

Options for restoring Lake Tuggeranong

October 2025

ACT Government

ACT Healthy Waterways

Acknowledgement of Country

Yuma

Dhawura nguna ngurumbangu gunanggu Ngunnawal. Nginggada dindi dhawura Ngunnawalbun yindjumaralidjinyin.

Mura bidji mulanggaridjindjula.

Naraganawaliyiri yarabindjula.

Hello,

This country is Ngunnawal (ancestral/spiritual) homeland. We all always respect elders, male and female, as well as Ngunnawal country itself.

They always keep the pathways of their ancestors alive.

They walk together as one.

We acknowledge the Ngunnawal people as traditional custodians of the ACT and recognise any other people or families with connection to the lands of the ACT and region. We acknowledge and respect their continuing culture and the contribution they make to the life of this city and this region.

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Citation

ACT Government (2025) Options for Restoring Lake Tuggeranong. Unpublished report.

Contributors

Woo O'Reilly, Katie Miller and Ralph Ogden

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Options for Restoring Lake Tuggeranong

- Executive summary



Executive summary

There is a rich history of Aboriginal use of the Tuggeranong valley and its waterways, with evidence of the Ngunnawal people occupying the valley for more than 20,000 years. The name 'Tuggeranong' comes from a Ngunnawal word for 'cold place' or 'cold plains'.

The valley has changed dramatically in the past 200 years, shifting the traditional life patterns that Traditional Custodians have understood and worked with for thousands of years. Sheep and cattle stations were established in the early 1800s. Since suburban development started in the 1970s, around 50% of the water catchment has been urbanised. Lake Tuggeranong was built in 1987 as a focal point for the growing town centre and to protect the downstream Murrumbidgee River from the water quality effects of development. Around the same time, a stormwater system was built to manage flood risk by converting natural creek lines such as Tuggeranong Creek into concrete channels.

Lake Tuggeranong has experienced elevated nutrient levels for more than ten years, which has led to frequent blue-green algal blooms. The algal blooms smell unpleasant, are unsightly and require the government to close the lake to activities such as swimming and water sports due to health risks. They also may pose health risks to residents of suburbs surrounding the lake who are exposed to aerosolised lake water on windy days.

Several key conclusions can be drawn from the analyses in this report:

- There is sufficient knowledge to have confidence that better water management can lead to a substantial reduction in the frequency of blue-green algal blooms in Lake Tuggeranong.



- A suite of pollution mitigation options to prevent nutrients entering the lake will be needed for success.
- Further research and adaptive management in implementation will lead to a refined suite of management options for Government to choose from and increase the overall cost-effectiveness of the restoration effort.
- There will be a limit to what can be done to prevent algal blooms; the best that can be achieved is to prevent algal blooms in three out of four years on average.
- Water managers may need to develop options to treat algal blooms when they do arise.

This report presents our current knowledge of options for preventing algal blooms in terms of impact and cost-effectiveness. This report builds on previous Healthy Waterways work in the Lake Tuggeranong catchment that saw the construction of nine important wetlands and funded research and community engagement to reduce the sources of nutrient pollutants.

Following consideration of community feedback on the report, the Government will present its preferred options for achieving a healthier Lake Tuggeranong as a Healthy Waterways Plan for Lake Tuggeranong (the Plan).

The vision

This report and the Plan that will follow address an ACT Government commitment for the 11th Assembly to Develop and deliver a 10-year plan for a healthier Lake Tuggeranong.

The 10-year vision is:

By 2035, Lake Tuggeranong is more consistently free of blue-green algal blooms and, when they do occur, they are short-lived so the Tuggeranong community can enjoy the lake most of the year.



The underpinning research and analyses

Research and modelling funded through the ACT Healthy Waterways program over the past decade has greatly improved understanding of blue-green algal blooms in Lake Tuggeranong. It is now well established that the inflow of phosphorus and other nutrients from the catchment is the main factor driving the blooms. They effectively feed the blooms.

There is currently far more phosphorus entering the lake from its catchment than is released to the water column from lake-bottom sediments. Phosphorus is generated from many diffuse sources across the urban catchment such as leaves, grass clippings, fertiliser products (including imported composts and manures), soil and sewage. Roughly half of it is in a dissolved form that is readily taken up by algae.

The stormwater flowing off the catchment carries an average annual generation of 1,656 kg phosphorus/year. The seven constructed wetlands built in Stage 1 of Healthy Waterways have reduced this by about 214 kg a year (to 1,442 kg). However, under current flow and levels of phosphorus supply, Lake Tuggeranong will remain in a eutrophic state—which means it is primed for algal growth.

Research shows that we can significantly reduce blue-green algal blooms if we curb or 'mitigate' the supply of phosphorus to the lake by about 50%, or around 700 kg a year. Once this happens, any further algal blooms can be prevented through in-lake actions. If the average annual amount of phosphorus entering the lake can be reduced by another 700 kg, the water quality models predict a eutrophic state can be avoided for an average of three out of four years.

The 700 kg target is based on annual averages. In very wet years the reductions in phosphorus will need to be higher, while in dry years they can be lower. Some blue-green algae will be present in all years—it naturally occurs in, but if the 700 kg target can be achieved, the likelihood of problem blooms would be lower than at present and the lake should usually be available for contact-based activities.

Options for removing phosphorus

It is possible to remove phosphorus from the system, or to treat algae directly, at three stages during the 'journey of the stormwater':

1. At the sources of pollution, by preventing pollution from occurring in the first place.
2. Within the stormwater system, by slowing the flow and filtering pollution from the stormwater.
3. In the lake, by using agents that compete with algae for nutrients, or by using algicides.

Some potential options are identified for reducing or mitigating phosphorus levels (pollution mitigation options) or directly treating algal blooms. A subset of ten options and variants of options are examined in detail. These were chosen because their costs and effectiveness could be well characterised based on local trials or the scientific literature.

The analyses clearly show that the most effective options for reducing phosphorus pollution are an increased frequency of street sweeping and building extra water quality assets, such as wetlands, which cleanse stormwater of pollutants. Street sweeping is by far the most cost-effective mitigation measure, decreasing phosphorus by 200–400 kg per year, depending on the frequency of sweeps. Constructing more water quality assets would decrease phosphorus by 100–200 kg per year, depending on the scale of the wetlands and other water quality assets already in the system.

However, no single option is a 'silver bullet' that has the potential to reach the phosphorus mitigation target on its own. Multiple options will be needed. Notably, options to prevent stormwater from getting polluted in the first place will be needed to substantially reduce the frequency of blue-green algal blooms.

Future research and monitoring

An active research and monitoring program has played a central role in the work to date. Ongoing research and monitoring will be critical to refining pollution mitigation options to maximise their effectiveness and minimise their costs. New evidence and knowledge can be incorporated into future versions of the Plan, and its implementation plans.

The highest research priorities are trials of promising options and investigations to better understand the fate of fertilisers applied to residents' blocks and to determine whether sewage (either through cross-connections or by other mechanisms) is a significant source of phosphorus in stormwater. It will be critical to continue to monitor the effectiveness of wetlands and other water quality assets, as well as other interventions.

Additional research will continue to refine knowledge and understanding of how to reduce phosphorus in the catchment. However, there is enough evidence already to identify priorities for restoration. Substantial improvements should occur in the lake within several years of the commencement of a material pollution mitigation program.

Next steps

The Government will create Version 1 of the Healthy Waterways Plan for Lake Tuggeranong based on this report, incorporating further inputs from First Nations people and feedback from the community. An implementation plan will then be developed to set out how the vision will be achieved over the next 10 years, including how it will be monitored and evaluated.



Floating wetland in Lake Tuggeranong



Aerial view of Lake Tuggeranong. Source: MetroMap

Part 1
Context

- The ACT Healthy Waterways Program
- Objective and scope of the report
- Vision
- Lake values
- Legislative and policy context for managing water quality in Lake Tuggeranong
- Lake Tuggeranong and its catchment



Part 1: Context

The ACT Healthy Waterways Program

Addressing water quality in our urban lakes, and specifically the issue of blue-green algae, is a major challenge. The ACT Healthy Waterways Program (Healthy Waterways) was created to address the issue of declining water quality in ACT's rivers and urban lakes.

Stage 1 Healthy Waterways (2014–21) was a joint Australian Government and ACT Government investment, while the ACT Government is fully funding Stage 2 (2021 to present).

Over the last decade, Healthy Waterways has delivered a comprehensive suite of activities to help improve water quality and improve our understanding of the problem. It has built water quality assets (such as wetlands and raingardens); invested in research, monitoring and data analyses; built water modelling capability; and initiated community partnership programs to uplift catchment management practices.

Through this work, we have greatly improved our understanding about how ACT's urban catchments operate, the different sources of nutrient pollution that enter waterbodies and lead to algal blooms, the in-lake processes that promote algal blooms, and how the community wishes to participate in caring for waterways.

Of the urban lakes, Lake Tuggeranong has suffered the most chronically from water quality issues in recent years and has been the primary focus of investigative efforts to date. This report will underpin a Healthy Waterways Plan for Lake Tuggeranong (the Plan; Figure 1), which is the first of four Healthy Waterways plans for urban waterways.

Objective and scope of the report

The objectives of this report are to:

1. determine whether it is possible to achieve a substantial reduction in the incidence of algal blooms in Lake Tuggeranong through better catchment and waterway management
2. evaluate various options for mitigating stormwater pollution that drives algal blooms.

The Government will finalise the report as a *Healthy Waterways Plan for Lake Tuggeranong* once the community has provided feedback on the options (Figure 1). Subsequently, it will consider what level of funding will be investigated for the Plan to be implemented. Any funded restoration activities will be monitored and evaluated, and further research and stakeholder engagement will be conducted. The Government will periodically update the Plan as new knowledge comes to hand to ensure the plan achieves maximum value for the community at least cost.

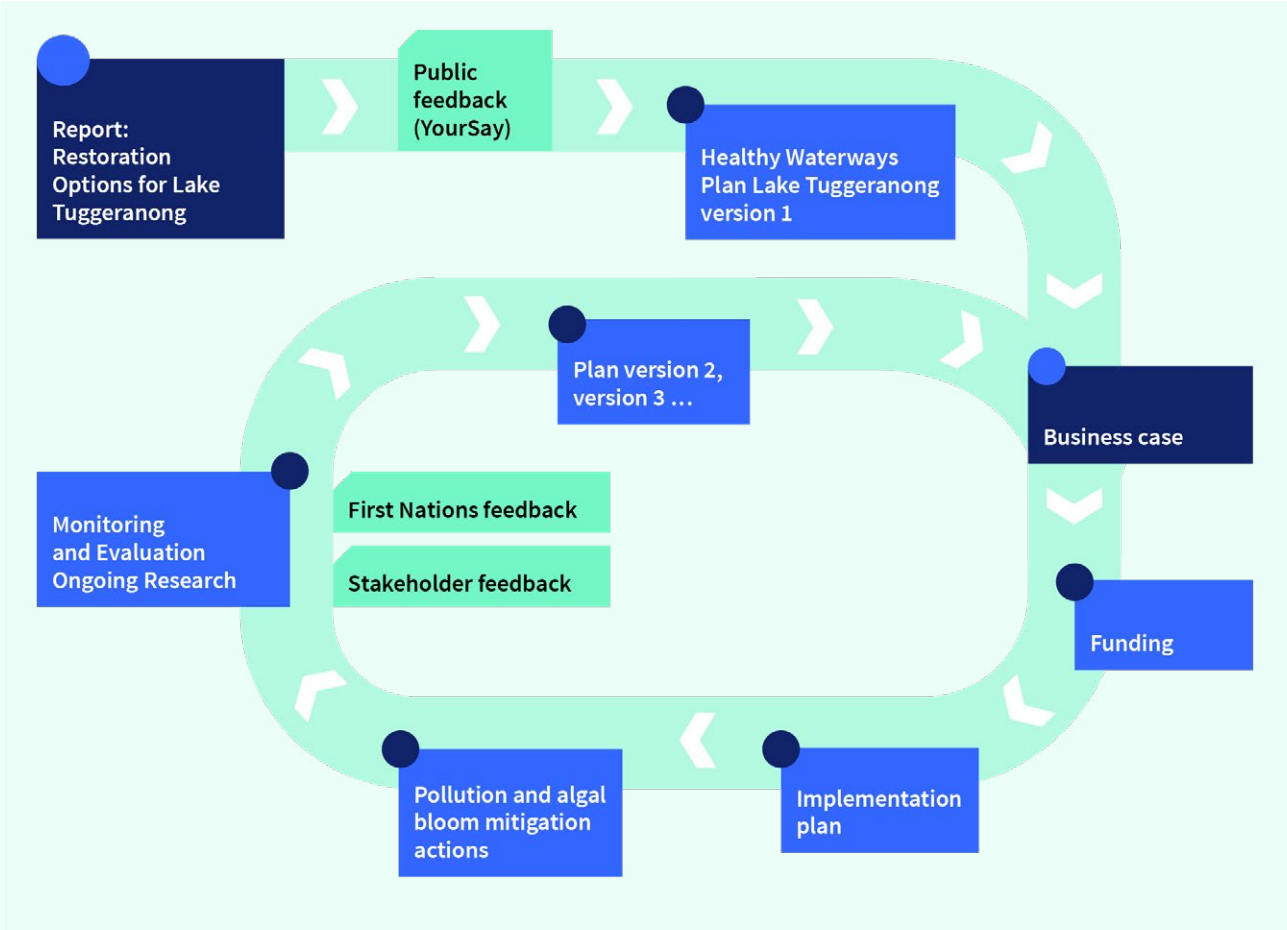


Figure 1. Role of Restoration Options for Lake Tuggeranong in the adaptive management cycle for mitigating algal blooms in the lake.

This report and the Plan prioritise focussing on algal blooms over other water quality issues because the ACT Government believes they are the highest priority for the Tuggeranong community (for example, TCC, 2024, Draft). Reducing the incidence of blue-green algal blooms in Lake Tuggeranong should improve its amenity and recreational values for residents and reduce health risks.

Vision

This report and the subsequent Plan address an ACT Government commitment for the 11th Assembly to Develop and deliver a 10-year plan for a healthier Lake Tuggeranong.

The 10-year vision is:
By 2035, Lake Tuggeranong is more consistently free of blue-green algal blooms and, when they do occur, they are short-lived so the Tuggeranong community can enjoy the lake for most of the year.

We need a 10-year time frame because new infrastructure assets will take time to build and become fully functional, and to allow enough time to assess the effectiveness of interventions while considering the background influence of year-to-year climate variability. Nevertheless, fulsome implementation of the Plan should lead to substantial improvements in water quality within several years.

Aquatic ecosystems in the ACT are highly valued by Traditional Custodians and the broader community as living systems that embody the interconnectedness of all life. Achieving this 10-year vision will support Traditional Custodian responsibilities to care for Country for future generations, as practiced for tens of thousands of years. This reflects Traditional Custodian understanding of water as an interconnected part of Country.

