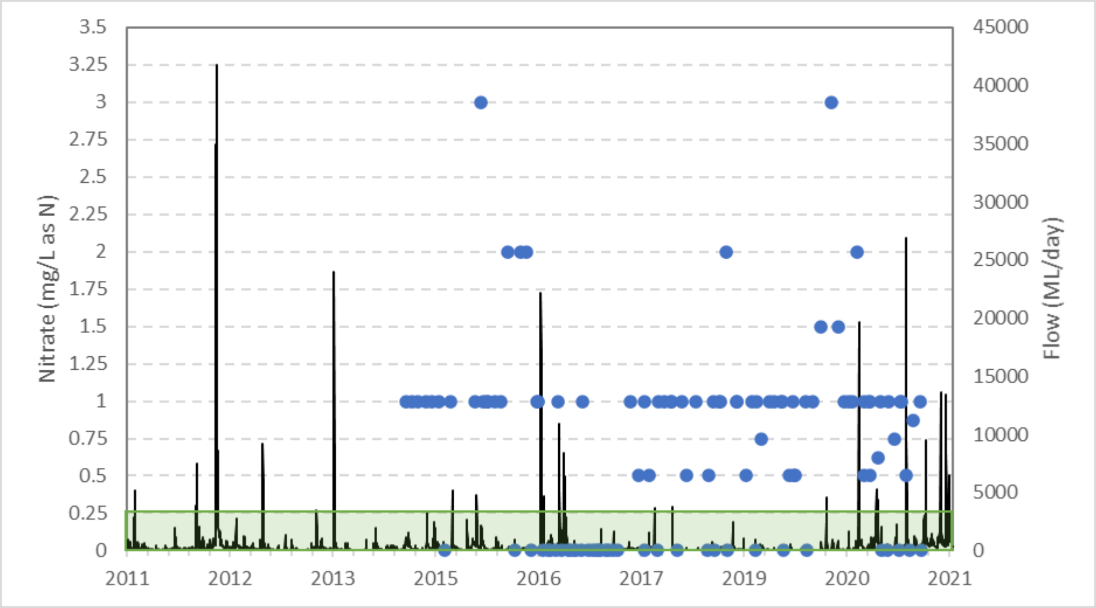

Figure 94. Nitrogen concentrations (mg/L) and flow (ML/day) within Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for nitrogen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

G.2 pH

pH recorded within the Molonglo River upstream of Lake Burley Griffin is, for the majority, within the acceptable range, with only two instances below the lower limit of 6 (Figure 95). The Molonglo River downstream of Lake Burley Griffin has recorded pH consistent within the acceptable range (Figure 96).

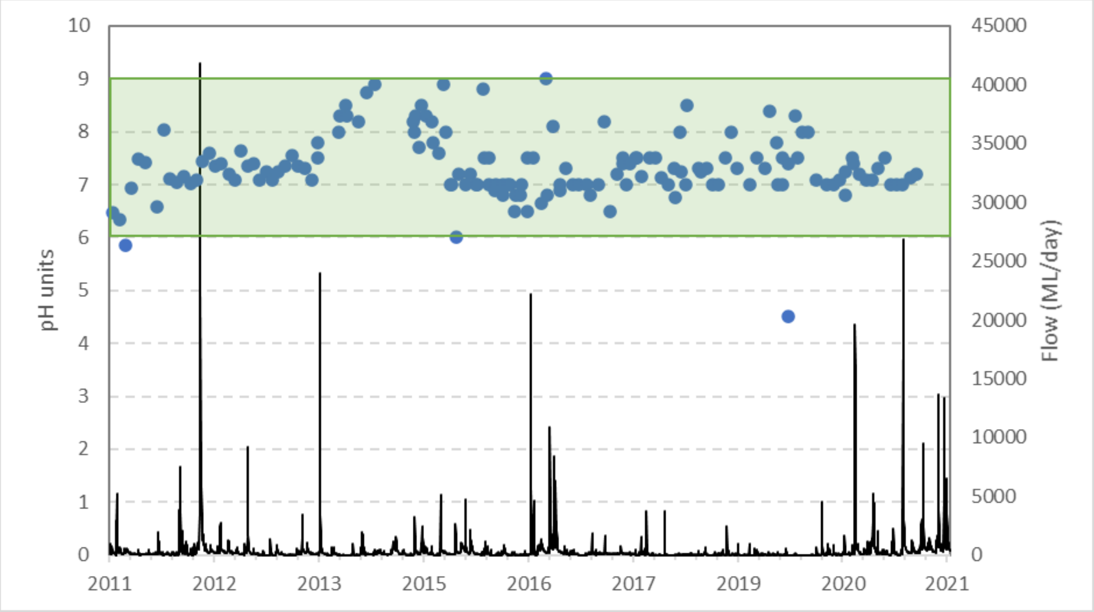

Figure 95. pH concentrations (mg/L) and flow (ML/day) within Molonglo River upstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

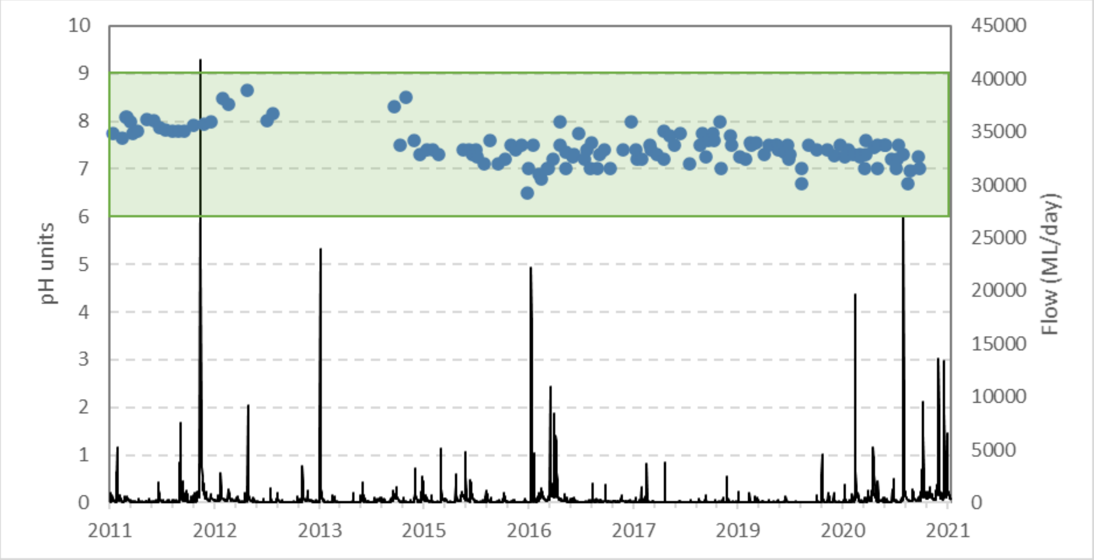

Figure 96. pH concentrations (mg/L) and flow (ML/day) within Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

G.3 Turbidity

Turbidity in the Molonglo River upstream of Lake Burley Griffin is similar to that recorded downstream of the lake, with recordings within acceptable range for < 50% of the time, with evidence of a slight improvement in turbidity readings downstream of the lake (Figure 97 and Figure 98).

The turbidity downstream of Lake Burley Griffin has been influenced by wetter conditions and releases from Scrivener Dam, with higher turbidity recorded in wetter years. There is a weak positive relationship between turbidity and flow (not shown). While 2020 and 2021 have been wet and very wet years, there has been a notable increase in the turbidity readings in the downstream reaches, with some particularly high readings observed (Figure 98) that cannot completely be attributed to the wetter conditions. It is likely that the urban development in the Molonglo Valley is having an observable effect on the quality of water in the river.

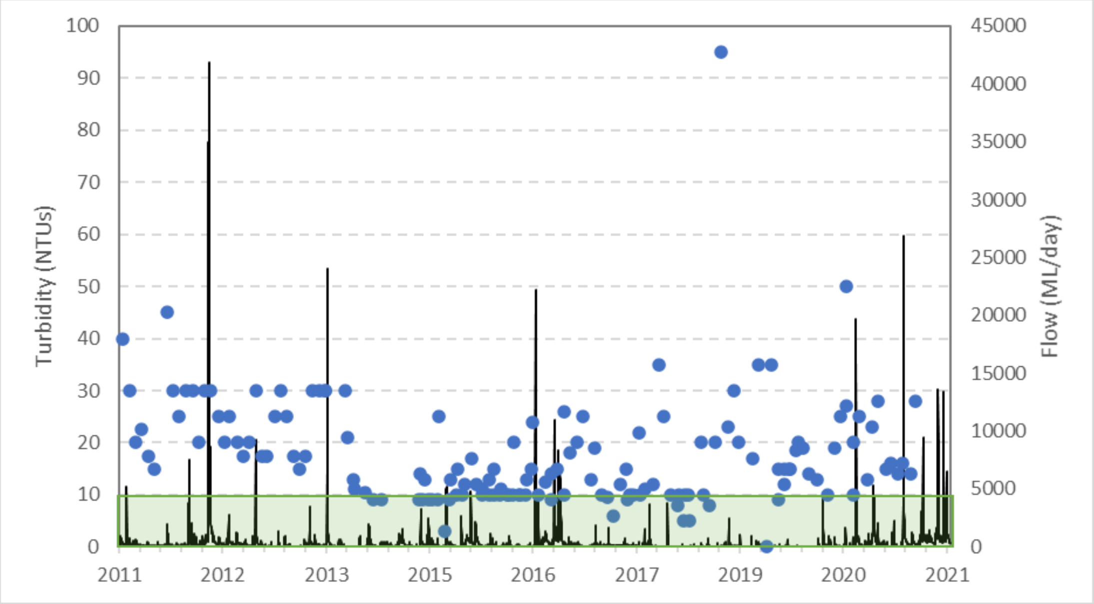

Figure 97. Turbidity (mg/L) and flow (ML/day) within Molonglo River upstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

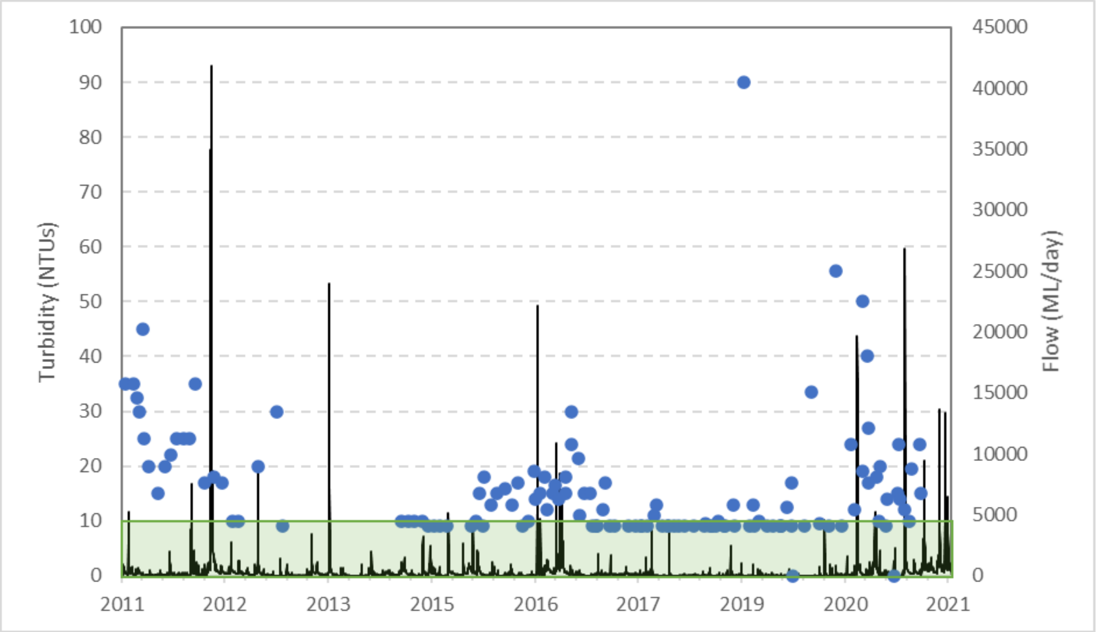

Figure 98. Turbidity (mg/L) and flow (ML/day) within Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

G.4 Electrical conductivity

Electrical conductivity recorded in the Molonglo River upstream of Lake Burley Griffin is generally the same as those recorded downstream and are, for the most part, within the acceptable range (Figure 99 and Figure 100). The data demonstrate an increase in electrical conductivity at both the upstream and downstream reaches between 2017 and 2019, possibly because of the drier conditions, as the return of wetter conditions in 2020 and 2021 have seen values declining again.

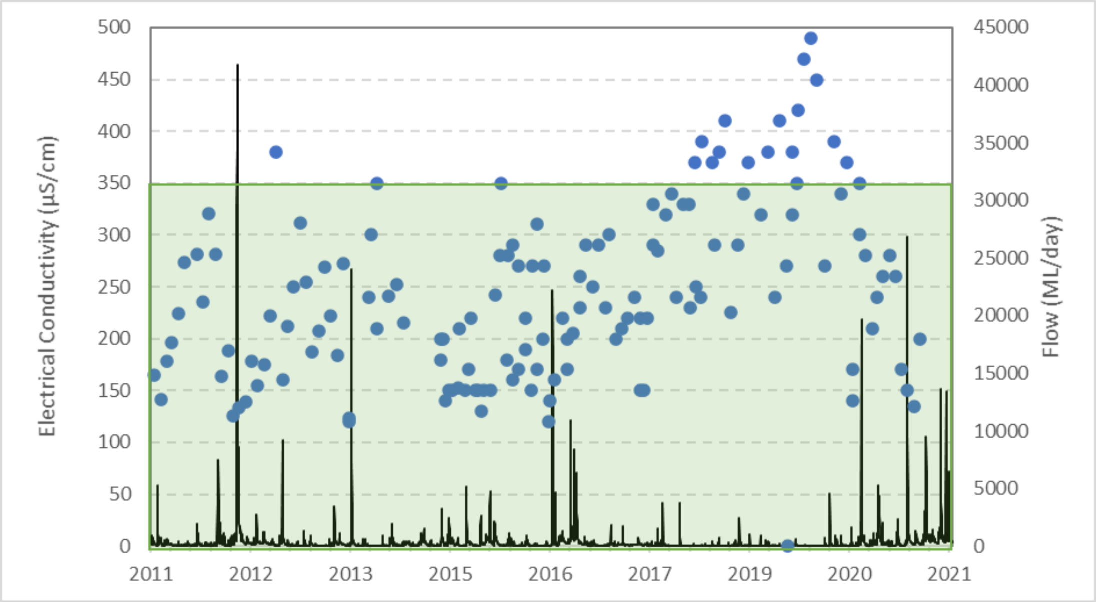

Figure 99. Electrical conductivity (mg/L) and flow (ML/day) within Molonglo River upstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for electrical conductivity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

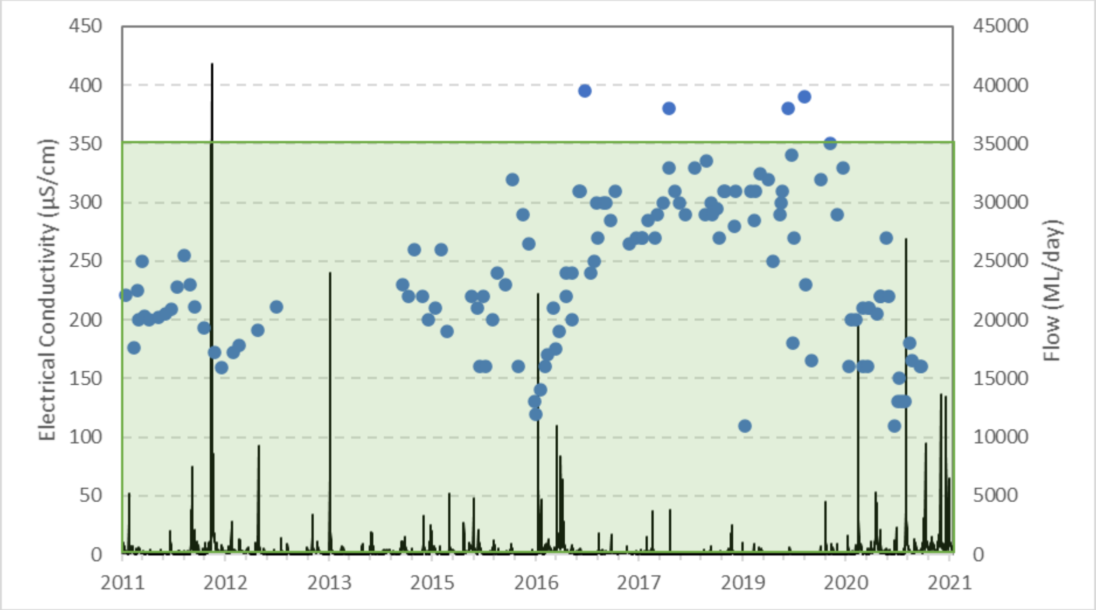

Figure 100. Electrical conductivity (mg/L) and flow (ML/day) within Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for electrical conductivity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

G.5 Dissolved oxygen

Dissolved oxygen concentrations in the Molonglo River upstream of Lake Burley Griffin are within acceptable range for 82% of the time, with a slight increase to 89% of the time for the downstream reaches (Figure 101 and Figure 102). Such a difference is not statistically significant given the variation in the data, and the concentrations of dissolved oxygen can be considered comparable between the upstream and downstream reaches.

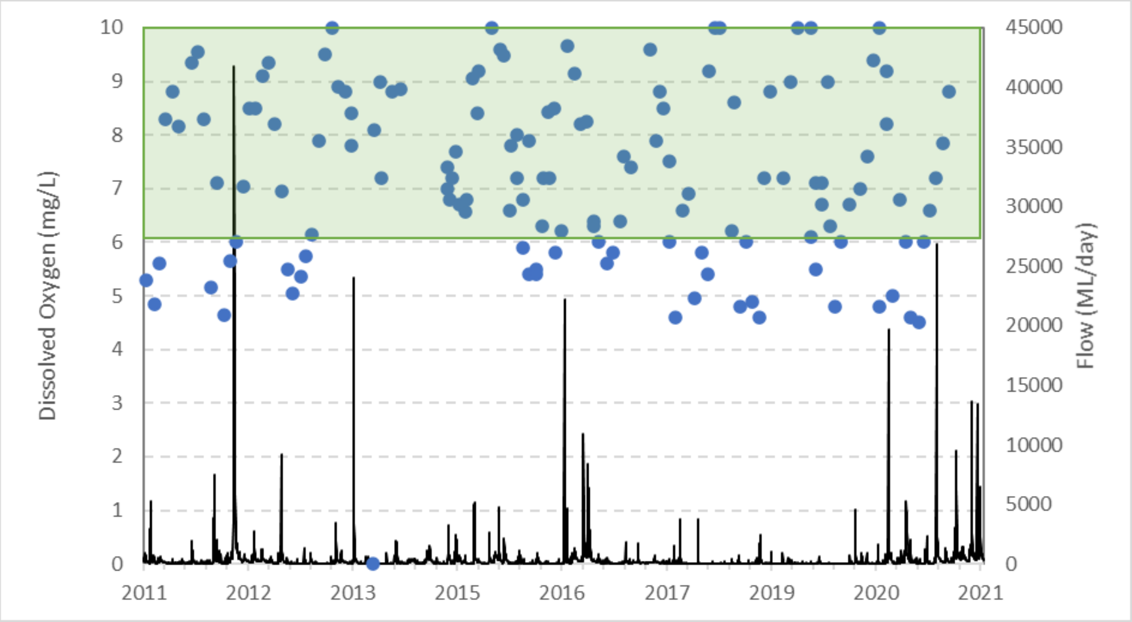

Figure 101. Dissolved oxygen concentrations (mg/L) and flow (ML/day) within Molonglo River upstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

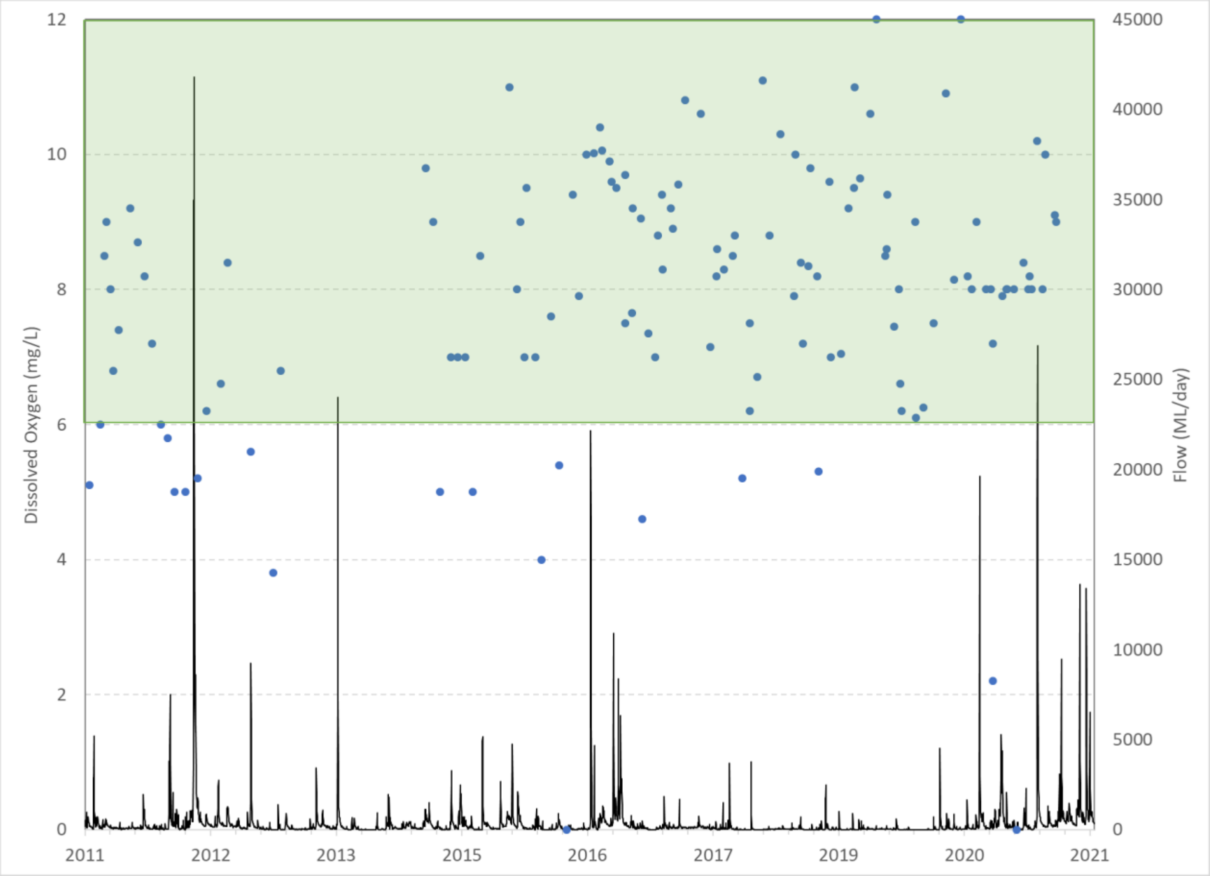

Figure 102. Dissolved oxygen concentrations (mg/L) and flow (ML/day) within Molonglo River downstream of Lake Burley Griffin from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

G.6 Ecological condition

Data collected in spring and autumn each year as part of the ACT Water Quality Monitoring Program indicate the macroinvertebrate communities of the Molonglo River upstream of Lake Burley Griffin are typically significantly to severely impaired. The spring macroinvertebrate community in the river has varied in condition over the 10 years, ranging from severely impaired to similar to reference (Figure 103). During 2020 and 2021, there was a decline in the condition of the autumn macroinvertebrate community (Figure 104), which may be a result of the drier autumns being experienced across the region.

As part of the Waterwatch program, macroinvertebrate data are collected from both upstream and downstream of Lake Burley Griffin. These data indicate the macroinvertebrate community is typically considered *good* (Figure 105 and Figure 106), but that there are notable instances where the community is considered *poor*. Since 2018, the spring macroinvertebrate community recorded at the most downstream site on the Molonglo River has been *poor*. The site further upstream (at Coppins Crossing) remained classed as *good*, suggesting that there may be some impact on the Molonglo between Coppins Crossing and the Murrumbidgee confluence. This may be attributable to the influence of the Lower Molonglo Water Quality Control Centre but would require further investigation to understand.

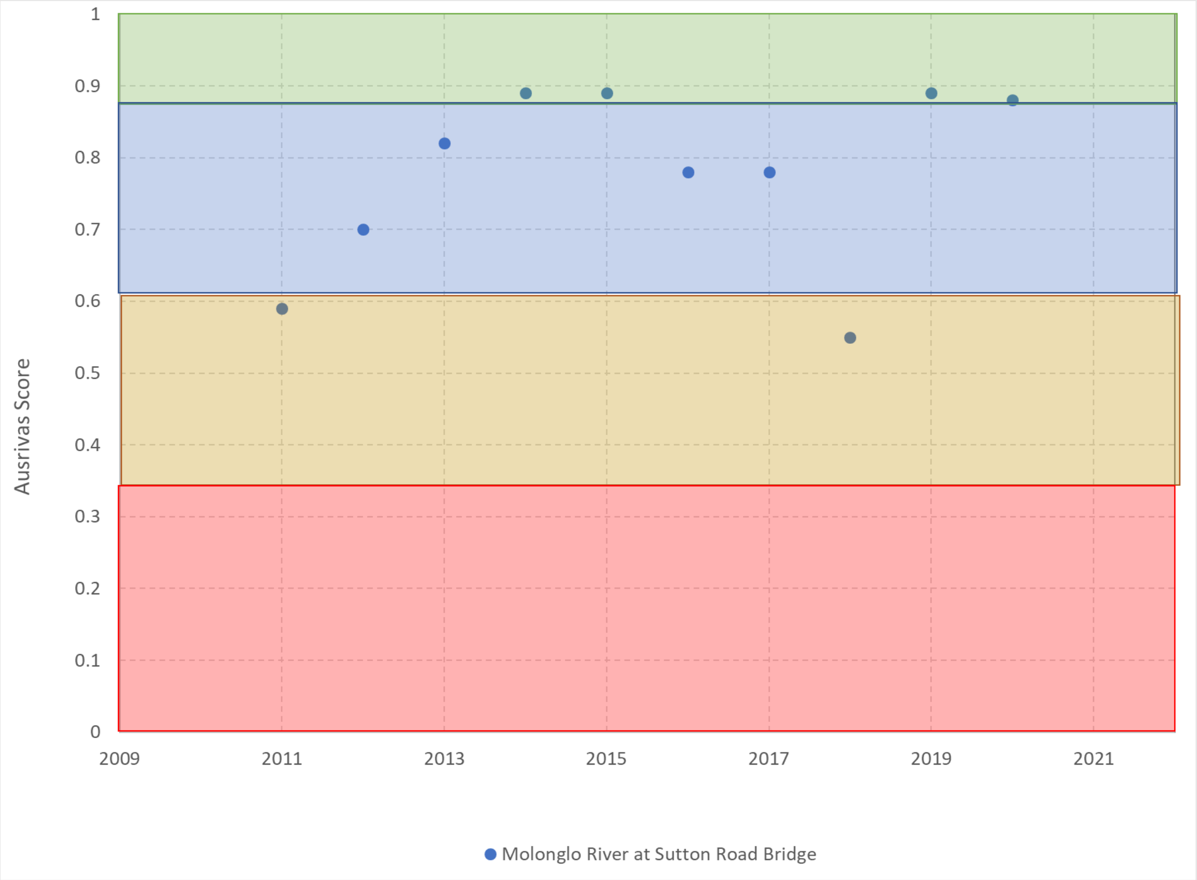

Figure 103. Spring AUSRIVAS scores for Molonglo River from 2011 to 2020.

Data from the ACT Monitoring Program. Coloured bands represent the AUSRIVAS O/E biological condition classes, where green is similar to reference (Band A), blue is significantly impaired (Band B), orange is severely impaired (Band C) and red is extremely impaired (Band D).

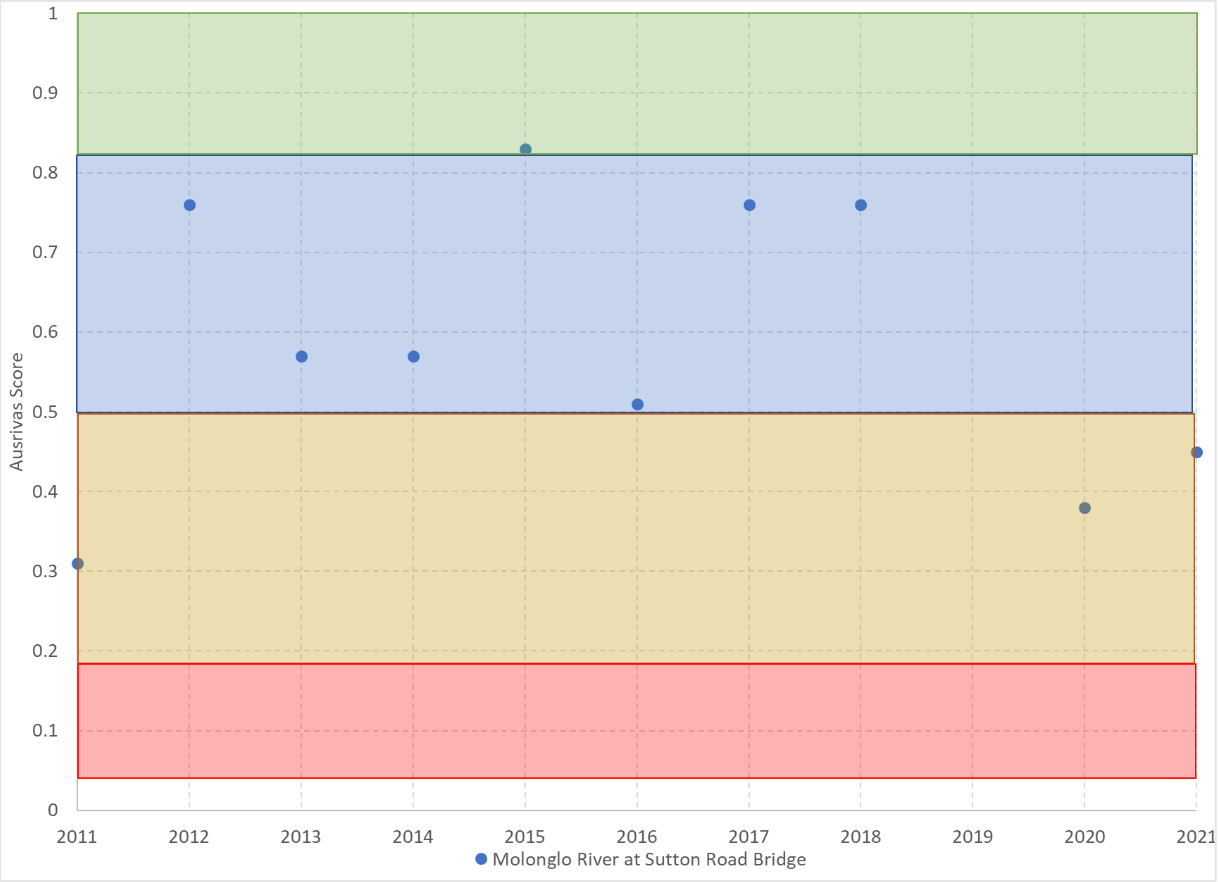

Figure 104. Autumn AUSRIVAS scores for the Molonglo River from 2011–2020.

Data from the ACT Monitoring Program. Coloured bands represent the AUSRIVAS O/E biological condition classes, where green is similar to reference (Band A), blue is significantly impaired (Band B), orange is severely impaired (Band C) and red is extremely impaired (Band D).

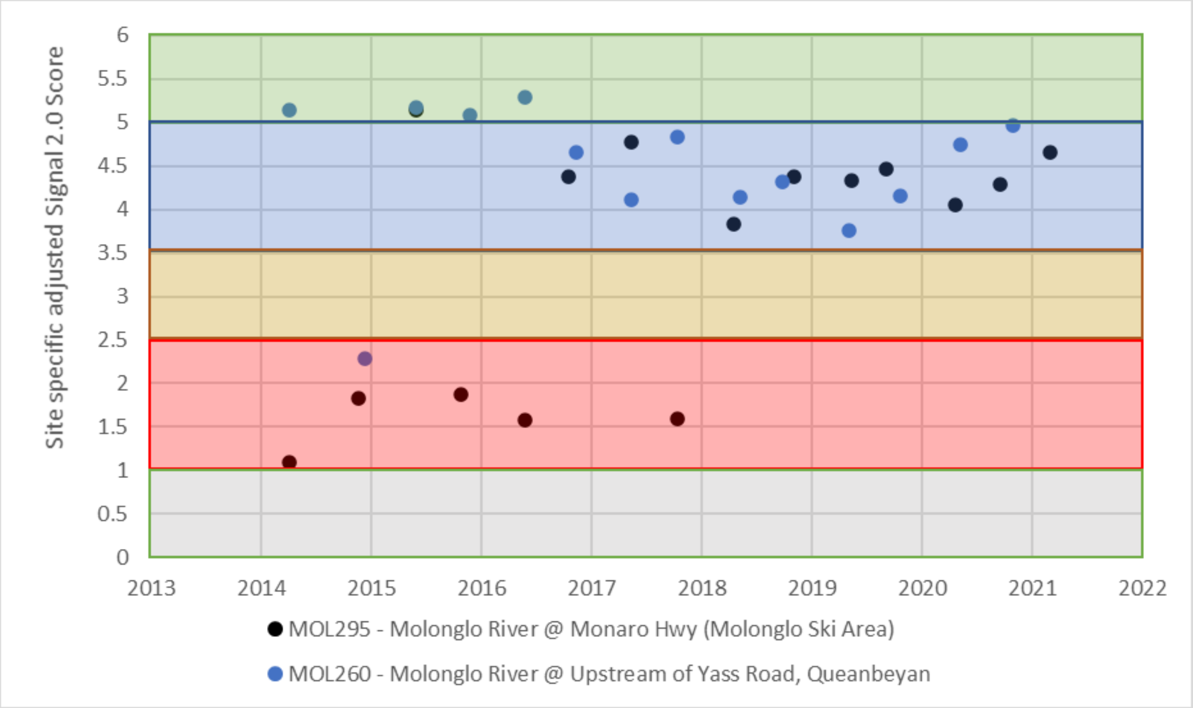

Figure 105. Adjusted SIGNAL 2.0 scores for Molonglo River upstream of Lake Burley Griffin from 2014 to 2021. Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes, where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

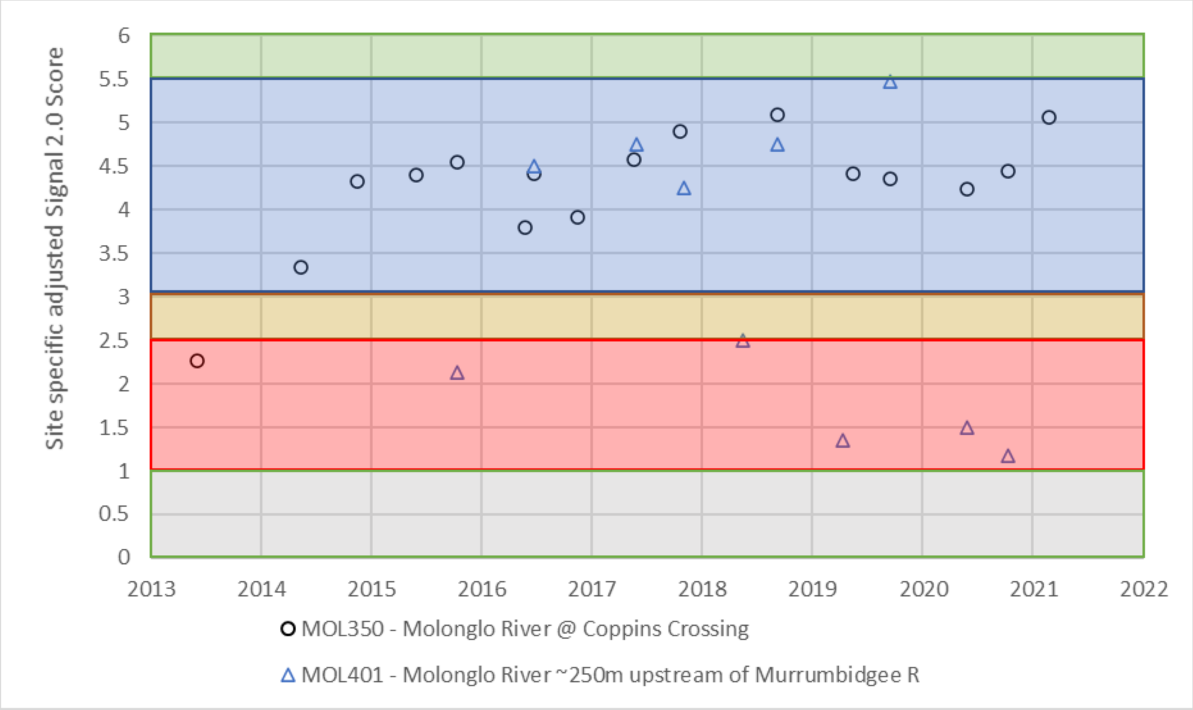

Figure 106. Adjusted SIGNAL 2.0 scores for Molonglo River downstream of Lake Burley Griffin from 2014 to 2021.

Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes, where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

H. Water quality data analysis: Sullivans Creek 2011–2021

Sullivans Creek commences in Goorooyarroo Nature Reserve near Old Joe Hill and flows through the rapidly developing suburbs of Throsby and Harrison and the grasslands of Kenny before flowing through the older suburbs of Canberra's inner north, including the ANU, and flowing into Lake Burley Griffin. There are essentially three reaches for Sullivans Creek: the upper reach, that runs from Old Joe Hill through to the north of Lyneham; the mid reach, that comprises a concrete drain through the older suburbs of inner north Canberra; and the lower reaches through the ANU. While some water quality monitoring is undertaken in the upper and mid reaches of the creek, data are either from wetlands rather than the creek, or sparse and cannot be confidently used to identify patterns and trends. Thus, the current assessment of Sullivans Creek uses three sites from the lower reach of the Creek, which are at Toad Hall Pond, Fellows Oval and the ANU boat ramp. It should be noted that these lower reaches of Sullivans Creek are not a true representation of the main creek system and therefore conclusions drawn do not indicate the overall state.

Summary data (Table 35) indicate that only pH and conductivity are commonly within the acceptable range for urban streams in Canberra, with the sites monitored in Sullivans Creek regularly displaying low dissolved oxygen concentrations, high phosphorus, nitrate and turbidity concentrations.

Table 35. Annual average of the percentage of data points recorded within Sullivans Creek that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4). Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range.

	Dissolved oxygen	pH	Total phosphorus	Nitrate	Electrical conductivity	Turbidity
2011	-	100	-	-	72	32
2012	-	100	-	-	70	52
2013	-	100	-	-	65	62
2014	45	100	44	-	86	63
2015	0	100	53	67	84	66
2016	57	100	17	55	72	55
2017	52	100	25	61	79	48
2018	52	100	12	64	56	52
2019	45	100	12	88	73	52
2020	54	100	40	80	90	17
2021	50	100	75	25	75	17

H.1 Nutrients

Around 70% of phosphorus concentrations and 35% of nitrate concentrations in Sullivans Creek have been above the acceptable range of concentrations, with some quite high concentrations recorded in the data set (Figure 107 and Figure 108). These concentrations are similar to those recorded by (Ubrihien et al. 2019a) at sites downstream of the urban ponds within the Sullivans Creek stream network.

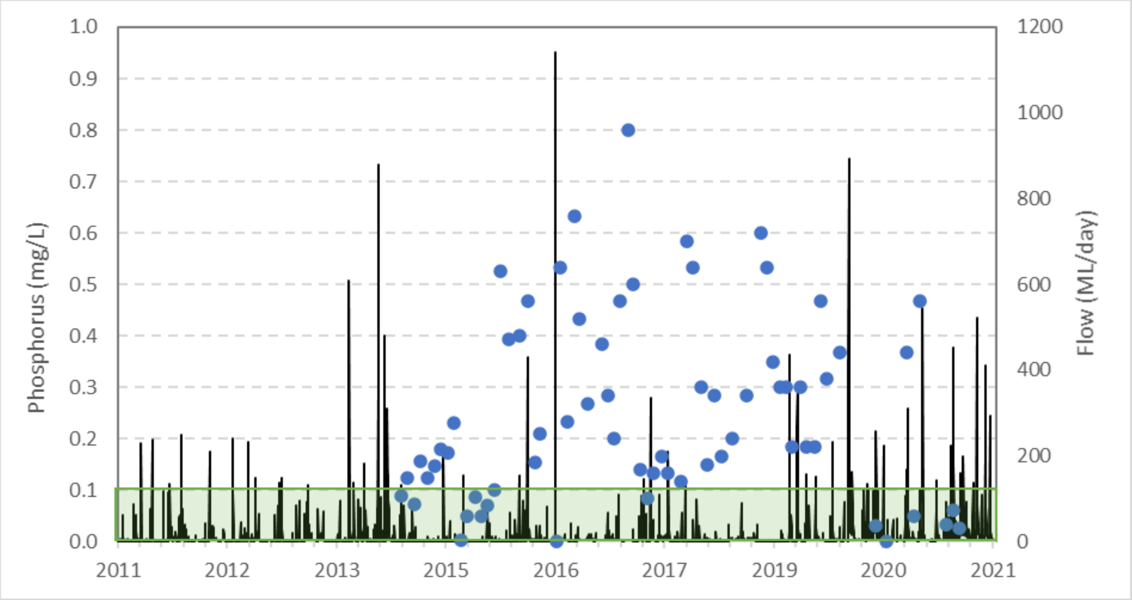

Figure 107. Phosphorus concentrations (mg/L) and flow (ML/day) within Sullivans Creek from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for phosphorus concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

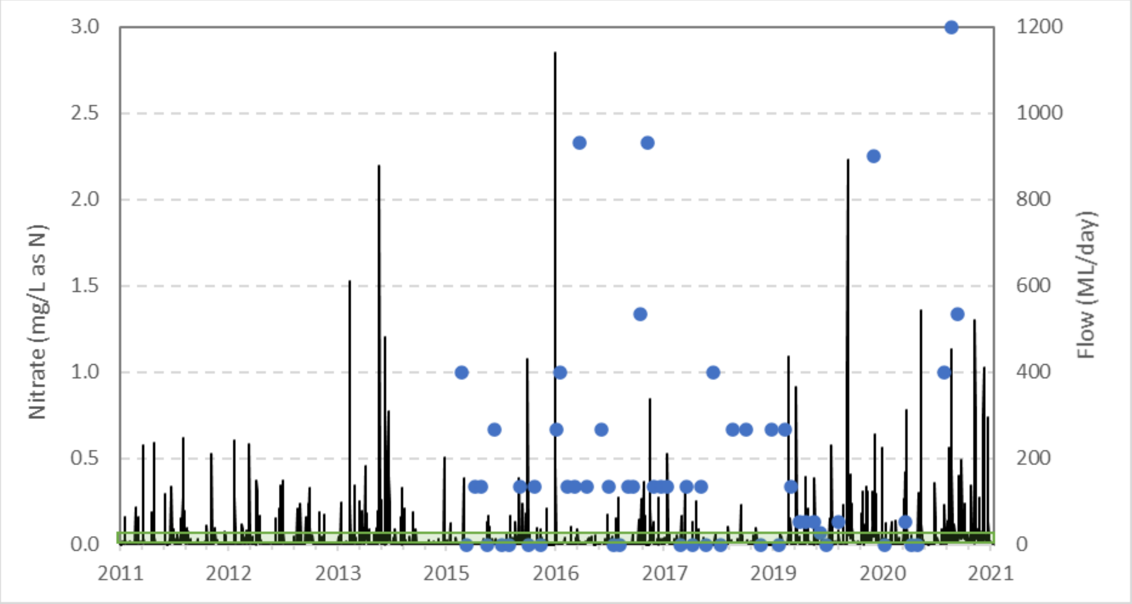

Figure 108. Nitrogen concentrations (mg/L) and flow (ML/day) within Sullivans Creek from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for nitrogen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

H.2 pH

pH recordings in Sullivans Creek are always within the acceptable range (Figure 109).

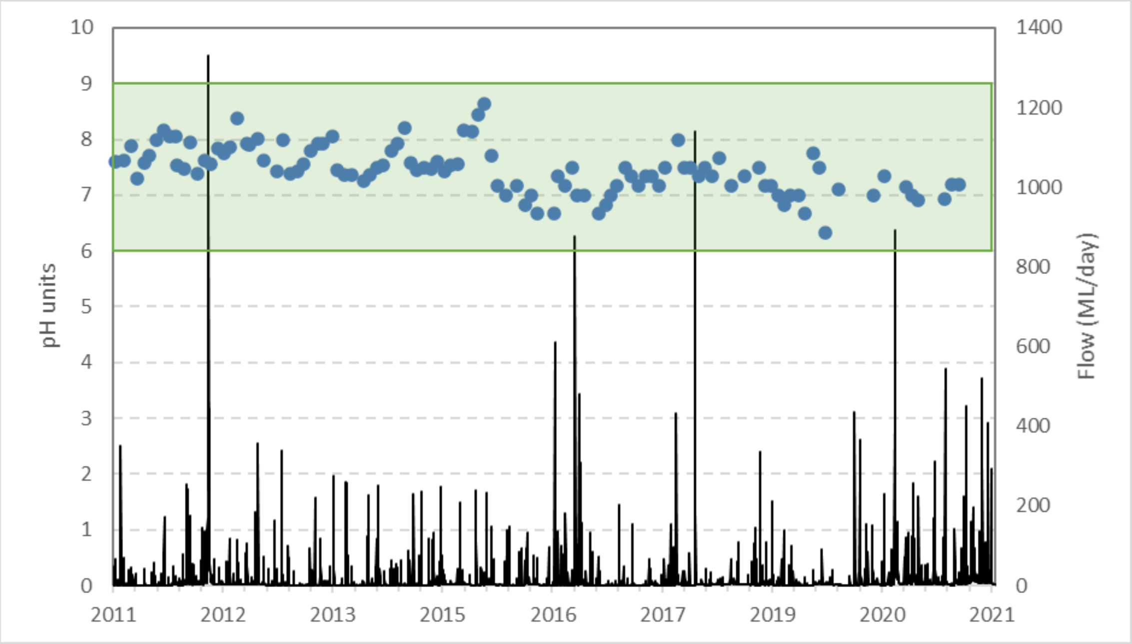

Figure 109. pH and flow (ML/day) within Sullivans Creek from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

H.3 Turbidity

Turbidity in Sullivans Creek is regularly outside the acceptable range, with around 70% of sampling points above 10 NTU (Figure 110). The highest concentrations appear to be associated with periods of higher flow in the creek, however there is not a strong relationship between flow and turbidity (data not shown), as there is considerable scatter in the data and there are few measurements when flows are higher than 50 ML/day.

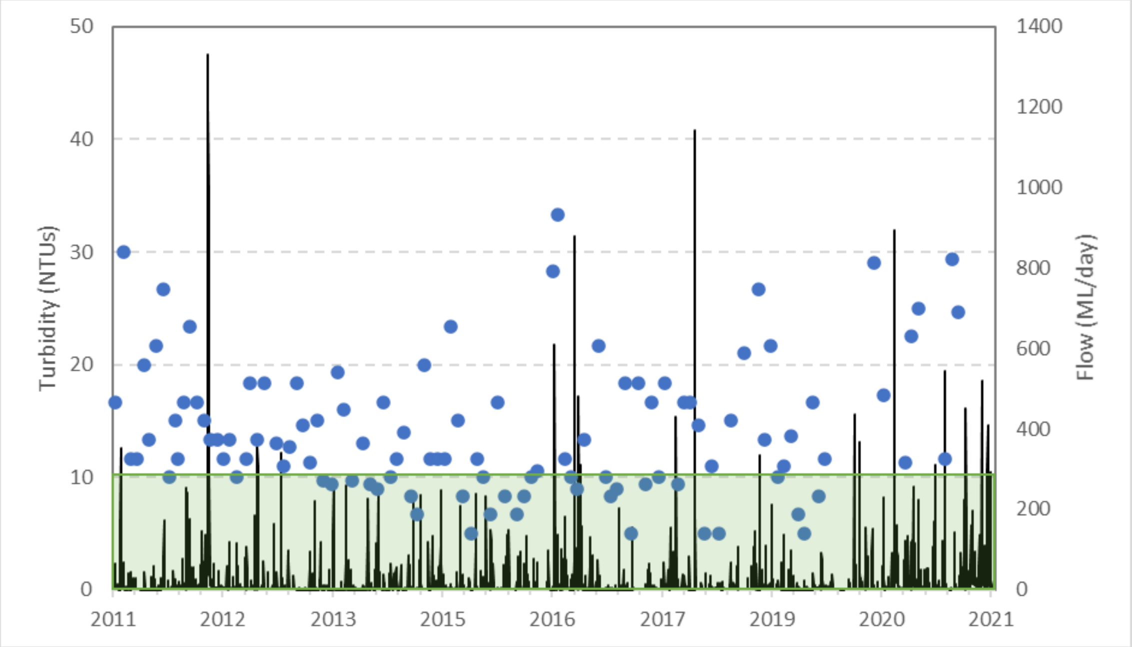

Figure 110. Turbidity (NTU) and flow (ML/day) within Sullivans Creek from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

H.4 Electrical conductivity

Electrical conductivity recordings within Sullivans Creek are within the acceptable range for 74% of the time (Figure 111) and are consistent with those recorded in the other urban creeks and rivers evaluated.

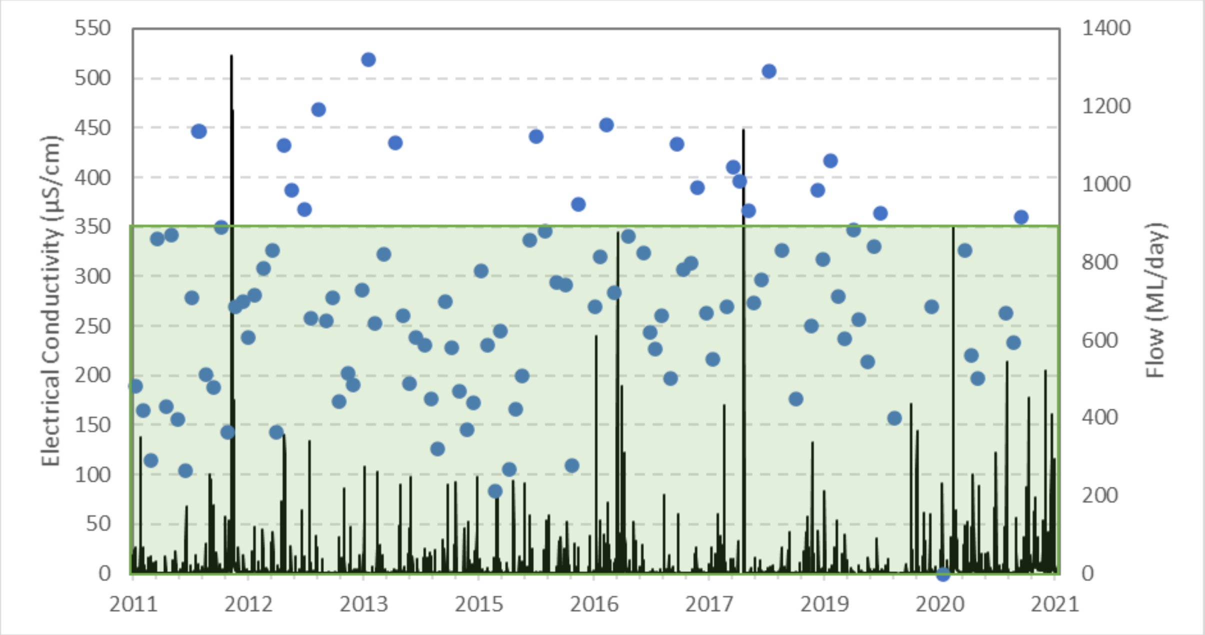

Figure 111. Electrical conductivity (µS/cm) and flow (ML/day) within Sullivans Creek from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for electrical conductivity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

H.5 Dissolved oxygen

Dissolved oxygen concentrations in the lower reach of Sullivans Creek are below acceptable levels for > 50% of sampling occasions (Figure 112). During 2015, all recorded concentrations were below acceptable concentrations, with readings ranging from 2.1 to 5.8 mg/L. The low dissolved oxygen concentrations are likely the result of the high biological oxygen demand in the creek from the accumulation of organic matter. In addition, the most downstream sampling point is heavily influenced by Lake Burley Griffin.

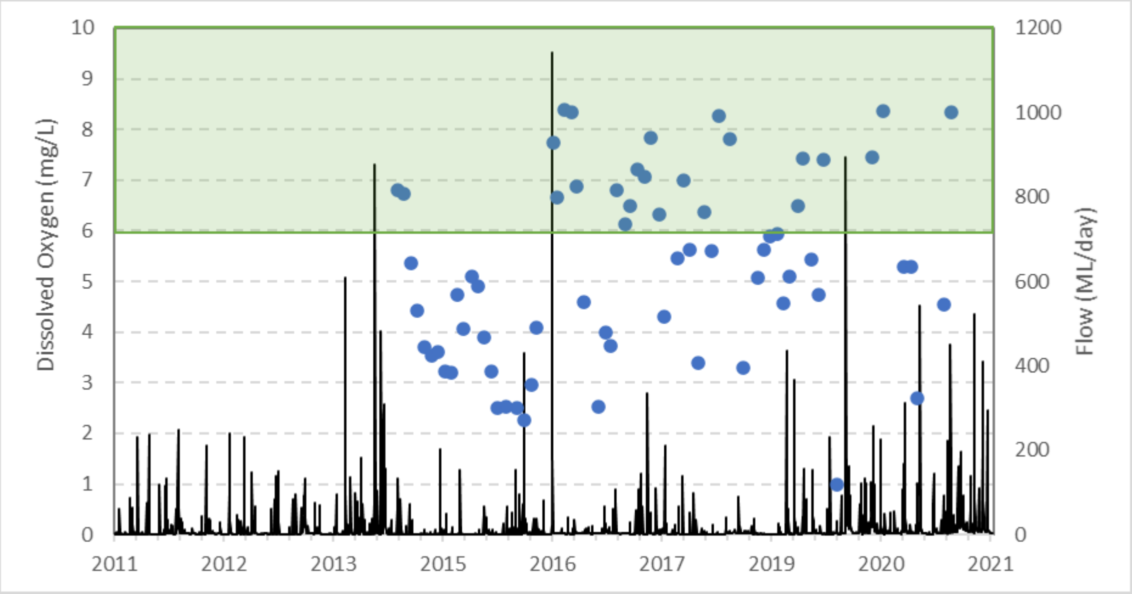

Figure 112. Dissolved oxygen (mg/L) and flow (ML/day) within Sullivans Creek from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

H.6 Ecological condition

Data collected from 2014 to 2021 as part of the Waterwatch Monitoring Program indicate that the condition of the macroinvertebrate communities of Sullivans Creek at the ANU boat ramp are consistently *good* (Figure 113). At the time of writing, insufficient data are available for further upstream sites to be able to assess overall condition of the entire Sullivans Creek system.

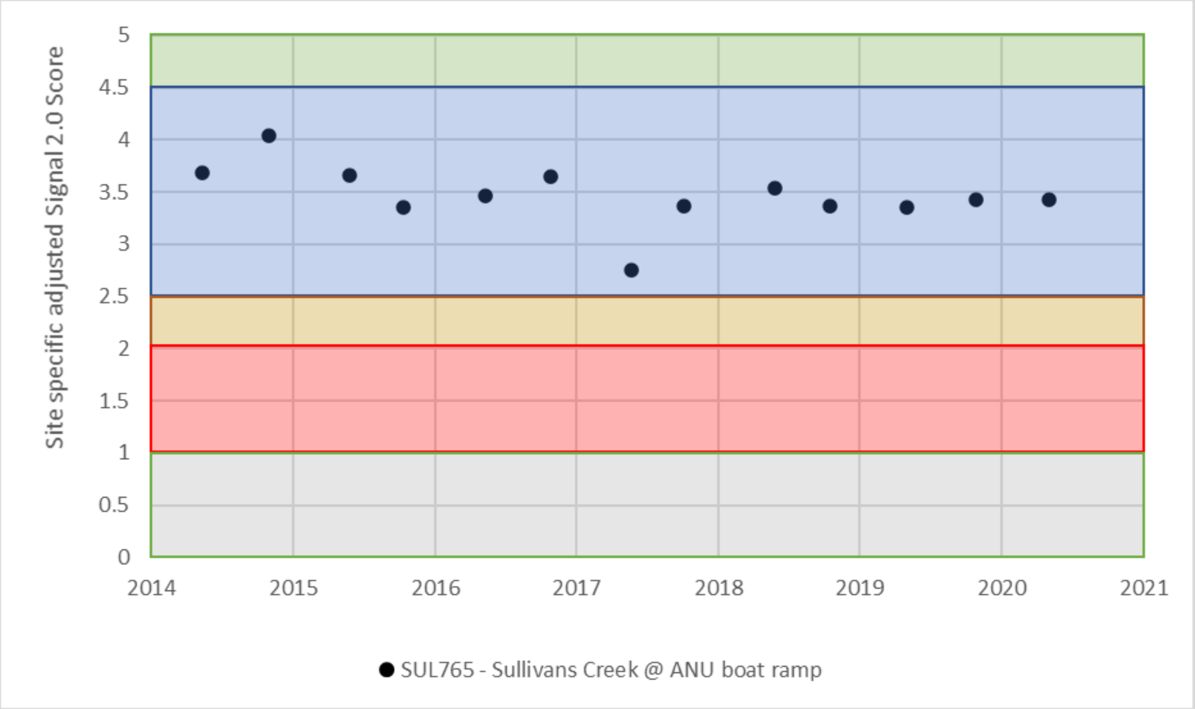

Figure 113. Adjusted SIGNAL 2.0 scores for the Sullivans Creek site SUL765 from 2014 to 2021.
Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes, where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

I. Water quality data analysis: Tuggeranong Creek 2011–2021

This assessment of Tuggeranong Creek incorporates data from four separate sampling locations upstream of Lake Tuggeranong and a single sampling location downstream of the lake, and uses data collected by the Waterwatch program, as well as the ACT Government Lakes and Rivers Water quality monitoring program (see Table 2), as it provides a data set that covers the duration required. Over the summer of 2019–2020, Ubrihien et al. (2020) investigated the concentrations and forms of nutrients in the creeks draining into Lake Tuggeranong, including Tuggeranong Creek. These data were collected weekly and included event sampling. Where appropriate, these data are included for comparison. Flow data are not currently available for Tuggeranong Creek upstream of Lake Tuggeranong.

Our focus in this analysis is Tuggeranong Creek and the data presented are from the sites upstream and downstream of Lake Tuggeranong. However, there are multiple creeks that drain into Lake Tuggeranong, including the major inputs of Kambah Creek and Village Creek. Because of these inputs, a simple upstream/downstream comparison of Tuggeranong Creek does not provide an appropriate interpretation of the water quality performance of the lake. To aid interpretation of the upstream/downstream differences in Tuggeranong Creek water quality, summary data from Ubrihien et al. (2020) is provided in tabular form.

Summary data for Tuggeranong Creek (Table 36) show that upstream of the lake, pH and concentrations of dissolved oxygen and phosphorus are typically within the acceptable range of values for urban streams for more than 80% of readings. In contrast, concentrations of nitrates, electrical conductivity and turbidity are frequently outside of the acceptable range of values for urban streams, with high nitrate concentrations and high electrical conductivity a feature of these sampling locations, reflecting the high proportion of concrete drains sampled.

Table 36. Annual average of the percentage of the Waterwatch data points recorded within Tuggeranong Creek upstream of Lake Tuggeranong that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4). Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range.

	Dissolved oxygen	pH	Total phosphorus	Nitrate	Electrical conductivity	Turbidity
2011	88	100	-	-	50	100
2012	88	100	-	-	100	88
2013	100	100	-	-	25	100
2014	100	40	100	60	40	80
2015	91	92	100	43	71	46
2016	98	93	100	51	82	50
2017	100	98	100	84	52	59
2018	97	92	100	69	39	83
2019	92	94	100	81	28	97
2020	85	86	96	39	79	75
2021	96	96	88	23	64	48

Downstream of Lake Tuggeranong (Table 37), dissolved oxygen concentrations and pH remain well within the acceptable range of values for urban streams, but total phosphorus concentrations are more frequently outside the acceptable range. This is most likely a consequence of the range of other high nutrient inputs to Lake Tuggeranong (Village Creek and Kambah Creek; see later commentary). Interestingly, at the sites downstream of Lake Tuggeranong, electrical conductivity values are almost always within the acceptable range of values, reflecting the more natural stream environment sampled and highlighting the influence of local stream character for some water quality attributes.

Table 37. Annual average of the percentage of the Waterwatch and ALS data points recorded within Tuggeranong Creek downstream of Lake Tuggeranong that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

	Dissolved oxygen	pH	Total phosphorus	Nitrate	Electrical conductivity	Turbidity
2011	75	92	-	-	92	58
2012	75	92	-	-	92	50
2013	75	100	-	-	92	92
2014	75	100	83	60	92	58
2015	56	89	100	11	88	44
2016	100	100	100	0	100	50
2017	78	100	100	11	100	89
2018	88	100	88	0	100	63
2019	100	100	89	0	100	44
2020	100	100	100	18	100	27
2021	100	100	86	0	100	43

I.1 Nutrients

The Waterwatch data show concentrations of phosphorus in Tuggeranong Creek upstream of Lake Tuggeranong are consistently within the acceptable range for 99% of the time (Figure 114), the exceptions are records from 2020 and 2021 (see Table 36). The concentrations of phosphorus recorded in baseflow concentrations in Tuggeranong Creek by Ubrihien et al. (2020) are consistent with those of Waterwatch, but those recorded from other creeks in the Tuggeranong catchment are considerably higher, particularly from Village Creek and the Wanniassa tributary (Table 38). This suggests there is considerable spatial variation in the nutrient concentrations in the urban creeks of the Tuggeranong catchment. Concentrations of phosphorus in event flows from all the Tuggeranong streams are considerably higher again (Ubrihien et al. 2020), indicating the low flow sampling conducted by the Waterwatch teams are under-representing the concentrations of nutrients in the stormwater network.

Phosphorus concentrations are higher in the site downstream of Lake Tuggeranong, with recorded levels within the acceptable range for > 80% of the time (Figure 115 and see Table 37), but as previously mentioned, comparing the downstream concentrations with concentrations only from Tuggeranong Creek inflows is not an appropriate indication of the performance of the lake.

Nitrate concentrations recorded in the upstream reaches of Tuggeranong Creek have been within the acceptable range for < 60% of sampling occasions (Figure 116), with the data collected in 2020 and 2021 more frequently outside the acceptable range (see Table 36). These data are consistent with those of Ubrihien et al. (2020) from Tuggeranong Creek, but are lower than the concentrations of nitrate and total nitrogen observed in other tributaries of the Tuggeranong Catchment (Table 39). Nitrogen concentrations are higher in Tuggeranong Creek downstream of Lake Tuggeranong, with only rare instances of records within acceptable range (Figure 117 and see Table 37). These concentrations are similar to those recorded in the lake (see Figure 49) and those of other Tuggeranong streams (Table 39).

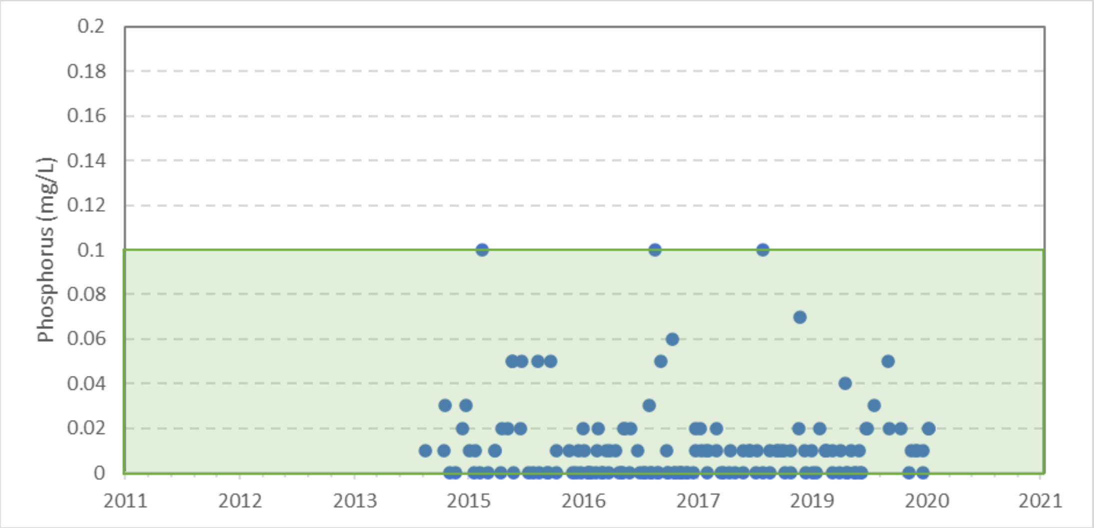

Figure 114. Phosphorus concentrations (mg/L) within Tuggeranong Creek upstream of Lake Tuggeranong from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for phosphorus concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

Table 38. Summary statistics for total phosphorus concentrations in baseflow sampling from the creeks within the Tuggeranong catchment. Data sourced from Ubrihien et al. (2020).

n = the number of samples, s.d. = the standard deviation in the data, min = the minimum value recorded, max = the maximum value recorded

		Total phosphorus concentrations (mg/L)				
Site	**n**	**Mean**	**s.d.**	**median**	**min**	**max**
Fadden Arm	80	0.064	0.059	0.052	0.009	0.380
Kambah Ck	70	0.080	0.148	0.038	0.003	0.932
Tuggeranong Ck	71	0.055	0.104	0.033	0.010	0.866
Village Ck	34	0.131	0.102	0.108	0.018	0.540
Wanniassa St	13	0.306	0.295	0.185	0.119	1.134

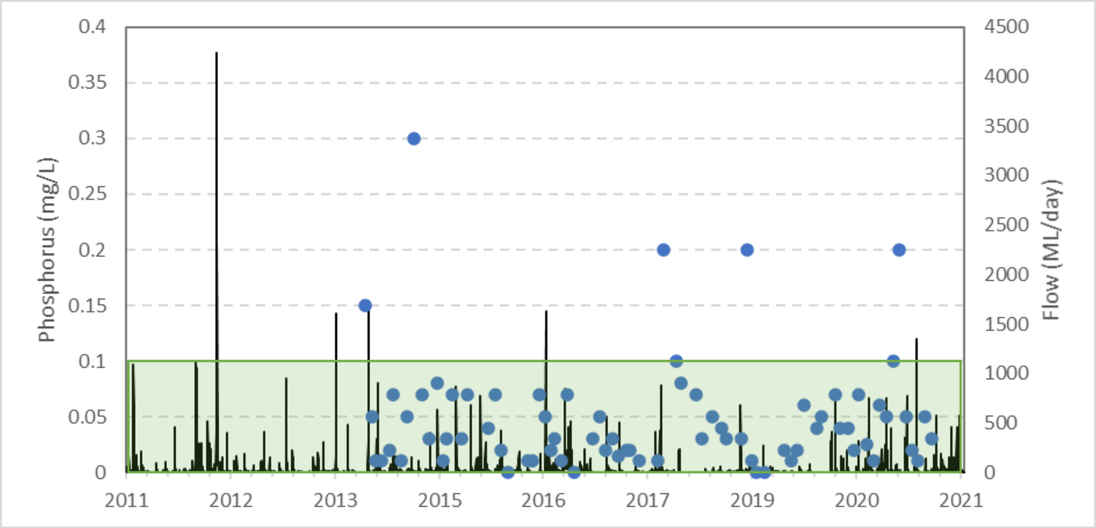

Figure 115. Phosphorus concentrations (mg/L) and flow (ML/day) within Tuggeranong Creek downstream of Lake Tuggeranong from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for phosphorus concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

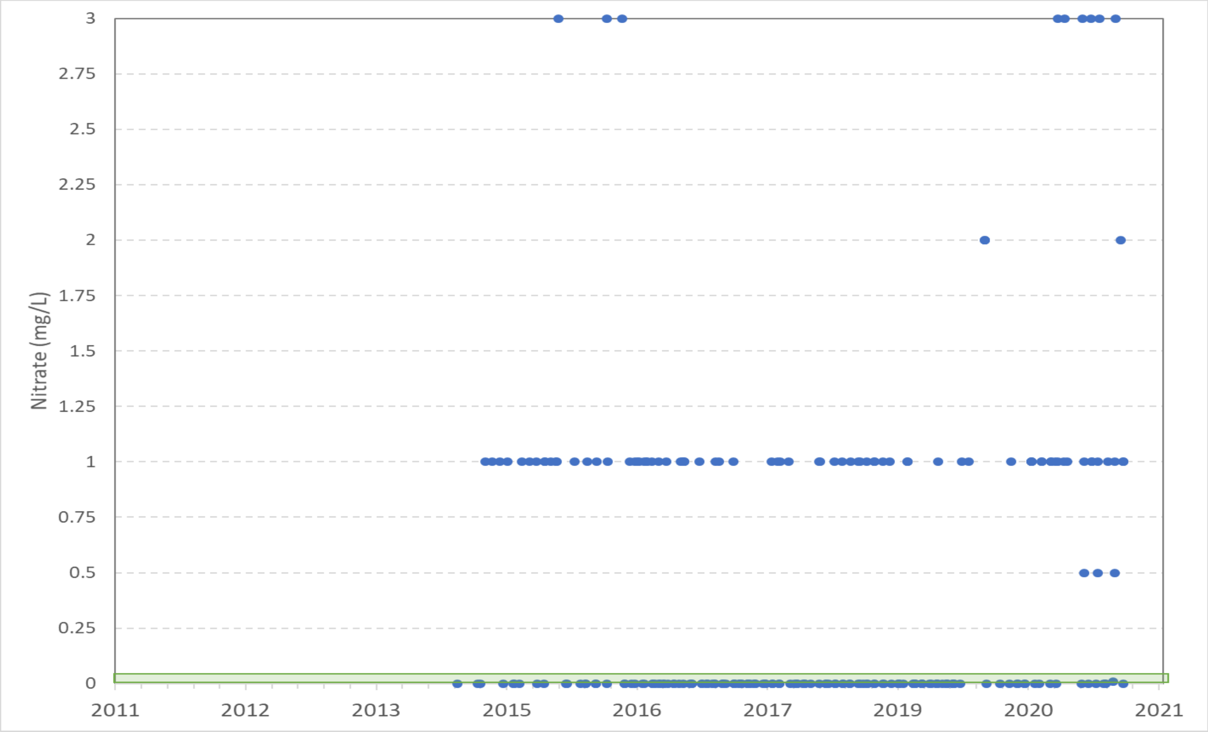

Figure 116. Nitrate concentrations (mg/L) within Tuggeranong Creek upstream of Lake Tuggeranong from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for nitrate concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