Lake values

Lake Tuggeranong provides multiple social, economic and environmental values for the ACT and region community. However, the 2022 State of the Lakes and Waterways report highlights that there are tensions between the competing values of urban lakes and waterways—for example the amenity of Lake Tuggeranong versus its role as a pollution trap—and widely differing expectations of urban water management (OCSE, 2022).

Mitigating downstream pollution

Canberra's lakes reduce downstream pollution by acting as sediment and pollution filters. NCEconomics (2023) estimated the market value of this function, known as 'avoided abatement cost', which describes how much it would cost to provide the equivalent pollution abatement if the lakes were not serving that function. They estimated the value of Canberra's urban lakes as pollution filters using a hypothetical comparison of water quality outcomes 'with' and 'without' the lake, where water quality upstream of the lake was used as a proxy for water quality 'without' the lake. The used total nitrogen as the water quality indicator because pollution abatement assets can reduce multiple pollutants at the same time, so only the highest-cost pollutant for each lake was used, to avoid the risk of double counting. The abatement costs were based on the cost of creating equivalent abatement capacity by building water quality assets. The cost of water quality assets was derived from construction costs in the ACT in the six years from 2017 to 2023.

The study estimated the net present value associated with Lake Tuggeranong's pollution abatement value is $133–144 million over 30 years. As discussed in Part 6, water quality assets are not the most cost-effective option for mitigating phosphorus pollution, so this is likely an overestimate of Lake Tuggeranong's pollution abatement value.

However, Lake Tuggeranong is not always effective as a pollution filter. The 2022 State of the Environment Report concludes, 'Lake Tuggeranong does not appear to be consistently mitigating the effects of urbanisation for the downstream waters with periods of higher phosphorus and nitrogen concentrations within and downstream of the lake compared to upstream of the lake'.

Providing opportunities for recreation and amenity

Canberra's urban lakes and their catchments provide important social values for residents. Access to blue spaces also contributes to improving people's physical, mental and spiritual wellbeing (UK Environment Agency, 2020; Dushkova et al., 2021; Lal and Akhikari, 2024). It follows that when algal blooms require the government to close the lake for long periods, there may be negative consequences for people's health and wellbeing.

The high value that Canberra residents place in their waterways is reflected in several surveys and community engagements undertaken from 2016 to 2023:

- A 2016 survey of more than 7000 people on Canberra's urban lake use found that the activity most often rated as 'highly important' was walking with other people, followed by picnics/barbeques, cycling and using playground areas (Schirmer & Mylek, 2016).
- In the findings of a 2018 ACT 'Better Suburbs' community survey, the citizen forum's first recommendation (out of 14) was to increase funding for lakes, ponds, wetlands, stormwater and water quality. This was ranked as more important for community members than issues such as street trees, roads, footpaths and public libraries (ACT Government, 2018).
- In community engagements as part of developing the Tuggeranong District Strategy, the Tuggeranong community said they value the lake for a range of recreational activities throughout the year, including walking, cycling, swimming, fishing and windsurfing (ACT Government, 2023b).
- A report commissioned by the ACT Government in 2023 explored residents' willingness to pay for environmental amenity and recreational use of Canberra's lakes (NCEconomics, 2023). The report found that the total annual non-market economic value of the lakes

based on pollution control and amenity was approximately $159 million a year for Lake Tuggeranong, with the economic value from benefits to the community significantly outweighing the benefits attributable to water quality management (pollution abatement) provided by the lakes (Figure 2). (The much lower value of Lake Tuggeranong for pollution abatement in Figure 2 compared with its net present value is because Figure 2 reports annualised data whereas net present value is assessed for a 30-year period.)

- The same report indicated they were prepared to pay up to $70/per person/quarter (or $280/per person/year) to greatly improve the environmental (visual and smell) amenity of Lake Tuggeranong (NCEconomics, 2023). Across all lakes, the survey found that most lake users are infrequent, casual users who draw more value from lake amenity and lakeside facilities than from primary and secondary contact activities like swimming and boating. This finding is also consistent with findings from the earlier survey of Schirmer & Mylek (2016).

Environmental values

There is limited information on the ecological values of the lake. The Waterwatch Catchment Health Indicator Program (CHIP) 2023 report notes the lake has poor riparian condition with little native vegetation, but Eastern Long-necked Turtles, water dragons and occasionally Rakali (Australian native water rats) are present in the wetlands at the southern end of the lake (Upper Murrumbidgee Waterwatch, 2023).

The 2022 State of the Lakes Report found that the aquatic health of the lake supported ecological values to a 'fair' degree, noting limited information to determine a trend. This conclusion was based on the CHIP assessments and because water quality and ecosystem health of the lake are sufficient for the survival of stocked native fish (OCSE, 2022). Murray Cod and Golden Perch are stocked, primarily to support recreational fishing, it also to improve biodiversity and help balance the fish composition by adding native predators to the system. There are a lot of carp in the lake; surveys in 2015 and 2018 showed carp comprised around 90% of all biomass caught. This decreased to 60% in 2024 due to increased stocking of native fish (ACT Government, unpublished data, 2025).

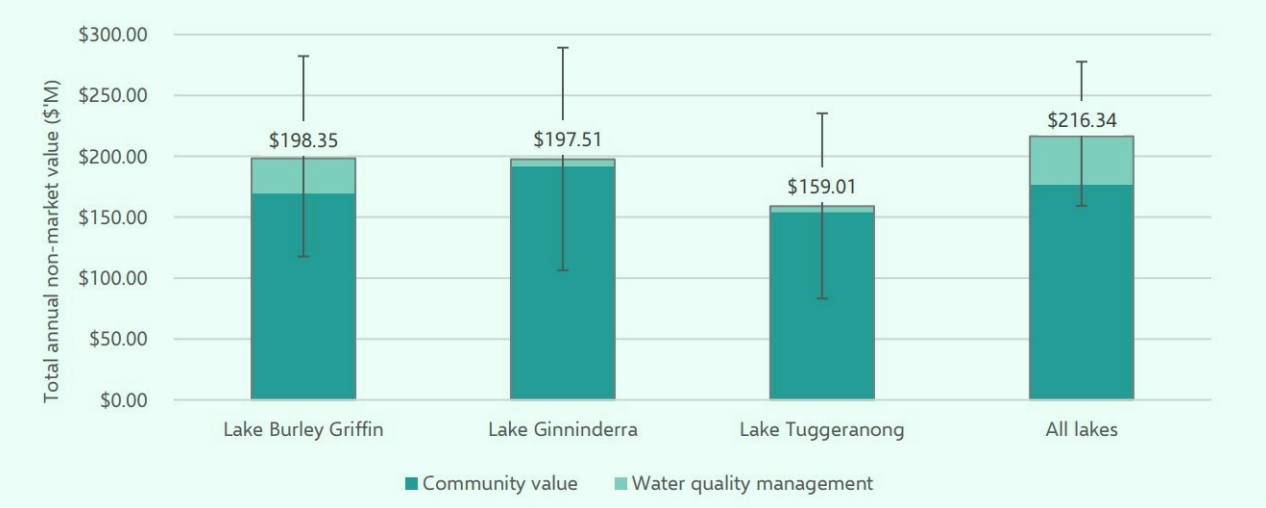


Figure 2. Total annual non-market value from ACT urban lakes. The community value is based on surveyed residents' willingness to pay for good water quality within the lakes through increases in rates. The water quality management value is based on the avoided cost of building water quality assets that provide the same level of treatment as the lake. Source: NCEconomics (2023).

Cultural values

Cultural values mapping can help to identify what First Nations cultural values and uses are associated with the lake, its tributaries and catchment.

An initial Ngunnawal Aboriginal Waterway Assessment (AWA) was conducted that assessed the health of Country and the waterways in the Tuggeranong catchment from a cultural perspective. The Assessment stressed the importance of:

- recognising Ngunnawal people as a part of the solution to restoring the health of Lake Tuggeranong
- reintroducing and respecting cultural practice in catchment management such as cultural burning and cultivation of pointer and keeping trees
- establishing Ngunnawal rangers
- continuing to conduct AWAs
- introducing more native plants to the creek and surrounding riparian and dry landscapes, including natives of cultural significance such as reeds for weaving
- restoring key features such as naturalising concrete drains
- creating a fully connected cultural way from the headwaters of Tuggeranong Creek to its confluence with the Murrumbidgee River
- avoiding pollution, including from blue-green algae, of the Tuggeranong Creek below Lake Tuggeranong
- considering river health and Country health as intertwined
- exploring opportunities for an entitlement to water for cultural purposes.

Further engagement should occur with Traditional Custodians as part of implementation planning to guide an integrated design approach that supports and enhances place-based management actions.



Lake Tuggeranong looking north towards Mount Taylor (photo: Jennifer Smits)

Legislative and policy context for managing water quality in Lake Tuggeranong

Lake Tuggeranong's management is prescribed by the *Planning Act 2023* (ACT), which prioritises management objectives for all public land (including waterways) in the following order:

- Prevent and control floods by providing a reservoir to receive flows.
- Prevent and control pollution of waterways.
- Provide for public use for recreation.
- Provide habitat for fauna and flora (Schedule 3 [Part 3.2]).

Since there is little urban infrastructure downstream of Lake Tuggeranong to protect from floods, the primary management objective for Lake Tuggeranong under the Planning Act is to prevent and control pollution.

The Plan aligns with and supports the implementation of other ACT legislative and policy commitments on water quality, specifically the following:

- The *Lakes Act 1976*, administered by the Environment Protection Authority (EPA), which provides for the administration, control and use of urban lakes in Canberra (other than Lake Burley Griffin).
- The ACT Water Strategy 2024–2044 Striking the Balance sets a 20-year vision for ACT water management as: *'A community working together, managing water wisely to support a vibrant, sustainable and thriving region.'* Outcome 1 of the Strategy—Healthy Catchments and Waterbodies—aims to achieve 'Well managed, functioning catchments that provide sufficient clean water for the environment and human consumption, support healthy waterbodies, and contribute to liveability of the ACT community'.
- Focus on improved water quality standards to support identified environmental values and permitted uses for Lake Tuggeranong. Environmental values and permitted uses are defined through the Water Use and Catchment General Code (the Code), a subordinate instrument of the *Water Resources Act 2007* (ACT). Under the Code, Lake Tuggeranong and its catchment is defined as drainage and open space with the following environmental values and permitted uses of:
  - discharge of stormwater
  - irrigation water supply
  - waterscape view
  - aquatic habitat (lowland streams, urban lakes and ponds, urban wetland)
  - water-based recreation (boating).
- Water quality standards are set through the Environment Protection Regulation 2005 (ACT) Schedule 4, a subordinate instrument under the *Environment Protection Act 1997* (ACT), and support the policies, management objectives and values of the Code. Access Canberra (EPA) ensures compliance with the Environment Protection Regulation, including s44 that 'a person must not place, or permit to be placed, a pollutant in a waterway if the pollutant is likely to cause environmental harm.'
- The ACT and Region Catchment Strategy 2016–2046 establishes a 30-year vision to guide priority actions for a healthy Upper Murrumbidgee River region (upstream of Burrinjuck Dam to Tantangara Dam in NSW). Developed in partnership with the Australian Government, ACT Government, NSW Government, local councils, Icon Water and the community, it is currently undergoing a 5-yearly review.
- The 2002 Legislative Assembly committed to manage downstream water quality through an agreed motion that the water leaving the ACT via the Murrumbidgee River should be of no less quality than the water flowing into the ACT (ACT Legislative Assembly motion 5 June 2002 9.1[b]).

- The Canberra Urban Lakes and Ponds Land Management Plan's vision is to: *enrich local communities through the aesthetic, recreational, sporting, tourism, cultural and ecological values of lakes and ponds, and to provide opportunities for people to be involved in their use, care and management*. Under this plan, 'recreation' and 'visual landscape' are listed as Lake Tuggeranong's highest values (ACT Government, 2022b).
- The ACT's Water Resource Plan, developed under the Murray–Darling Basin Plan, contains a Water Quality Management Plan that sets locally relevant water quality targets.

None of these legislative and policy commitments consider whether and how to reduce the problem of blue-green algal blooms in Lake Tuggeranong, but they do underpin this report, which fills that gap.

Management of the ACT's lakes and ponds represents a collaborative effort across government, the private sector and the community (residents). ACT Government agencies and other organisations with responsibilities include:

- City and Environment Directorate
  - delivers the Healthy Waterways Program, undertakes water science, monitoring and modelling, implements the ACT Aquatic and Riparian Strategy;
  - implements Murray-Darling Basin commitments;
  - undertakes planning to include water sensitive urban design;
  - owns, manages, maintains the stormwater system and water sensitive urban design assets;
  - manages urban open spaces, water quality services (dredging, street sweeping, GPT cleaning) recreation services on lakes and ponds, and dam safety;
  - includes the Environment Protection Authority – the statutory decision maker under the *Water Resources Act 2007* and *Environment Protection Act 1997*, administers Environment Protection Regulations on environment, water quality and waterway health.
- Health and Community Services Directorate – monitors water quality of recreational water sites.
- ACT Emergency Services Agency – undertakes strategic and emergency flood risk management.
- Icon Water – owns, operates, maintains drinking water supply and wastewater system, undertakes long-term water resource planning.
- National Capital Authority – manages Lake Burley Griffin's water quality and waterway health.



Lake Tuggeranong and its catchment

Three major tributaries deliver inflows to Lake Tuggeranong—Kambah and Village creeks in the north (draining a fully urban area) and Tuggeranong Creek in the south (draining urban and rural areas)—as do several minor drains (Figure 3). Tuggeranong Creek runs through a series of settling ponds to improve water quality—Isabella Pond then Lake Tuggeranong wetlands—before discharging into Lake Tuggeranong (Figure 3). Key lake statistics are shown in Table 1 and Figure 4.

Geographical setting and early history

Before it was developed, the Tuggeranong Creek catchment featured hills and valleys with a large, shallow gravel aquifer with 1.5 times the current lake's volume. Tuggeranong Creek would have had a hydrology consistent with a 'chain-of-ponds' system (Lawrence, 2012). Chain-of-ponds systems usually occur in shallow, alluvial valleys where a river doesn't carry flow under baseflow conditions; instead of a continuous channel the river forms a series of irregularly spaced ponds (Mould and Fryirs, 2016). The other tributaries may originally also have been damp valleys, chains of ponds or small creeks.

There is evidence to suggest Ngunnawal people have occupied the Tuggeranong Valley for more than 20,000 years (Flood et al. 1987). The name 'Tuggeranong' comes from a Ngunnawal word for 'cold place' or 'cold plains'. Tuggeranong Creek would have provided an important source of water. Important cultural sites in the valley include scarred trees found at Lanyon (canoe tree) and the Wanniassa–Kambah area (ACT Heritage Council, 2024). Axe-grinding grooves have been found in a sandstone outcrop in what is now the suburb of Theodore (Flood, 1996). Tuggeranong Creek remains a culturally and spiritually important part of country for Ngunnawal people today, and undertaking further cultural values mapping would help provide us with a better understanding of this.

Europeans began grazing the valley with sheep and cattle in the late 1820s and homesteads were established close to watercourses, including Tuggeranong Creek. Lanyon Station was established in 1835 and the Tuggeranong and Lanyon Homesteads, which remain today, are reminders of this period.