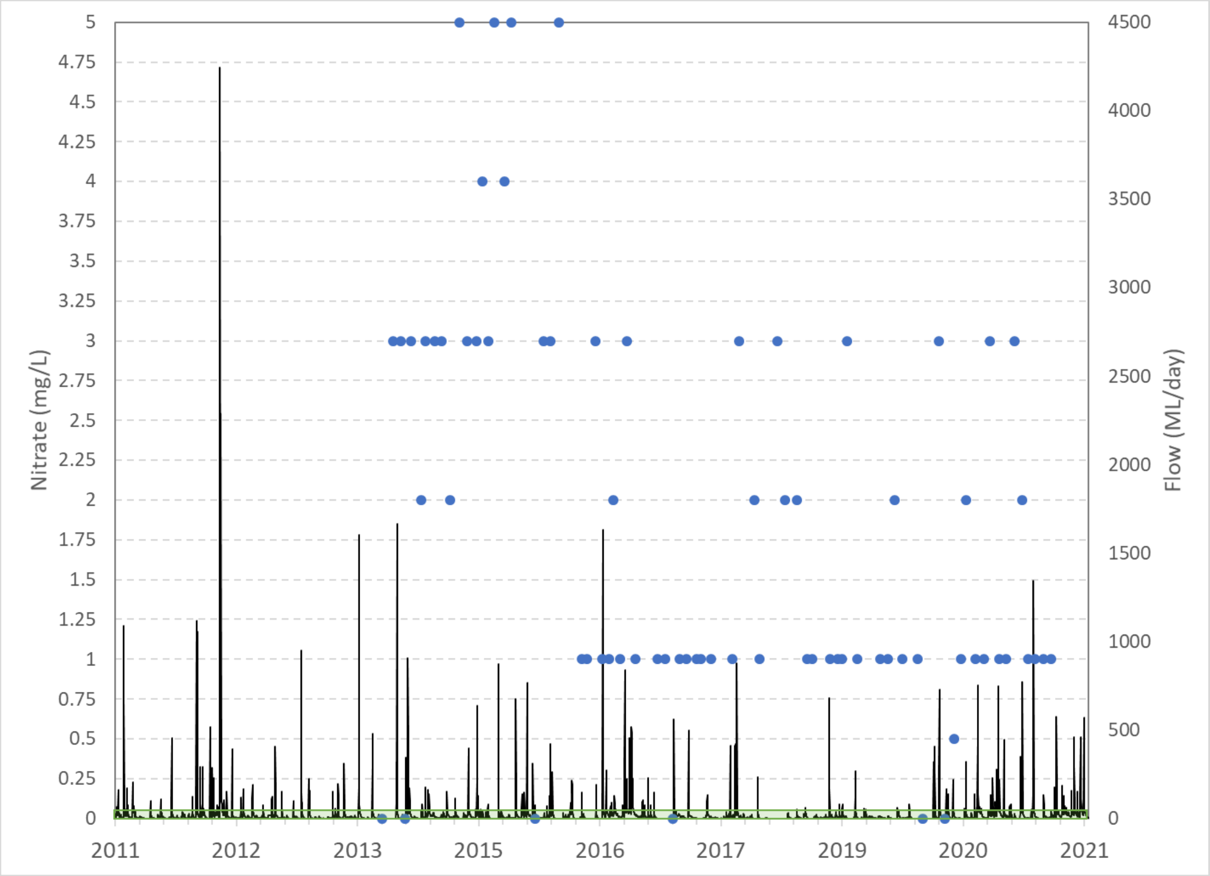

Figure 117. Nitrate concentrations (mg/L) and flow (ML/day) within Tuggeranong Creek downstream of Lake Tuggeranong from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for nitrate concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

Table 39. Summary statistics for total nitrogen and nitrate/nitrite concentrations (mg/L) in baseflow sampling from the creeks within the Tuggeranong catchment. Data sourced from (Ubrihien et al. 2020).

n = the number of samples, s.d. = the standard deviation in the data, min = the minimum value recorded, max = the maximum value recorded

		Total nitrogen concentration (mg/L)					Nitrate and nitrite concentration (mg/L)				
Site	n	mean	s.d.	med	min	max	mean	s.d.	med	min	max
Fadden Arm	80	1.29	1.46	0.96	0.20	10.40	0.51	0.89	0.17	0.02	5.60
Kambah Ck	70	2.40	1.68	2.22	0.22	6.51	1.55	1.29	1.29	0.02	6.95
Tugg Ck	71	0.83	0.40	0.76	0.20	2.38	0.23	0.32	0.10	0.02	1.97
Village Ck	34	2.84	2.43	2.41	0.48	13.60	1.62	1.45	1.33	0.05	6.35
Wanniassa St	13	3.28	2.24	2.14	0.77	7.40	1.48	1.80	0.39	0.02	4.45

I.2 pH

pH recordings in Tuggeranong Creek upstream of Lake Tuggeranong are within the acceptable range for > 90% of the time, with some occurrences of high readings (pH of 10) during the 2014 sampling period (Figure 118). pH recordings in Tuggeranong Creek downstream of the lake are consistently within the acceptable range for 95% of the time (Figure 119).

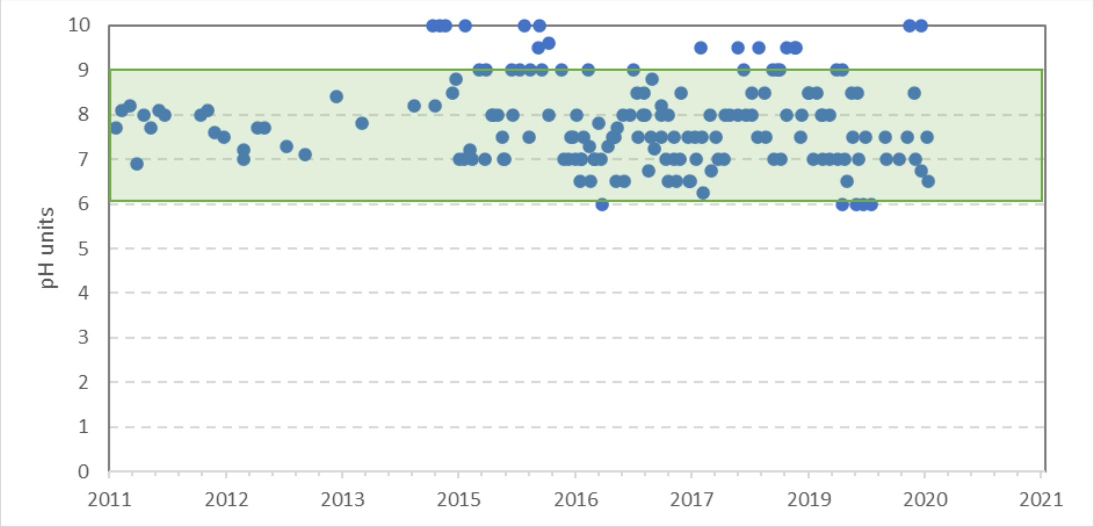

Figure 118. pH within Tuggeranong Creek upstream of Lake Tuggeranong from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

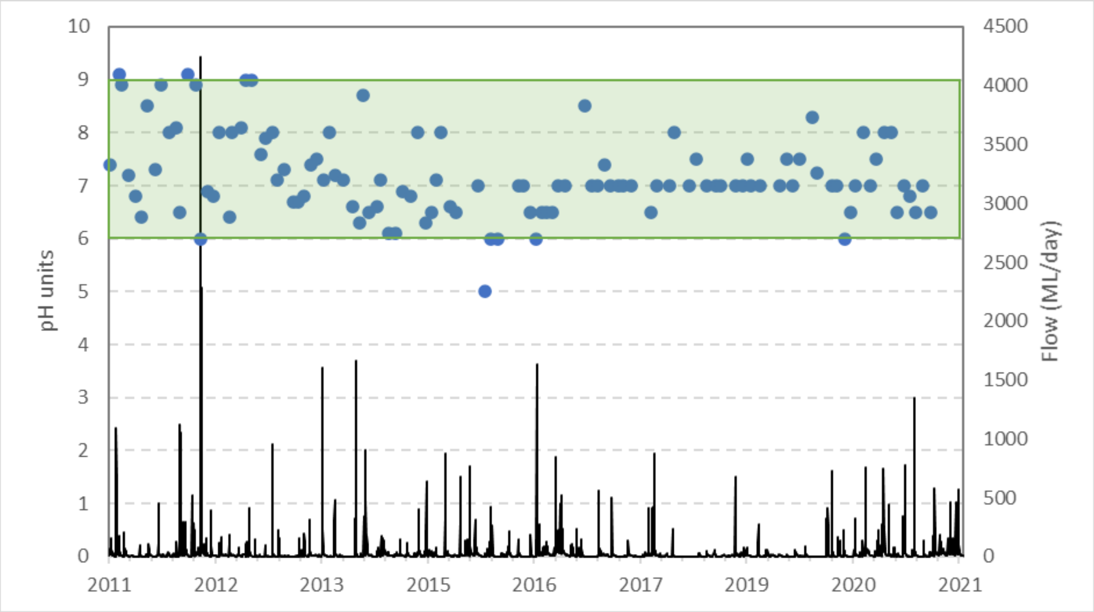

Figure 119. pH and flow (ML/day) within Tuggeranong Creek downstream of Lake Tuggeranong from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for pH concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

I.3 Turbidity

Turbidity in Tuggeranong Creek upstream of Lake Tuggeranong is outside of acceptable levels for > 60% of the time (Figure 120). Between 2015 and 2019, there were considerable periods of time when the recorded turbidity was well above the acceptable levels. There is no clear reason for this in the records kept for the region, but it may have been caused by local construction work. The data indicate that turbidity readings downstream of the lake were outside of acceptable levels for > 70% of the time (Figure 121), suggesting the lake was not effective at improving the turbidity levels in Tuggeranong Creek.

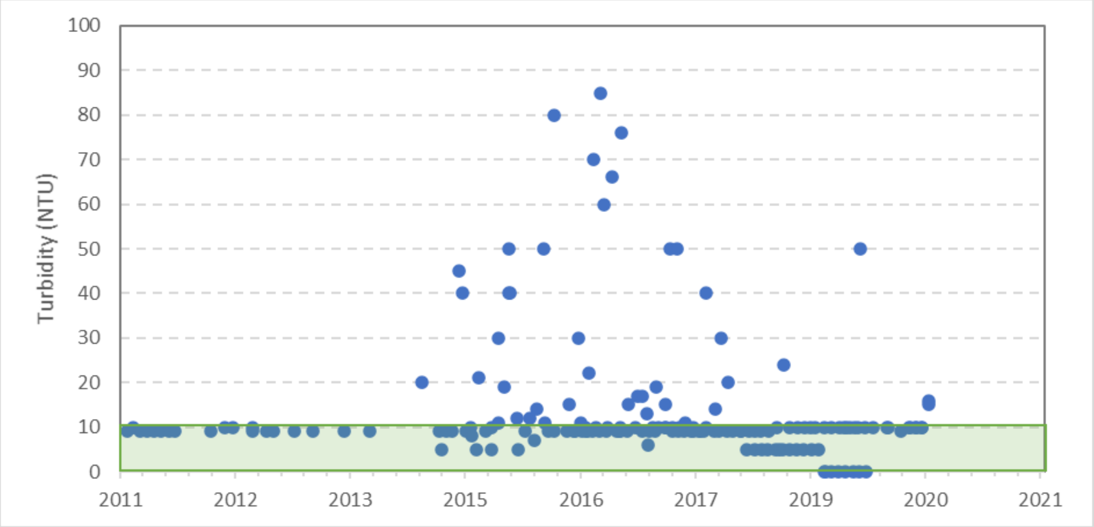

Figure 120. Turbidity within Tuggeranong Creek upstream of Lake Tuggeranong from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

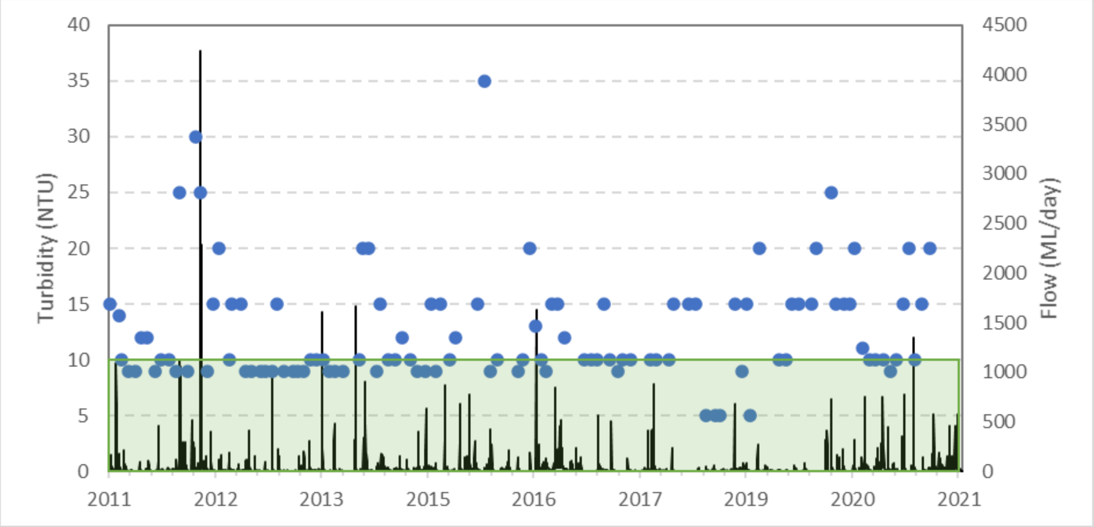

Figure 121. Turbidity and flow (ML/day) within Tuggeranong Creek downstream of Lake Tuggeranong from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for turbidity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

I.4 Electrical conductivity

Electrical conductivity recordings in Tuggeranong Creek upstream of Lake Tuggeranong are within the acceptable range for < 60% of the time, with an improvement to > 95% of the time in the downstream reaches of Tuggeranong Creek (Figure 122 and Figure 123). The upstream reaches of Tuggeranong Creek displayed higher concentrations from 2015 to 2019, possibly because of drier conditions, with a decline in values from 2020 to 2021 with the return of wetter conditions.

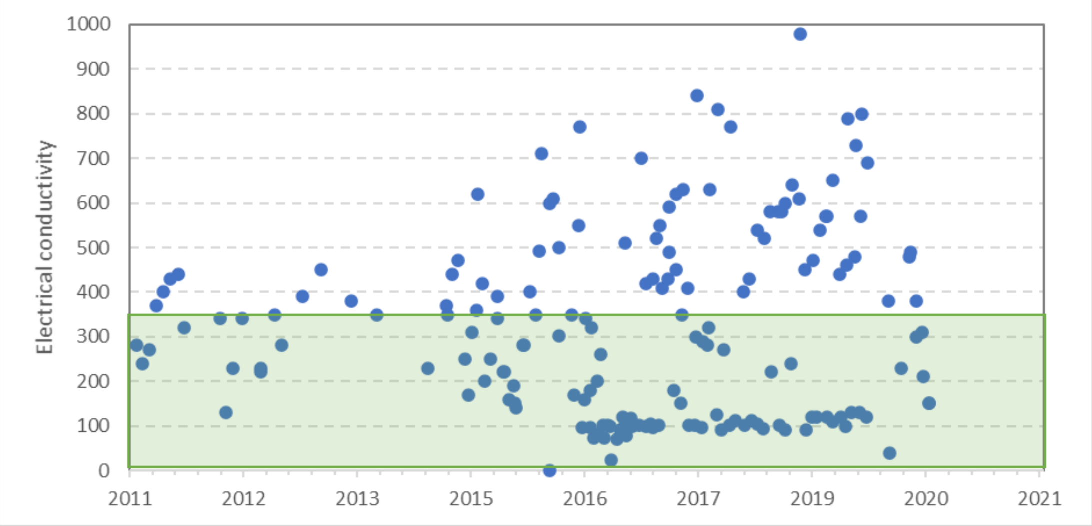

Figure 122. Electrical conductivity within Tuggeranong Creek upstream of Lake Tuggeranong from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for electrical conductivity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

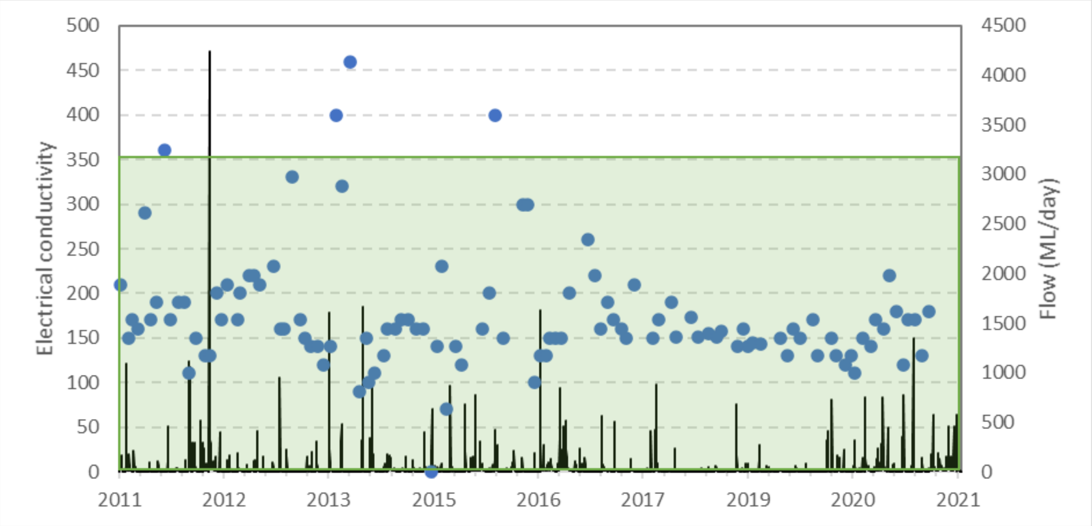

Figure 123. Electrical conductivity and flow (ML/day) within Tuggeranong Creek downstream of Lake Tuggeranong from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for electrical conductivity outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

I.5 Dissolved oxygen

Dissolved oxygen concentrations in Tuggeranong Creek upstream of Lake Tuggeranong are within acceptable levels for 95% of the time (Figure 124). In the reaches downstream of Lake Tuggeranong, dissolved oxygen concentrations are within acceptable limits for 80% of the time (Figure 125). It is not clear why this is the case. It is possible this is an artefact of differences in sampling frequency in the data between 2011 and 2015 when most low dissolved oxygen occurrences in the downstream sites were observed. Since 2016, the data are far more comparable (see Table 36 and Table 37).

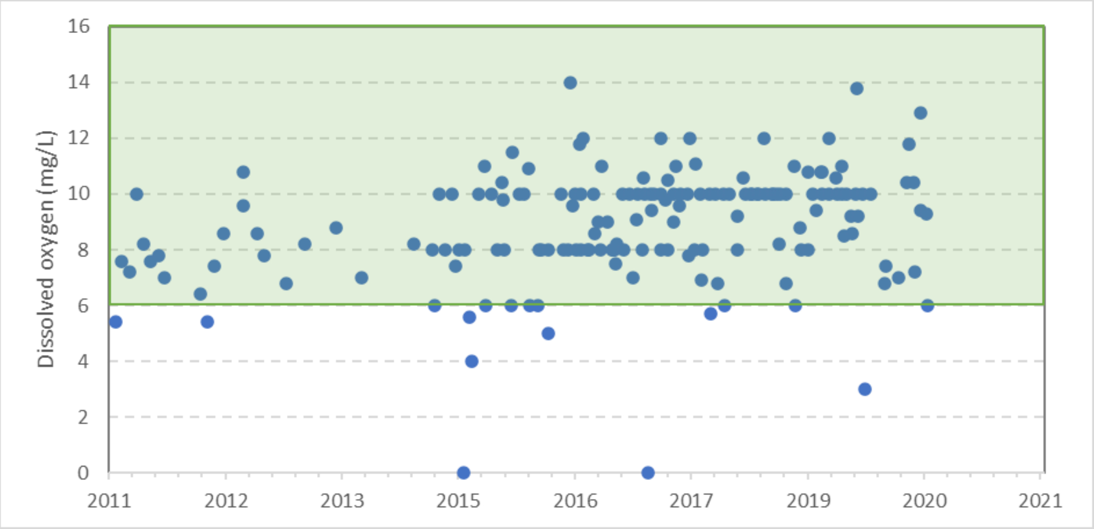

Figure 124. Dissolved oxygen within Tuggeranong Creek upstream of Lake Tuggeranong from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

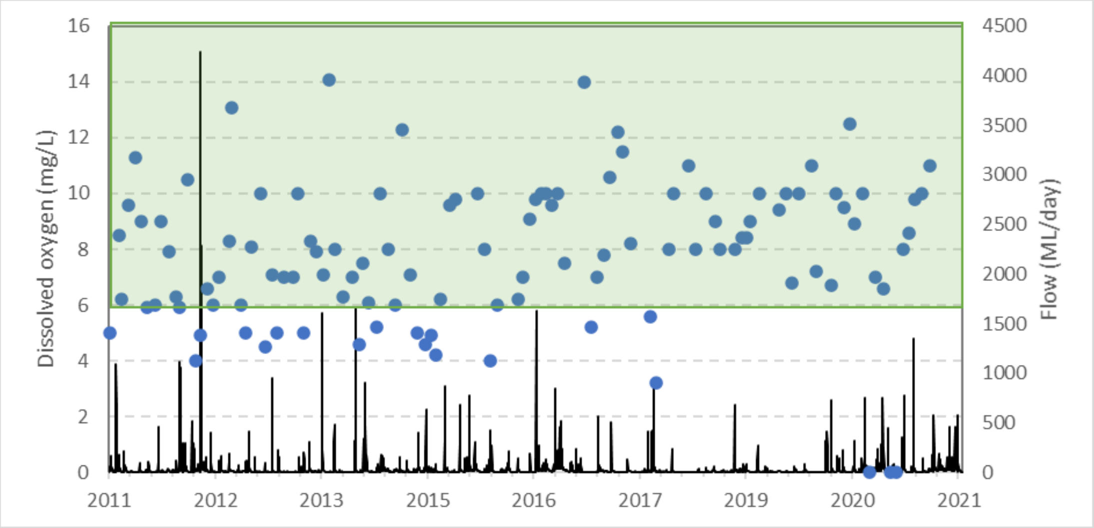

Figure 125. Dissolved oxygen and flow (ML/day) within Tuggeranong Creek downstream of Lake Tuggeranong from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green band shows the acceptable range for dissolved oxygen concentrations outlined in the Environment Protection Regulation 2005 values for urban drains and streams (AQUA/4).

I.6 Ecological condition

Data collected in spring and autumn each year as part of the ACT Water Quality Monitoring Program indicate the macroinvertebrate communities of the Tuggeranong Creek downstream of Lake Tuggeranong are typically significantly to severely impaired (Figure 126 and Figure 127). The spring macroinvertebrate community in the river has varied in condition over the 10 years, ranging from severely impaired to almost similar to reference, with the data from 2018 to 2020 very close to being classed as similar to reference (Figure 126). The autumn data are more consistently classed as significantly impaired but there is an overarching, slight trend of improving condition over the past 10 years, the reasons for which are unclear (Figure 127). Macroinvertebrate data collected as part of the Waterwatch program tells a similar story (

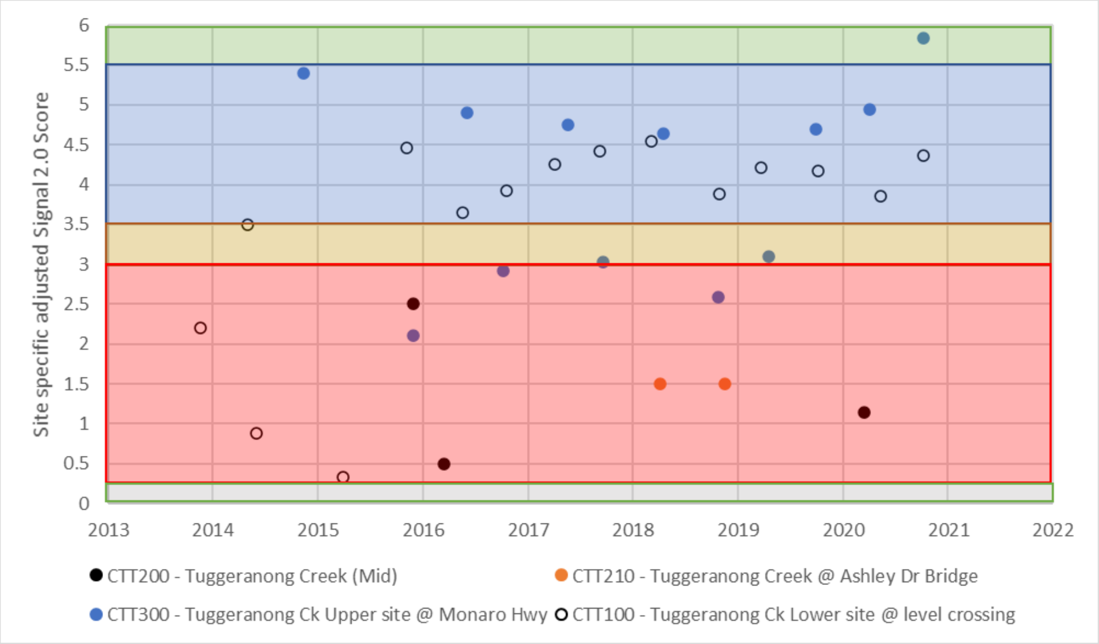

Figure 128), with sites downstream of Lake Tuggeranong consistently classed as displaying a *good* macroinvertebrate community. Upstream of Lake Tuggeranong, the results are more variable and often classed as *poor*.

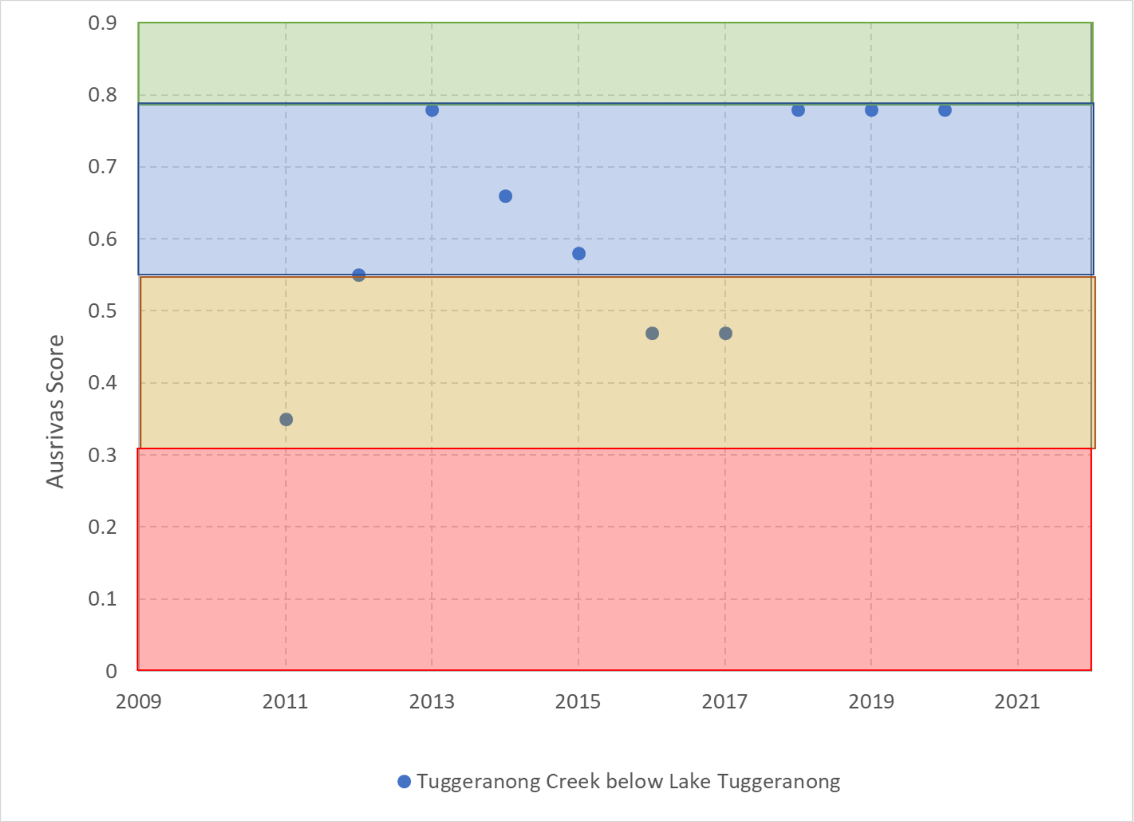

Figure 126. Spring AUSRIVAS scores for Tuggeranong Creek from 2011 to 2020.

Data from the ACT Monitoring Program. Coloured bands represent the AUSRIVAS O/E biological condition classes, where green is similar to reference (Band A), blue is significantly impaired (Band B), orange is severely impaired (Band C) and red is extremely impaired (Band D).

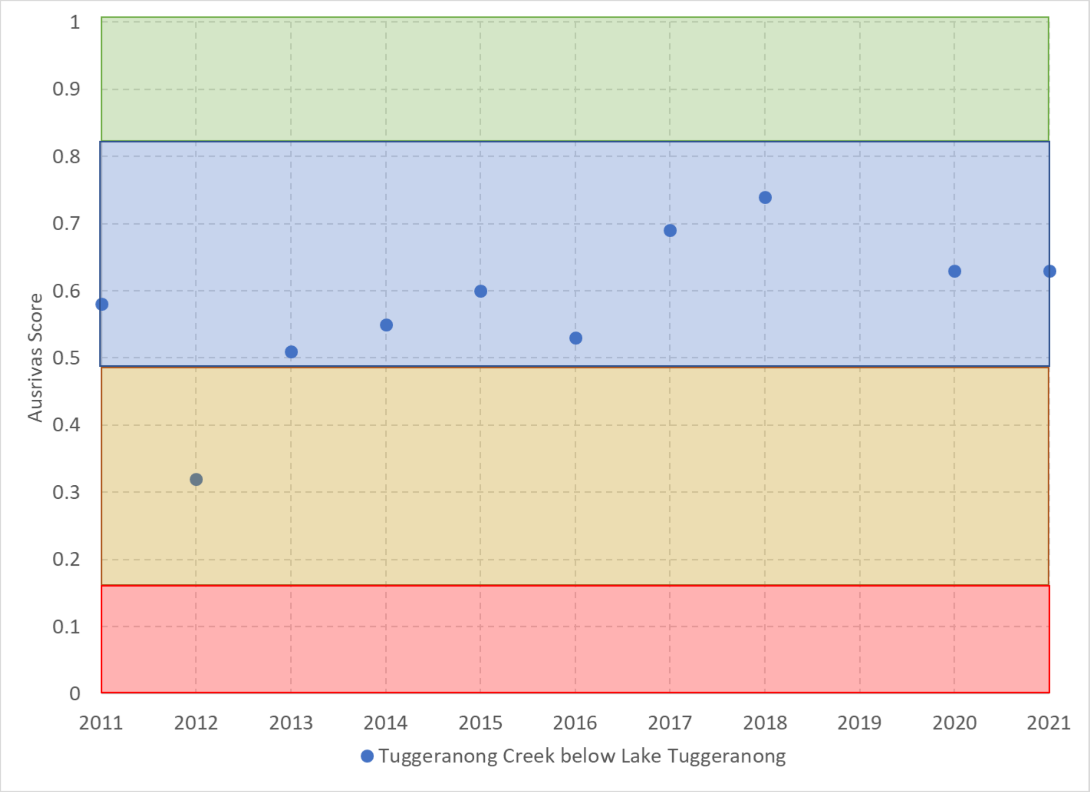

Figure 127. Autumn AUSRIVAS scores for Tuggeranong from 2011 to 2020.
Data from the ACT Monitoring Program. Coloured bands represent the AUSRIVAS O/E biological condition classes, where green is similar to reference (Band A), blue is significantly impaired (Band B), orange is severely impaired (Band C) and red is extremely impaired (Band D).

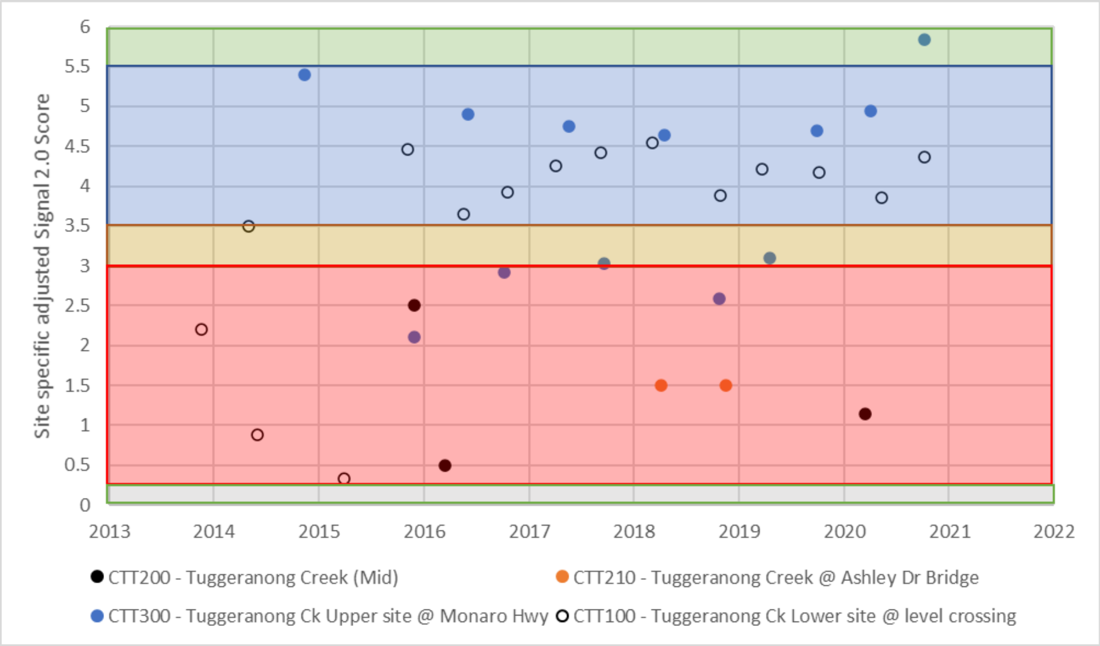

Figure 128. Adjusted SIGNAL 2.0 scores for Tuggeranong Creek upstream sites CTT200, CTT210 and CTT300, as well as Tuggeranong Creek downstream site CTT100 from 2014 to 2021.
Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes, where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

J. Riparian character of the urban creeks and rivers

Vegetation of the urban creeks and rivers in the ACT is made up of both native and invasive plant species, with the riparian zones consisting of grasses, trees and shrubs. This vegetation acts as a habitat for nesting birds, amphibians and small mammals that live along the creek side. In-stream vegetation provides refuge for aquatic animals and water bugs, with strong flows having a direct impact on this important refuge.

Creeks and rivers form an important part of the hydrological cycle, moving water across the landscape and transporting large amounts of nutrients and wastes. Streams with excellent riparian vegetation act as a filtration system for the water before it directly enters the waterbody, removing pollutants and re-charging the groundwater system.

In many suburbs, creeks such as Sullivans Creek and Yarralumla Creek have been lined with concrete to improve the transport of floodwaters away from life and property. In these areas, the riparian zone consists of mown grass, and lacks the vegetation that would support more natural ecosystems.

The Rapid Appraisal of the Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent*, *good*, *fair*, *poor* or *degraded* conditions. The average long-term data indicate the vegetation condition across the ACT's creeks and rivers are in *poor* condition for 61% of the time (Figure 129). No sites recorded *excellent* or *good* conditions, and Tuggeranong Creek upstream from Lake Tuggeranong recorded a *degraded* condition for 70% of the time (Figure 129). Tuggeranong Creek downstream from Lake Tuggeranong recorded the best condition, with 65% of recorded values in *fair* condition (Figure 129).

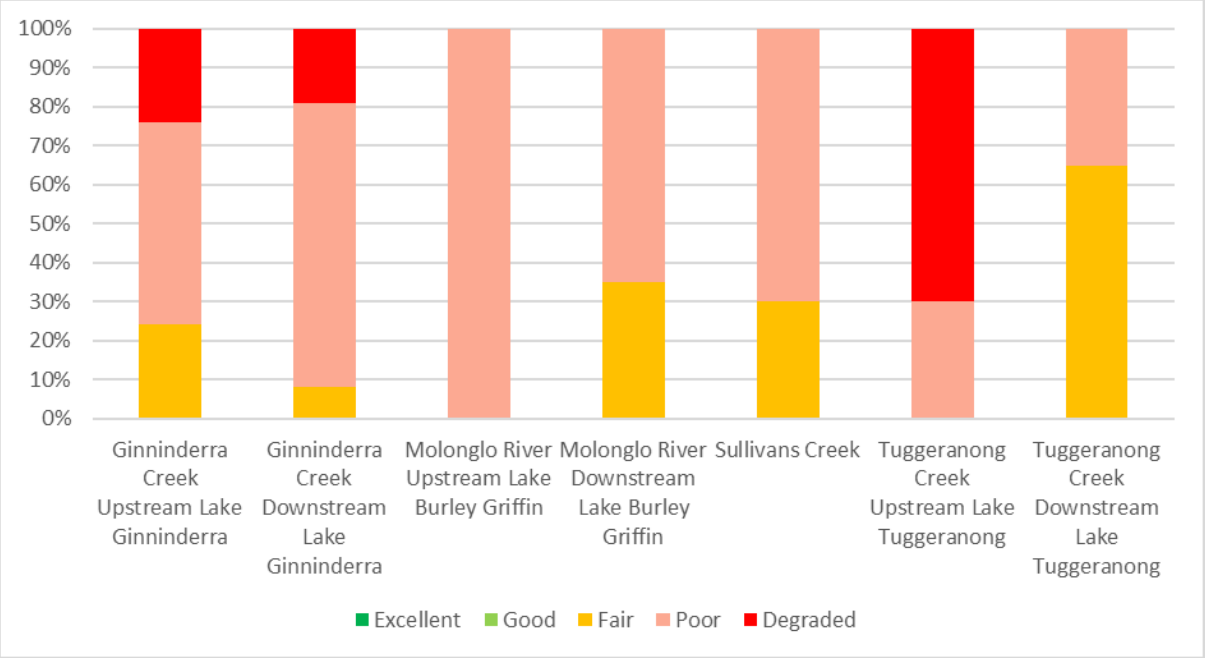

Figure 129. Relative proportions of riparian condition scores (using the Rapid Appraisal of Riparian Condition (RARC)) scores recorded between 2015 and 2021 for specific urban creeks and rivers in the ACT.

K. ACT’s Urban Ponds and Wetlands Technical Appendices

K.1 Document review: ACT’s urban ponds and wetlands water quality history

There are limited historical water quality assessments of the urban ponds and wetlands in the ACT. However, there are sites that have significant long-term data sets, in particular Point Hut Pond, which has been monitored since 1993.

A project conducted by Ubrihien et al. (2019a) monitored six ponds in the ACT between 2017 and 2019 to investigate and assess the water quality and ecological effects from fluctuating water levels. The study focused on nutrient removal and macrophyte community distribution and diversity. The ponds that were monitored were Coombs A Pond, Coombs B Pond, Dickson Pond, Lyneham Pond, Jarramlee Pond and Fassifern Pond. Of these, only Dickson Pond, Lyneham Pond and Jarramlee Pond are assessed in the current report as these have additional long-term data sets available that allows a longer-term assessment to be completed.

Ubrihien et al. (2019a) found the nutrient concentrations for nitrogen and phosphorus within the ponds were highly variable at both a spatial and temporal scale, with some concern that peak concentrations indicate some misuse of the stormwater system. Results indicated that water at the inflow of the ACT’s urban ponds was often high in nutrients and suspended solids (SS), and there was evidence of a general trend in a reduction of nutrient concentrations and SS from the inflow to the downstream section of the ponds. The substantial decreases in nitrogen concentrations and small decreases in phosphorus concentrations reported suggest the ponds are less effective at removing phosphorus than they are at removing nitrogen. Overall, the study demonstrated the urban ponds were effective at reducing nutrients and SS concentrations moving through the stormwater network and are therefore providing a valuable service to Canberra’s urban environments.

Alluvium (2016) undertook a review and analysis of the water quality management infrastructure at a range of locations in the ACT that included 14 urban pond/wetland sites. For the study, the ponds assessed were Dickson Pond, Lyneham Pond, Giralang Pond, Point Hut Pond, Coombs A Pond, Coombs B Pond, Yerrabi Pond, Isabella Pond, Lower Stranger Pond, Crace Wetland, Norgrove Park Wetland, Emu Bank Wetland, David Street Wetland and Gungahlin Pond. Of these sites only Dickson Pond, Lyneham Pond, Point Hut Pond, Yerrabi Pond, Isabella Pond, David Street Wetland and Gunghalin Pond are assessed in this current report because of lack of long-term data sets for other sites.

The report by Alluvium (2016) highlighted the current water quality monitoring studies have mostly focused on the catchment and waterway health, rather than being able to measure the performance of stormwater systems. It also identified that poor water quality, algal blooms and weed outbreaks are a common occurrence in the ponds, with low dissolved oxygen, high nutrient concentrations and high chlorophyll a, all common issues.

Aquatic plants, otherwise known as macrophytes, are important features of water quality management ponds. Plants perform many roles in wetlands: they stabilise the banks and bed of the wetland to prevent erosion and provide a natural filtering system; they use nutrients from the water column; they transfer oxygen to sediments that enhances the ability of the wetland to process nitrogen (denitrification) and promote organic matter breakdown; and they provide habitat for wildlife in the wetland, increasing local biodiversity (Brix 1997). Macrophyte assessments undertaken by Alluvium (2016) indicated the condition is very poor or that macrophytes are not well established in most wetlands and are therefore not able to perform to their potential.

The report highlighted that, generally, there is no routine maintenance undertaken in the ACT's urban ponds or wetlands, with occasional desilting actioned when needed, and that before sediment reaches a level that requires desilting, many of the ponds appear to have water quality issues associated with pollutants within the waterbody.

A previous case study of the Upper Stranger Pond undertaken in the 1990s demonstrated the pond was functioning well and removing significant concentrations of total suspended solids, phosphorus and nitrogen from the catchment (Sharpin and Harbidge 1994). Alluvium (2016) also identified, where data are available, the urban ponds and wetlands in the ACT generally appear to have pollutant concentrations that are consistent with those seen elsewhere in Australia.

During the Millennium drought, the urban ponds received attention as a potential alternative source of water to meet demands for watering public open spaces. Harvesting water from the urban ponds would result in fluctuating water levels and questions were raised about the potential water quality and ecological outcomes. Abbott et al. (2008) presented an overview of the likely impacts of changes in water levels on water quality, ecological and biological features of ponds and aesthetics in an urban environment. Although this report does not detail specific water quality or ecological conditions of the urban ponds and wetlands in the ACT, it does consider the effects on the ability of the ponds to provide pollutant control of stormwater and urban runoff.

Abbott et al. (2008) investigated Dunlop Pond 1, Dunlop Pond 2, Gordon Pond, Gungahlin Pond, Isabella Pond, Lower Stranger Pond, Upper Stranger Pond, Point Hut Pond, West Belconnen Pond, and Yerrabi Pond. They concluded that water quality of these urban ponds is often variable and reflects long-term climatic conditions. They identified a suite of risks associated with harvesting water for secondary uses and dropping water levels in the ponds. These included the risk of soil and wetland acidification, loss of habitat, fish mortality, greater access to islands by feral pests and changes to macrophyte communities, which are essential for the ponds primary function of pollution control. These risks, in turn, could potentially impact the in-pond water quality and ecological processes. While many risks are outlined in the report, it was also suggested that fluctuating water levels may also have a positive impact on the function and value of the ponds, particularly on promoting the breakdown of organic materials.

Abbott et al. (2008) highlighted that all ponds that were investigated contain invasive fish species as well as native fish species, with particular mention of Yerrabi Pond and Gunghalin Pond, which have previously been stocked with native golden perch and Murray cod. Another wildlife species of note was the protected Latham's snipe, where sightings have been reported at Yerrabi Pond and Dunlop Pond. Although Abbott et al. (2008) do not include data on these notable species, they do identify that any management of the urban ponds needs to take into consideration the ecological requirements of these species.

K.2 Water quality data analysis: urban ponds

Of the 198 of constructed ponds and wetlands in the ACT, only 15 have sufficient recorded data sets to enable analysis of long term trends from 2011–2021 for water quality. In this assessment of the ACT's urban ponds and wetlands, the authors provide a detailed analysis of the water quality and ecological values from five pond and wetland sites as case studies (Appendices L to P), followed by an overarching analysis of data from 15 sites (Appendix Q). The five case study ponds are:

- Coombs A and B: as examples of recently constructed ponds in suburbs that are being actively developed. These online (connected to a natural waterway) wetlands do not have a long data set, but were monitored in detail as part of the research conducted by Ubrihien et al. (2019a) and provide some insight as to recently constructed ponds.
- Dickson Pond: an offline (not connected to a natural waterway) wetland in north Canberra, constructed in 2010–2011 within an established suburban area. This pond is regularly monitored by Waterwatch volunteers, but was also studied in detail by Ubrihien et al. (2019a).
- Jarramlee Pond: an online wetland constructed in 1994 as part of the suburban development in the catchment of Ginninderra Creek. This pond was also studied in detail by Ubrihien et al. (2019a), but has a long history of monitoring by Waterwatch volunteers.
- Lyneham Pond: an online wetland constructed in 2012 as part of the inner north reticulation scheme. This pond is regularly monitored by Waterwatch volunteers and is monitored as part of the ACT Government Lakes and Rivers Water quality monitoring program. It was also studied in detail by Ubrihien et al. (2019a).
- Yerrabi Pond: an online wetland located on east Ginninderra Creek constructed in 1994 as part of the suburban development of Gungahlin. This pond is regularly sampled by Waterwatch volunteers and has been sampled as part of the ACT Government Lakes and Rivers Water quality monitoring program.

The 15 sites used in the overarching analysis are detailed in Table 53.

L. Water quality data analysis: Coombs A and Coombs B Ponds 2017–2019

This assessment of both the Coombs A and Coombs B Ponds incorporates data from three separate sampling locations at each pond and uses data collected during a study from 2017 to 2019 by Ubrihien et al. (2019a). These data were collected weekly and included event sampling. There are currently no long-term data available for either pond but are included here as newly constructed ponds within a rapidly developing urban area.

Summary data (Table 40 and Table 41) show the water quality attributes recorded at the two ponds were commonly within the acceptable range of values for urban wetlands throughout the sampling period. The exception was in 2018, when high conductivity values were frequently recorded at both Coombs A and Coombs B, possibly associated with construction activity in the area. In 2018, the pH values recorded at Coombs A were above the acceptable range almost 40% of the time which is likely to be a consequence of construction activities in the area.

Table 40. Annual percentage of data points recorded at Coombs A Pond that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).
Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range. Note that for TN there are currently no set acceptable ranges specified for urban wetlands.

	pH	Total phosphorus	Total nitrogen	Turbidity	Total suspended solids	Dissolved oxygen	Conductivity
2017	87	100	N/A	96	86	99	94
2018	62	94	N/A	83	75	95	51
2019	91	100	N/A	95	99	-	98

Table 41. Annual percentage of data points recorded at Coombs B Pond that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).
Note that for TN there are currently no set acceptable ranges specified for urban wetlands. Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range.

	pH	Total phosphorus	Total nitrogen	Turbidity	Total suspended solids	Dissolved oxygen	Conductivity
2017	81	99	N/A	96	86	100	91
2018	85	92	N/A	90	88	100	67
2019	97	97	N/A	90	94	-	91

L.1 Nutrients

The average annual data indicate that phosphorus concentrations at both the Coombs A and Coombs B Ponds were within the acceptable range for the majority of the time (Figure 130), with concentrations recorded in the Coombs B Pond generally higher than those recorded at Coombs A. At the Coombs A Pond, there is an inconsistent change in phosphorus concentrations across the ponds between sampling years (Figure 132), but the changes are not statistically significant, suggesting the pond is not affecting phosphorus concentrations. In contrast, the Coombs B Pond data show a reduction in phosphorus concentrations from inflow to outflow during 2017 and 2018 but shows a substantial increase from inflow to outflow during the 2019 sampling season (Figure 133). The reason for this increase in 2019 is not clear, and the work of Ubrihien et al. (2019a) did not identify the possibly causes.

Average annual nitrate concentrations at the Coombs A Pond demonstrate a slight decrease from 2017 to 2019 whereas the Coombs B Pond has indicated an increase from 2017 to 2019 (Figure 140) and the reason for this increase is not clear. Total nitrogen concentrations at both the Coombs A and Coombs B Ponds indicate a significant reduction in nitrogen concentrations from inflow to outflow across all sampling years (Figure 132 and Figure 133), which suggests the ponds are more effective at reducing nitrogen concentrations than phosphorus.

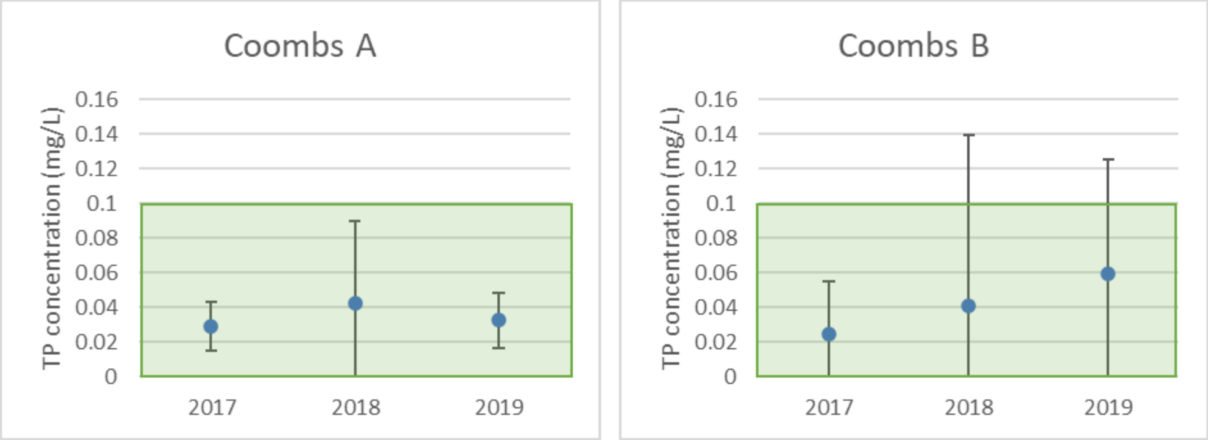

Figure 130. Annual average total phosphorus (TP) concentrations at Coombs A and Coombs B Ponds from 2017 to 2019.

Error bars represent the standard deviation. The green shading shows the acceptable range for TP specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

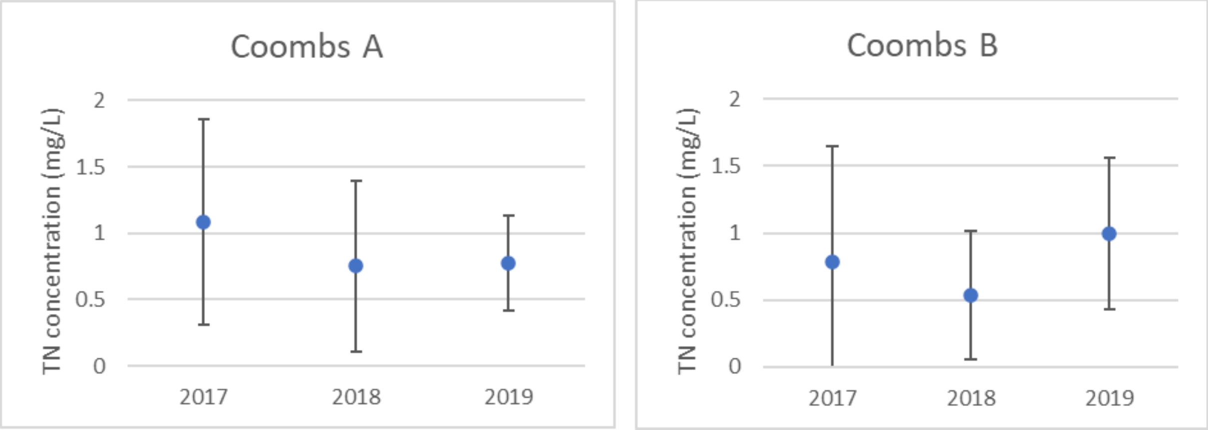

Figure 131. Annual average total nitrogen (TN) concentrations at Coombs A and Coombs B Ponds from 2017 to 2019.

Error bars represent the standard deviation. Note that for TN, there are currently no set acceptable ranges specified for urban wetlands.

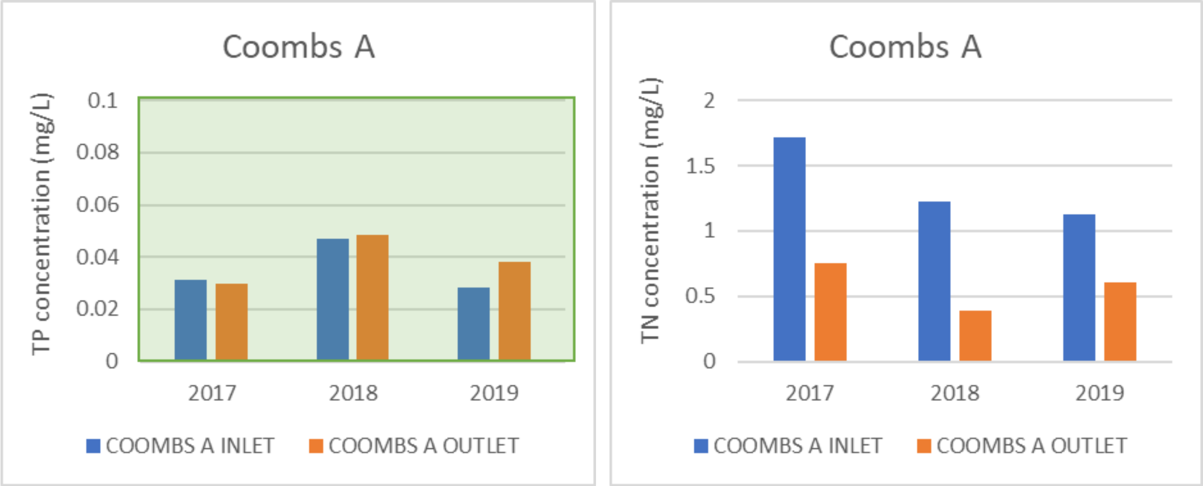

Figure 132. Annual average total phosphorus (TP) concentrations and total nitrogen (TN) concentrations at the inlet and outlet sites for Coombs A Pond from 2017 to 2019.

The green shading shows the acceptable range for TP specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5). Note that for TN, there are currently no set acceptable ranges specified for urban wetlands.

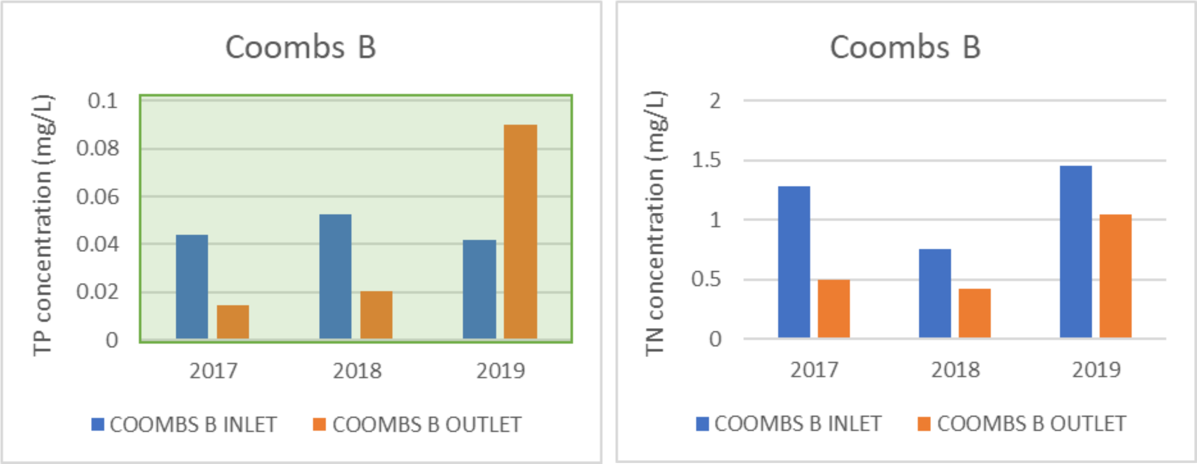

Figure 133. Annual average total phosphorus (TP) concentrations and total nitrogen (TN) concentrations at the inlet and outlet sites for Coombs B Pond from 2017 to 2019.

The green shading shows the acceptable range for TP specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5). Note that for TN, there are currently no set acceptable ranges specified for urban wetlands.

L.2 pH

The annual average pH recorded at the Coombs A and Coombs B Ponds are within the acceptable range across all samping years (Figure 134), however 40% of pH readings for the Coombs A Pond were recorded above the upper limit of 9 (data not shown). Such high pH values may be associated with construction in the area as it appears to drop to more acceptable levels over time.

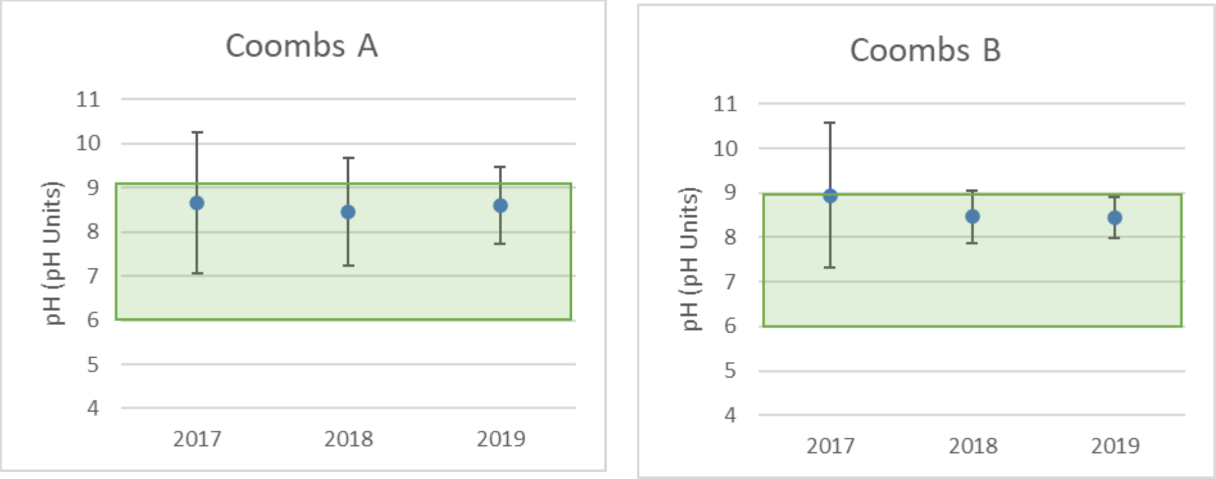

Figure 134. Annual average pH concentrations at Coombs A and Coombs B Ponds from 2017 to 2019. The green shading shows the acceptable range for pH specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

L.3 Turbidity/Suspended sediment

Annual average turbidity levels are within the acceptable range for both Coombs A and Coombs B Ponds for the majority of the time (Figure 135). The Coombs A Pond recorded a single data value of 1,000 NTU during the 2017 sampling season, which was associated with runoff from nearby earthworks; all other data for 2017 were below 33 NTU. This high value means it appears that the Coombs A Pond has seen a decrease in the annual average turbidity from 2017 to 2019, but it is more likely that turbidity has been reasonably consistent across the sampling years. The average annual turbidity levels at the Coombs B Pond have been consistent between 2017 to 2019 (Figure 135).

The annual average total suspended solids (TSS) recorded at both the Coombs A and Coombs B Ponds often exceeded acceptable values (Figure 136), with recorded data on occasion exceeding 100 mg/L. The Ubrihien et al. (2019a) study noted that, in general, the Coombs B Pond was effective at reducing suspended sediment loads in the urban stormwater system. In particular, the Coombs B downstream sampling locations recording significantly lower concentrations than the inflows.

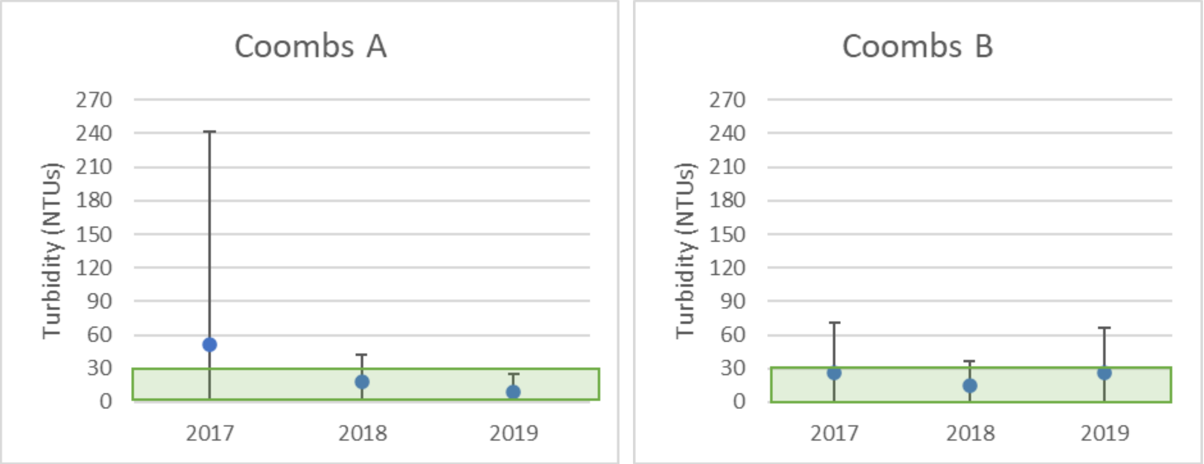

Figure 135. Annual average turbidity (NTU) concentrations at Coombs A and Coombs B Ponds from 2017 to 2019.

The green shading shows the acceptable range for turbidity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

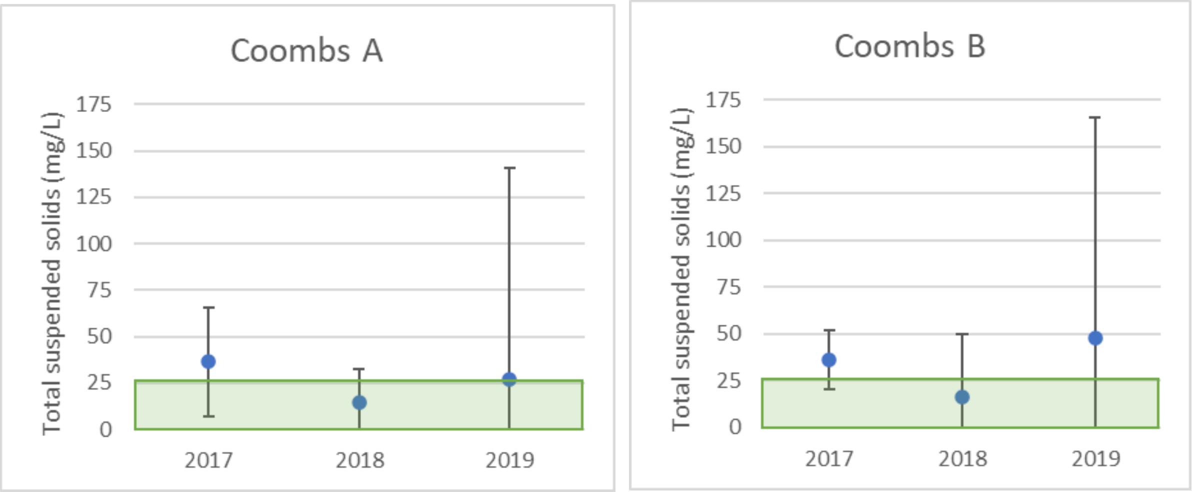

Figure 136. Annual average total suspended solids (TSS) concentrations at Coombs A and Coombs B Ponds from 2017 to 2019.

The green shading shows the acceptable range for TSS specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

L.4 Conductivity

The average annual conductivity recorded at the Coombs A Pond is within the acceptable range for all sampling years, but the data highlights the annual average at the Coombs B Pond consistently exceeds the acceptable values (Figure 137). Both the Coombs A and Coombs B Ponds recorded elevated values during 2018 (Figure 137), possibly because of drier conditions or local catchment development.

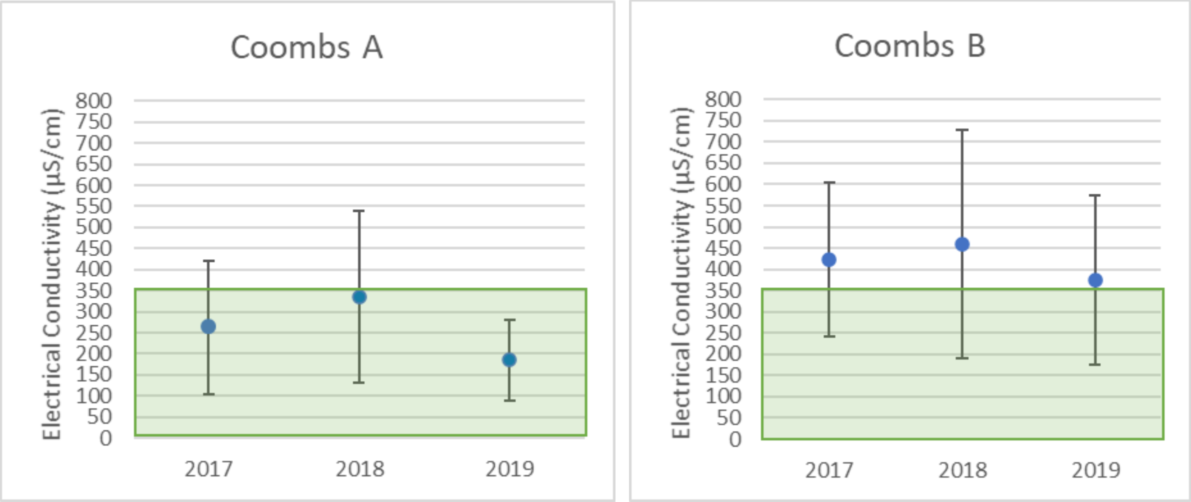

Figure 137. Annual average conductivity at Coombs A and Coombs B Ponds from 2017 to 2019. The green shading shows the acceptable range for conductivity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

L.5 Dissolved oxygen

The average annual dissolved oxygen concentrations in the Coombs A Pond are generally well within the acceptable range, being between 4 and 32 mg/L (Figure 138), with occasional (< 5% of readings) instances below acceptable levels. Concentrations recorded in the Coombs B Pond are within the acceptable range for 100% of the time, being between 4 and 44 mg/L (Figure 138).

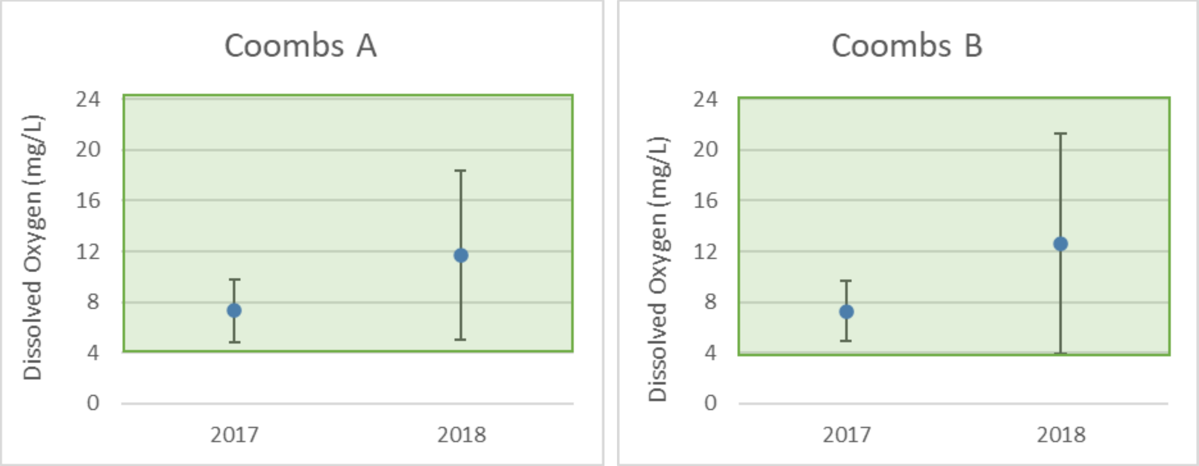

Figure 138. Annual average dissolved oxygen concentrations at Coombs A and Coombs B Ponds from 2017 to 2019.