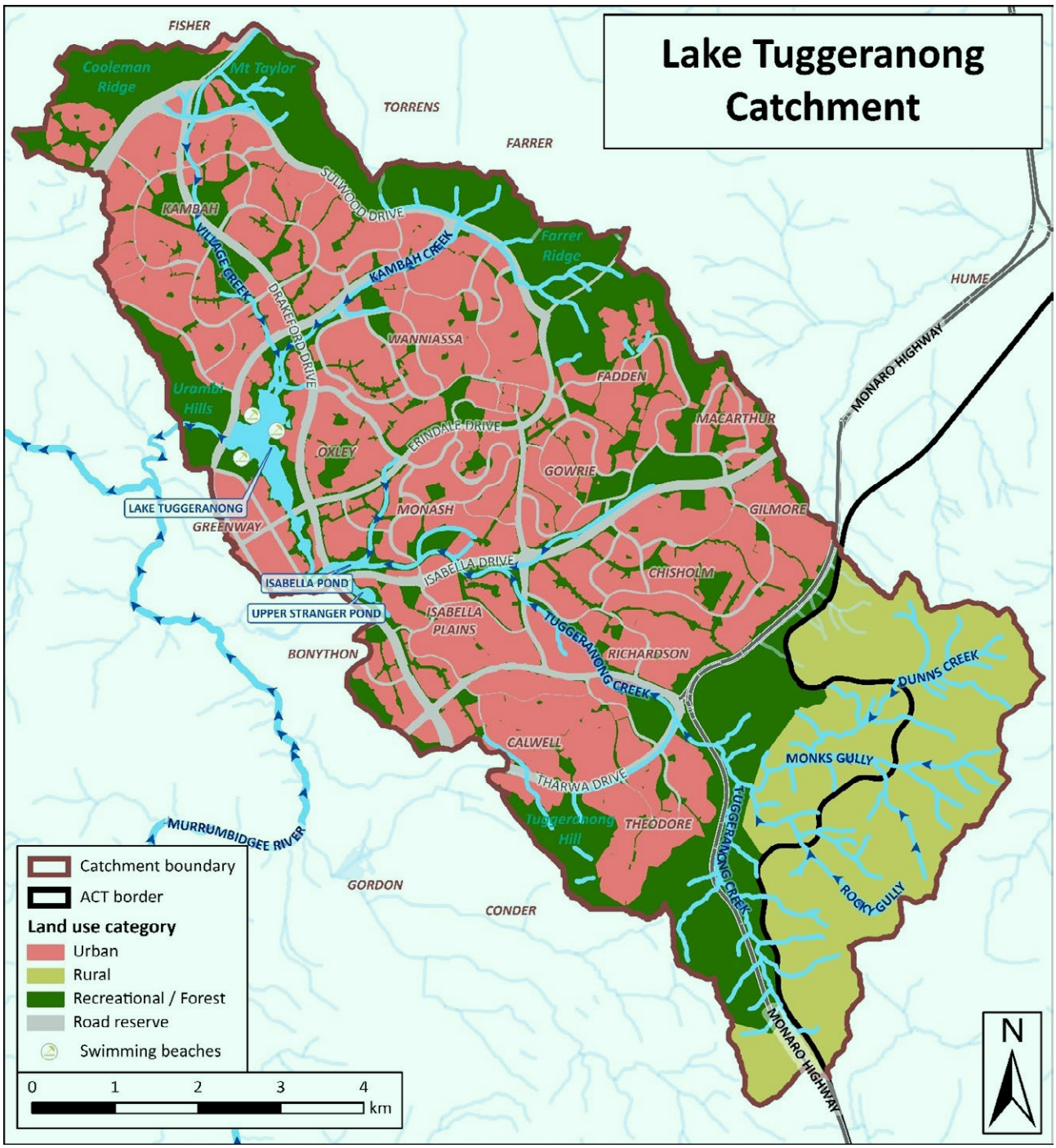


Figure 3. Lake Tuggeranong catchment showing its tributaries. The lake discharges into a short section of Tuggeranong Creek via an outflow channel and weir at the west corner of the lake. This creek then flows into the Murrumbidgee River.

Table 1. Lake characteristics and Tuggeranong climate. Source: (GHD, 2024) and www.bom.gov.au

Lake characteristic	
Size	57 hectares
Volume	1790 megalitres (at normal operation)
Average depth	2.9 metres
Maximum depth	12.2 metres
Average residence time of water	58 days
Average annual inflows	9000 megalitres
Minimum inflows (dry year)	3000 megalitres
Maximum inflows (wet year)	18000 megalitres
Tuggeranong climate	
Summer mean maximum temperature	28.1° Celcius
Summer mean minimum temperature	13.6° Celcius
Winter mean maximum temperature	14.4° Celcius
Winter mean minimum temperature	0.7° Celcius

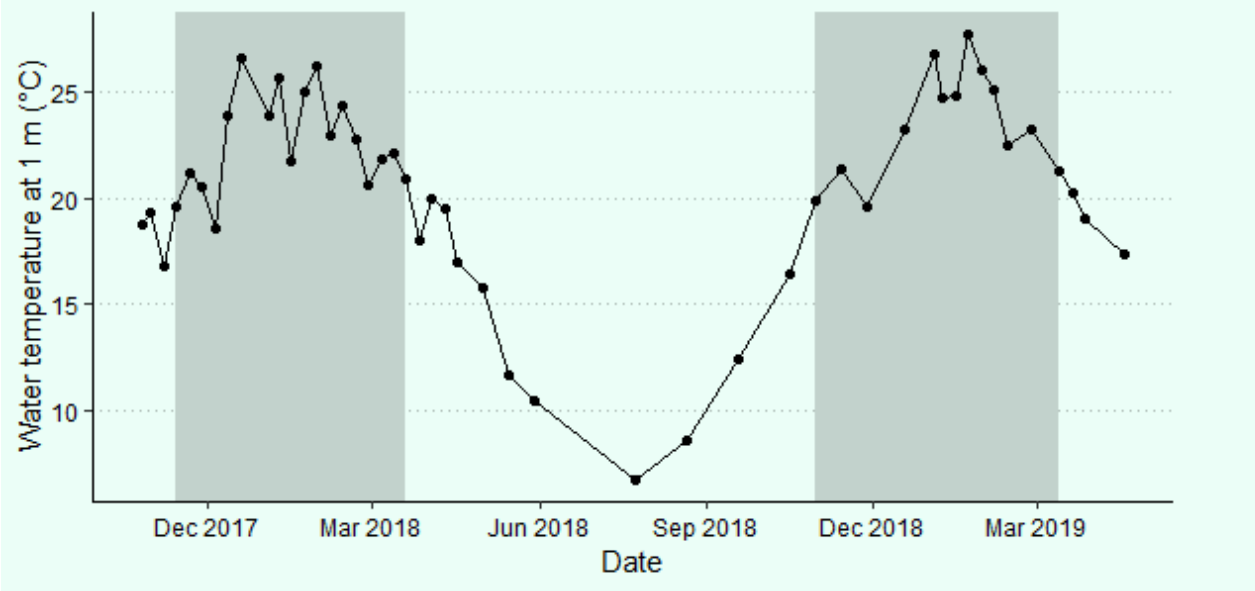


Figure 4. Surface water temperature in Lake Tuggeranong: Mean water temperature at a depth of 1 metre in the central basin of the lake. The grey rectangles that overlay the plot indicate the period from the first detected stratification to the final breakdown of stratification in the lake for the year. (Source: Figure 4-2 in Ubrihien et al., 2019, p.77).

An urbanised catchment—a new lake to filter sediment and concrete drains to channel flows

Tuggeranong was earmarked to be the third town centre of Canberra and was rapidly developed into suburbs throughout the 1970s and 1980s. Much of the shallow aquifer was drained using agricultural drains, stormwater pipes and concreting of the channel bed inset into the aquifer (Lawrence, 2012). To manage the flood impacts of urban runoff, most of the catchment's tributaries have been modified to become a constructed stormwater system of concreted open channels and underground pipes. Lake Tuggeranong was built in 1987 by damming the Tuggeranong Creek at Athllon Drive. While some rural land still exists within the Tuggeranong catchment, it now has a built-up area of more than 50% (Table 2).

Urbanisation changes flow regimes by increasing the impervious surface area (Walsh et al., 2012). Dey et al. (2024) estimated that runoff is four times higher in the Lake Tuggeranong catchment now than when it was a natural catchment. This is because roofs, roads, buildings and concrete are water-resistant materials that prevent water from being absorbed into the landscape. This leads to high surface water runoff that makes its way to the stormwater system (Ladson et al., 2006), carrying pollutants with it.

Table 2. Land use in the Tuggeranong catchment (Dey et al. 2024).

Built-up area		**Green space area**	
Urban	41.2%	Rural land	28.3%
Roads/transport	8.9%	Urban open space	10.2%
Commercial land use	1.8%	Natural bushland	9.5%
Approx total	**52%**	**Approx total**	**48%**



Concreting of the Tuggeranong Creek channel bed

Part 2
Water quality problems in Lake Tuggeranong

- Blue-green algae
- Faecal indicator bacteria



Part 2: Water quality problems in Lake Tuggeranong

Lake Tuggeranong currently experiences frequent blue-green algal blooms and periods of elevated faecal bacteria levels. Other water quality issues in the lake or its tributaries include high turbidity and industrial pollution events; for example, from paint (Upper Murrumbidgee Waterwatch, 2022).

This report and the subsequent Healthy Waterways Plan for the lake focus primarily on addressing algal blooms over other water quality issues. This is because of the higher potential health risk associated with blue-green algal blooms, the fact they contribute to a large proportion of lake closures, and the significant visual and odour impact on the community during severe blooms, such as reported in TCC (in draft).

Blue-green algae

Blue-green algae (Cyanobacteria) are a group of bacteria present in virtually all aquatic environments worldwide. Blue-green algae are not plants but are photosynthetic bacteria, reproducing rapidly when given sunlight and warm, nutrient-rich conditions (Joehnk et al., 2008). Most are buoyant, forming surface scums known as a blue-green algal bloom. When this happens, they block the light that would otherwise be available for favourable plant growth, discolour the water and may release a range of toxins. Such blooms are a persistent problem in Lake Tuggeranong, especially in summer. Algal blooms reduce visual amenity, release foul odours, pose a health hazard to residents and visitors and require the ACT Government to close the lake to recreational use.

Blue-green algae and human health

Some types of blue-green algae produce toxins (cyanotoxins) that can be harmful for humans, domestic animals and livestock that drink or make contact with the water, and for fish and other organisms living in the water.

There is increasing research and community interest in Australia and overseas into potential associations between cyanobacteria and neuro-degenerative diseases in humans (as noted, for example, by NSW Health, 2023). For example, studies have found an increased incidence of motor neurone disease in people living near waterbodies with blue-green algal blooms (Cox et al., 2003; Caller et al., 2009; Andrew et al., 2017; ABC Online, 2023; Torbick et al., 2018), although most of these studies could not confirm whether direct exposure to cyanobacteria had occurred.

The link between exposure to blue-green algae through primary or secondary contact and neuro-degenerative diseases has not been proven, except where foods have been grown in the presence of blue-green algae (Cox et al. 2003). Clusters of residents with motor neurone disease might be caused by a myriad of factors unrelated to blue-green algae blooms. However, researchers have yet to fully evaluate all plausible cause–effect mechanisms related to blue-green algae blooms and there is an argument for adopting the precautionary principle to mitigate potential risks to human health (Dunlop et al., 2021; Cox, 2021). This is particularly important while investigating airborne exposure pathways such as chronic exposure to aerosolised cyanotoxins downwind of affected waterbodies (Sutherland et al., 2021; Schaefer et al., 2020; Plaas & Paerl, 2021).



Lake Tuggeranong experienced a significant blue-green algae bloom over the summer of 2019-20 (photo: Alica Tschierschke)

Blue-green algae monitoring and lake closures

The Environment Protection Authority (EPA) monitors five sites in Lake Tuggeranong during the recreational season, which runs from October to April. The lake is closed to recreational use if either blue-green algae or faecal bacteria concentrations exceed the levels specified in the ACT Guidelines for Recreational Water Quality. Data analysed from 2015 to 2024 shows frequent closures throughout the recreational season with at least one swimming beach closed for more than 50% of the time for seven of those nine years (Figure 5).

In the 2022–23 season, EPA monitoring showed that all three swimming beaches were closed for almost the entire recreational season. In addition, blue-green algal blooms kept the lake closed to primary contact recreation from mid-January 2023 through to the beginning of June 2023, well beyond the recreational season.

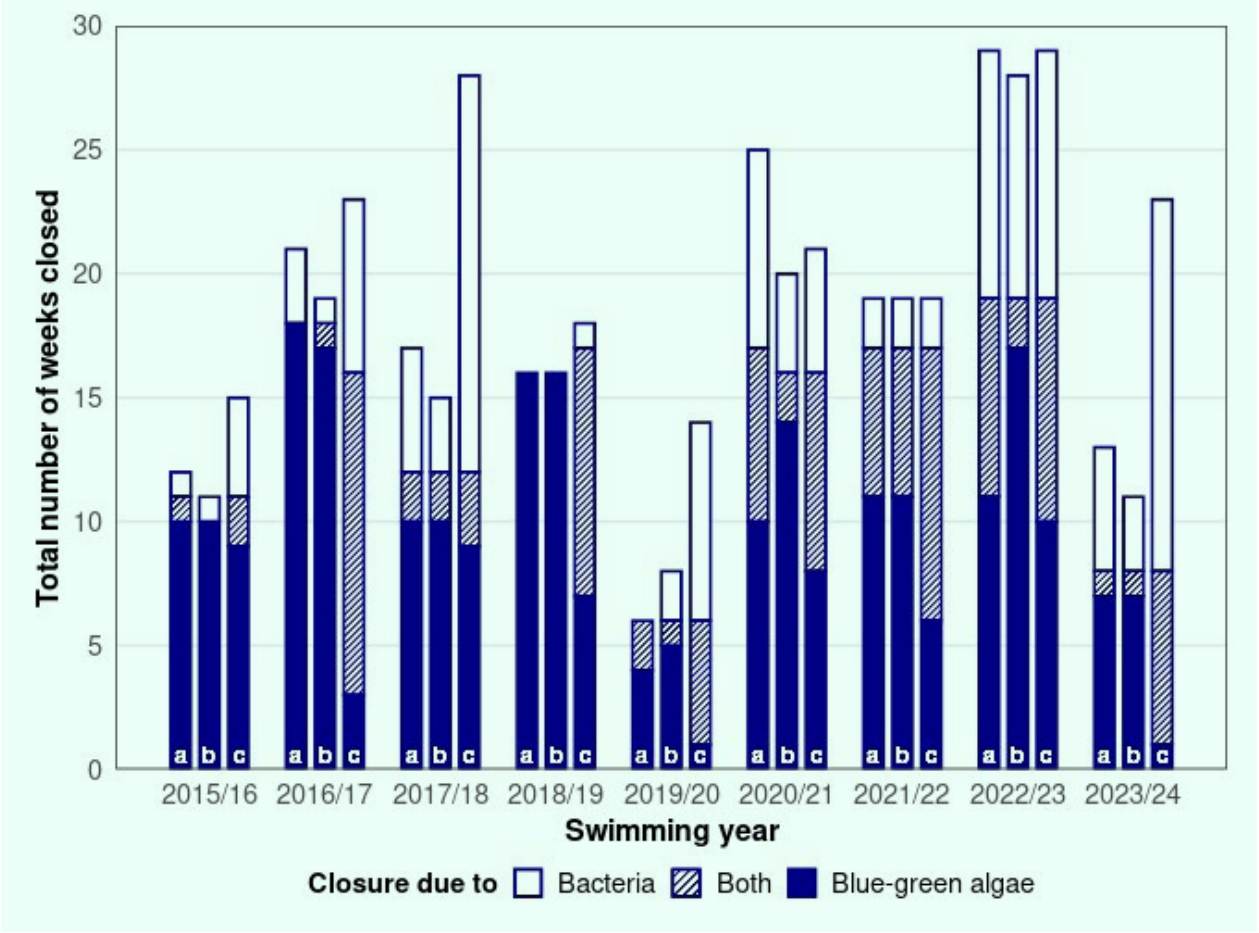


Figure 5. Number of weeks of the swimming season (30 weeks from Oct–April) that Lake Tuggeranong was closed to swimming at one or more beaches due to blue-green algae or bacteria between 2015 and 2024. Column a: Ngadyung Beach, Column b: Nguru Beach, Column c: Tuggeranong Town Beach

Information about how water quality in Lake Tuggeranong is monitored, and current alerts and closures, is published on the ACT City Services website www.cityservices.act.gov.au.