The green shading shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

L.6 Ecological values

The condition of vegetation and available habitat, as well as the performance at both the Coombs A and Coombs B Ponds are not documented. The condition of macroinvertebrate communities within both the Coombs A and Coombs B Ponds are also not documented.

M. Water quality data analysis: Dickson Pond 2011–2021

This assessment of Dickson Pond incorporates data from three separate sampling locations within the pond and uses Waterwatch and ACT Government Lakes and Rivers Water quality monitoring program data. During 2017 to 2019, Ubrihien et al. (2019a) conducted a more detailed study to investigate nutrient concentrations and suspended sediment concentrations within urban ponds including Dickson Pond. These data were collected weekly and included event sampling. Where appropriate, these data are included for comparison as they provide additional information to aid interpretation of the data.

Summary data (Table 42) shows that all water quality attributes recorded in Dickson Pond are almost always within the acceptable range of values for urban wetlands, suggesting the quality of water in the pond is very good.

Table 42. Annual percentage of data points recorded at Dickson Pond that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).
Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range. Note that for TN, there are currently no set acceptable ranges specified for urban wetlands.

	pH	**Total phosphorus**	**Total nitrogen**	**Turbidity**	**Total suspended solids**	**Dissolved oxygen**	**Conductivity**
2011	100	-	N/A	100	-	100	100
2012	100	-	N/A	75	-	100	75
2013	100	-	N/A	100	-	92	100
2014	89	100	N/A	100	100	91	100
2015	86	71	N/A	100	88	100	100
2016	96	96	N/A	100	75	93	100
2017	100	96	N/A	100	88	100	100
2018	100	91	N/A	100	100	91	100
2019	90	95	N/A	100	100	95	100
2020	100	100	N/A	100	100	100	100
2021	100	100	N/A	95	100	100	100

M.1 Nutrients

The average annual data indicate that phosphorus concentrations at Dickson Pond are within acceptable range for the majority of the time (Figure 139), with a reduction in phosphorus from inflow to outflow for less than half of all sampling years (Figure 141). Average annual nitrate concentrations at Dickson Pond demonstrate a gradual decrease from 2015 to 2021 (Figure 140). From inflow to outflow, nitrate concentrations either increased or showed no change from across the majority of sampling years (Figure 142). Ubrihien et al. (2019a) also found that, at the Dickson Wetlands, the concentrations of nitrogen in the open water were significantly higher than at the inflow. The reason for this was thought to be a potable water leak that was contributing permanently to the Dickson channel and thus providing low nutrient water at the inflows.

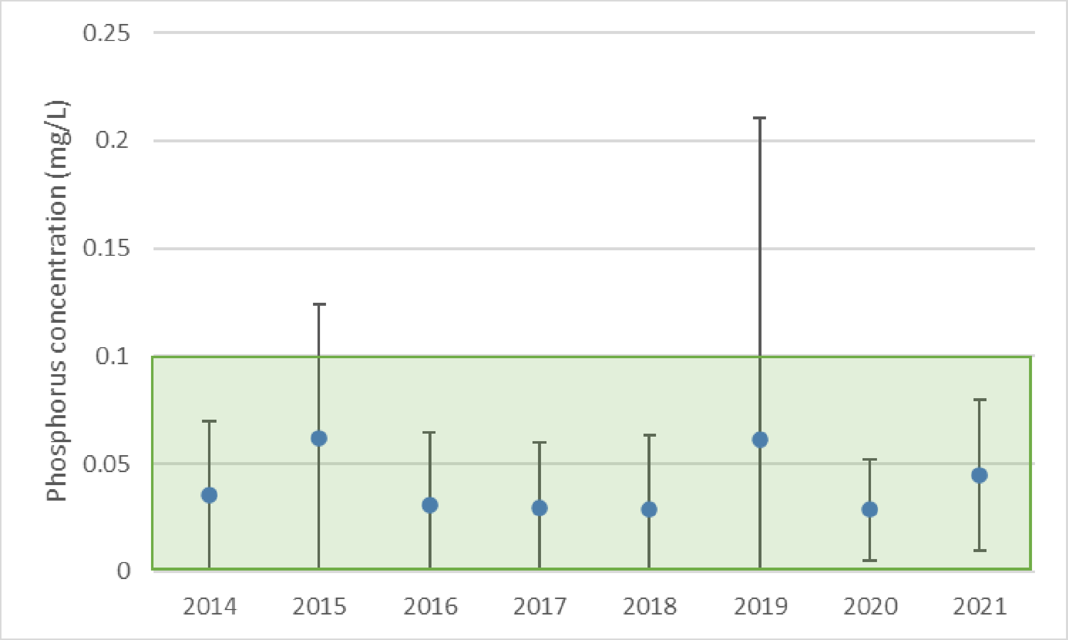

Figure 139. Annual average phosphorus concentrations at Dickson Pond from 2014 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for phosphorus specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

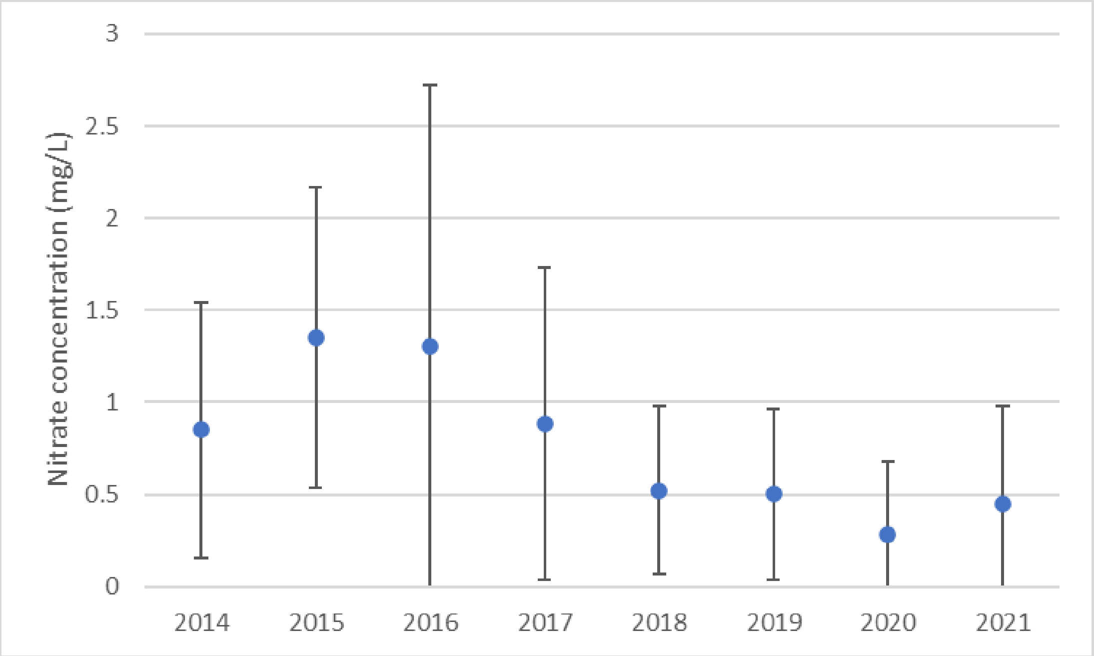

Figure 140. Annual mean nitrate concentrations at Dickson Pond from 2014 to 2021.

Note the data from 2021 are incomplete at the time of writing. Note that for nitrate, there are currently no set acceptable ranges specified for urban wetlands.

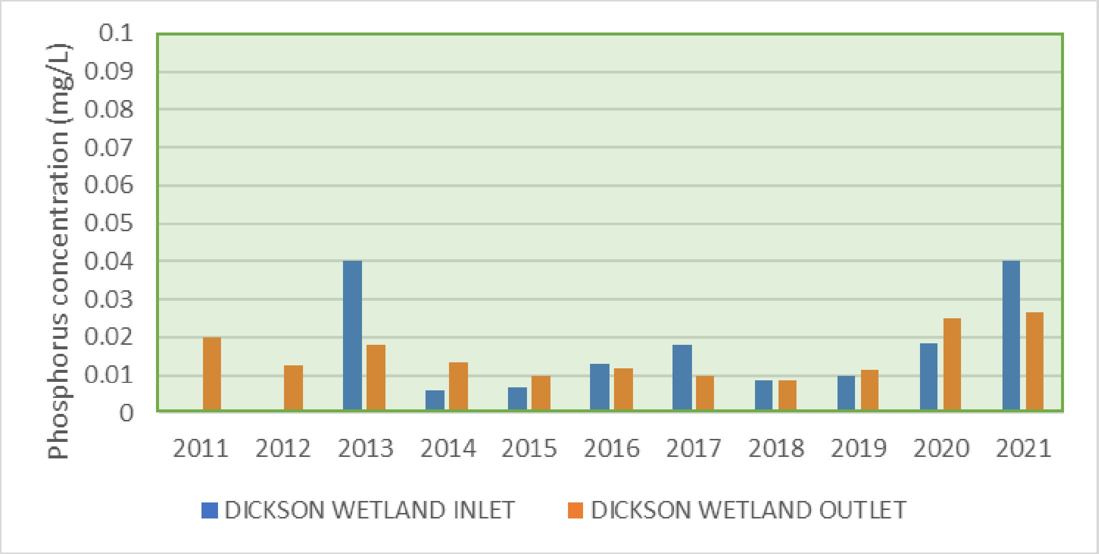

Figure 141. Annual mean phosphorus concentrations for the inlet and outlet sites at Dickson Pond from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for phosphorus specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

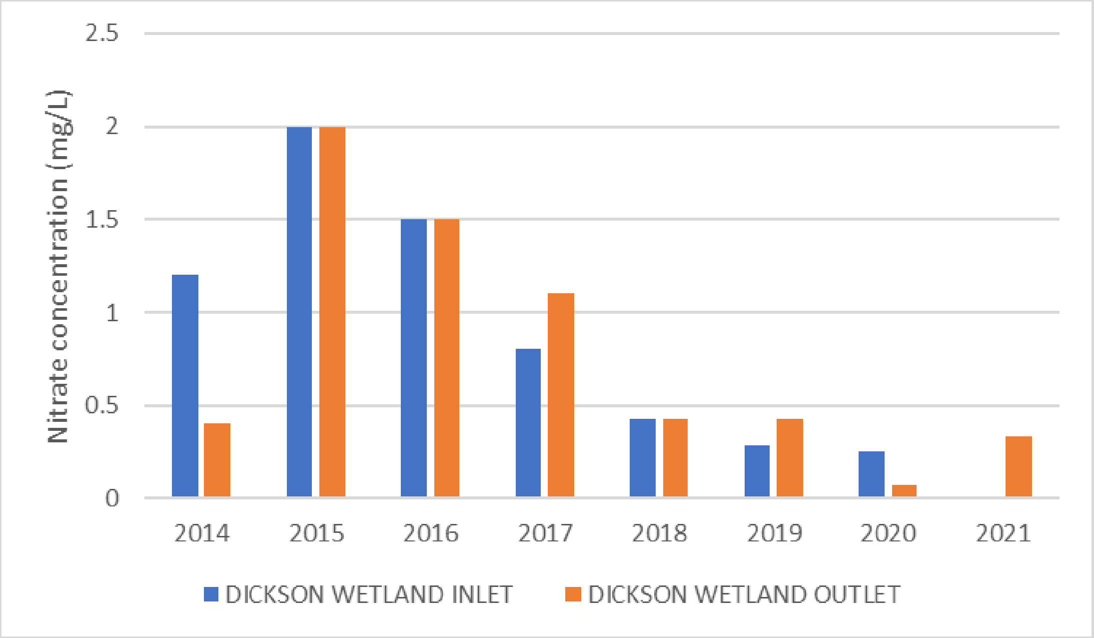

Figure 142. Annual mean nitrate concentrations for the inlet and outlet sites at Dickson Pond from 2014 to 2021.

Note the data from 2021 are incomplete at the time of writing. Note that for nitrate, there are currently no set acceptable ranges specified for urban wetlands.

M.2 pH

The average annual pH recorded within the Dickson Pond has consistently been within the acceptable range across all samping years (Figure 143).

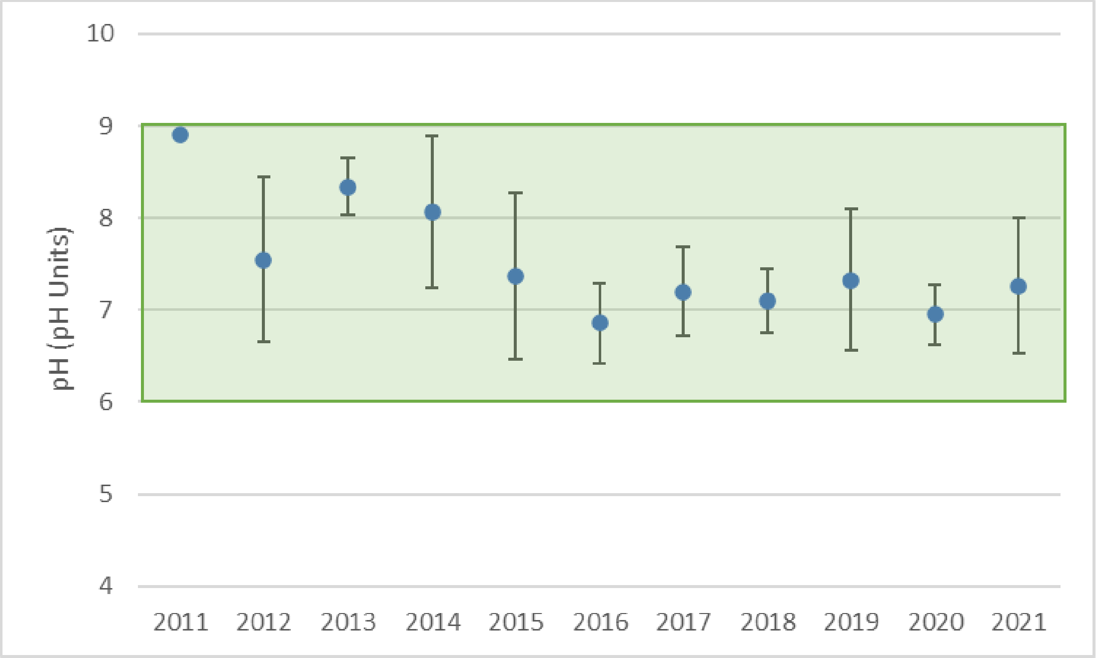

Figure 143. Annual average pH concentrations at Dickson Pond from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for pH specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

M.3 Turbidity/Suspended sediment

Annual average turbidity levels are within the acceptable range for all sampling years at Dickson Pond (Figure 144), with a single data value of 50 NTU during the 2012 sampling season. The annual average total suspended solids (TSS) recorded at Dickson Pond are within acceptable values for all sampling years, with recorded data rarely exceeding 25 mg/L. (Figure 145). There are no long-term data recorded to assess a reduction from inflow to outflow for total suspended solids at this site, but data (Ubrihien et al. 2019a) indicated there was an increase in TSS concentrations in the open water and downstream samples relative to inflows at Dickson Pond (Table 43).

Table 43. Summary statistics for total suspended solids (TSS) concentrations comparing inflow, open water and downstream sites at Dickson Pond. Data sourced from Ubrihien et al. (2019a)

Site	Total Suspended Solids (mg/L)					
	Wetland position	Mean	Standard deviation	Median	Minimum	Maximum
Dickson	Inflow	7.4	9.4	4.0	0.0	35.3
	Open water	11.9	5.6	12.0	3.3	27.3
	Downstream	13.2	6.8	13.0	2.0	31.3

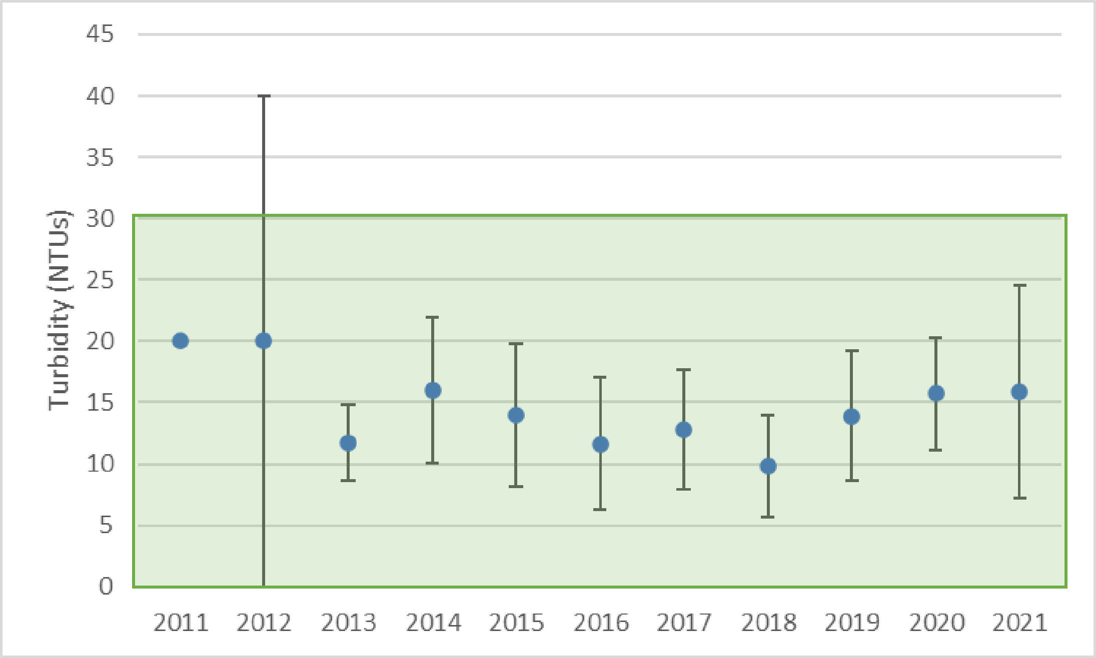

Figure 144. Annual average turbidity (NTU) concentrations at Dickson Pond from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for turbidity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

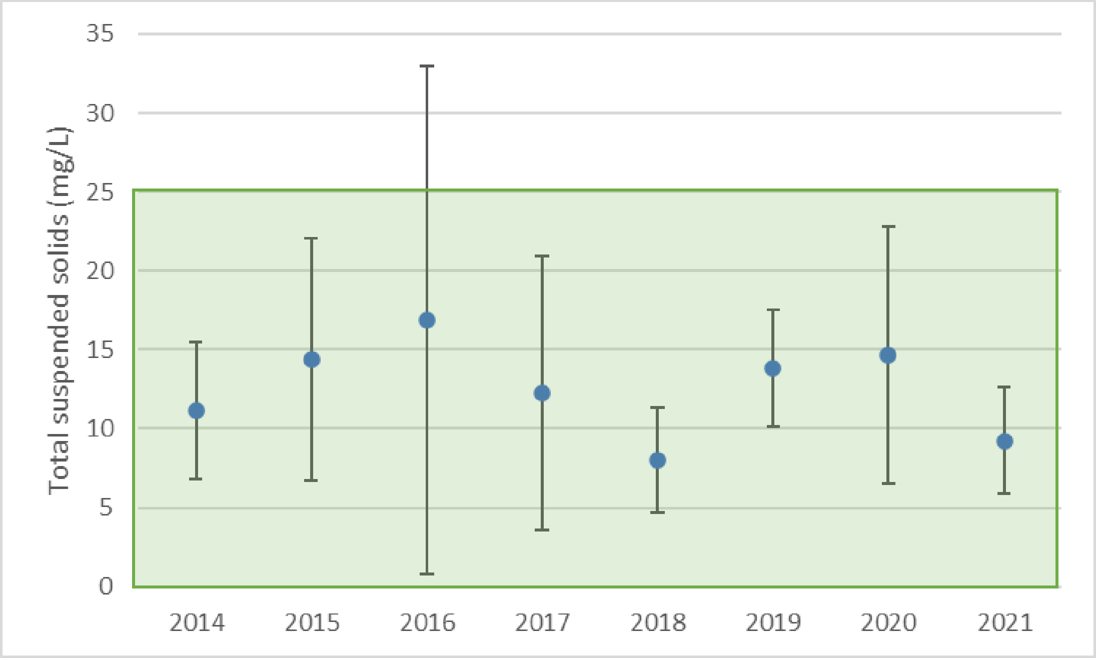

Figure 145. Annual average total suspended solids (TSS) concentrations at Dickson Pond from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for TSS specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

M.4 Conductivity

The annual average conductivity recorded at Dickson Pond is within the acceptable range for all sampling years, with a slight (non-significant) decrease in values from 2016 to 2021 (Figure 146), which may be caused by increased rainfall conditions during recent years.

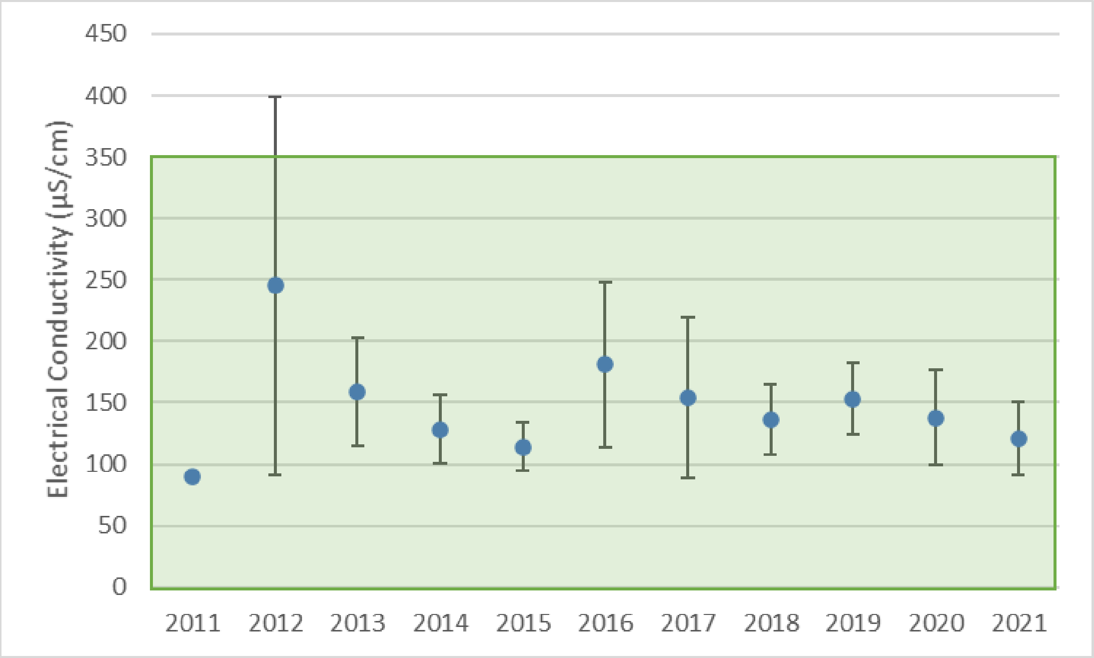

Figure 146. Annual average conductivity at Dickson Pond from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for conductivity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

M.5 Dissolved oxygen

The annual average dissolved oxygen concentrations in Dickson Pond are generally well within the acceptable range, being between 4 and 13 mg/L (Figure 147), with occasional (< 1% of readings) instances below acceptable levels.

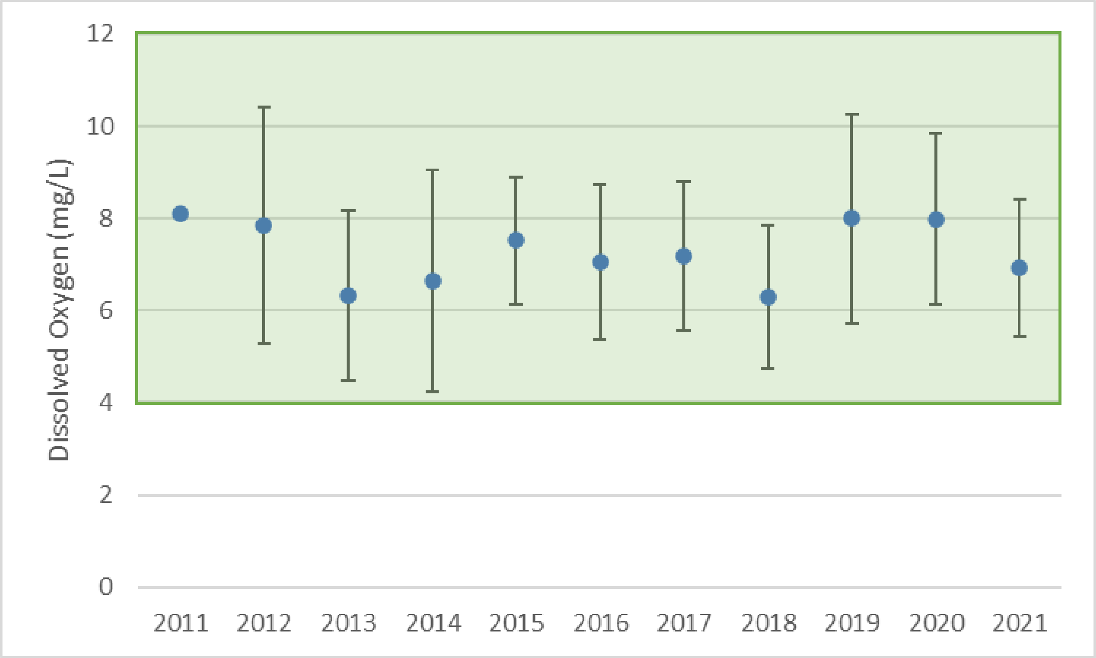

Figure 147. Annual average dissolved oxygen concentrations at Dickson Pond from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

M.6 Ecological values

The Rapid Appraisal of the Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent, good, fair, poor* or *degraded* conditions. The appraisal occurs every two years, and has been assessed in the years 2015, 2017, 2019 and 2021. The condition of the vegetation around the Dickson Pond between 2015 and 2021 was classed as being *poor* for 25% of the time and *fair* for 75% of the time.

Data collected from 2014 to 2021 as part of the Waterwatch Monitoring Program indicate a generally consistent macroinvertebrate condition of *good* at Dickson Pond, with two single instances of *poor* condition during 2015 and 2021 (Figure 148). The *poor* condition ratings are likely to be due to reduced taxa richness at the site, but the actual causes are not known.

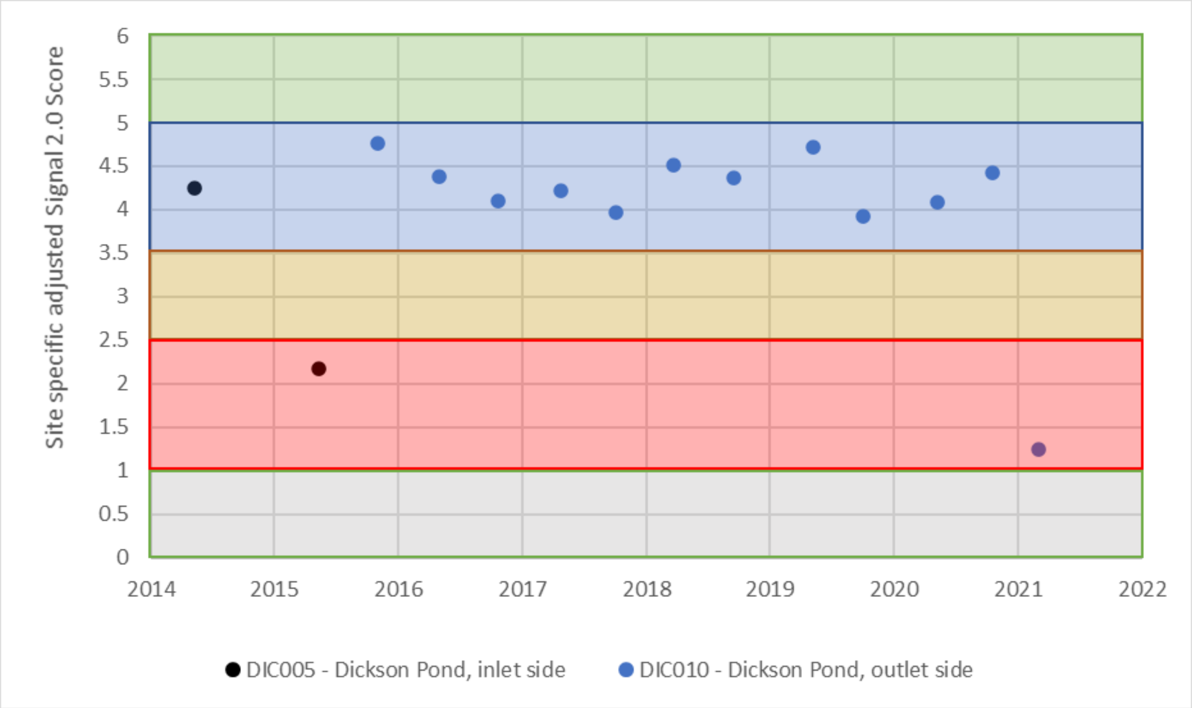

Figure 148. Adjusted SIGNAL 2.0 scores for Dickson Pond from 2014 to 2021.
Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

N. Water quality data analysis: Jarramlee Pond 2011–2021

This assessment of Jarramlee Pond incorporates data from a single sampling location within the pond and uses Waterwatch data as it provides a data set that covers the duration required. During 2017 to 2019, Ubrihien et al. (2019a) conducted a more detailed study to investigate nutrient concentrations and suspended sediment concentrations within urban ponds including Jarramlee Pond. These data were collected weekly and included event sampling. Where appropriate, these data are included for comparison as they provide additional information to aid interpretation of the data.

Summary data (Table 44) indicate all water quality attributes recorded in Jarramlee Pond are almost always within the acceptable range of values for urban wetlands, suggesting the quality of water in the pond is very good.

Table 44. Annual percentage of data points recorded at Jarramlee Pond that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).
Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range. Note that for TN there are currently no set acceptable ranges specified for urban wetlands.

	pH	Total phosphorus	Total nitrogen	Turbidity	Total suspended solids	Dissolved oxygen	Conductivity
2011	91	-	N/A	100	-	100	100
2012	100	-	N/A	100	-	100	100
2013	100	-	N/A	100	-	100	100
2014	100	100	N/A	100	-	100	100
2015	100	100	N/A	100	-	100	100
2016	100	92	N/A	100	-	92	100
2017	100	100	N/A	100	-	100	100
2018	100	100	N/A	100	-	100	100
2019	100	100	N/A	100	-	100	100
2020	91	100	N/A	100	-	91	100
2021	100	100	N/A	100	-	78	100

N.1 Nutrients

The average annual data indicates that phosphorus concentrations at Jarramlee Pond are within the acceptable range for all sampling years (Figure 149). The data indicates a slight increase in nitrate concentrations from 2019 to 2021 (Figure 150). There are no long-term data recorded to assess a reduction from inflow to outflow for nutrients at this site, but data from Ubrihien et al. (2019a) indicated that Jarramlee Pond was effective at removing both nitrogen and phosphorus concentrations from the inflow to the downstream site (Table 45 and Table 46).

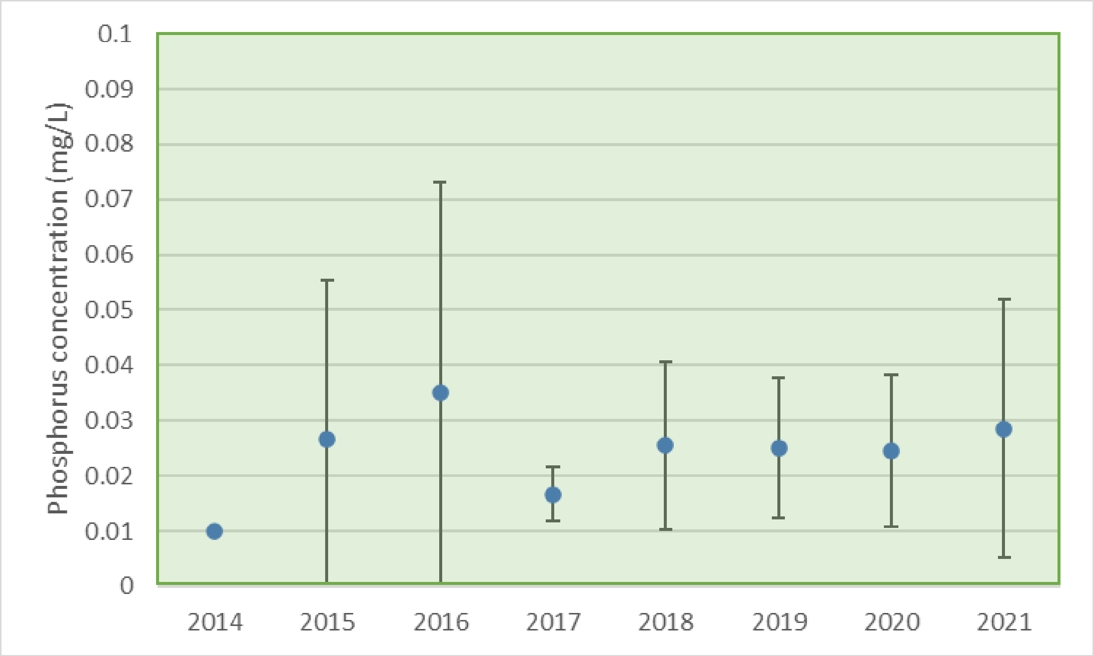

Figure 149. Annual average phosphorus concentrations at Jarramlee Pond from 2014 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for phosphorus specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

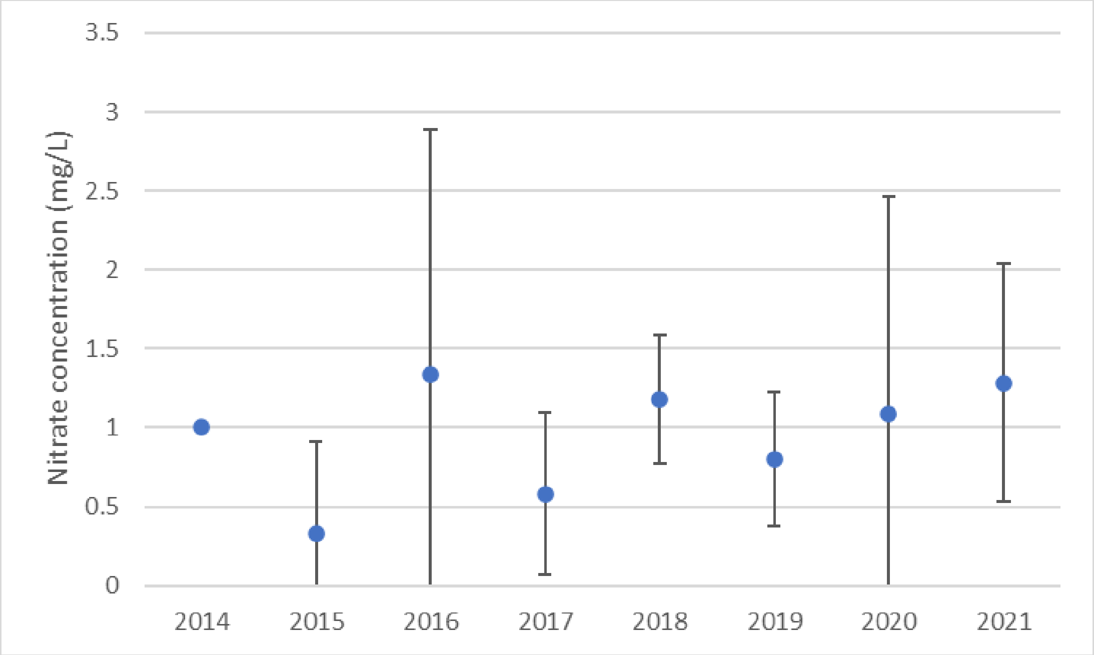

Figure 150. Annual average nitrate concentrations at Jarramlee Pond from 2014 to 2021.

Note the data from 2021 are incomplete at the time of writing. Note that for nitrate there are currently no set acceptable ranges specified for urban wetlands.

Table 45. Summary statistics for total phosphorus (TP) concentrations comparing inflow, open water and downstream sites at Jarramlee Pond. Data sourced from Ubrihien et al. (2019a).

		Total phosphorus (mg/L)				
Site	**Wetland position**	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**
Jarramlee	Inflow	0.13	0.15	0.1	0.04	0.83
	Open water	0.14	0.11	0.11	0.002	0.57
	Downstream	0.1	0.04	0.1	0.06	0.18

Table 46. Summary statistics for total nitrogen (TN) concentrations comparing inflow, open water and downstream sites at Jarramlee Pond. Data sourced from Ubrihien et al. (2019a).

		Total nitrogen (mg/L)				
Site	**Wetland position**	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**
Jarramlee	Inflow	4.00	1.83	4.22	0.92	8.25
	Open water	1.17	0.66	0.87	0.48	3.11
	Downstream	1.00	0.28	0.95	0.60	1.36

N.2 pH

The annual average pH recorded within Jarramlee Pond is consistently within the acceptable range, with a slight decreasing trend from 2011 to 2021 (Figure 151). The reasons for the decline in pH are not clear.

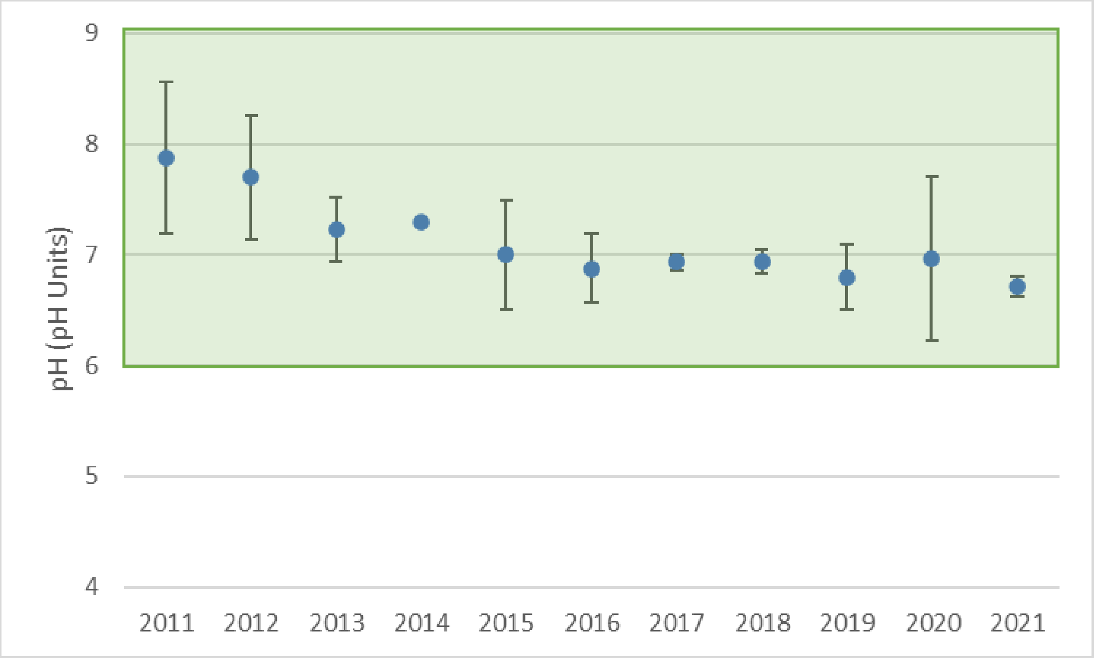

Figure 151. Annual average pH concentrations at Jarramlee Pond from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for pH specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

N.3 Turbidity/Suspended sediment

Annual average turbidity levels are within the acceptable range for all sampling years at Jarramlee Pond (Figure 152). There are no long-term data recorded for total suspended solids or turbidity to assess a change from inflow to outflow for this site. However, data from Ubrihien et al. (2019a) recorded mean TSS concentrations at the three sampling sites within the acceptable range, and also indicated that there was a small reduction in TSS from inflow to downstream sites at Jarramlee Pond (Table 47).

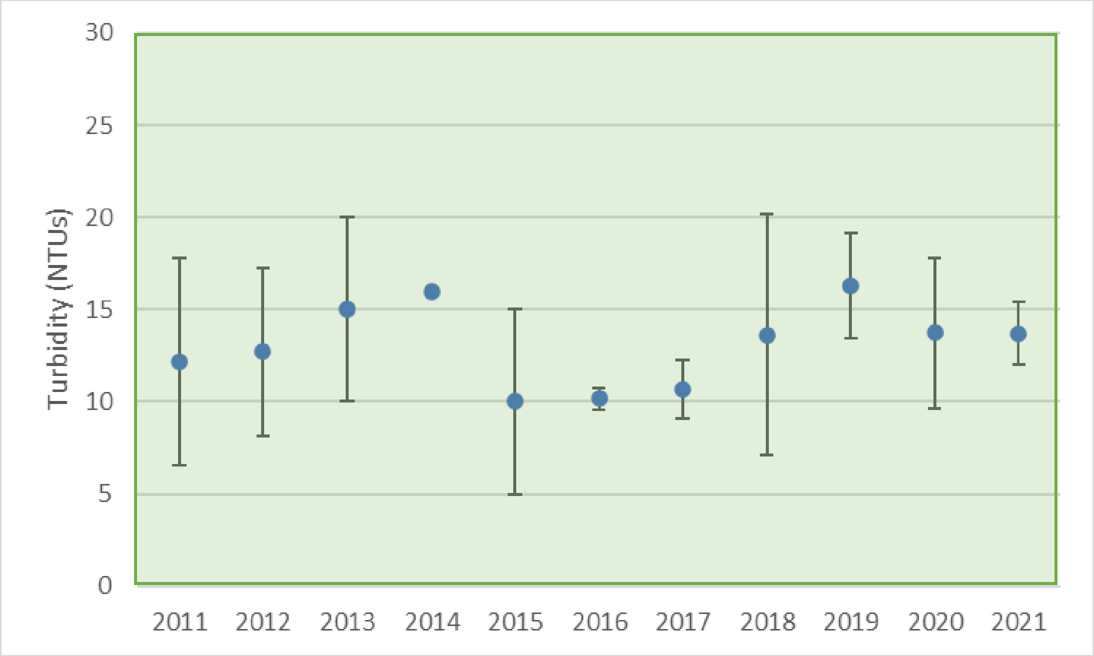

Figure 152. Annual average turbidity (NTU) concentrations at Jarramlee Pond from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for turbidity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

Table 47. Summary statistics for total suspended solids (TSS) concentrations comparing inflow, open water and downstream sites at Jarramlee Pond. Data sourced from Ubrihien et al. (2019a).

		Total suspended solids (mg/L)				
Site	**Wetland position**	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**
Jarramlee	Inflow	16.3	15.5	10.3	0.7	51.3
	Open water	14.9	11.4	12.0	2.7	46.7
	Downstream	15.1	6.5	14.0	8.0	28.0

N.4 Conductivity

The annual average conductivity recorded at Jarramlee Pond is within the acceptable range for all sampling years, with a slight decrease in values from 2016 to 2019 (Figure 153). It is not clear what may have caused this decline.

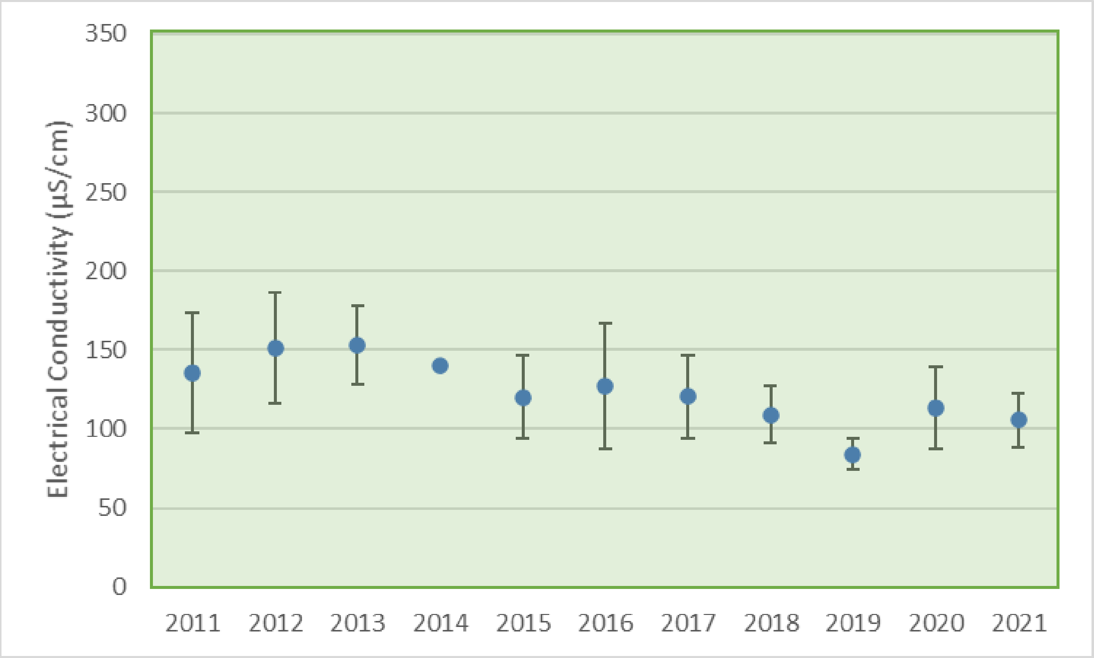

Figure 153. Annual average conductivity at Jarramlee Pond from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for conductivity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

N.5 Dissolved oxygen

The annual average dissolved oxygen concentrations in Jarramlee Pond are consistently within the acceptable range, being between 4 and 13 mg/L (Figure 154), with only a single instance below acceptable level.

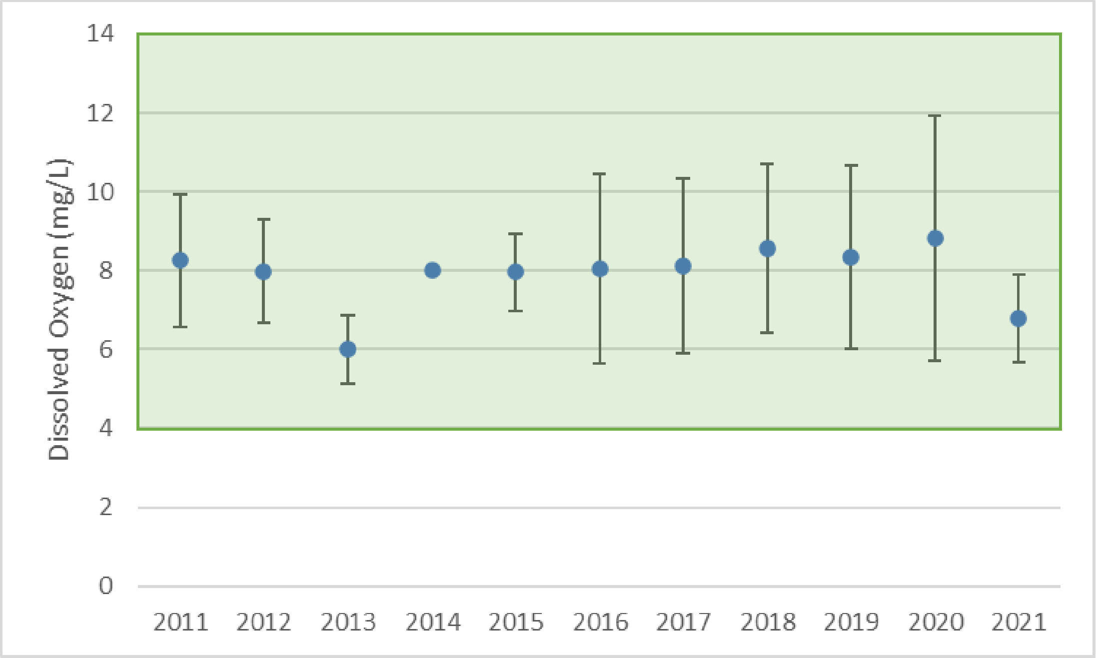

Figure 154. Annual average dissolved oxygen concentrations at Jarramlee Pond from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

N.6 Ecological values

The Rapid Appraisal of the Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent, good, fair, poor* or *degraded* conditions. The appraisal occurs every two years, and has been assessed in the years 2015, 2017, 2019 and 2021. The condition of the vegetation around Jarramlee Pond between 2015 and 2021 was classed as being *poor* 100% of the time. The condition of macroinvertebrate communities within Jarramlee Pond is not documented.

O. Water quality data analysis: Lyneham Pond 2011–2021

This assessment of Lyneham Pond incorporates data from a single sampling location within the pond and uses Waterwatch and ACT Government Lakes and Rivers Water quality monitoring program data to provide a data set that covers the duration required. During 2017 to 2019, Ubrihien et al. (2019a) conducted a more detailed study to investigate nutrient concentrations and suspended sediment concentrations within urban ponds, including Lyneham Pond. These data were collected weekly and included event sampling. Where appropriate, these data are included for comparison as they provide additional information to aid interpretation of the data.

Summary data (Table 48) show that pH, turbidity and conductivity are almost always within the acceptable range of values for urban wetlands. In contrast, total phosphorus concentrations, total suspended solids and dissolved oxygen are often outside the acceptable range. It would normally be expected that turbidity and suspended solids would be well correlated and display similar patterns over time. The notable differences in the proportion of readings within the acceptable ranges for turbidity and total suspended solids is probably because they are collected through different sampling programs (turbidity is recorded by Waterwatch and total suspended solids is through the ACT Government Lakes and Rivers Water quality monitoring program) and likely sampled on different days and at different points within the pond.

Table 48. Annual percentage of data points recorded at Lyneham Pond that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).
Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range. Note that for TN, there are currently no set acceptable ranges specified for urban wetlands.

	pH	Total phosphorus	Total nitrogen	Turbidity	Total suspended solids	Dissolved oxygen	Conductivity
2011	-	-	N/A	100	-	-	-
2012	-	-	N/A	100	-	-	-
2013	-	-	N/A	100	-	-	-
2014	100	22	N/A	100	100	-	-
2015	90	20	N/A	100	50	57	100
2016	93	33	N/A	100	50	60	100
2017	90	45	N/A	91	63	64	100
2018	100	20	N/A	93	63	33	100
2019	95	37	N/A	95	43	58	84
2020	100	69	N/A	92	100	62	92
2021	91	82	N/A	89	75	73	100

O.1 Nutrients

The average annual data indicate that phosphorus concentrations at Lyneham Pond exceed the acceptable range for the majority of sampling years, with some improvement in 2020 and 2021 (Figure 155). The data indicate consistent nitrate concentrations from 2015 to 2021 (Figure 156).

There are no long-term data recorded to assess a reduction from inflow to outflow for nutrients at this site, but data from Ubrihien et al. (2019a) indicated that there were reductions in both nitrogen and phosphorus concentrations from the inflow to downstream site at Lyneham Pond (Table 49 and Table 50).

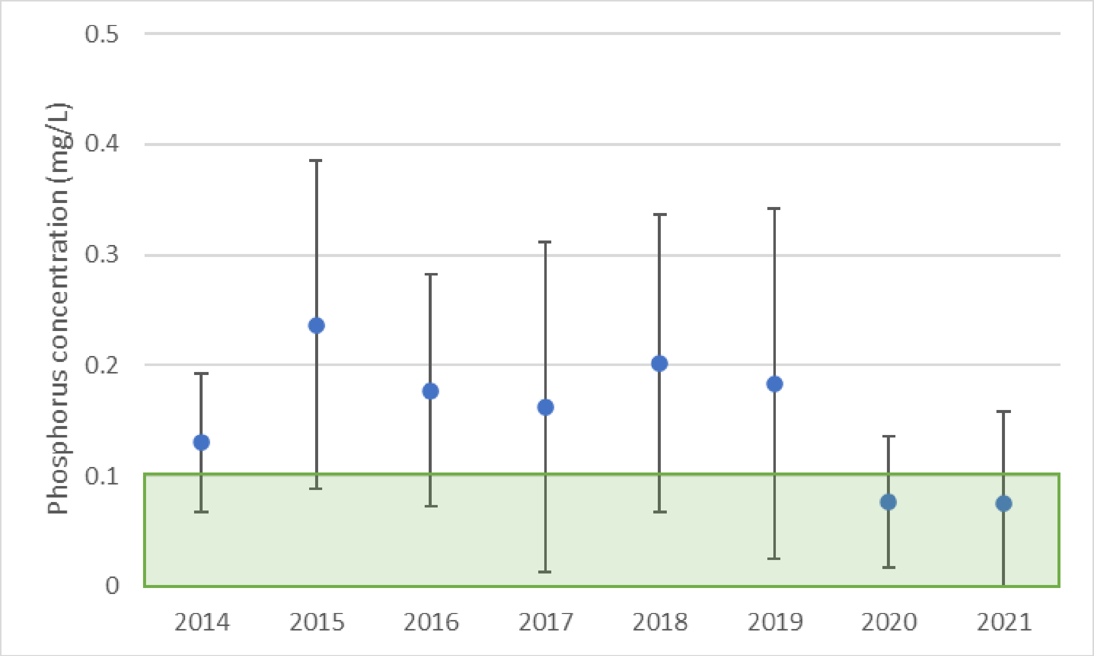

Figure 155. Annual average phosphorus concentrations at Lyneham Pond from 2014 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for phosphorus specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

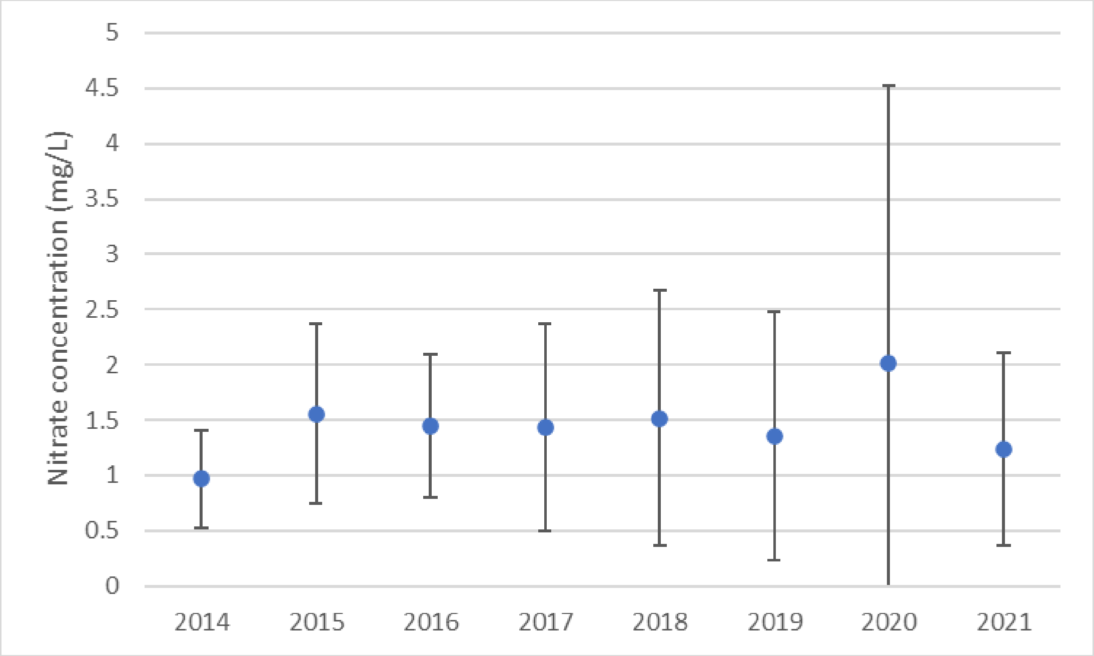

Figure 156. Annual average nitrate concentrations at Lyneham Pond from 2014 to 2021.
Note the data from 2021 are incomplete at the time of writing. Note that for nitrate, there are currently no set acceptable ranges specified for urban wetlands.

Table 49. Summary statistics for total phosphorus (TP) concentrations comparing inflow, open water and downstream sites at Lyneham Pond. Data sourced from Ubrihien et al. (2019a).

		Total phosphorus (mg/L)				
Site	**Wetland position**	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**
Lyneham	Inflow	0.27	0.24	0.18	0.06	1.1
	Open water	0.23	0.17	0.19	0.03	0.78
	Downstream	0.21	0.12	0.18	0.07	0.57

Table 50. Summary statistics for total nitrogen (TN) concentrations comparing inflow, open water and downstream sites at Lyneham Pond. Data sourced from Ubrihien et al. (2019a).

		Total nitrogen (mg/L)				
Site	**Wetland position**	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**
Lyneham	Inflow	2.65	3.59	1.59	0.61	19.72
	Open water	1.74	1.07	1.35	0.20	4.64
	Downstream	1.59	0.80	1.28	0.56	3.77

O.2 pH

The average annual pH recorded within Lyneham Pond has consistently been within the acceptable range across all samping years (Figure 157).

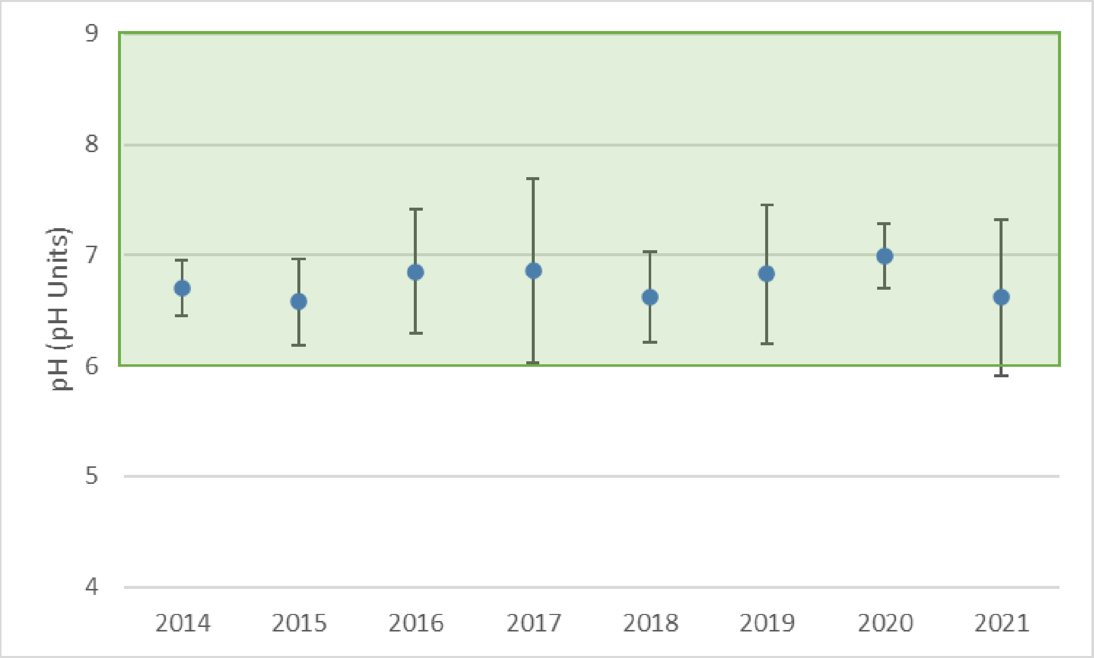

Figure 157. Annual average pH concentrations at Lyneham Pond from 2014 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for pH specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

O.3 Turbidity/Suspended sediment

Annual average turbidity levels are within the acceptable range at Lyneham Pond for all sampling years, with a generally increasing trend from 2014 to 2021 (Figure 158). The annual average total suspended solids (TSS) recorded has exceed acceptable values for half of the sampling years (Figure 159), with 35% of recorded data exceeding 25 mg/L. As mentioned previously, similar patterns are expected between turbidity readings and total suspended solids measurements. The differences in the data sets are likely to be the result of differences in sampling between the Waterwatch volunteers and the staff undertaking TSS sampling. The differences observed make it difficult to interpret the data, but the majority of records are within the acceptable range.

There are no long-term data recorded to assess a reduction from inflow to outflow for total suspended solids at this site, but data from Ubrihien et al. (2019a) indicated that there was no significant reduction in TSS from inflow to downstream sites at Lyneham Pond (Table 51).

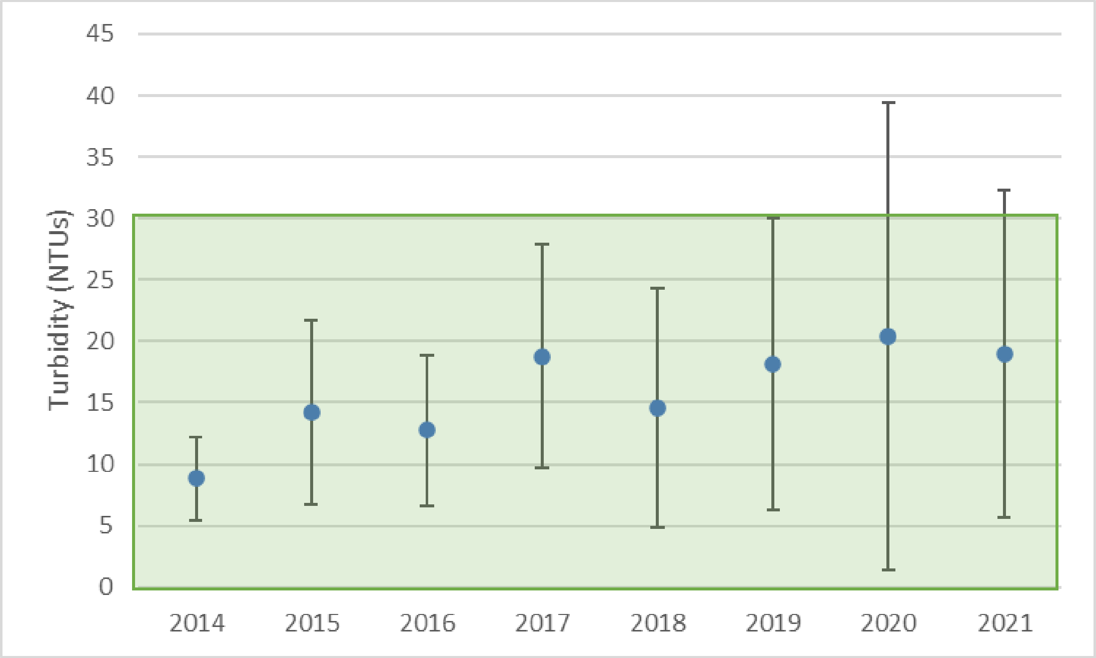

Figure 158. Annual average turbidity at Lyneham Pond from 2014 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for turbidity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

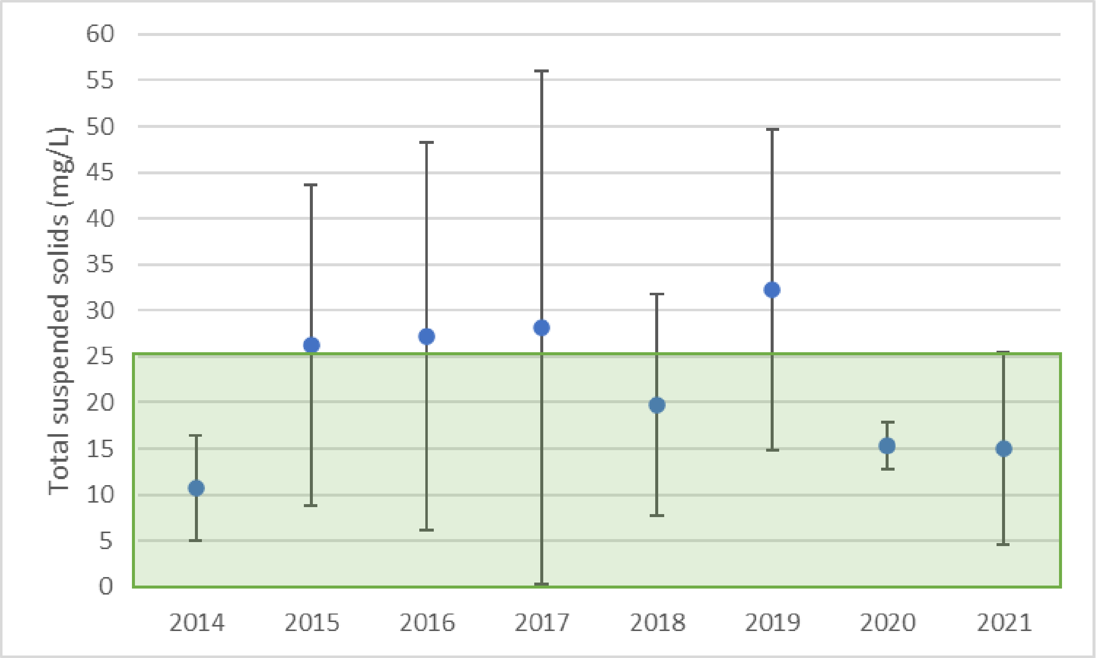

Figure 159. Annual average total suspended solids (TSS) concentrations at Lyneham Pond from 2014 to 2021. Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for TSS specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

Table 51. Summary statistics for total suspended solids (TSS) concentrations comparing inflow, open water and downstream sites at Lyneham Pond. Data sourced from Ubrihien et al. (2019a).

		Total Suspended Solids (mg/L)				
Site	**Wetland position**	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**
Lyneham	Inflow	17.1	11.7	14.7	2.0	48.7
	Open water	24.7	15.9	20.7	3.3	65.3
	Downstream	18.0	9.6	18.0	2.0	42.0

O.4 Conductivity

The annual average conductivity recorded at Lyneham Pond is within the acceptable range for all sampling years (Figure 160).

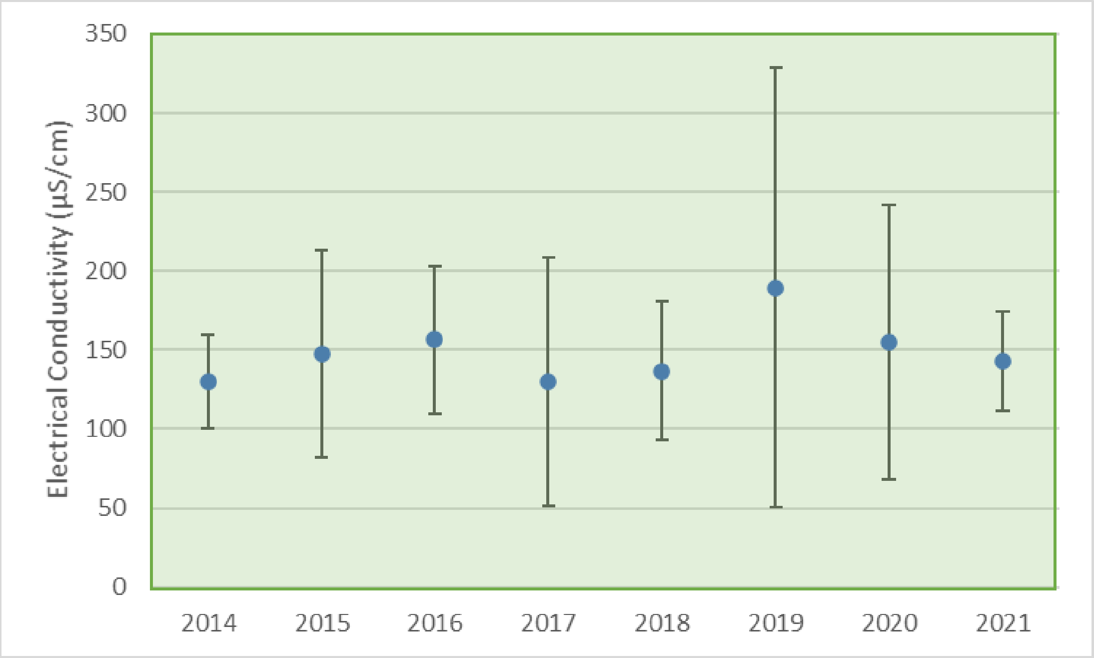

Figure 160. Annual average electrical conductivity at Lyneham Pond from 2014 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for electrical conductivity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

O.5 Dissolved oxygen

The annual average dissolved oxygen concentrations in Lyneham Pond are, for the majority, within the acceptable range (Figure 161), but there are more than 40% of data instances that fall below acceptable levels.

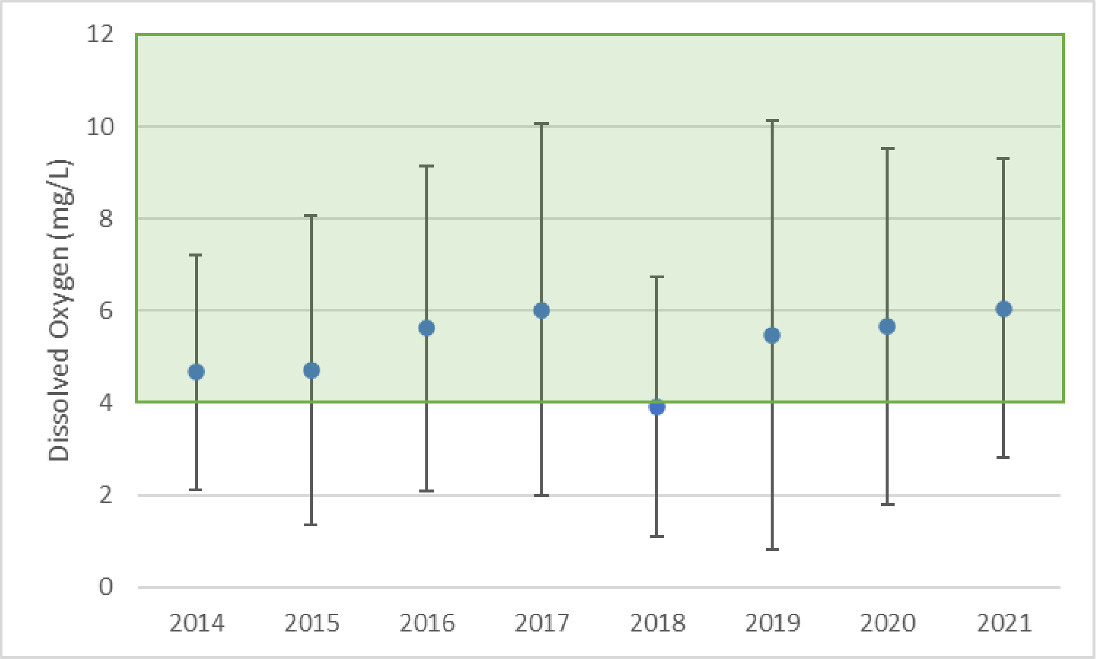

Figure 161. Annual average dissolved oxygen concentrations at Lyneham Pond from 2014 to 2021. Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

O.6 Ecological values

The Rapid Appraisal of the Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent, good, fair, poor* or *degraded* conditions. The appraisal occurs every two years, and has been assessed in the years 2015, 2017, 2019and 2021. The condition of the vegetation around the Lyneham Pond between 2015 and 2021 was classed as being *poor* for 75% of the time and *fair* for 25% of the time.