Faecal indicator bacteria

As Figure 5 shows, lake closures can also be due to the presence of faecal indicator bacteria, with Tuggeranong Town Beach showing a higher incidence of closures due to this cause.

ACT Health routinely tests ACT lakes for faecal contamination using the faecal indicator bacteria enterococci. These are a group of bacteria found in the intestines of humans and animals; their presence in water may indicate domestic sewage leaks or contamination from diffuse sources of human and animal waste. Water managers use enterococci as the standard faecal indicator bacteria to test water quality in recreational waters in Australia because they are well understood, easy to detect and their presence reliably predicts health risks associated with exposure to waterborne bacterial pathogens.

Monitoring work using Microbial Source Tracking is currently underway to understand the extent the faecal matter is coming from human or animal sources. Findings from this work will inform future iterations of the Plan. In the meantime, many of the interventions proposed to reduce algal blooms will also remove bacteria and other pollutants, such as excess carbon, nitrogen and total dissolved solids, that are potentially causing issues in the catchment.

Part 3
The cause of algal blooms

- Drivers of algal blooms
- Supply of phosphorus: catchment versus lake sediments
- Catchment sources of phosphorus



Part 3: The cause of algal blooms

Drivers of algal blooms

The prevalence of blue-green algae is linked to the trophic state of a water body. Trophic state is a description of the biological productivity of a water body and depends on factors such as the concentration of nutrients used by plants (and blue-green algae) such as phosphorus and nitrogen (South Dakota State University Extension, 2022).

Water bodies in an oligotrophic state have very low nutrient concentrations and tend to have very clear water with little plant or algal growth and high oxygen concentrations that depress the release of algal nutrients stored in lake-bottom sediments. Hence, oligotrophic lakes are not prone to algal blooms. Water bodies in a mesotrophic state have a moderate amount of nutrients, moderately clear water, some algal blooms in late summer and oxygen depletion at bottom of lake as biomass decomposes. Most of the time, the water quality is within an acceptable limit to provide recreation, amenity and ecological benefits. Finally, water bodies in a eutrophic state are nutrient rich, with highly productive plant growth and high turbidity. They are seasonally deficient in oxygen, which may lead to fish kills. Eutrophic lakes may experience regular algal blooms.

When a waterway is in a eutrophic state, nutrient concentrations are so high that blue-green algae blooms are likely to occur whenever the conditions are stable (low flow), the water is warm enough and there is enough light penetrating through the water column (Paerl, 1988). These have been the conditions in Lake Tuggeranong for more than a decade, with blooms occurring every summer.

Nutrient overload in Lake Tuggeranong

It is widely accepted that phosphorus is the main nutrient that drives algal blooms in freshwater systems; without it, algal growth is severely limited (Carvalho et al., 2013), including in Lake Tuggeranong (Ubrihien et al. 2019). While nitrogen is also essential for algal growth, its absence in lake water does not limit algal growth in the same way as phosphorus because blue-green algae can source nitrogen from the atmosphere (a process called nitrogen fixing) as well as from the water. Therefore, to reduce the incidence and severity of algal blooms, we need to reduce the availability of phosphorus in the system. However, most management options to reduce phosphorus in stormwater will also reduce nitrogen.

To reduce the phosphorus available to blue-green algae in the lake, and therefore the risk of severe algal blooms, we need to know where the phosphorus is coming from; whether it's mainly coming from the Tuggeranong catchment and reaching the lake via stormwater inflows, or if it is mainly coming from phosphorus already trapped within the lake bottom sediments (Lawrence et al. 2000; e.g. Nikolai and Dzialowski, 2014).

Phosphorus is transported to the lake in stormwater, either in a dissolved or particulate form. Particulate forms are small pieces of plant matter containing phosphorus or phosphorus bound to sediments. Sediment-bound phosphorus is often a result of erosion in the catchment or is blown into drains as dust and dirt. In its dissolved forms, phosphorus, especially phosphate, is more readily available for use by blue-green algae (bioavailable; Lawrence et al. 2000), making it more immediately problematic in causing algal blooms.

Supply of phosphorus: catchment versus lake sediments

Much of the particulate phosphorus that is washed by storms into Lake Tuggeranong settles on the bottom of the lake and creates a nutrient-rich sediment layer. This creates an internal supply of phosphorus in the lake that can be released in a dissolved form later to become bioavailable through in-lake processes (Box 1).

Research by the University of Canberra (Ubrihien et al., 2019) found that the concentration of phosphorus observed in the surface water of Lake Tuggeranong was more than three times that required to support an algal bloom, with further significant amounts detected in sediments at the bottom of the lake. The internal supply of phosphorus—released from lake-bottom sediments—was enough to drive an algal bloom. However, the research found that the external supply of phosphorus to the lake from its catchment was five times the internal supply of phosphorus from lake sediments.

These findings suggest that internal supply of phosphorus is not driving most algal blooms in Lake Tuggeranong. Therefore, to mitigate blooms, water managers need to address catchment sources of phosphorus pollution before dealing with sources within Lake Tuggeranong.

Catchment sources of phosphorus

There are many potential sources of nutrients and other pollutants from urban catchments (as shown, for example, by Muller et al. 2020). Recent research and water quality monitoring in the Tuggeranong catchment has found that:

- phosphorus is mainly coming from urban, not rural, areas (Ubrihien et al., 2020; Upper Murrumbidgee Waterwatch, 2023)
- phosphorus is coming from many small sources across the whole catchment (diffuse sources), rather than from one or two large, concentrated locations (point-source) (Ubrihien et al. 2019)
- around 50% of the catchment-based phosphorus is in dissolved, bioavailable forms (Ubrihien et al., 2019), meaning it is available for uptake by blue-green algae
- leaves, grass clippings, fertiliser products (including composts and manures), soil and sewage are all likely contributing to catchment-based phosphorus (Ubrihien et al., 2019; Concepts of Change, 2023).

Soil

Soil can contain phosphorus both in its crystalline structure and adsorbed to soil particles. Sediments can release the adsorbed portion of phosphorus to water, after which algae can take it up. Because this is a slow process, most of the adsorbed phosphorus is not immediately bioavailable. However, sediments may release phosphorus over time once they are deposited in a lake.

Phosphorus adsorbed to clays suspended in the water column can take hours to weeks or longer to be released into water and available for uptake by algae.

Box 1. Why did dry weather in 2019–2020 limit algal blooms?

The Tuggeranong catchment experienced a dry period from September 2019 to January 2020, with only 6 mm of rain falling in the catchment. In Lake Tuggeranong, no blooms occurred and there were no lake closures due to blue-green algae during that time.

Dry conditions impact the lake's susceptibility to algal blooms by impacting in-lake processes. During the warmer months, Lake Tuggeranong experiences thermal stratification. This is where a stable zone of cooler water forms at depth in the lake where daylight does not penetrate and a warmer, light-filled, less-dense layer of water sits on top. In this top layer the light allows for photosynthesis to occur and bacteria, algae and other micro-organisms consume the available nutrients, most of which are washed in from the catchment. During dry periods, these top-layer nutrients are not replenished as they are consumed, which prevents blue-green algae from blooming.

Catchment phosphorus can also end up in the cool lower layer, with much of it bound to sediment on the lake floor where it's not bioavailable. Carbon also gets washed into the lake from the catchment as organic matter such as leaves. As bottom-dwelling bacteria feed on the carbon, they use up oxygen in the water; if the lake is stratified for a long time, this process creates an oxygen-depleted (anoxic) environment. Under anoxic conditions, phosphorus can be released from the sediment to become bioavailable. The released, bioavailable phosphorus can be brought to the top layer by diffusion or by mixing of bottom and surface waters as stratification later weakens or breaks down with winds, cool weather or rainfall.

In autumn in Lake Tuggeranong, the top layer of water cools and eventually sinks, forcing the bottom water, with its bioavailable phosphorus, to the surface. This is known as turnover and can cause a late season blue-green algal bloom. These are often of a shorter duration and less severe than summer blooms.

Blue-green algae can also access nutrients in bottom waters by modifying their buoyancy to move up and down through the water column.

University of Canberra researchers monitored phosphorus concentrations in the lake over the 2019–20 dry period and hypothesised that blooms didn't occur during this time because low baseflows meant there was a limited supply of nutrients in the top layer of the lake (Ubrihien et al., 2020). Their data also suggested that lack of carbon inputs may have led to reduced bacterial activity in the bottom layer, meaning less oxygen was consumed and the phosphorus remained bound to the sediments rather than becoming bioavailable.

One implication of this is that removing sources of phosphorus and carbon in the catchment may have a greater combined impact on reducing the incidence of algal blooms. The influence of dry vs wet weather conditions is also a key part of understanding year-to-year variability in the number, duration and intensity of blue-green algal blooms in Lake Tuggeranong.

Development sites

Tuggeranong District's population is predicted to be stable between 2022 and 2060, but there is still a potential future housing demand of 1,100 dwellings by 2050 in the district forecast (ACT Government, 2022b, 2023b). While there are no greenfield suburbs planned, there are plans to redevelop existing areas through infill, and smaller-scale construction projects like knock-down rebuilds or major home renovations will also occur.

Development sites might contribute phosphorus to the stormwater system as phosphorus bound to the sediments in drainage or from roads that construction vehicles track mud onto. The University of Canberra examined the overall effect of urban development sites on the stormwater system in Lake Tuggeranong catchments in 2024 (Ubrihien et al., 2024b). They found that during storms, stormwater concentrations of total suspended solids were significantly higher downstream of development sites compared to upstream. However, levels of total and dissolved phosphorus did not vary significantly between stormwater sampled above and below development sites. The sediments from development sites are likely to be subsurface soils and thus low in phosphorus.

Leaf litter and grass

Phosphorus from plant materials can make up a substantial portion of the total phosphorus inputs in an urban catchment (Duan et al., 2014; Janke et al. 2017; Selbig, 2016; Muller et al. 2020). Plant materials have different amounts of phosphorus depending on the plant species and part of the plant (blossoms, fruits or leaves; Hill, et al., 2022).

Leaf litter (leaves, sticks, nuts, flowers) and grass clippings release nutrients as they decompose or are wet. This can happen quickly; research in the Tuggeranong catchment by the University of Canberra suggests that leaves will leach out most of their phosphorus within two days of either continuous or periodic inundation (Ubrihien et al., 2024a). In an urban environment with lots of impervious surfaces, leached, dissolved phosphorus cannot soak into the soil where soil particles could absorb it, or vegetation take it up. Instead, it enters the stormwater system where concrete channels and pipes convey it rapidly to lakes and waterways.

While much of Canberra is known for its deciduous street trees, nearly 80% of street trees in the Tuggeranong catchment are eucalypts (ACT Government, 2022a). From December 2022 to November 2023 the University of Canberra investigated the potential contribution of street trees' leaves to nutrients in the Tuggeranong catchment (Ubrihien et al. 2024a). They measured the deposition rate of leaves for the four most common eucalypt species onto impervious surfaces to determine their potential nutrient leaching rates, and then extrapolated this across the catchment by using estimates of tree canopy hanging over impervious surfaces. They found:

- the amount of leaf fall from these species was greatest in summer
- the phosphorus leached from leaves differed greatly between eucalypt species, with *Eucalyptus sideroxylon* leaching the most phosphorus
- the annual supply to Lake Tuggeranong of dissolved nitrogen, phosphorus and organic carbon contributed by leaves across the catchment as 25, 43 and 6,748 kg per year, respectively. They note these are probably underestimates because they only capture litter that falls directly from the overhanging canopy, not any that is blown or washed onto roads.

The phosphorus content of *E. sideroxylon* leaves as measured here is comparable to the average phosphorus content of leaves from a variety of deciduous trees measured in northern hemisphere studies (Duan et al. 2014; Hill et al. 2022). The average phosphorus content of leaves from all the eucalypt species studied in the Tuggeranong catchment was generally slightly lower than the average for deciduous leaves.

In the same study the University of Canberra also measured grass clippings deposition (Ubrihien et al. 2024a). It found:

- nutrient deposition from grass clippings varies between seasons (with higher releases in summer) and between different mowing events
- an average 'mowing event' releases 33–76 mg of phosphorus for each square metre of impervious surface next to a mown area. The average varied depending on the season and whether clippings were continuously or intermittently soaked during the experiments.

Booksmythe et al. (2024) extrapolated these estimates to all the road surface within two metres of mown open space in the Lake Tuggeranong catchment, multiplied by the around 11 mowing events per year undertaken by ACT City Services, and found that this equates to clippings contributing between 85–200 kg of phosphorus per year to the lake.

Together, according to these estimates, leaves and grass contribute around 130–240 kg phosphorus per year on average to Lake Tuggeranong.

Urban open space mowing

ACT City Services manage the mowing of all urban open spaces in accordance with Canberra's Lakes and Ponds Land Management Plan and the complementary Urban Open Space Land Management Plan. Together, these plans require that:

- mowing programs aim to improve the ACT's water quality outcomes
- verge managers remove cut vegetation from guttering
- mowing cannot occur within five metres of waterbodies
- verge managers seek the Conservator of Flora and Fauna's advice on mowing areas next to certain waterbodies including Lake Tuggeranong District Park (south) and Isabella Ponds grassland.
- However, some cut vegetation will still end up blowing into gutters. The government is exploring ways to minimise this impact.

Fertiliser

Some residents and businesses use fertilisers to enrich soils with nutrients important for plant growth and health, including phosphorus, nitrogen and potassium. They fertilise residential lawns and gardens as well as public and private green spaces like sports fields, golf courses and gardens. Fertilisers can be a major source of phosphorus pollution of stormwater (Muller et al. 2020).

Fertiliser products come in different forms (manure, compost, chemical/synthetic) and have different release rates. The type of fertiliser used, how much is applied and when it is applied determine how well the plants can take it up, and whether it will stay in (or on) the soil or be transported out of the lawn, turf or garden bed and into waterways.

Nutrients can end up being 'exported' from residences to waterways either in dissolved or particulate form if too much fertiliser is applied (more than can be taken up by soils and plants), it is applied just before rain, or it is applied to soils that don't absorb water well.

Household fertiliser use

A Healthy Waterways funded survey in 2023 heard from 400 Canberra residents about the type and quantity of fertiliser they use (Concepts of Change, 2023). The findings of this survey were that:

- households use an average 84 kg of garden nutrient boosters (fertilisers, manures, compost) annually, which equates to 0.59 kg of phosphorus per household
- 6% of households use a paid gardening service and these accounted for 0.11 kg of annual phosphorus use by households, making a total of 0.70 kg phosphorus applied per household
- around half of Canberra residents use no fertiliser at all, with most of the fertiliser applied by the top 20% of users
- by volume, compost and manure are the most used fertiliser.

There are 21,000 low to medium density residential, detached and semi-detached dwellings with gardens in Tuggeranong (Booksmythe et al. 2024). Survey data on the amount of fertiliser applied by Canberra householders to their blocks combined with data from a literature review on the proportion of phosphorus that leaks into stormwater from different fertilisers (Booksmythe et al. 2024) yields a wide-ranging estimate of around 90–1,200 kg of phosphorus per year entering stormwater from fertilisers applied by householders, with an intermediate estimate of around 550 kg per year. The wide range is because of significant uncertainty in the export rates for phosphorus in fertilisers applied by residents or their gardeners.

Sports field fertiliser use

The Tuggeranong catchment includes approximately 70 hectares of managed sports grounds. Most of these are public grounds managed by ACT City Services Sport and Recreation, with about 7 hectares being privately managed.

The University of Canberra's research in the Tuggeranong catchment found that water samples taken near sports fields had slightly elevated phosphorus concentrations (total and dissolved) (Ubrihien et al., 2020). While they still represent a relatively small component of overall catchment phosphorus, they warrant further investigation.

More work is needed to understand the nutrient transport pathways around sports fields. Soil moisture testing and on-ground observations of public sports fields don't indicate high volumes of surface water runoff, so it's possible the elevated concentrations detected represent historical fertiliser use (going back decades) that is leaching out through the system at a subsurface level.

In general, both public and private sports field managers practice careful application of fertiliser as it represents a significant input cost. In 2022 several private sports field managers were surveyed about their fertiliser application practices (Edmonson, 2022). The survey found that private managers had a detailed knowledge of turf nutrient requirements and, as fertiliser is a major expense, were managing fertiliser application as efficiently and effectively as possible.

ACT City Services Sport and Recreation manage public sports fields in Tuggeranong using practices to improve irrigation efficiency and water retention, prevent surface water runoff and manage the chemical composition of the soil profile to improve nutrient uptake. These help prevent nutrients being exported from sports fields in runoff.

Installing additional bioretention swales between a sports field and the stormwater channel would help intercept and filter any nutrients exported from the sports fields.

Leaky sewerage pipes

Leaking sewers can be a major contributor to water quality issues in urban areas, causing increased nutrients, suspended solids and microbial pollutants to enter waterways. Sewers can become defective and leak from structural problems (broken joints, cracks, fractures and holes), operational problems (root intrusion, sediment accumulation and grease build up) and hydraulic capacity failures (Nguyen & Venohr, 2021). As holes are drilled in urban catchments for a variety of purposes, pipes can be damaged and leak into the stormwater system.

Healthy Waterways has commissioned a study to help characterise how large a problem sewage leaks might be, noting that they might affect not only nutrient concentrations but levels of faecal pollution, which can also result in lake closures. Results will be delivered in 2025 and will be incorporated into later versions of the Plan.

Part 4
The target – how much phosphorus to mitigate?

- Form of phosphorus
- Water quality modelling approach
- Inputs of phosphorus from the catchment
- Current and target supply of phosphorus to the lake
- Reconciling some estimates based on research and modelling



Part 4: The target – how much phosphorus to mitigate?

Form of phosphorus

The models and other analyses presented below predict total phosphorus or its effects. There are not enough data to inform what proportion of the particulate fraction of phosphorus in Tuggeranong stormwater is bioavailable, so total phosphorus is used to predict algal responses—and total phosphorus data used in model calibrations—rather than dissolved or bioavailable phosphorus. So, even though algae actually take up dissolved phosphate, in these analyses, 'phosphorus' refers to total phosphorus.

Water quality modelling approach

Dey et al. (2024) developed two coupled water quality models to help estimate how much the supply of phosphorus from the catchment to the lake needs to drop to substantially decrease the incidence of algal blooms in the lake.

The first model is a catchment model that predicts how much water and phosphorus will reach Lake Tuggeranong and how this changes with daily variations in rainfall. The researchers initially used pollution generation rates from different types of land use, derived from the scientific literature, which they then calibrated with observations of water quality and flow in storm events that came from research by the University of Canberra (Ubrihien at al. 2019, 2020).

The second model is a simple in-lake model that predicts how phosphorus concentrations in the lake will change in response to varying runoff and inflow of phosphorus, and then the amount of algae that will grow in response to this. Kahn and Dey (2024) predicted the algal response indirectly using chlorophyll *a* concentration. Chlorophyll *a* is a pigment in many plants and algae that helps them absorb light and is used to assess the amount of algae (ANZECC and ARMCANZ, 2000). They then assigned predicted concentrations of chlorophyll *a* concentration to trophic states: Oligotrophic <5 µg/L, Mesotrophic <15 µg/L, and Eutrophic >15 µg/L.

Current supply of phosphorus to the lake

The water quality modelling has shown that that the stormwater flowing off the catchment carries very high levels of phosphorus, with an average annual supply to the lake of 1,656 kg phosphorus/yr (Dey et al., 2024; Table 3). This is greater than the annual estimate of 500 kg estimated by Ubrihien, et al. (2019), which was based on data collected in a dry period, with reduced inflows from the catchment.

Table 3. Modelled annual total phosphorus (TP) supply to Lake Tuggeranong (kg/yr) generated for each combination of functional land use and surface type imperviousness: road, hardstand, roof and pervious (from Appendix 5 in Dey et al., 2024).

FUNCTIONAL LAND USE	Road TP (kg/yr)	Hardstand TP (kg/yr)	Roof TP (kg/yr)	Pervious TP (kg/yr)	Total TP (kg/yr)
Suburban	322	169	314	140	945
Commercial	17	45	30	16	108
Open space	243	76	5	88	412
Rural	0	0	1	132	133
Sports field	0	0	0	58	58
Total annual supply (kg/yr)	582	290	350	434	1,656

Based on research data (Ubrihien et al., 2019, 2020), about 50% of this input is in a dissolved form, with most of it ready for uptake by algae. Dey et al. (2024) predict that the seven constructed wetlands built in Stage 1 of Healthy Waterways have reduced the amount of phosphorus entering the lake annually by 214 kg, or 13%, from 1,656 kg to 1,442 kg.

Target supply of phosphorus to the lake

Current supply

Kahn and Dey (2024) used an in-lake algal response model to determine the phosphorus mitigation target (Figure 6). Under current flow and levels of phosphorus supply (Figure 6, 'No P reduction'), their modelling clearly indicates that Lake Tuggeranong will remain in a eutrophic state, with chlorophyll *a* concentrations over 15 µg/L, even in years with relatively little rainfall when smaller amounts of nutrient are transported to the lake. This fits with observations of consistently high levels of phosphorus and frequent blue-green algal blooms in the lake in recent years. It also supports the findings of a 1982 hydrological study of the catchment, which predicted that based on nutrient levels at the time, the lake would exist in a eutrophic state for most of the time (Beer et al., 1982).

A suitable and realistic chlorophyll *a* concentration target range to aim for in Lake Tuggeranong, correlating to a mesotrophic state, is in the range of 5–15µg/L. This target range is based on the following considerations:

- The model predicts that in a predevelopment scenario (when the area was entirely native bushland), Lake Tuggeranong would typically have been in a mesotrophic state, with a chlorophyll a concentration in the range of 0–18 mg/L (Figure 6: 'Predevelopment') (Dey et al., 2024).
- The ANZECC guidelines specify a range of 5–15 mg/L for mesotrophic conditions (see Table 8.2.1 in ANZECC and ARMCANZ, 2000).
- In the nearby Googong Reservoir, a water supply with a reduced level of disturbance, chlorophyll a concentrations are typically in the range of 0–28 mg/L, with annual averages consistently in the range of 4–10 mg/L.
- The Australian Environment Council recommends that chlorophyll a concentrations in recreational waterbodies be kept below 20 mg/L for recreational lakes and 5 mg/L for water supply reservoirs (AEC, 1987). In the ACT, the Environment Protection Regulation sets a more stringent target of less than 10 mg/L for contact-based activities (noting that direct observations of algal counts rather than chlorophyll a concentrations are used to determine when to close lakes in the ACT).

Target supply to mitigate algal blooms

Kahn and Dey (2024) predict that a mesotrophic state can be achieved in Lake Tuggeranong for most the time if the average annual phosphorus supply to the lake is reduced by 700 kg, having already accounted for the effect of the seven constructed wetlands built in Stage 1 of Healthy Waterways (Figure 6). They did not adopt a higher target because the further reduction in phosphorus would not significantly reduce algal blooms but would cost a lot more to achieve.

A target of 700 kg represents 49% of the total supply of phosphorus to the lake from the catchment.

Note that these targets are indicative only, developed for the purpose of communicating the benefits of different management scenarios. While the 700 kg target is based on annual averages, the required reductions will be higher in very wet years and lower in dry years.

How will the lake behave if the target phosphorus reduction is achieved?

With a 700 kg annual reduction in phosphorus, modelling by Kahn and Dey (2024) suggests the lake will be in a mesotrophic state—or better, in an oligotrophic state—in approximately 75% of years (3 out of 4 years; Figure 6). Under these conditions, some blue-green algae would be present, but the likelihood of problem blooms would be lower than now, and the lake should mainly be in a condition suitable for contact-based activities. Closures may still occur due to elevated levels of faecal indicator bacteria.

The modelling also reveals there will likely always be considerable variation in the concentration of phosphorus in Lake Tuggeranong over time, driven by variation in climatic conditions. Specifically, in very wet years the significant amount of phosphorus coming off the catchment will likely overwhelm any attempts to reduce nutrient levels in the lake, leading to eutrophic conditions.

For example, with a target 700 kg annual reduction in phosphorus, the modelling predicts that in about 25% of years (the wettest years) the lake will still be in a eutrophic state, with sufficient nutrients to promote algal blooms. However, wet years also tend to be relatively cooler, which would reduce the likelihood of severe blooms. Some algae would also flush from the lake in wet years.

Conversely, in relatively dry years, any phosphorus removed from the system represents a relatively larger proportion of the total supply reaching the lake. So, for a target 700 kg annual reduction in phosphorus, modelling by Kahn and Dey (2024) suggests about 25% of years (the driest years) will experience oligotrophic conditions in the lake, with very low concentrations of nutrients, relatively clear water and very little risk of algal blooms occurring.

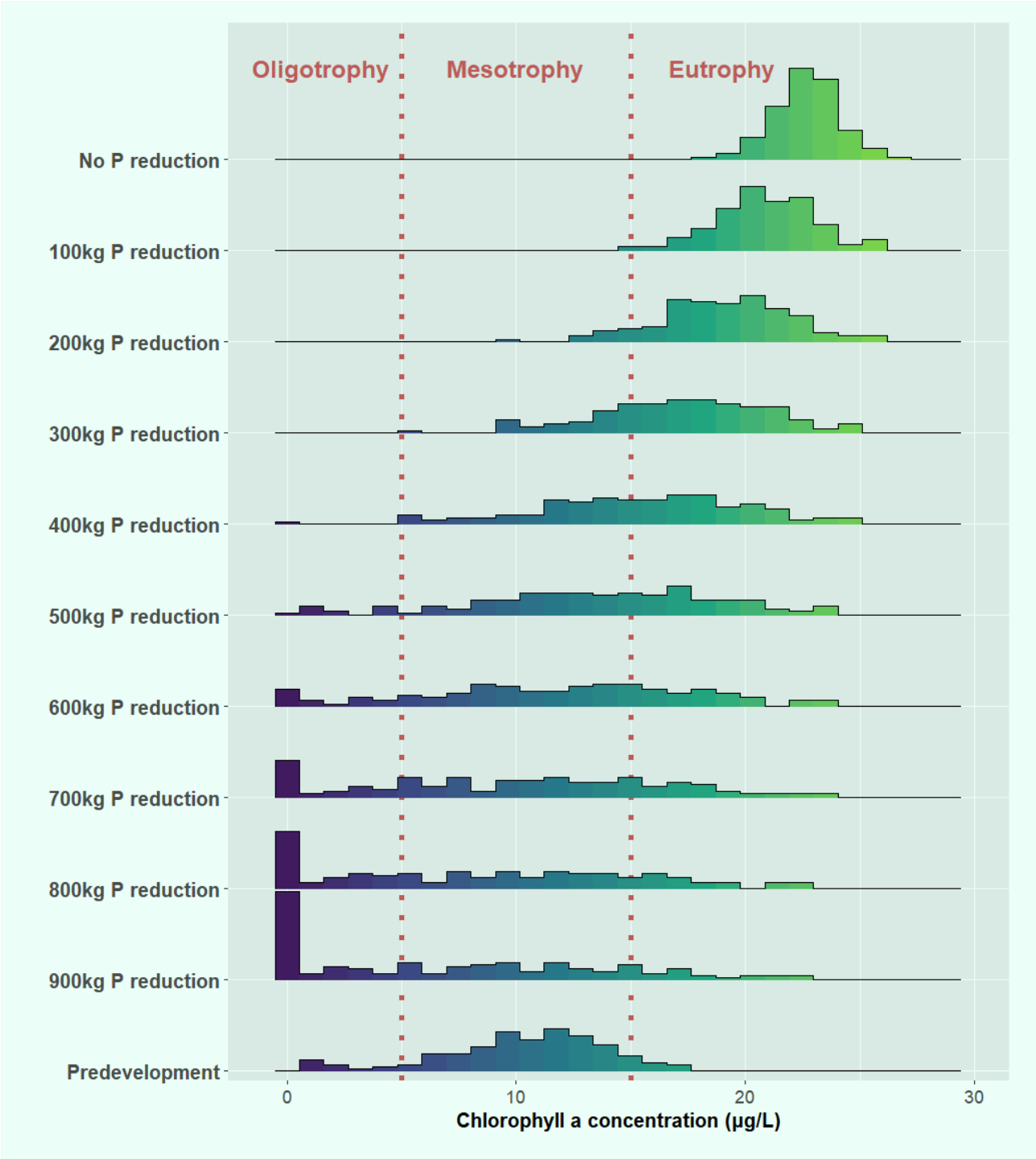


Figure 6. Modelled distribution of predicted chlorophyll a concentrations (an indicator of trophic state) in Lake Tuggeranong under varying supply of phosphorus (P). The top row 'No P reduction' shows the lake in its current, eutrophic state. The bottom, 'Predevelopment' row shows the predicted chlorophyll a concentrations if there were no urban development upstream of the lake, indicating that it would have been in a mesotrophic state in most years, but still occasionally have reached a eutrophic state, supporting algal blooms.