Data collected as part of the Waterwatch Monitoring Program from 2015 to 2021 at the Lyneham Pond indicates that the majority of macroinvertebrate condition is rated *poor*, with the best condition during the 2017 sampling year (Figure 162). The *poor* ratings are because of low taxa richness at the site, that is likely to be caused by low water levels, rubbish present within the site and limited available habitat.

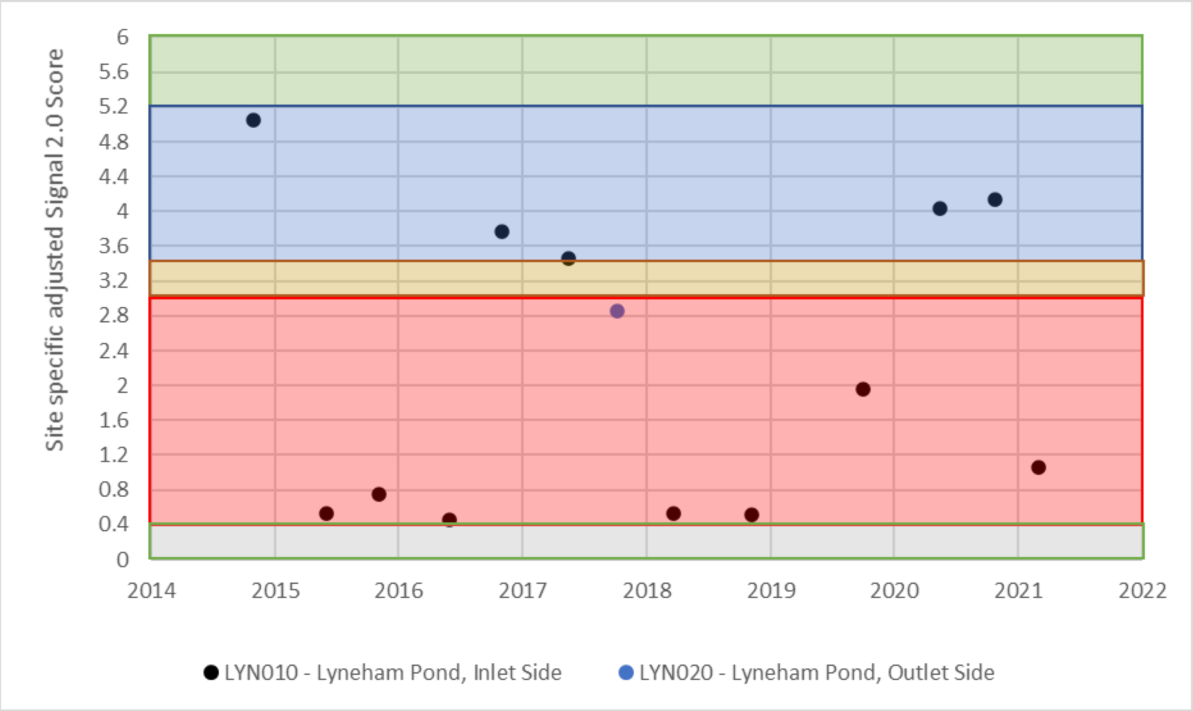

Figure 162. Adjusted SIGNAL 2.0 scores for Lyneham Pond from 2015 to 2021.
Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

P. Water quality data analysis: Yerrabi Pond 2011–2021

This assessment of Yerrabi Pond incorporates data from three separate sampling locations within the pond and uses Waterwatch and ACT Government Lakes and Rivers Water quality monitoring program data to provide a data set that covers the duration required.

Summary data (Table 52) indicate that all water quality attributes recorded in Yerrabi Pond are almost always within the acceptable range of values for urban wetlands, suggesting the quality of water in the pond is very good. Rare years are observed when pH, total suspended solids or conductivity are more frequently outside the acceptable range.

Table 52. Annual percentage of data points recorded at Yerrabi Pond that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).
Note that for TN, there are currently no set acceptable ranges specified for urban wetlands. Colours are used to illustrate a low (yellow) to high (green) proportion of data points within the acceptable range.

	pH	Total phosphorus	Total nitrogen	Turbidity	Total suspended solids	Dissolved oxygen	Conductivity
2011	100	100	N/A	88	88	89	100
2012	100	100	N/A	93	100	93	94
2013	100	100	N/A	100	100	100	100
2014	93	96	N/A	100	100	99	74
2015	98	100	N/A	100	100	100	100
2016	92	100	N/A	100	100	97	90
2017	95	100	N/A	100	100	100	83
2018	95	100	N/A	100	100	95	85
2019	78	100	N/A	100	100	98	86
2020	100	100	N/A	100	100	97	83
2021	100	94	N/A	100	67	93	100

P.1 Nutrients

The average annual data indicates that phosphorus concentrations at Yerrabi Pond are consistently within acceptable range (Figure 163), with lower phosphorus concentrations recorded at the outflow compared with the inflow in the majority of sampling years (Figure 165).

Average annual nitrate concentrations are variable with recent years (post-2018), displaying a greater range of concentrations than earlier years (Figure 164). Nitrate concentrations are often markedly different between the inflow and outflow sampling locations, but the difference is not consistent. In some years (2017, 2019 and 2020), the concentrations at the outflow are substantially lower than those recorded at the inflow. In 2021, the converse is the case, with markedly higher concentrations of nitrate recorded at the outflow compared with very low concentrations recorded at the inflows (Figure 166). The reason for the difference observed in 2021 is not clear. It is worth continuing to observe these concentrations carefully to determine if it is an issue with pond performance.

Overall, the data suggest that Yerrabi Pond is effective at reducing nutrient concentrations, but the variation in response suggests that this may not always be the case.

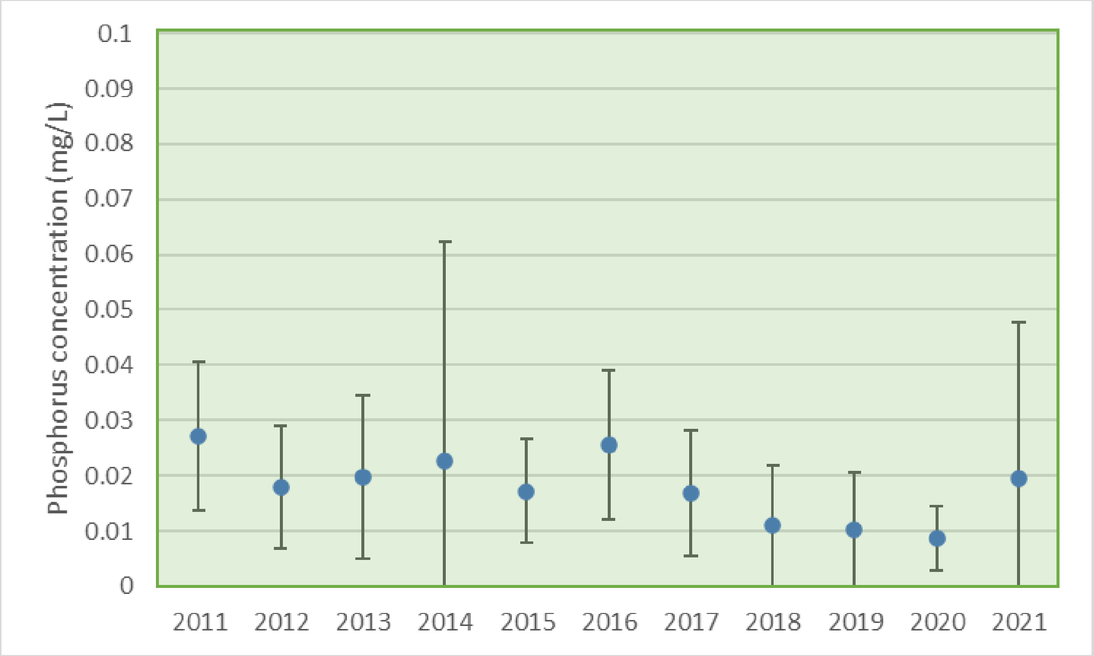

Figure 163. Annual average phosphorus concentrations at Yerrabi Pond from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for phosphorus specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

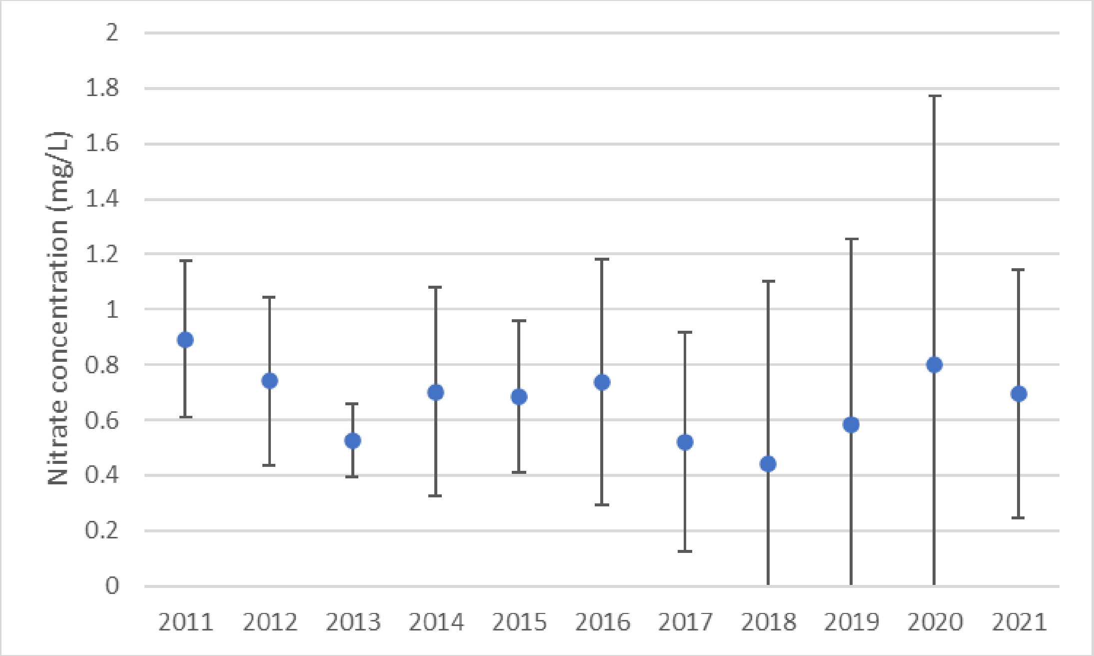

Figure 164. Annual average nitrate concentrations at Yerrabi Pond from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. Note that for nitrate, there are currently no set acceptable ranges specified for urban wetlands.

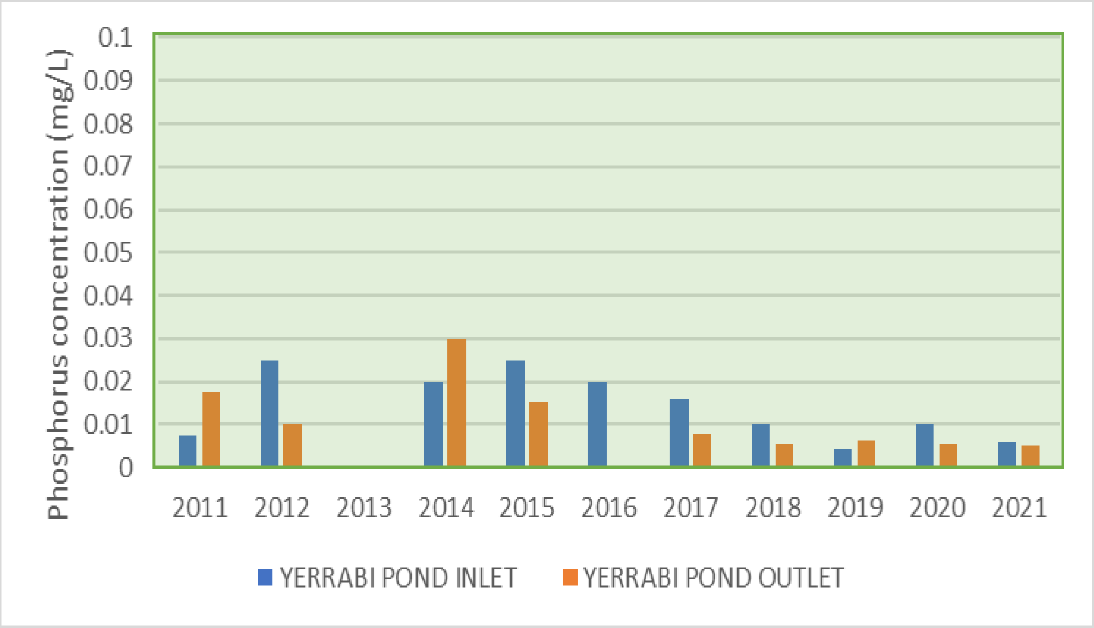

Figure 165. Annual average phosphorus concentrations for the inlet and outlet sites at Yerrabi Pond from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for phosphorus specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

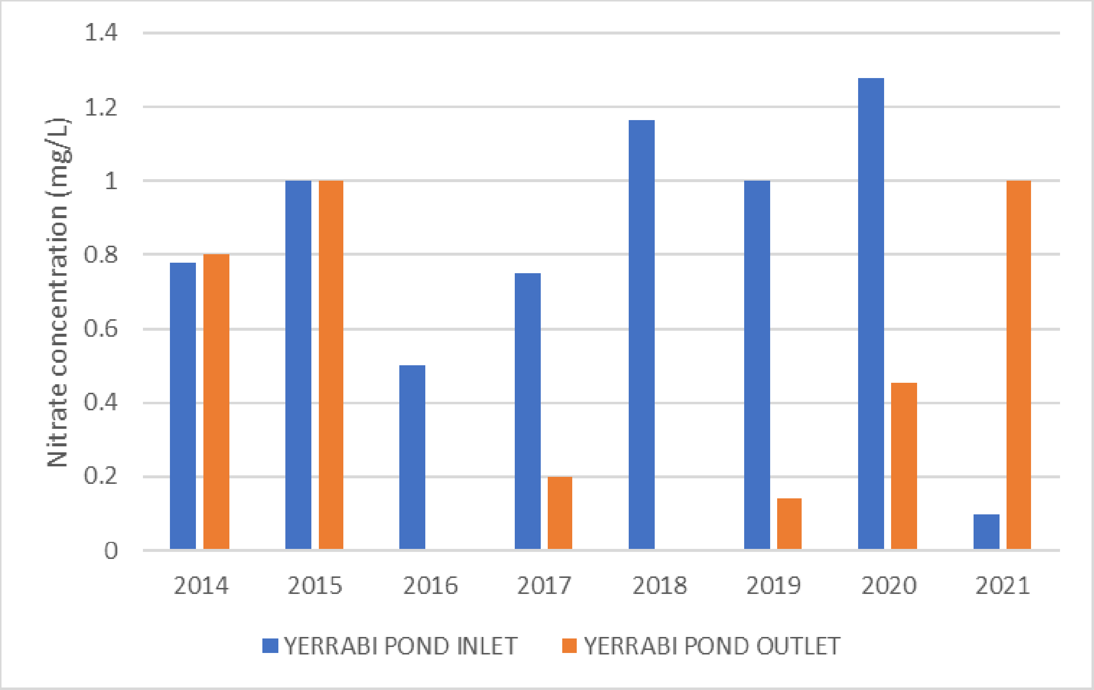

Figure 166. Annual average nitrate concentrations for the inlet and outlet sites at Yerrabi Pond from 2014 to 2021.

Note the data from 2021 are incomplete at the time of writing. Note that for nitrate, there are currently no set acceptable ranges specified for urban wetlands.

P.2 pH

The average annual pH recorded within the Yerrabi Pond has consistently been within the acceptable range across all samping years (Figure 167).

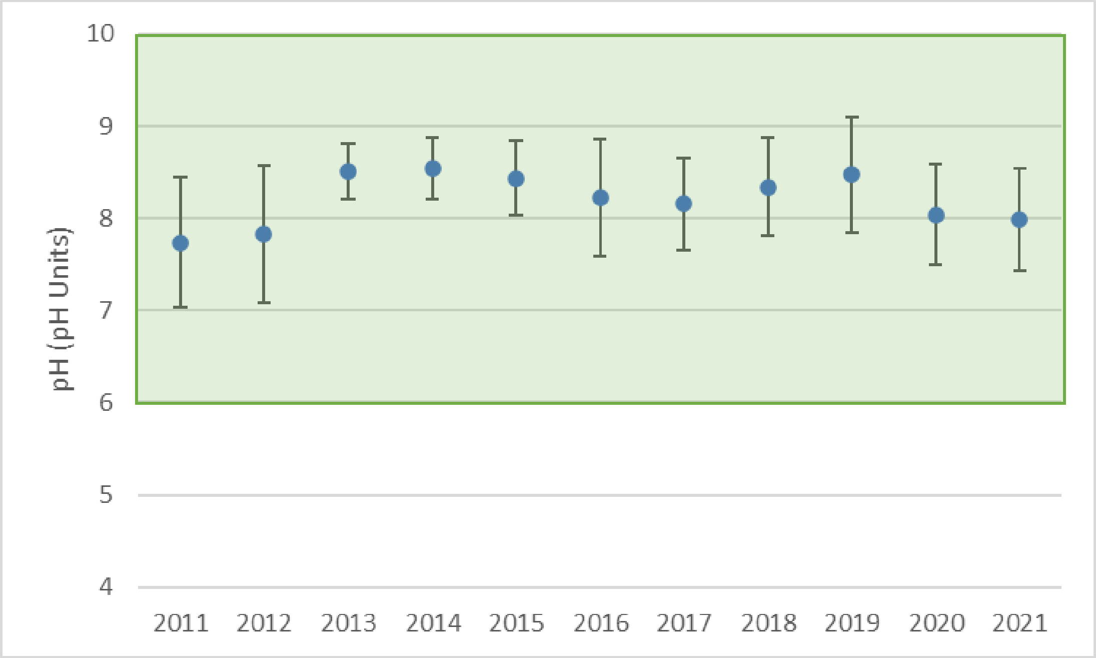

Figure 167. Annual average pH concentrations at Yerrabi Pond from 2011 to 2021.
Note that the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for pH specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

P.3 Turbidity/Suspended sediment

Annual average turbidity levels are within the acceptable range for all sampling years at Yerrabi Pond (Figure 168). The annual average total suspended solids (TSS) recorded at Yerrabi Pond are also within acceptable values for all sampling years, with recorded data rarely exceeding 25 mg/L (Figure 169). It is interesting there were very high concentrations of suspended sediment recorded in 2021 that may indicate that the high rainfall that occurred throughout 2021 was contributing higher sediment loads to the pond.

There are no long-term data recorded to assess a reduction from inflow to outflow for total suspended solids at this site.

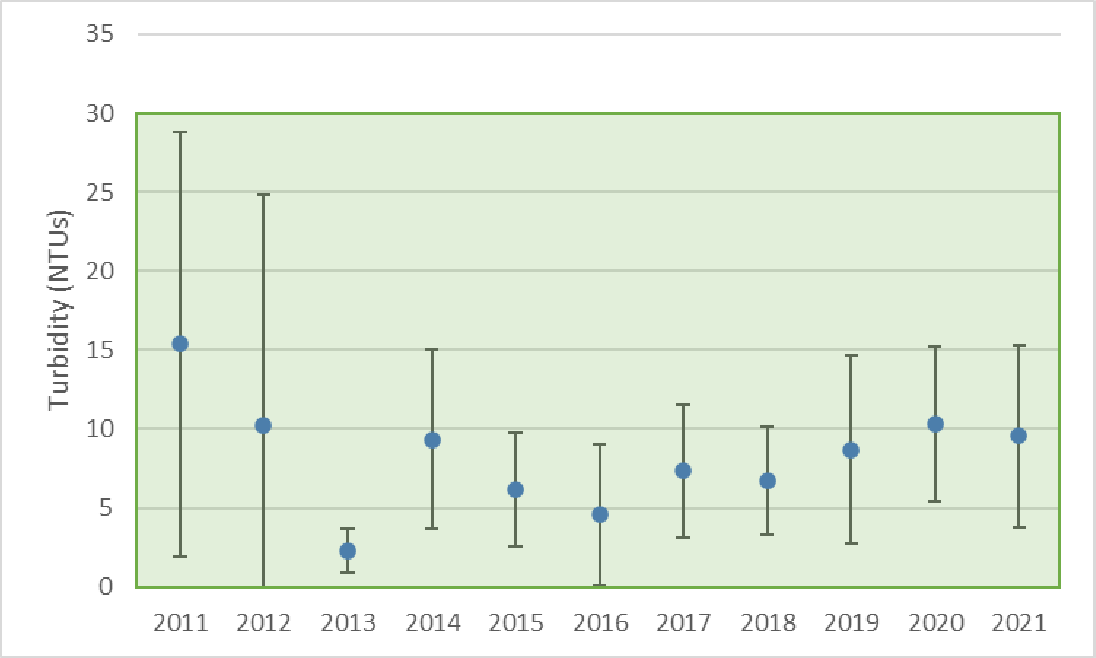

Figure 168. Annual average turbidity at Yerrabi Pond from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for turbidity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

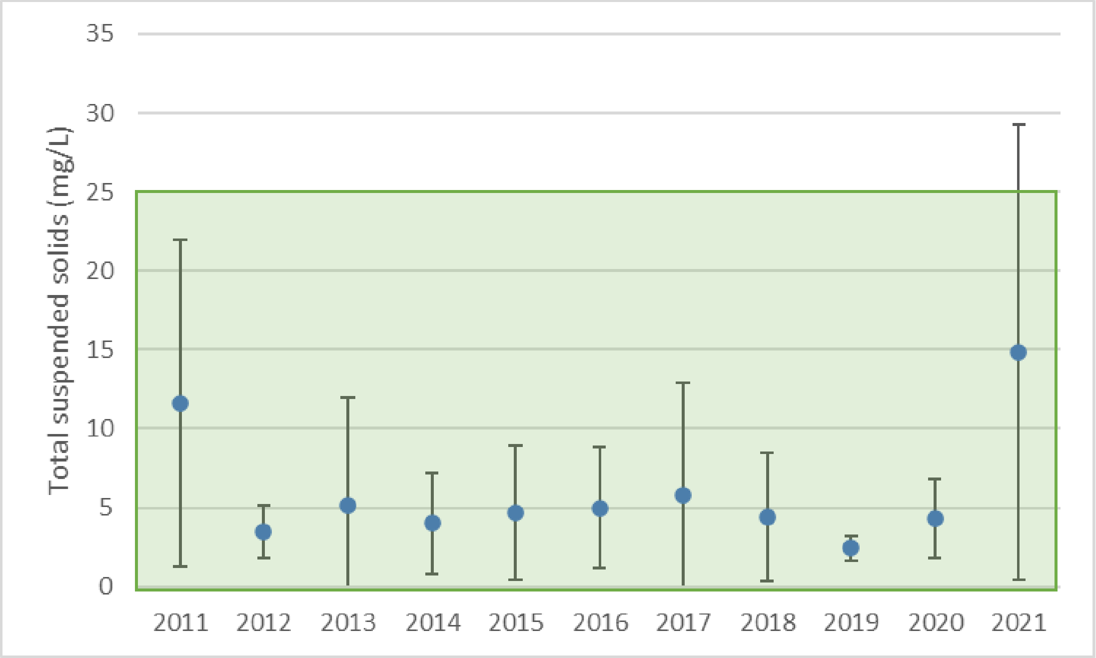

Figure 169. Annual average total suspended solids (TSS) concentrations at Yerrabi Pond from 2011 to 2021.

Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for TSS specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

P.4 Conductivity

The annual average conductivity recorded at Yerrabi Pond is within the acceptable range for all sampling years (Figure 170).

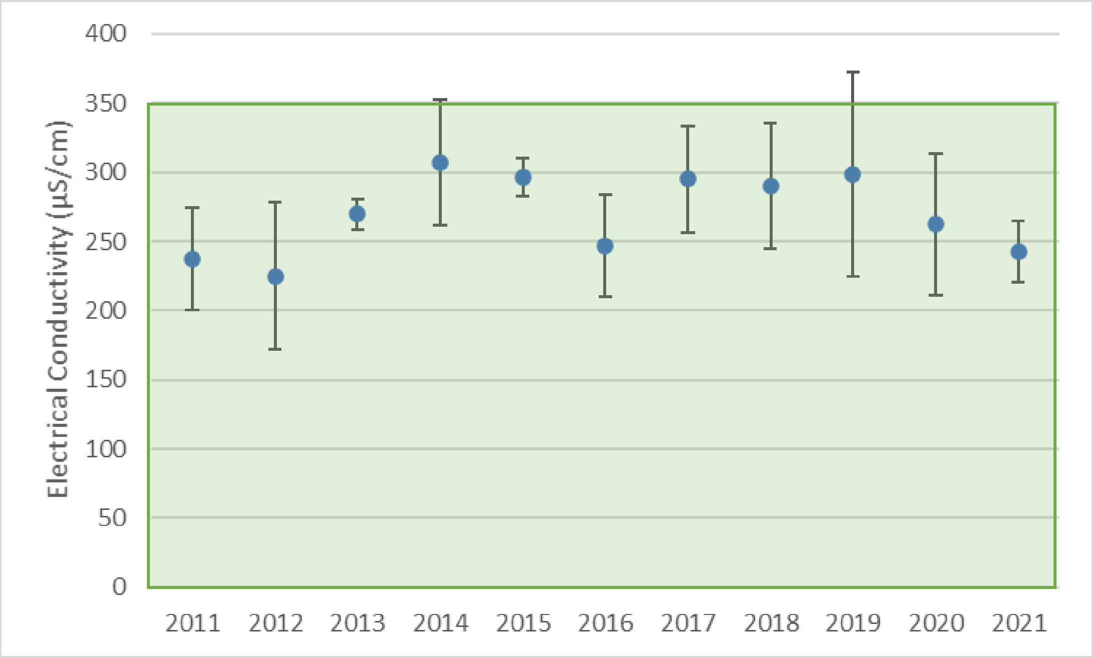

Figure 170. Annual average conductivity at Yerrabi Pond from 2011 to 2021.
Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for conductivity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

P.5 Dissolved oxygen

The annual average dissolved oxygen concentrations in Yerrabi Pond are consistently within the acceptable range, with values between 4 and 16mg/L (Figure 171). Fewer than 4% of readings were below acceptable levels.

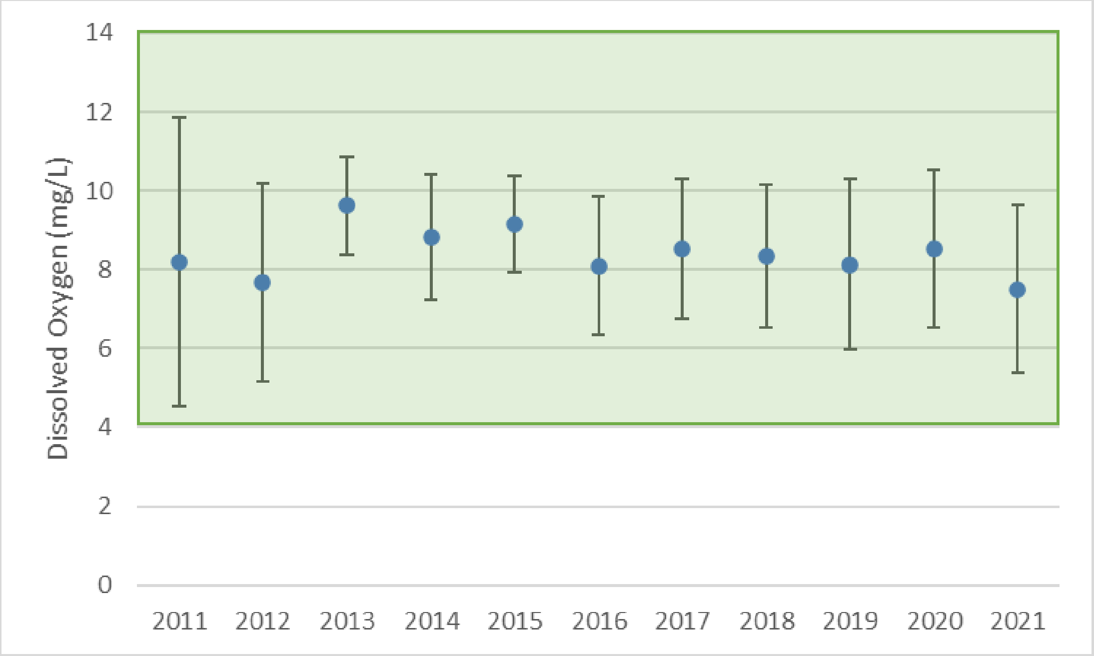

Figure 171. Annual average dissolved oxygen concentrations at Yerrabi Pond from 2011 to 2021. Note the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

P.6 Ecological values

The Rapid Appraisal of the Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent, good, fair, poor* or *degraded* conditions. The appraisal occurs every two years, and has been assessed in the years 2015, 2017, 2019 and 2021. The condition of the vegetation around Yerrabi Pond between 2015 and 2021 was classed as being *poor* for 86% of the time and *degraded* for 14% of the time.

Reports of fish kills at Yerrabi Pond were recorded in 2014 (ACT Government 2014c), with a large number of Murray cod killed over a 25-day period. Investigations failed to determine the reasons for the fish kill, but it was considered likely that warm temperatures and low dissolved oxygen conditions may have been contributing factors.

Data collected from 2014 to 2021 as part of the Waterwatch Monitoring Program indicate that, for the majority of the time, the condition of the macroinvertebrate communities of Yerrabi Pond is *good* (Figure 172) and has remained consistently good from 2017 onwards. The *poor* ratings of 2015 and 2016 are the result of low taxa richness, the cause of which is unclear.

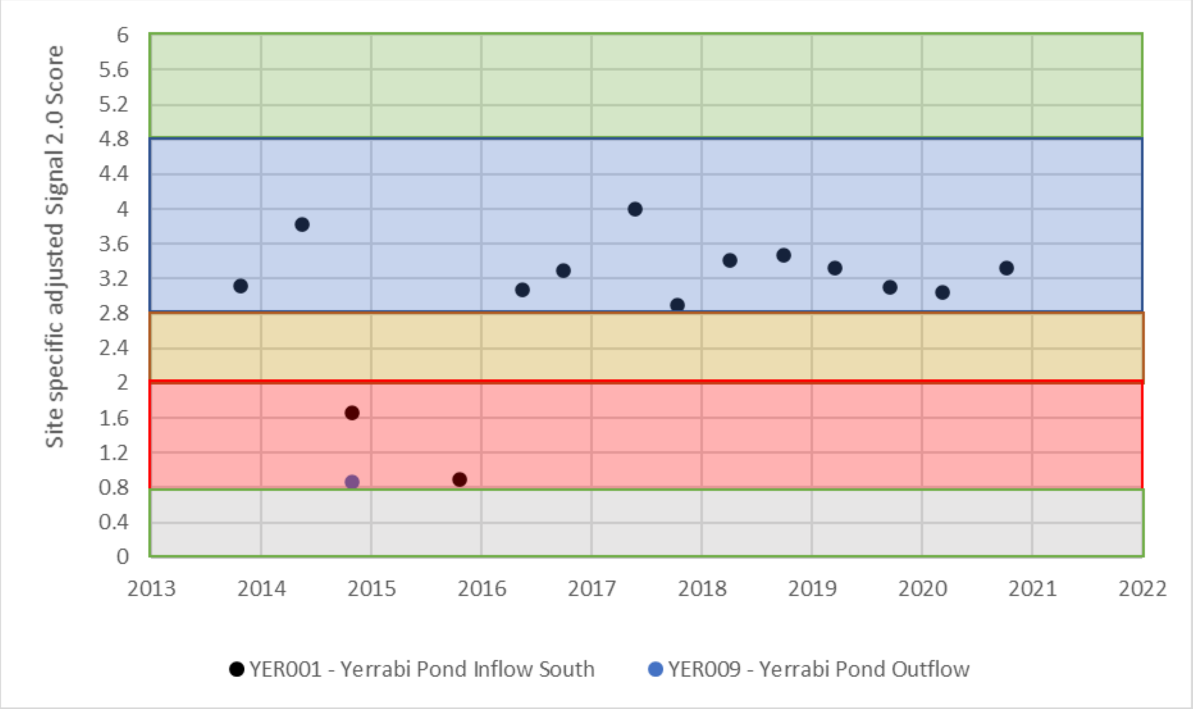

Figure 172. Adjusted SIGNAL 2.0 scores for the Yerrabi from 2014 to 2021.
Data from the Waterwatch Monitoring Program. Coloured bands represent the Waterwatch threshold classes where green is 'excellent', blue is 'good', orange is 'fair', red is 'poor' and grey is 'degraded'.

Q. Water quality data analysis: ACT’s Urban Ponds and Wetlands 2011–2021

Of the 198 of constructed ponds and wetlands in the ACT, only 15 have sufficient recorded data sets to be able to analyse long term trends from 2011 to 2021 for water quality. This assessment of the ACT’s urban ponds and wetlands incorporates data from 15 sites, with a combined 26 sampling locations, and uses Waterwatch and ACT Government Lakes and Rivers Water quality monitoring program data as these provide a data set that covers the duration required. The sites analysed in this section are detailed in Table 53.

Table 53. Fifteen of the ACT's urban ponds and wetlands used for this assessment.