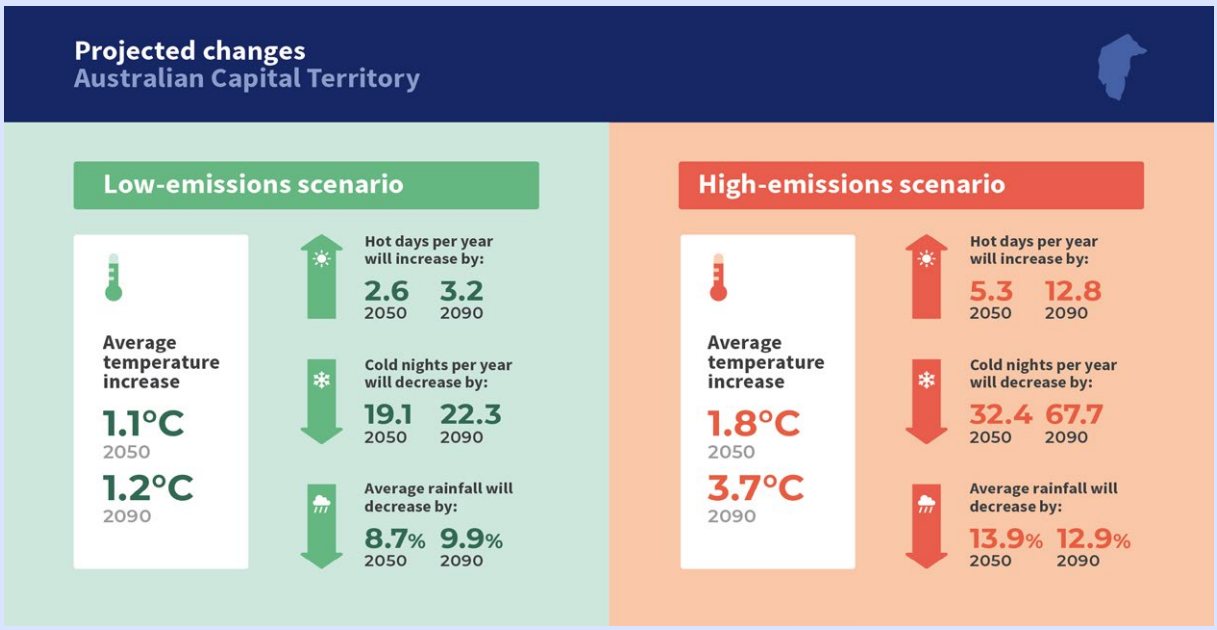
Box 2. How will climate change affect nutrient dynamics and algal blooms?

In the future, the ACT will experience hotter average temperatures, more hot days per year and decreased average rainfall, particularly in spring (NSW Department of Climate Change, the Environment and Water, 2024). Across Australia, including the ACT, extreme rainfall events (storms) will become more intense. The Australian Rainfall and Runoff Guidelines projectpredict the biggest increases forwill be in very short storms. For example, under scenario SSP3-7.0, storms of under one hour will increase in intensity by 18% by 2030, and by 29% by 2050 (Wasko et al., 2024). More intense localised storms may increase the frequency of 1% Annual Exceedance Probability (AEP) (in layman's terms, 1 in 100 year storms) flooding events in the ACT. The ACT Government's ACTMapi website shows the extent of riverine flooding that would be expected during a 1% AEP flood event.

These changes to temperature, rainfall averages and storm intensity will likely impact nutrient dynamics in the Tuggeranong catchment, for example:

- higher storm intensity will impact streamflow and the way that nutrients are mobilised in, and transported through, the catchment
- hotter temperatures will affect when eucalypt species drop their leaves, how much they drop and the phosphorus content of the leaves
- higher water temperatures will affect in-lake processes like thermal stratification and turnover.

These effects are anticipated but have not yet been studied or quantified in the Lake Tuggeranong context. However, a response framework developed for Victoria's waterbodies argues that climate change will exacerbate blue-green algal blooms through factors including increased temperatures, stronger stratification, increased nutrient levels due to extreme wet/dry periods, longer residence times of water in water bodies and storm events (HydroNumerics, 2020).



Climate change projections for the ACT (NARCliM 2024)

Reconciling some estimates based on research and modelling

There are two notable instances where the predictions from catchment water quality modelling and results from catchment research are not fully aligned.

The first relates to the contribution that fertiliser applied on residential gardens makes to phosphorus levels in stormwater. The Lake Tuggeranong catchment water quality model predicts that only around 140 kg/year of phosphorus is generated from pervious suburban land use (Table 3). This is the land use category representing residential yards and gardens, which would include fertiliser use by residents or their gardeners and other sources of phosphorus from residential blocks. The model is based on published literature of phosphorus draining from household blocks and was calibrated to the observed data on phosphorus concentrations in runoff and waterways around the catchment.

In Part 3, the amount of phosphorus entering stormwater from residences, based on surveys of residents, is conservatively estimated at around 90–1,200 kg of phosphorus per year, with an intermediate estimate of around 550 kg per year. The model prediction of around 140 kg/year leakage is within, but at the very lower end, of the estimate of around 90–1,200 kg of phosphorus per year based on the surveys of residents. Since 140 kg/year is well below the middle estimate of 550 kg/year, the difference between the prediction based on modelling and the estimate based on research warrants further investigation.

The second instance where the catchment water quality model and research yield different results relates to the contribution of phosphorus due to leaves and grass. The effect of nutrients leaching from leaf and grass litter—and soils and other road detritus—on roads was assessed through the catchment model as 582 kg/year (Table 3). This is greater than the research estimate of around 130–240 kg/year based on leaf-fall patterns plus biomass of grass on road verges in Part 3 (Ubrihien et al., 2024a). However, there are reasons to believe that the estimates for leaf-fall biomass are underestimated (see Part 3). To date there have been no independent estimates for how much soil and non-leaf debris is on the roads and how much extra phosphorus this contains.

Further research is required to ensure fertilisers applied to household blocks are not making a larger contribution than suggested by the modelling, and to clarify the contribution of leaves and grass. However, both sources of phosphorus pollution are likely to be significant and are preventable so consideration needs to be given to reducing both sources of pollution.

Part 5
Options to mitigate phosphorus pollution

- Reduce the amount of phosphorus entering stormwater at the source
- Slow the flow and filter the stormwater
- Treat the polluted water in-lake



Part 5: Options to mitigate phosphorus pollution

Previous research and programs in the ACT and elsewhere have identified and trialled a range of potential phosphorus mitigation options. For this report, options were shortlisted based on the availability of data to support cost-effectiveness analyses. In some instances, cost-effectiveness data were based on local trials of options. The Healthy Waterways team has yet to evaluate some other very promising options, or variants of options, because of a lack of relevant data on which to base cost-effectiveness. These options will be evaluated as data on their cost-effectiveness becomes available through ongoing research and trials.

Conceptually, there are three stages in the 'journey of the stormwater' where phosphorus might be removed from the system or algae may be directly treated through various options (Table 4 and Figure 7). This section describes these stages.

Table 4. Pollution mitigation options to remove phosphorus in the 'journey of the stormwater'.

	Where to remove phosphorus/treat algae	Mechanism
1	**At the source/s**	Reduce the amount of phosphorus before it enters the stormwater system (phosphorus pollution prevention).
1.1	Targeted street sweeping	Optimise street sweeping (for frequency, location and seasonality)
1.2	Pollution prevention partnerships	Promote waterways-friendly gardening practices by working with community and business.
1.3	Water sensitive urban design (WSUD)	Adopt suburb designs—or retrofit elements to existing suburbs—that minimise the impacts of urban development on the natural water cycle and better integrate suburbs into the natural landscape.
2	**In the stormwater system**	Use water sensitive urban design infrastructure to divert runoff in storms, allowing it to slow down, be filtered naturally by wetlands and/or to seep slowly back into the landscape.
2.1	Infrastructure that reduces stormwater peaks	Retain stormwater in green belts, detain it in tanks and/or recycle it.
2.2	Infrastructure that improves stormwater quality	Create various types of constructed wetlands.
2.3	Maximised effectiveness of water quality infrastructure	Sequentially place constructed wetlands and other water quality/ quantity assets along drainage lines and waterways to reach end-of-system targets and maintain the infrastructure in good condition.
3	**In the lake**	Use anti-algal agents that either compete with algae or treat the algae once it grows to bloom proportions.
3.1	Reduction of nutrient levels and/or competition with blue-green algae	Deploy materials or processes that remove nutrients from surface waters, where algae live, or promote natural competitors to algae.
3.2	Direct treatment of algae	Apply algicides or physical mechanisms to destroy or remove algae.

Reduce the amount of phosphorus entering stormwater at the source

There are several ways to prevent waters from becoming polluted in the first place, rather than allowing them to become polluted and then treating the pollution or its effects within the stormwater system.

Targeted street sweeping

The ACT Government's street sweeping program removes leaves and debris from kerbs and gutters along Canberra's urban roads. Every street in Canberra receives at least two full sweeps each year, with additional local sweeps between April and September during the heavy period of leaf-fall (See: https:// www.cityservices.act.gov.au/roads-and-paths/road-infrastructure-and-maintenance/street-sweeping).

One option is to increase the frequency of sweeps. As described in Part 4, leaf litter and grass clippings release nutrients quickly as they decompose or are wet. They lose most of their phosphorus within two days of either continuous or periodic inundation (Ubrihien et al., 2024a). The intent of increasing the frequency of street sweeping is therefore to remove leaf and grass litter from gutters before the phosphorus and other nutrients have had a chance to leach out of the litter. Other ways to optimise street sweeping regimes include concentrating sweeping during summer seasons or in locations with greater tree canopy near roads.

Pollution prevention partnerships

Canberra's residents affect waterway health in the way they manage leaves, grass and fertilisers on their blocks. Through Healthy Waterways, the ACT Government has been building expertise in supporting households to prevent stormwater pollution since 2016. It is working with the community to improve awareness and to support households to adopt practices that promote waterway health, like collecting leaves from the road verge.

Since the evidence began to point strongly to leaf litter in gutters and on paved surfaces as one of the top pollutants, programs have been developed and tested that target leaves directly.

From 2020–23, the government partnered with Griffith University and community stakeholders to test numerous interventions under the project title 'The Leaf Collective'. Three iterations of the program were run—two during autumn and one during summer. In all three campaigns householders reported an increase in the volume of leaf litter they collected from areas draining to stormwater. On average, they collected 20% more than the control groups collected. Attitudes towards the value of leaf litter also changed, with more people adding leaves to compost or using them to create leaf mould, and fewer people disposing of them inappropriately in their general waste bins.

From 2023–25, the government has delivered a smaller program. It features the most popular elements of the earlier pilots, such as the leaf-bag giveaway and leaf cages in schools and is gradually building in more offerings. Community stakeholders and individual community members consistently give positive feedback about these initiatives.

Our understanding of the impacts of fertiliser use on phosphorus pollution in stormwater is less advanced. The ACT Government piloted a 'Love the Lakes' program in May 2024 that aimed to reduce garden fertiliser use in households that use high amounts. Concepts of Change (2023) interviewed 600 households across Tuggeranong and coached householders (via telephone or in-person) about ways they could reduce fertiliser use. When the householders were contacted again in late 2024, they reported an average 36% decrease in fertiliser use during spring.

There are three points in the 'journey of stormwater' where phosphorus may be removed or algae treated directly.



1.
At the sources of phosphorus pollution, by preventing nutrient pollution from occurring in the first place.

2.
Within the stormwater system, by slowing the flow of water and allowing it to be filtered naturally by wetlands and/or to seep slowly back into the landscape where it is naturally cleansed.

3.
In the lake, using anti-algal agents that either compete with algae or treat the algae once it grows to bloom proportions

Figure 7. Phosphorus can be removed from stormwater at the source, within the stormwater system or in the lake.

Garden service providers were also contacted. They reported applying an average 1.78 kg of phosphorus per garden per year, which accounts for about 15% of the total amount of phosphorus applied across Canberra. Working with garden service providers offers another potential avenue to reduce fertiliser use.

Water Sensitive Urban Design

For many decades, town planning adopted engineering solutions aimed at flood mitigation that turned many ACT waterways into straight pipes and concrete drains. These engineered systems are very efficient at conducting stormwater, and the nutrients it carries, rapidly and directly out of urban landscapes to the natural waterways without opportunities for treatment by catchment soils and vegetation. Studies into urban runoff in storms suggest it has fewer adverse impacts on water quality in natural waterways if there is less direct flow from impervious surfaces, such as roads, to natural waterways (Ladson et al 2006, Walsh et al. 2022).

Water Sensitive Urban Design (WSUD) planning, landscaping and infrastructure promote infiltration of urban stormwater into the soil, increase water retention, reduce flow rates and filter out nutrients from stormwater in the catchment. Using WSUD helps reduce runoff and improve water quality before stormwater enters natural waterways such as Lake Tuggeranong (for example, see Ubrihien et al. 2020).

WSUD infrastructure has been a key feature of Healthy Waterways over its 10 years to date. The program has built 27 water quality assets, predominantly ponds, wetlands, rain gardens and channel restorations across urban Canberra since 2014.

In developing these assets, Healthy Waterways worked across government to ensure the asset designs were either approved against Municipal Infrastructure Standards (MIS) or Municipal Infrastructure Technical Standards (MITS) or are new and effective designs. The new designs allow for an expansion of the MIS and MITS standards, which means there are now more options in the infrastructure toolkit that water managers can use to improve stormwater quality.

Infrastructure that reconnects storm runoff with its catchment

WSUD infrastructure may target either reducing the amount of runoff in storms or improving stormwater quality or both. Features can be added to an urban area to retain water in the landscape or route small streams of stormwater back into green space, such as castellated kerbs and landscape contours (Table 5). This allows stormwater to soak back into natural catchment areas where it is mostly retained (for example, it evaporates or is taken up by plants) or is cleansed by surface vegetation and soils. At one end of the spectrum these features are capital works; for example, Healthy Waterways built some small runoff infrastructure assets such as castellated kerbs to reduce the volume of water in the stormwater system. At the other end of the spectrum, landcare groups can improve stormwater retention simply by roughening drainage lines (Alluvium, 2023). In the case of stormwater recycling, water is diverted from pipes, drains or WSUD infrastructure and usually treated before being used, sometimes to irrigate green space like sports fields and golf courses, and sometimes for other purposes, such as in construction.

Table 5. Types of runoff infrastructure built in the ACT.

Type of infrastructure	How it works
Castellated kerbs	Roadside drains have gaps in them where some of the stormwater is diverted into adjacent green space where the stormwater can be absorbed into the soil.
Landscape roughening	Small mounds are dug into slopes to temporarily capture runoff and allow it to sink into the soil (Alluvium, 2023).
Rainwater tanks	Hold water in the landscape using above or below ground storage tanks for rainwater usually sourced from roofs.
Detention tanks	Built underground to temporarily store stormwater sourced from drains and often used to irrigate sports fields.
Stormwater recycling	Stormwater is diverted to tanks before being cleaned and used instead of potable water; for example, to irrigate sports fields. It may be cleaned by a combination of constructed wetlands, groundwater aquifers, and/or a filtering unit in a shipping container.

Slow the flow and filter the stormwater

Infrastructure that reduces stormwater peaks

Tanks can be used to temporarily store stormwater before the water is either used (for example, to water resident's gardens) or released back into the stormwater system. The delayed release of stormwater reduces peak flows and allows downstream wetlands and ponds more time to process and treat a greater volume of the stormwater.

Infrastructure that improves stormwater quality

WSUD infrastructure is built with a primary function of treating pollutants and improving water quality. This infrastructure includes a variety of constructed wetlands, where plants and soil media filter nutrients and fine sediment particles from the stormwater. Different types of constructed wetlands are shown in Table 6. Constructed wetlands can also have several added benefits such as providing riparian (waters-edge) and aquatic habitat for wildlife within urban areas, reducing urban heat, enhancing values of importance to Traditional Custodians and contributing to urban amenity. The wetlands, ponds and raingardens built in the Healthy Waterways program are examples of WSUD infrastructure that target improving stormwater quality by removing pollutants.

In the Tuggeranong catchment, research by the University of Canberra has shown that most nutrients are mobilised and transported during big storm events where flow volumes are high (Ubrihien et al., 2020). In this situation, wetlands are only able to treat a small proportion of the nutrient-laden flows, with the remainder bypassing the wetlands. Part 6 further considers the implications of this.

Maximising the effectiveness of WSUD infrastructure

Treatment trains

The effectiveness of water quality assets can be maximised through careful design and sequential placement of different types of assets. A series of assets working in sequence to reduce and improve stormwater quality is known as a treatment train.

Box 3. Urban catchments create more runoff in storms

Phosphorus pollution in Lake Tuggeranong is, in large part, a result of urbanisation. Water that flows over the land surface is known as runoff, which in urban areas quickly enters the engineered stormwater system.

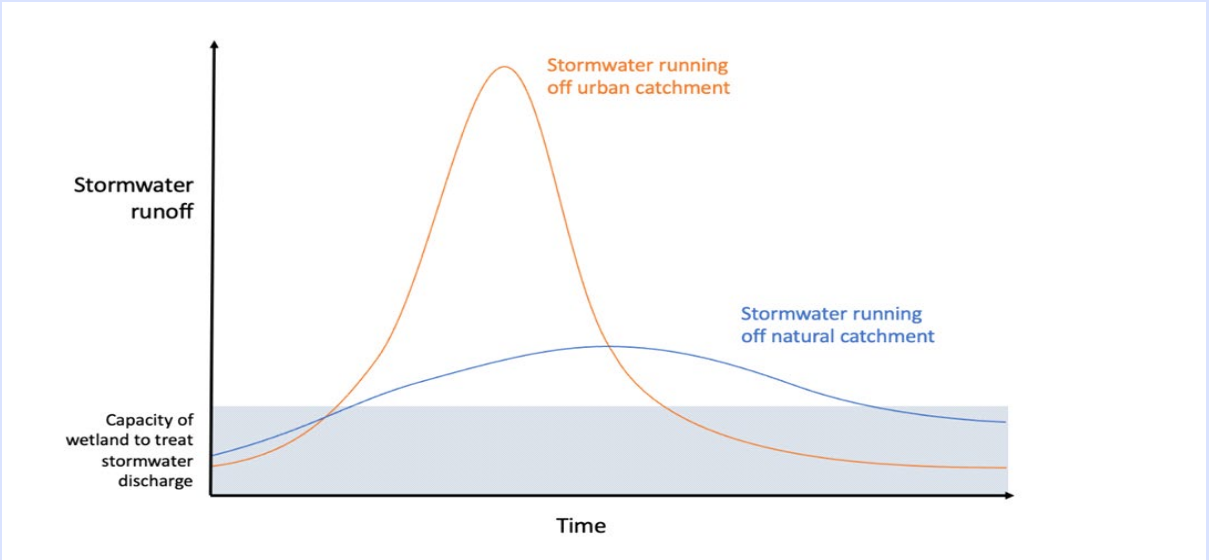
In a natural catchment, rain falls on trees and vegetation, which take energy out of the water and allow it to be absorbed into the soil and bedrock. When the ground is saturated, water will eventually start to run off, but at lower volumes and speeds than in an urbanised catchment. When the runoff ceases, water will be slowly released from the landscape, allowing waterways to flow at a gentler rate over a longer period.

The highly urbanised nature of the Lake Tuggeranong catchment means that much of the catchment is covered by roofs, buildings, roads, concrete paving and other surfaces that water can't soak into, known as impermeable surfaces (Codner et al., 1988). Rain therefore runs off impermeable surfaces. This runoff washes lots of phosphorus from these impermeable surfaces into the stormwater system, which is also highly impermeable, and on to Lake Tuggeranong.

Models estimate that the volume of runoff from the Lake Tuggeranong catchment is three times higher than that of a natural catchment (Dey et al., 2024). Consequently, urban stormwater systems are very 'flashy' waterways, with water levels rising quickly after rainfall, and falling back to baseflow levels almost as quickly (see the hydrograph in the figure below).

Large amounts of runoff in an urban system make it difficult to treat the high levels of phosphorus in stormwater. A wetland only has the capacity to treat a limited amount of stormwater per hour, so the smaller the volume and longer the duration of flow from a storm event, the greater the proportion of stormwater that will be treated.

By reconnecting more runoff and stormwater back into the landscape, we can start to return the catchment to a more natural flow state. This would provide more opportunities for water to be absorbed into the landscape, and for wetlands and their plants to better capture phosphorus from the remaining stormwater and prevent it from reaching Lake Tuggeranong.



Idealised depiction of stormwater flow in an urban vs natural catchment and the capacity of a wetland to treat the stormwater. The grey area indicates the volume of water that a wetland can treat over a given period and shows the 'flashy' nature of stormwater coming off an urban catchment.

For example, placing runoff infrastructure such as castellated kerbs higher up in the catchment can divert water back onto grassy areas, which reduces the volume of phosphorus-laden stormwater running down the drains. Detention tanks, like rainwater tanks connected to roofs of houses, can capture stormwater peaks and either release some of the stormwater slowly after the storm has passed (for example, by using a specially designed 'leaky tank') or be used for watering gardens. Around playing fields, smaller swales and raingardens filter out coarse sediments and some nutrients from the stormwater before it flows downstream to bigger wetlands and ponds.

Using a treatment train in this way is particularly effective during big storm events by allowing bigger wetlands downstream to more effectively treat more of a storm event's runoff (and for longer) because flow volumes have been reduced upstream and the first pass through smaller filtering infrastructure that has already filtered some nutrients and sediments, reducing the pressure on the bigger downstream wetland.

Maintenance

When sediments do build up in a constructed wetland and the water plants absorb all the nutrients they can, the wetland needs to be maintained to retain its ability to clean the stormwater. This is an often-overlooked part of managing them for optimal effectiveness. Maintenance can include removing built-up sediments, which reduce the wetland's capacity to hold and filter stormwater and harvesting water plants regularly to remove the nutrients they contain from the system and prevent them from decaying back into the water.

Raingardens are renowned within the stormwater industry as particularly sensitive to poor maintenance. They can become completely dysfunctional if their inlets become blocked and their surface sediments clogged and overgrown with trees or weeds that disrupt their ability to function properly. Operational and maintenance requirements are a key design feature of WSUD infrastructure. The choice of assets and the level of maintenance funding need to be considered before committing to such projects.

Table 6. Types of constructed wetlands built in the ACT.

Type of infrastructure	How it works
Ponds	Stormwater is routed to one or more settling ponds fringed with emergent aquatic plants. The overflow is returned to the stormwater channel.
Traditional wetlands	Stormwater is diverted from channels and routed through a sequence of pools and shallower beds of emergent aquatic plants before being returned to the stormwater drain.
Raingardens	Stormwater floods the soil surface, which has dense growth of emergent aquatic plants, then percolates downwards through the soil and is collected in pipes and returned to the stormwater drain.
Bioretention swales	These smaller, vegetated drains operate in the same way as raingardens and are often targeted at point sources of pollution such as sports fields.
Subsurface wetlands	Stormwater is routed horizontally through gravel beds overlain by soils and emergent aquatic plants. Plant roots extend into the gravel beds. The overflow is returned to the stormwater drain. The aquatic plants remove dissolved nutrients, as in a hydroponic garden.
Channel re-naturalisations	Concrete stormwater open drains or channels are replaced with various combinations of pools, riffles, runs and beds of aquatic plants. In the process, the channels may be reconnected with surrounding floodplain sediments and aquifers.

Box 4. Examples of Water Sensitive Urban Design (WSUD) infrastructure in Tuggeranong

WSUD infrastructure has been a key feature of Healthy Waterways. Twenty water quality assets, predominantly ponds, wetlands, rain gardens and channel restorations, were built in Healthy Waterways Stage 1. Seven of eight assets have been built in Stage 2, with the final asset slated to be built in 2025.



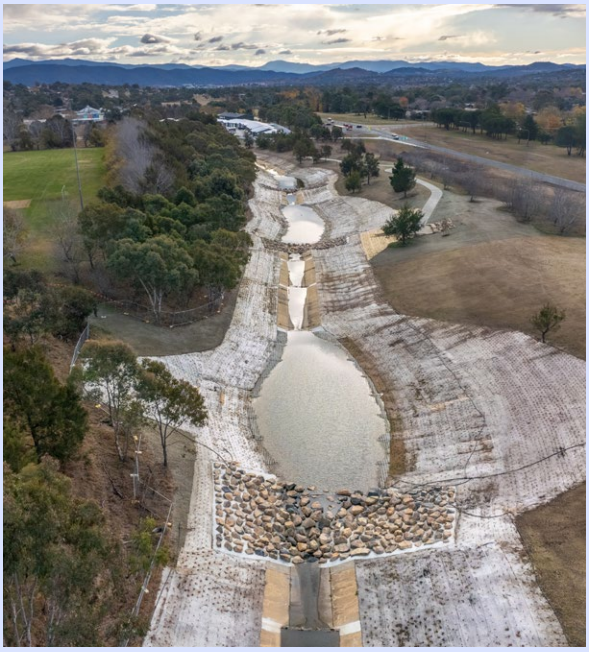
1. Bioretention swale at Kambah District Playing Fields



3. Drain naturalisation at Tuggeranong Creek in Calwell – before



2. Pond at Kett St near the Kambah shops



4. Drain naturalisation at Tuggeranong Creek in Calwell – after (but before plantings have grown)

Treat the polluted water in-lake

Alongside pollution reduction programs and infrastructure, in-lake treatments are a complementary management tool to further reduce nutrient levels in the system and curb blue-green algal blooms. Blue-green algal blooms are an issue across Australia and globally, affecting drinking water catchments, recreational water bodies and the agricultural industry. Governments, industry and the research community have invested heavily in trying to find solutions and a range of in-lake treatments have been developed (see Table 7).

Broadly, these in-lake treatments try to address blue-green algal bloom by either:

- reducing nutrient levels in a waterbody (adsorptive materials, lake water treated by a lakeside bioretention, biological competitors, water treatment plant) or
- treating the algae directly with chemicals such as algicides or through physical actions or with water treatment plant.

Trials of in-lake treatments —past and future

In 2019–2020 the ACT Government engaged the University of Canberra to conduct in-lake mesocosm experiments using Phoslock™ (adsorptive material), Diatomix™ (modifies the nutrient composition of the water to favour species that promote the growth of diatoms at the expense of blue-green algae) and peroxide (an algicide). The experiments found these methods to be ineffective at reducing established blue-green algal blooms in Lake Tuggeranong. However, the timing of their application, after a bloom was established, may have limited the effectiveness of at least the Phoslock and peroxide treatments. The experiment report suggests that Phoslock offers a promising way to limit internal phosphorus loading, provided catchment sources can be controlled first. It recommends further trials that apply treatments before the onset of a bloom (Ubrihien et al., 2019).

Two floating wetlands have been deployed; one in Lake Tuggeranong and the other outside the Tuggeranong catchment at Yerrabi Pond. The floating wetlands directly compete with algae for light and nutrients. They have yet to be evaluated for their performance.

A range of existing and emerging technologies and methods to treat phosphorus in the lake have been identified, including filtration, sedimentation, floatation, biological and chemical removal (GHD, 2024). This work pointed to potential opportunities to use a combination of bioretention basins and phosphorus adsorptive (chemically binding) material. For example, Poseidon Pellets™ are a patented product made of magnesium carbonate beads, which adsorb phosphorus and ammonia from water. They could be used in a variety of ways; a water-permeable bag containing the beads can be placed in stormwater or suspended in the surface waters of the lake or in a bioretention basin. Once the pellets become saturated with phosphorus they need to be replaced.

Other in-lake treatments may also be trialled in the future through the Healthy Waterways research program, but the immediate priority will be to reduce catchment sources of phosphorus.

Table 7. Different types of in-lake treatments. All have potential adverse environmental impacts and most are likely to have low effectiveness until pollution from the Lake Tuggeranong catchment is reduced. Only a small number of these treatments have been trialled in Canberra, where the focus has been on reducing pollution in the catchment.

Treatment type	How it works
By reducing nutrient levels and/or competing with blue-green algae	
Adsorptive materials	Materials deployed to the lake bind phosphorus strongly, removing dissolved forms from water so the phosphorus is not available for uptake by blue-green algae.
Bubblers	Bubblers increase levels of dissolved oxygen in the water column, which encourages the formation of iron and manganese precipitates that bind dissolved phosphorus. The precipitates then sink and are stored in the lake sediments.
Bioretention	Water from the lake is circulated through raingardens at the edges of the lake, which partially filter the phosphorus by binding it to soil media and incorporating it into plant biomass.
Biological competitors	Competitors promote the growth of water plants or beneficial algae or bacteria that compete with blue-green algae, suppressing their growth.
By treating algae directly, either in-lake or with water treatment plant	
Algicides	Chemical agents aim to selectively kill algae.
Physical	Physical methods either physically break up blue-green algal cells or force them to the surface of the lake where they can be removed by skimming.

Conclusion for in-lake treatments

Unfortunately, there is no treatment that is effective in all contexts or that may not adversely affect the aquatic environment. Since in-lake treatments are unlikely to ever be effective enough to curb nutrient levels that fuel algal blooms, and the excessive use of algicides would present a heightened risk of impacts to non-target organisms, they do not represent a sustainable, stand-alone solution. However, water managers may need to use them both as an interim measure over the next decade, while we work to mitigate the sources of catchment loads, and then as a periodic solution when algal blooms arise despite best efforts to prevent them.