Site name	**Location**	**Site characteristics**	**Catchment area**	**Age***	**Values***	**Water Quality Data**
Banksia Street Wetland	-35.25729 149.11833	Banksia Street Wetland is an off-line wetland. Low flows from the concrete stormwater channel are diverted into the water body. Once the water has made its way through the wetland, it overflows through an outlet into an underground pipe that discharges back into the stormwater channel. From there, the water makes it way down the channel, eventually discharging into Lake Burley Griffin. The wetland includes two sections; a pond that is approximately 1.4 metres deep in the centre at normal operating level and an ephemeral zone that ranges from 0 to 0.3 m deep. Banksia Street is Canberra's first retrofitted urban wetland to incorporate an ephemeral section designed to dry out during summer (*)	Located within the Sullivans Creek Catchment. Reach network length: approx. 0.2ha (#) 667,629 m^2 (1)	2010 (*)	This wetland provides multiple benefits, including: • water quality improvements (trapping nitrogen and phosphorus) and sediments • contributing to urban biodiversity from a diverse array of locally-occurring aquatic and terrestrial plants • recreational, educational and volunteering opportunities for the community The wetland is expected to reduce pollutants from the stormwater flows collected from the concrete channel and provide habitat for water birds, turtles, yabbies, water bugs and frogs (*)	Waterwatch (2011–2014 and 2017–2021)
Conder Wetlands	-35.461942 149.105254	Conder Wetlands are situated on Conder Creek, which arises in the Rob Roy Nature Reserve and flows into Point Hut Pond (#)	Unknown	Unknown	Together with Point Hut Pond, Conder Wetlands makes up a stormwater system that reduces flows and includes verge vegetation to reduce negative impacts from suburban runoff (#)	Waterwatch (2011–2021)
David Street Wetland	-35.26327 149.12372	David Street Wetland is an offline pond adjacent to Sullivans Creek, located in the inner north Canberra suburb of O'Connor. It is located along the westerly branch of Sullivans Creek, which flows in a concrete stormwater channel. This wetland takes low flows that pass through the wetland back into the westerly concrete channel just before it joins the main northern branch of Sullivans Creek. The water body occupies an area of around 800 m^2. The banks of the pond have been planted with emergent plants (macrophytes) to act as a deterrent to children entering the water. The pond is not intended for swimming or other aquatic activities (*) (#)	Located within the Sullivans Creek Catchment. Reach network length: approx. 0.21ha (#)	2001 (*)	This water body was constructed to help improve the urban water quality in the Sullivans Creek Catchment and provide urban habitat. It aims to: • improve water quality (particularly remove nitrogen and phosphorus from stormwater) • provide aquatic and terrestrial habitat for animals • manage stormwater by detaining water during high rainfall events • provide an attractive outdoor space with a visible water body (*)	Waterwatch (2011–2021
Dickson Wetlands	-35.250732 149.14873	Dickson Wetlands is an offline wetland located opposite the main playing fields in Dickson. A large concrete stormwater channel is fed into the constructed wetland under low	Located within the Sullivans Creek Catchment.	2010 (*) 2011 (#)	These wetlands provide multiple benefits, including: • water quality improvements by reducing excess nutrients and suspended solids	Waterwatch (2013–2021) ACT Government Lakes and Rivers Water quality

Site name	Location	Site characteristics	Catchment area	Age*	Values*	Water Quality Data
		flows, but during high rainfall events, flows bypass the wetland, remaining in the concrete channel. Water that passes through the wetland flows back into the concrete channel and through to Lyneham Wetland just upstream of the confluence with Sullivans Creek (#) The site includes seating, informal play areas, viewing spots, pedestrian paths, artwork and shade. Excess stormwater is piped to the Dickson Playing Fields and stored in tanks on site (*)	Reach area: approx. 1Ha (#) 5,241,842 m² (1)		• flood detention • the provision of aquatic and terrestrial habitat in urban areas • the provision of an attractive area associated with a waterbody • new recreational, volunteering and educational opportunities • a supply of stormwater to irrigate playing fields • restoration of concrete channels to living systems • increased values of surrounding properties (*)	monitoring program (2014–2021)
Flemington Pond	-35.22529 149.14336	Flemington Pond consists of two constructed wetlands on an ephemeral section of Sullivans Creek downstream of the industrial area of Mitchell, where it includes the stormwater channel from Exhibition Park (#)	Unknown	2009–2010 (*)	Flemington Pond aims to: • increase supplies of non-potable water to save about 600,000 kilolitres of potable water per annum and provide a diversified 'fit for purpose' water source at a cheaper cost to end users. • improve water quality in Sullivans Creek • reduce peak flood flows • create habitat and improve the aesthetic appeal of the site (*)	Waterwatch (2011–2021) ACT Government Lakes and Rivers Water quality monitoring program (2011–2021)
Gungaderra Pond	-35.2054 149.1364	Gungaderra Pond is located within the Gungaderra Creek reach, that starts in the southern suburbs of Gungahlin, flows through the Gungaderra Grassland Reserve and into Ginninderra Creek at Giralang Pond just upstream of Lake Ginninderra. It also includes a stormwater channel from the University of Canberra and Canberra Stadium, and has moderate urban stormwater inflow (#)	Unknown	Unknown	Unknown	Waterwatch (2011–2021)
Gunghalin Pond	-35.1914 149.1099	Gunghalin Pond was constructed as part of the Gungahlin Stormwater Pollution Control and Belconnen Flood Protection Strategy. It receives water from the upper section of Ginninderra Creek, which mostly comprises ephemeral creeks fragmented by stock dams. These reaches also include inflows of urban stormwater from surrounding suburbs and new developing suburbs. The pond has extensive open water areas, with limited macrophyte zones around their margins. It also has gross	5,000 ha (^)	1989 (^)	Gungahlin Pond has been designed to: • limit pollutant loading on Lake Ginninderra by trapping nitrogen, phosphorus and sediments • Improve the aesthetic character of the area • Provide recreational opportunities for the community • Provide flood attenuation, reducing peak stormwater flows (^).	Waterwatch (2011–2021) ACT Government Lakes and Rivers Water quality monitoring program (2011–2021)

Site name	Location	Site characteristics	Catchment area	Age*	Values*	Water Quality Data
		pollutant traps installed on the inlets to limit litter discharge (^) (#)				
Isabella Pond	-35.420433 149.08276	Isabella Pond is the main settlement pond for stormwater entering Lake Tuggeranong from the south-western Tuggeranong suburbs. Water passes over a high weir at its western end into Lake Tuggeranong (#)	Located in the Lake Tuggeranong Catchment. Reach network area: approx. 5.8Ha (#)	Unknown	Unknown	Waterwatch (2012–2021)
Jarramlee Pond	-35.2037 149.0135	Unknown	752,424 m2 (1)	1994 (1)	Unknown	Waterwatch (2011–2021)
Lyneham Wetlands	-35.254520 149.130681	Lyneham Wetlands are an online wetland that takes all runoff, including high flows following storms. Urban stormwater from Dickson, Downer, Hackett and Watson flows to Lyneham Wetlands through the stormwater network of concrete pipes and channels. Lyneham Wetlands overflow into Sullivans Creek when water levels are sufficiently high. The site includes seating, informal play areas, viewing spots, pedestrian paths, artwork and shade (#) (*)	Located within the Sullivans Creek Catchment. Reach area: approx. 1Ha (#) 9,026,985 m^2 (1)	2012 (*)	These wetlands provide multiple benefits, including: • water quality improvements by reducing excess nutrients and suspended solids • flood detention • the provision of aquatic and terrestrial habitat in urban areas • the provision of an attractive area associated with a waterbody • new recreational, volunteering and educational opportunities • a supply of stormwater to irrigate playing fields • restoration of concrete channels to living systems • increased values of surrounding properties (*)	Waterwatch (2014–2021) ACT Government Lakes and Rivers Water quality monitoring program (2014–2021)
North Watson Wetlands (Billabong Park)	-35.23244 149.15636	The North Watson Wetlands are located on the lower western slopes of Mt Majura Nature Reserve. They comprise a drainage line with two dams. Further down, a small, constructed wetland receives runoff from the adjacent suburb, and a small wetland soak takes overflows at the bottom of the reach. The water then flows via pipes into Sullivans Creek (#)	Reach network length: approx. 1.4km (#)	Unknown	Unknown	Waterwatch (2011–2016 and 2018–2021)
Point Hut Pond	-35.45189 149.08282	Point Hut Pond is a sediment control pond in the suburb of Gordon. Together with the Conder Wetlands, they make up a stormwater system that has been engineered to reduce flows and verge vegetation to lower the negative impacts from suburban runoff. The water from this system then	Reach network length: approx. 2.5km (#)	1980's	Specific values have been identified with Point Hut Pond, including: • water quality improvements by reducing excess nutrients and suspended solids • flood detention	Waterwatch (2011–2021) ACT Government Lakes and Rivers Water quality monitoring program (2011–2021)

Site name	Location	Site characteristics	Catchment area	Age*	Values*	Water Quality Data
		flows into the Murrumbidgee River just downstream of Point Hut Crossing (#)			• the provision of aquatic and terrestrial habitat in urban areas • the provision of an attractive area associated with a waterbody • recreational fishing opportunities • informal recreational opportunities that people associate with lakes and ponds • a limited range of facilities which cater for competitive water sports (^)	
Stranger Pond	-35.4292 149.0682	The Stranger Pond system consists of Upper Stranger and Lower Stranger Ponds connected by a tapped pipe (normally closed) under Drakeford Drive. The whole system is immediately to the south of Lake Tuggeranong and provides stormwater treatment for the suburb of Bonython. (#)	Reach network area: approx. 4Ha (#)	1980's	Unknown	Waterwatch (2012–2021)
The Valley Ponds	-35.1869 149.1235	Originally an old farm dam and artificial seepage grassland, The Valley Ponds was a unique habitat within the Ginninderra catchment. The site has since been redeveloped into urban wetland for the Gungahlin Town Centre and parts of Palmerston. It is now a high-quality education and recreational wetland (#) The wetlands also feature walking paths, an outdoor classroom and boardwalk, rock jetties and interpretive signage (*)	Located in the Gungaderra Creek Catchment: approx. 800 ha (^)	2012 (#)	These ponds provide multiple benefits, including: • water quality improvements, improving stormwater quality before it reaches Ginninderra Creek • flood detention, attenuating flows from the Gungahlin Town Centre • contributing to urban biodiversity by providing aquatic and terrestrial habitat in urban areas • a supply of stormwater to irrigate playing fields. (*)	Waterwatch (2011, 2014–2015, 2017–2021)
Yerrabi Pond	-35.174744 149.13869	Yerrabi Pond was constructed as part of the Gungahlin Stormwater Pollution Control and Belconnen Flood Protection Strategy. It is formed by the Mirrabei Drive embankment across east Ginninderra Creek. The pond receives moderate inflows from stormwater from the surrounding suburbs. The pond has extensive open water areas, with limited macrophyte zones around its margins. It also has gross pollutant traps installed on the inlets to limit litter discharge (^) (#)	2,060 ha (^)	1994 (^)	Yerrabi Pond has been designed to: • limit pollutant loading on Lake Ginninderra by trapping nitrogen, phosphorus and sediments • improve the aesthetic character of the area • provide recreational opportunities for the community • provide flood attenuation, reducing peak stormwater flows by providing substantial temporary stormwater storage during periods of high rainfall (^)	Waterwatch (2011–2021) ACT Government Lakes and Rivers Water quality monitoring program (2011–2021)

** information obtained and adapted from (ACT Government 2021b)*
^ information obtained from (ACT Government 2021a)
 # information obtained and adapted from www.act.waterwatch.org.au/
1. information obtained and adapted from (Ubrihien et al. 2019a)

Summary data (Table 54) suggest that, across the 15 urban ponds, all water quality attributes recorded are almost always within the acceptable range of values for urban wetlands. This suggests that as a collective, Canberra’s urban wetlands generally display good water quality. There are obviously site-based differences (see Appendices L to P), but the majority have acceptable water quality.

Table 54. Annual percentage of data points recorded across 15 sites (Table 53) that are within the acceptable ranges specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).
Note that for TN, there are currently no set acceptable ranges specified for urban wetlands.

	pH	**Total phosphorus**	**Total nitrogen**	**Turbidity**	**Total suspended solids**	**Dissolved oxygen**	**Conductivity**
2011	96	100	N/A	86	84	99	92
2012	95	97	N/A	84	81	99	84
2013	98	94	N/A	87	94	91	83
2014	94	82	N/A	94	100	89	82
2015	97	84	N/A	88	84	96	88
2016	97	91	N/A	92	83	95	94
2017	98	94	N/A	93	80	94	88
2018	96	91	N/A	93	90	87	90
2019	93	93	N/A	95	83	93	91
2020	99	96	N/A	94	94	91	88
2021	98	96	N/A	95	79	90	95

Q.1 Nutrients

Nutrient concentrations within the 15 urban ponds are generally within the acceptable range for urban wetlands, but there are regular instances of very high concentrations of both phosphorus (Figure 173) and nitrates (Figure 174), including some extreme concentrations. While irregular high concentrations of nutrients have been observed in the ACT’s waterways (e.g. in Ubrihien et al. 2019a and Ubrihien et al. 2019b), concentrations such as these in surveillance monitoring should trigger a process to respond to them. Nitrate concentrations of 10 mg/L can adversely affect large numbers of species of freshwater invertebrates, fish and amphibians (Camargo et al. 2005), which would suggest that at least some of the concentrations recorded should be cause for concern.

As highlighted in Appendices L to P, the performance of the ponds and wetlands in improving water quality is variable, and there are not data commonly available that would inform an evaluation of their performance. Where data are available, they suggest that the wetlands are generally better at removing nitrogen from the system, rather than phosphorus but there are some instances where phosphorus is removed by the pond or wetland (e.g. Jarramlee Pond — see Appendix N).

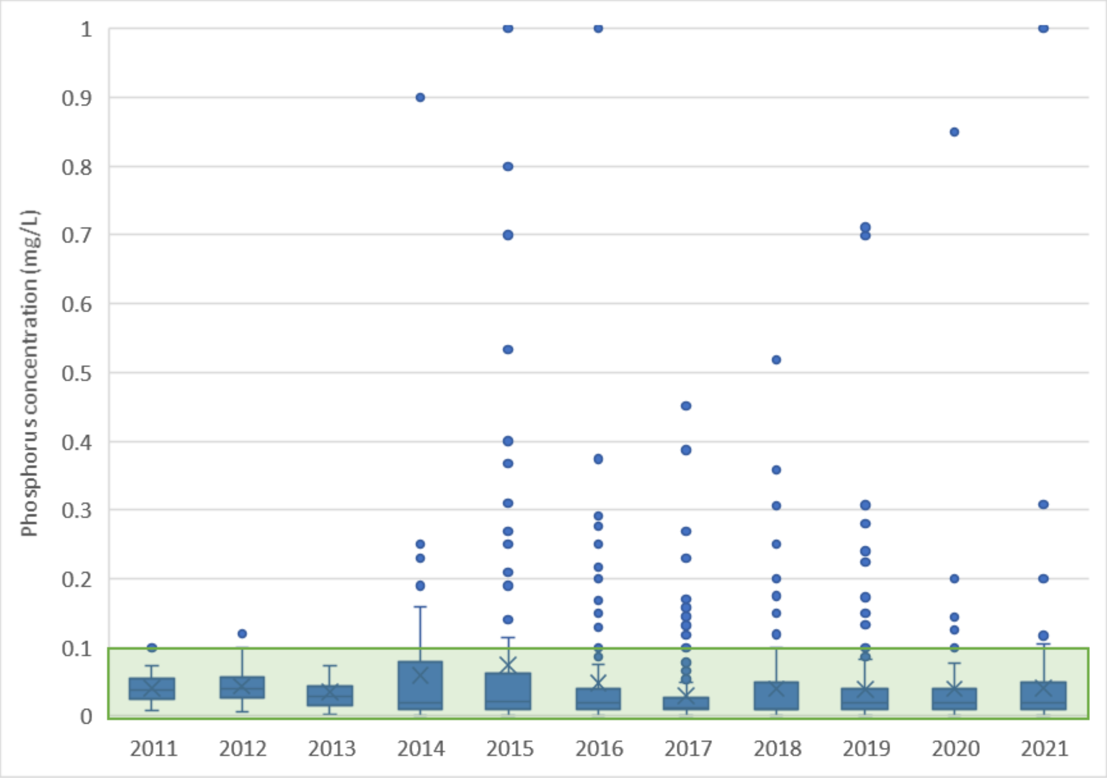

Figure 173. Phosphorus concentrations in the urban ponds and wetlands of the ACT from 2011 to 2021.
Data are from 15 sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for phosphorus specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

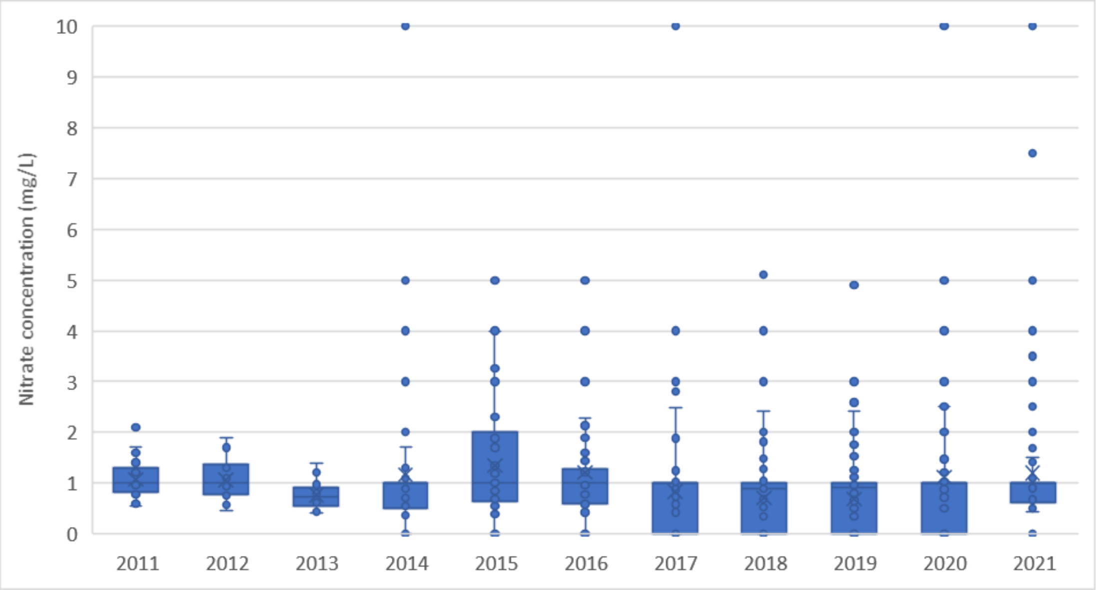

Figure 174. Nitrate concentrations in the urban ponds and wetlands of the ACT from 2011 to 2021.
Data are from 15 sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. Note that for nitrate there are currently no set acceptable ranges specified for urban wetlands.

Q.2 pH

The average long-term data indicates that the urban ponds and wetlands across all sampling years are within the acceptable range for pH for more than 90% of the time (Figure 175). Lower Stranger Pond records an acceptable range of pH for 100% of the time and Banksia Street Wetland was the only site that was below acceptable range for less than 90% of the time.

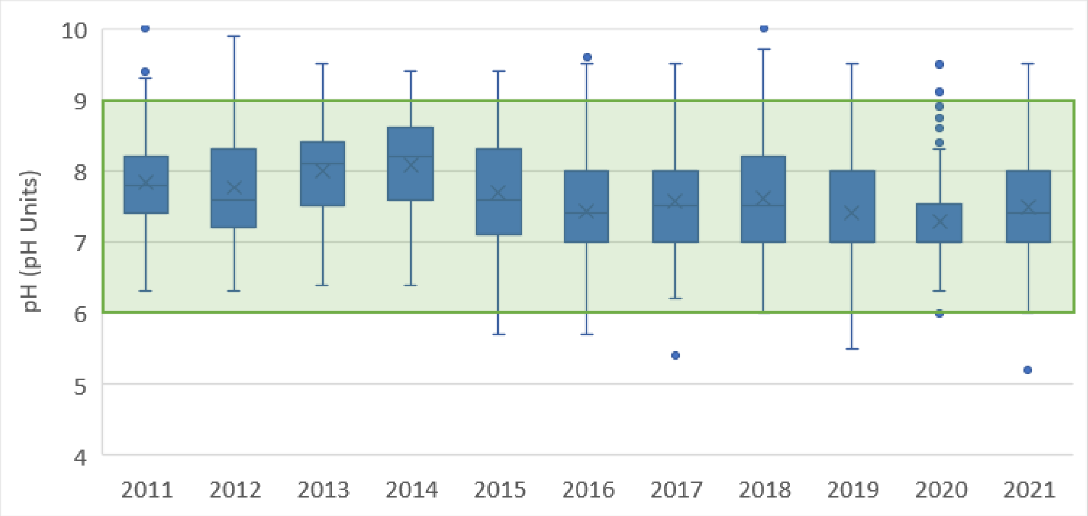

Figure 175. pH concentrations in the urban ponds and wetlands of the ACT from 2011 to 2021.
Data are from 15 sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for pH specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

Q.3 Turbidity/Suspended sediment

Overall, the current data indicate that turbidity varies across sampling years and locations, with most sites recording concentrations below the threshold of 10 NTU mg/L for 90% of the time (Figure 176). Gungahlin Pond was the only site to record average concentrations within thresholds for less than 80% of the time.

Long term monitoring data for total suspended solids (TSS) within the ACT's urban ponds and wetlands is currently only available for six sites — Dickson Pond, Gungahlin Pond, Point Hut Pond, Flemington Road Pond, Lyneham Pond and Yerrabi Pond. The data are collected from a single sampling point at each site, which does not allow for the assessment of reduction of TSS from the inflow to the outflow and therefore provides insufficient data to determine how well these sites are performing at removing TSS. Ubrihien et al. (2019a) noted that, in general, the ponds studied were effective at reducing suspended sediment loads in the urban stormwater system, with the Banksia Street Wetland and Coombs B Pond downstream sampling locations in particular recording significantly lower concentrations than the inflows to these ponds.

Overall, the current data indicate that concentrations of TSS vary across sampling years and locations, with the majority of sites recording concentrations below the threshold of 25 mg/L for 86% of the time (Figure 177). Both Gungahlin Pond and Lyneham Pond have recorded mean TSS concentrations above the threshold on multiple occasions (data not shown), with a notable increase at the Gungahlin Pond site during the 2017 and 2021 sampling years. The analysis conducted by Ubrihien et al. (2019a) also highlighted that the mean TSS concentrations at the Banksia Street Wetland, Coombs A Pond, Coombs B Pond and David Street Wetland also exceed the threshold of 25 mg/L.

The cause of these elevated sediment concentrations may be a combination of local sediment run off from urban development or rainfall events. The ACT Water Report for the year 2012–2014 (ACT Government 2022) recognised that TSS at Point Hut Pond in 2012–13 was often elevated, which may have reflected building activity and gardening in the catchment. It has been suggested that a driver of increased sediment loads within Lyneham Pond may have been the accumulation of sediment and organic material within the pond from an underperforming gross pollutant trap (GPT) at the inlet of the pond (Alluvium 2016).

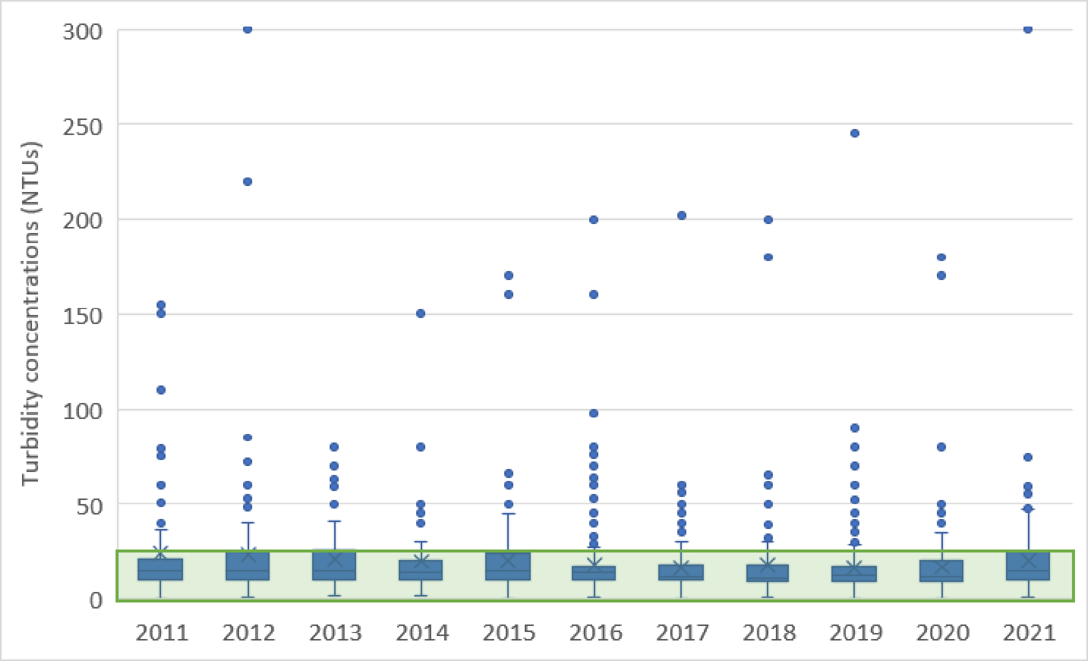

Figure 176. Turbidity in the urban ponds and wetlands of the ACT from 2011 to 2021.
Data are from 15 sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for turbidity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

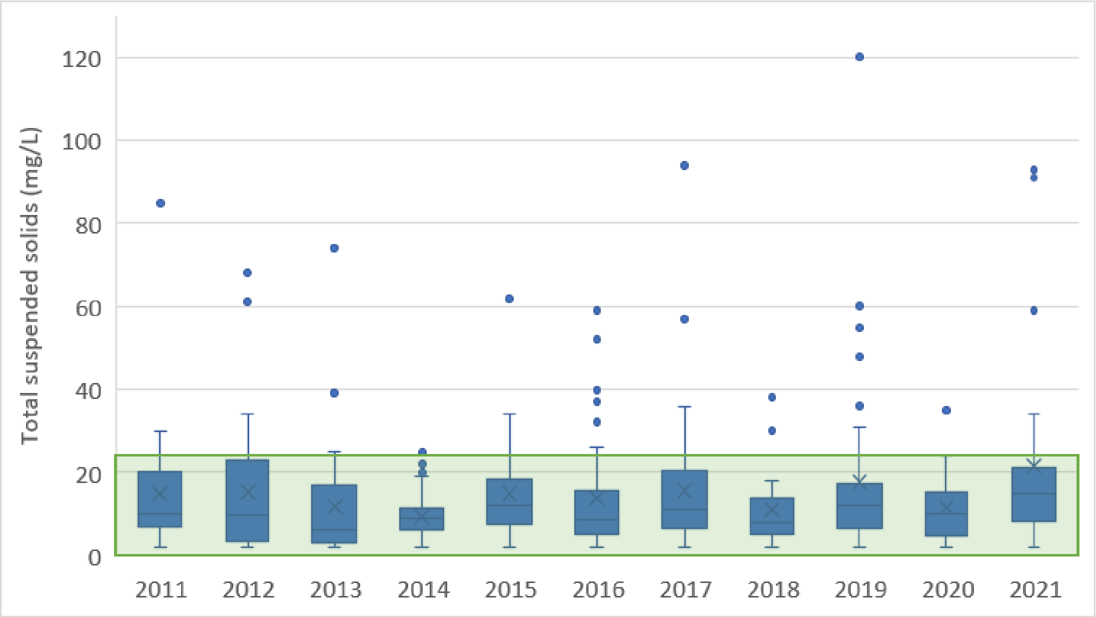

Figure 177. Total suspended solids (TSS) concentrations in the urban ponds and wetlands of the ACT from 2011 to 2021.

Data are from 15 sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for TSS specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

Q.4 Conductivity

Conductivity within the ACT’s urban ponds and wetlands are within the acceptable range for 89% of the time (Figure 178). For most of the urban ponds and wetlands, conductivity is almost always within the acceptable range, with the exception of The Valley Ponds, where values exceeded 350 µS/cm at 79% of sampling occasions.

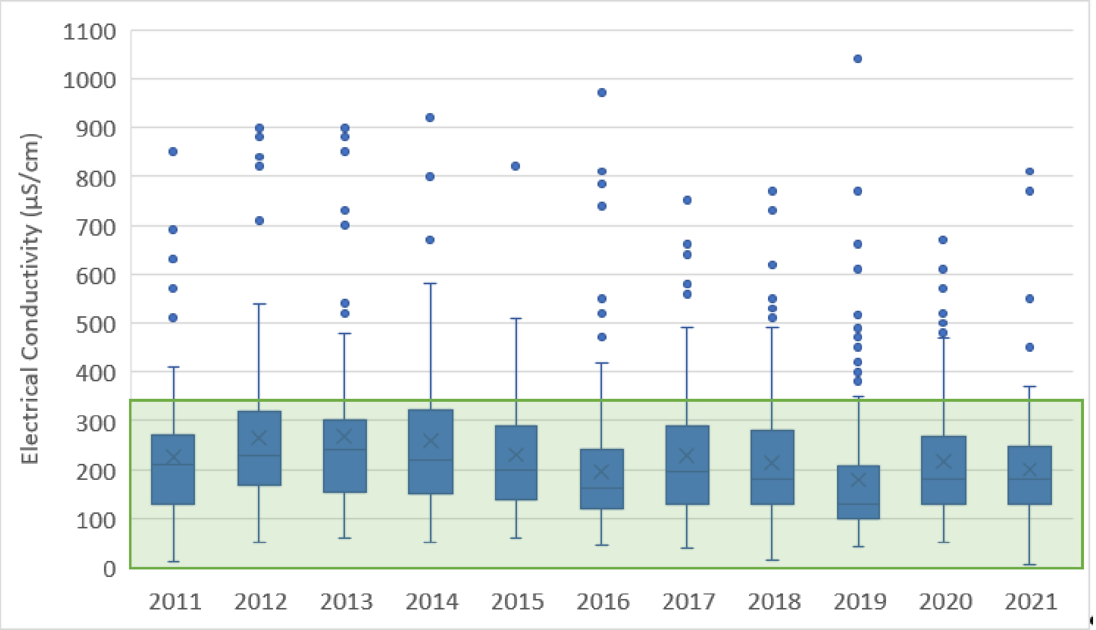

Figure 178. Electrical conductivity in the urban ponds and wetlands of the ACT from 2011 to 2021. Data are from 15 sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for electrical conductivity specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

Q.5 Dissolved oxygen

Dissolved oxygen concentrations in the surface waters are generally within the acceptable range of 6 to 10 mg/L (Figure 179), with occasional (7% of readings) instances, in particular Lyneham Pond and David Street Wetland, where concentrations were below acceptable levels. Concentrations in the bottom waters are lower and are consistent with those of ponds that stratify over summer (data not shown).

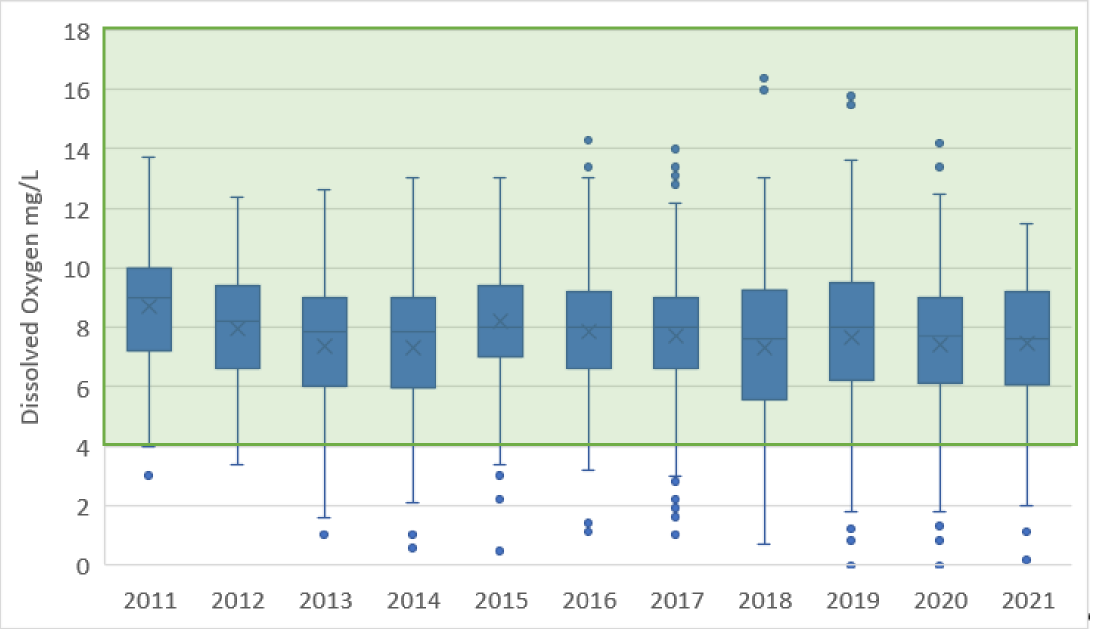

Figure 179. Dissolved oxygen concentrations in the urban ponds and wetlands of the ACT from 2011 to 2021. Data are from 15 sites for each calendar year, noting the data from 2021 are incomplete at the time of writing. The green shading shows the acceptable range for dissolved oxygen specified in the Environment Protection Regulation 2005 values for urban wetlands (AQUA/5).

Q.6 Ecological values

The Rapid Appraisal of the Riparian Condition (RARC) score is used by Waterwatch to give an indication of the riparian condition, with values meeting *excellent, good, fair, poor* or *degraded* conditions*.* The appraisal occurs every two years, and has been assessed in the years 2015, 2017, 2019 and 2021. The average long-term data indicate the vegetation condition across the ACT's urban ponds and wetlands across is *poor* for 67% of the time (Figure 180). No sites recorded *excellent* conditions and Yerrabi Pond, Isabella Pond and Point Hut Pond recorded a *degraded* condition at least once during the sampling years. David Street Wetland demonstrated the best vegetation condition, with only *good* and *fair* conditions recorded across the sampling years.

Reports of fish kills at Yerrabi Pond were recorded in 2014 (ACT Government 2014c), with a large number of Murray cod killed over a 25-day period. Investigations failed to determine the reasons for the fish kill, but it was considered likely that warm temperatures and low dissolved oxygen conditions may have been contributing factors.

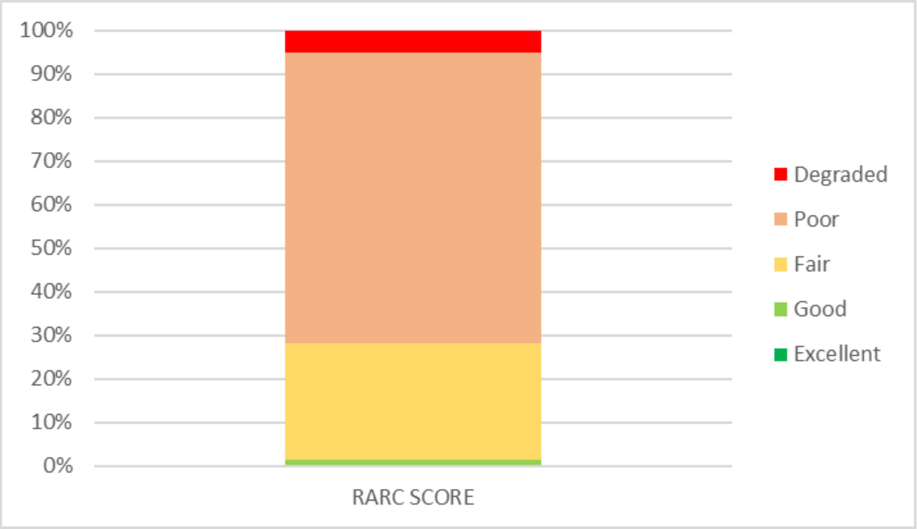

Figure 180. Percentage of all RARC (Rapid Appraisal of Riparian Condition) scores from the urban ponds and wetlands of the ACT from 2015 to 2021 that are classified as excellent, good, fair, poor or degraded. Data are from 15 sites, noting the data from 2021 are incomplete at the time of writing.

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