Part 6
Benefits and cost-effectiveness of options

- Selection of options for analysis
- Benefits and cost-effectiveness of options
- Can we reach the phosphorus reduction target?



Part 6: Benefits and cost–effectiveness of options

Selection of options for analysis

Booksmythe et al. (2024) analysed a subset of options for mitigating phosphorus pollution for their potential to contribute to solving the algal bloom problem in Lake Tuggeranong (Table 8). They only analysed options or variants of options if their costs and effectiveness could be well characterised based on local trials or scientific literature. Of the nine selected options to remove phosphorus before it enters the lake, five prevent it entering the stormwater system and four treat it once it's in the system.

They did not select any options for directly treating algae in-lake and selected only one in-lake treatment for reducing nutrient levels and/or competing with blue-green algae (floating wetlands). This is because the initial focus is to mitigate the phosphorus pollution that is driving algal blooms. Other in-lake options will be considered in future once their costs and benefits (and risks) are better understood and phosphorus pollution to Lake Tuggeranong has been reduced.

Benefits and cost–effectiveness of options

Method for determining cost–effectiveness

Booksmythe et al. (2024) defined four investment levels for each pollution mitigation option (Table 8). For example, for the option 'increased street sweeping', the investment levels were 12, 24, 36 and 48 sweeps a year.

They then derived data for costs and effectiveness (in terms of phosphorus reduction) of the investment levels from the scientific literature and the results of local trials. They estimated the benefits (kg phosphorus removed), costs (Net Present Value or 'NPV' over a 30-year period) and cost-effectiveness ($/kg phosphorus removed) of all investment levels. Cost-effectiveness represents the cost/effectiveness ratio of each investment level and was calculated as marginal annual benefit (kg phosphorus removed/year) / marginal annual cost (NPV to implement over 30 years divided by 30). The ongoing operation and maintenance costs were discounted by 7% per annum after the first year.

The researchers used a 30-year timeframe to calculate total costs because it allows for the comparison of options with very different cost schedules. For example, some options have large upfront costs, but low ongoing costs (for example, castellated kerbs) and some options have lower upfront costs, but higher ongoing costs (for example, street sweeping).

Results

Table 9 and Figures 8 and 9 present the annual load of phosphorus removed (the benefit or effectiveness of an option), the 30-year cost and the cost-effectiveness of each option's four levels of investment to mitigate phosphorus pollution. Note that the 30-year cost in Table 9 is the total cost of this option/investment level and any previous investment levels of the option.

It is clear from these data that street sweeping and adding extra water quality assets are the most effective options for reaching the 700 kg target, with the rest of the options bunched below these two in their effectiveness.

An important conclusion of this work is that options to prevent waters from becoming polluted in the first place—street sweeping and ensuring grass clippings from road verges do not enter drains—are more cost-effective than all other options, most notably, the construction of water quality assets. Thus, the most cost-effective way to improve water quality is to prevent waters from becoming polluted rather than relying on water treatment to achieve clean water.

Table 8. Options considered in this report to reduce phosphorus pollution of stormwater (Booksmythe et al., 2024).

Option	Description
Street sweeping	Increase the amount of street sweeping in the catchment to remove more organic material from the roads, preventing it from leaching phosphorus into the stormwater drains. The implementation level reflects sweeping frequencies of 12 to 48 sweeps per year. Other ways to optimise street sweeping regimes have yet to be evaluated.
Fertiliser management	Identify and target the relatively small number of households that use excessive amounts of fertiliser to help them use either low-phosphorus fertiliser or no fertiliser at all. The implementation level reflects the reach of the program.
Open space mowing	Reduce the amount of grass clippings from municipal mowing that end up on the road, preventing them from leaching phosphorus into the stormwater drains. The implementation level reflects different management approaches, from having designated street sweeping trucks follow immediately after mowing events to towing electric blowers behind mowers to divert clippings away from the road.
Rainwater tanks	Capture stormwater from roofs for reuse on residential blocks. This may aid in removing some phosphorus in the system as well helping to reduce urban runoff. The implementation level reflects the number of houses that would have a tank installed.
Stormwater recycling	Divert and filter stormwater to storage tanks at sports fields for use in irrigating the fields. The implementation level reflects the number of sports field sites at which water managers would install this infrastructure.
Castellated kerbs	Retrofit outlets into road kerbs to divert some of the stormwater to open green space and allow it to filter into the ground. The implementation level reflects the number of outlets installed (water managers are limited by availability of suitable places in the Tuggeranong catchment; that is, areas adjacent to green space).
New water quality infrastructure—sports fields	Build swales around sports fields to potentially capture any phosphorus leaching out from fertiliser. Sports field managers currently appear to be fertilising optimally and the leaching may be more a legacy issue. The investment level reflects the number of sports field sites at which water managers would install this infrastructure.
New water quality infrastructure	Construct more wetlands at suitable locations in the catchment to treat phosphorus in the stormwater. The implementation level reflects the number of wetlands constructed, ranging from the two most effective builds to the ten most effective builds
Maintenance of existing water quality infrastructure	Ensure maintenance (such as dredging out built-up sediment and harvesting plants) of existing WSUD infrastructure in the Lake Tuggeranong catchment to maximise its performance and capture the largest amount of nutrients possible. The implementation level reflects the number of assets maintained.
Floating wetlands	Install more floating wetlands on Lake Tuggeranong to draw phosphorus out of the lake water. The implementation level reflects the number and size of wetlands installed.

Table 9. Summary of phosphorus (P) removal performance, total 30-year cost and cost-effectiveness for four levels of investment for each of ten pollution mitigation options assessed independently (Booksmythe et al., 2024). 30-year total lifecycle cost is the estimated cost of implementing and operating a mitigation option over 30 years, with annual operation and maintenance costs discounted by 7% per annum after the first year.

P mitigation option and level	Unit	P removed (kg/year)	30-year cost ($)	Cost-effectiveness ($/kg P)
Install additional WSUD 1	Build 2 new WSUD assets	106.21	$22,507,500	$7,064
Install additional WSUD 2	Build 5 new WSUD assets	169.67	$48,369,492	$9,502
Install additional WSUD 3	Build 8 new WSUD assets	226.22	$73,862,467	$10,884
Install additional WSUD 4	Build 10 new WSUD assets	240.46	$84,519,403	$11,716
Maintenance of existing WSUD 1	Enhanced maintenance of 2 assets	35.84	$10,177,128	$9,465
Maintenance of existing WSUD 2	Enhanced maintenance of 3 assets	61.78	$19,086,579	$10,298
Maintenance of existing WSUD 3	Enhanced maintenance of 4 assets	79.93	$26,352,433	$10,990
Maintenance of existing WSUD 4	Enhanced maintenance of 5 assets	88.02	$30,352,433	$11,495
Increase street sweeping 1	12 street sweeps per year	203.70	$7,030,414	$1,150
Increase street sweeping 2	24 street sweeps per year	320.10	$14,060,827	$1,464
Increase street sweeping 3	36 street sweeps per year	372.50	$21,091,242	$1,887
Increase street sweeping 4	48 street sweeps per year	395.80	$28,121,656	$2,369
Manage grass clippings 1	Blow clippings into verge, low P removal estimate	16.40	$2,018,874	$4,103
Manage grass clippings 2	Blow clippings into verge, high P removal estimate	26.10	$2,018,874	$2,578
Manage grass clippings 3	Sweep clippings in verge, low P removal estimate	32.70	$1,521,462	$1,551
Manage grass clippings 4	Sweep clippings in verge, high P removal estimate	52.30	$1,565,956	$998
Sports field fertilizer management 1	Protect 25% of sports fields with bioretention swales	14.93	$4,204,451	$9,387
Sports field fertilizer management 2	Protect 50% of sports fields with bioretention swales	29.85	$11,817,327	$13,196
Sports field fertilizer management 3	Protect 75% of sports fields with bioretention swales	44.78	$19,430,204	$14,463
Sports field fertilizer management 4	Protect 100% of sports fields with bioretention swales	59.70	$31,445,222	$17,557
Household fertilizer management 1	Low P target (assume cost is $10,000/kg P/year)	20.00	$6,000,000	$10,000
Household fertilizer management 2	Medium P target (assume cost is $10,000/kg P/year)	32.67	$9,800,000	$10,000

P mitigation option and level	Unit	P removed (kg/year)	30-year cost ($)	Cost-effectiveness ($/kg P)
Household fertilizer management 3	High target (assume cost is $10,000/kg P/year)	45.33	$13,600,000	$10,000
Household fertilizer management 4	Very high target (assume cost is $10,000/kg P/year)	58.00	$17,400,000	$10,000
Install castellated kerbs 1	Install 1 kerb outlet for every 4 sumps (or 453 outlets)	15.56	$4,532,500	$9,708
Install castellated kerbs 2	Install 1 kerb outlets for every 3 sumps (or 604 outlets)	20.75	$5,990,823	$9,624
Install castellated kerbs 3	Install 1 kerb outlets for every 2 sumps (or 906 outlets)	31.13	$8,539,901	$9,146
Install castellated kerbs 4	Install a kerb outlet for every sump (or 1813 outlets)	62.25	$14,349,291	$7,684
Install floating wetlands 1	Deploy 1000 m2 of wetland	3.00	$1,226,000	$13,622
Install floating wetlands 2	Deploy 2000 m2 of wetland	6.00	$2,452,000	$13,622
Install floating wetlands 3	Deploy 3000 m2 of wetland	9.00	$3,678,000	$13,622
Install floating wetlands 4	Deploy 1000 m2 of wetland	12.00	$4,904,000	$13,622
Stormwater recycling for irrigation 1	Build best 2	8.81	$2,673,863	$10,115
Stormwater recycling for irrigation 2	Build best 4	15.12	$4,588,909	$10,115
Stormwater recycling for irrigation 3	Build best 6	19.19	$7,339,284	$12,748
Stormwater recycling for irrigation 4	Build best 8	21.78	$10,816,870	$16,558
Household rainwater tanks 1	2,500 new households to install water tanks	15.00	$12,500,000	$27,778
Household rainwater tanks 2	2,500 new households to install water tanks	30.00	$25,000,000	$27,778
Household rainwater tanks 3	2,500 new households to install water tanks	45.00	$37,500,000	$27,778
Household rainwater tanks 4	2,500 new households to install water tanks	60.00	$50,000,000	$27,778

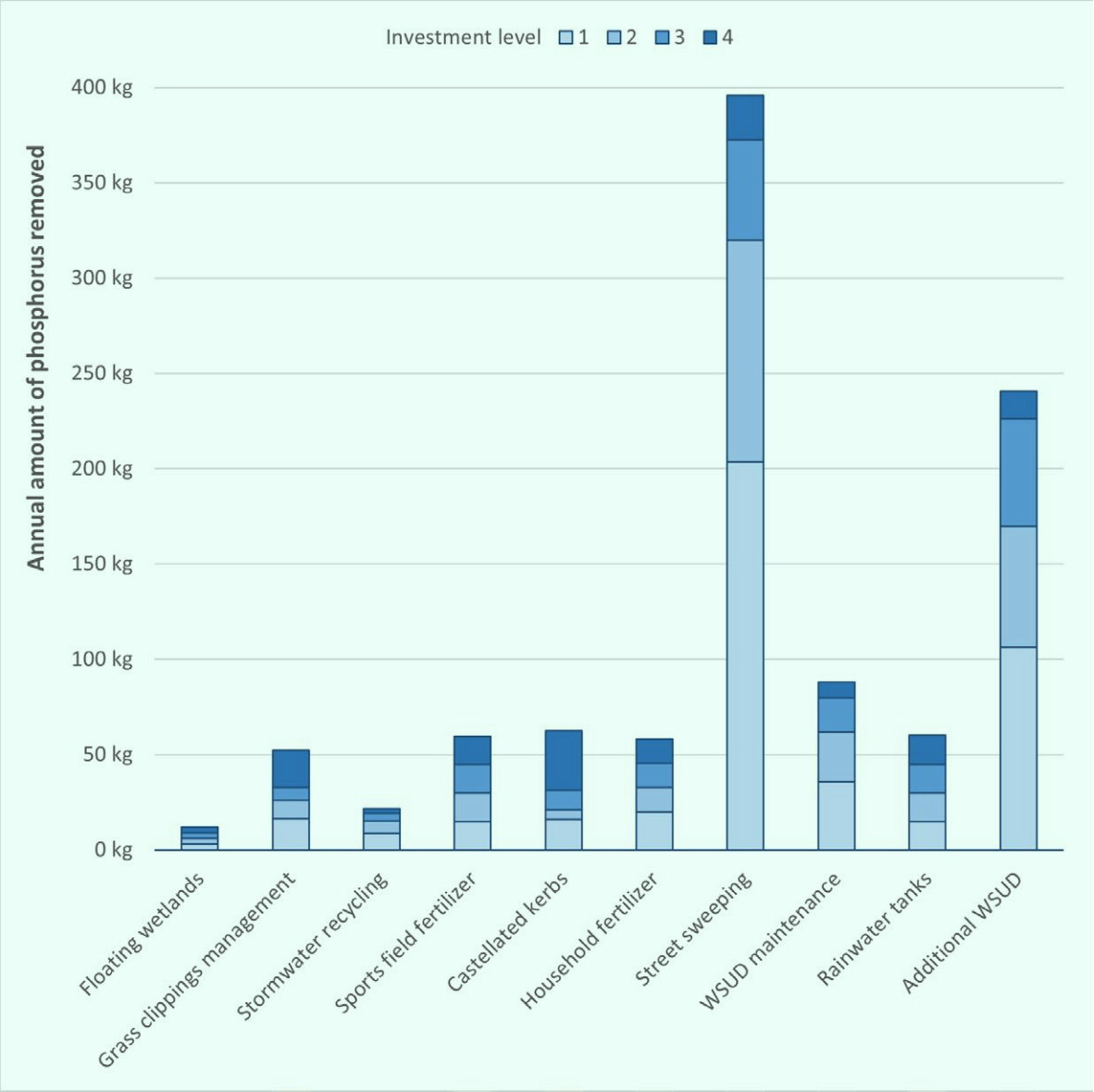


Figure 8. Benefit (or effectiveness) of different levels of investment in pollution mitigation options, from Table 9. Each stacked histogram represents the incremental benefit of the four levels of investment in each option.

Implications

Several key findings emerge from these results:

- There are no silver bullets; no pollution mitigation option has the potential to reach the 700 kg/year phosphorus mitigation target on its own. Managers will need to implement multiple options to reduce phosphorus pollution to a substantial extent and thus restrict the incidence of algal blooms.
- Street sweeping is the most cost-effective option in both scenarios and removes the largest amount of phosphorus (as also indicated in Figures 8 and 9).
- Large water quality assets placed low down in catchments are necessary to treat unavoidable pollution but are not sufficient on their own to achieve the target reduction in phosphorus pollution of stormwater. Managers will need to implement options that prevent stormwater from getting polluted in the first place to substantially reduce the incidence of blue-green algal blooms in Lake Tuggeranong.

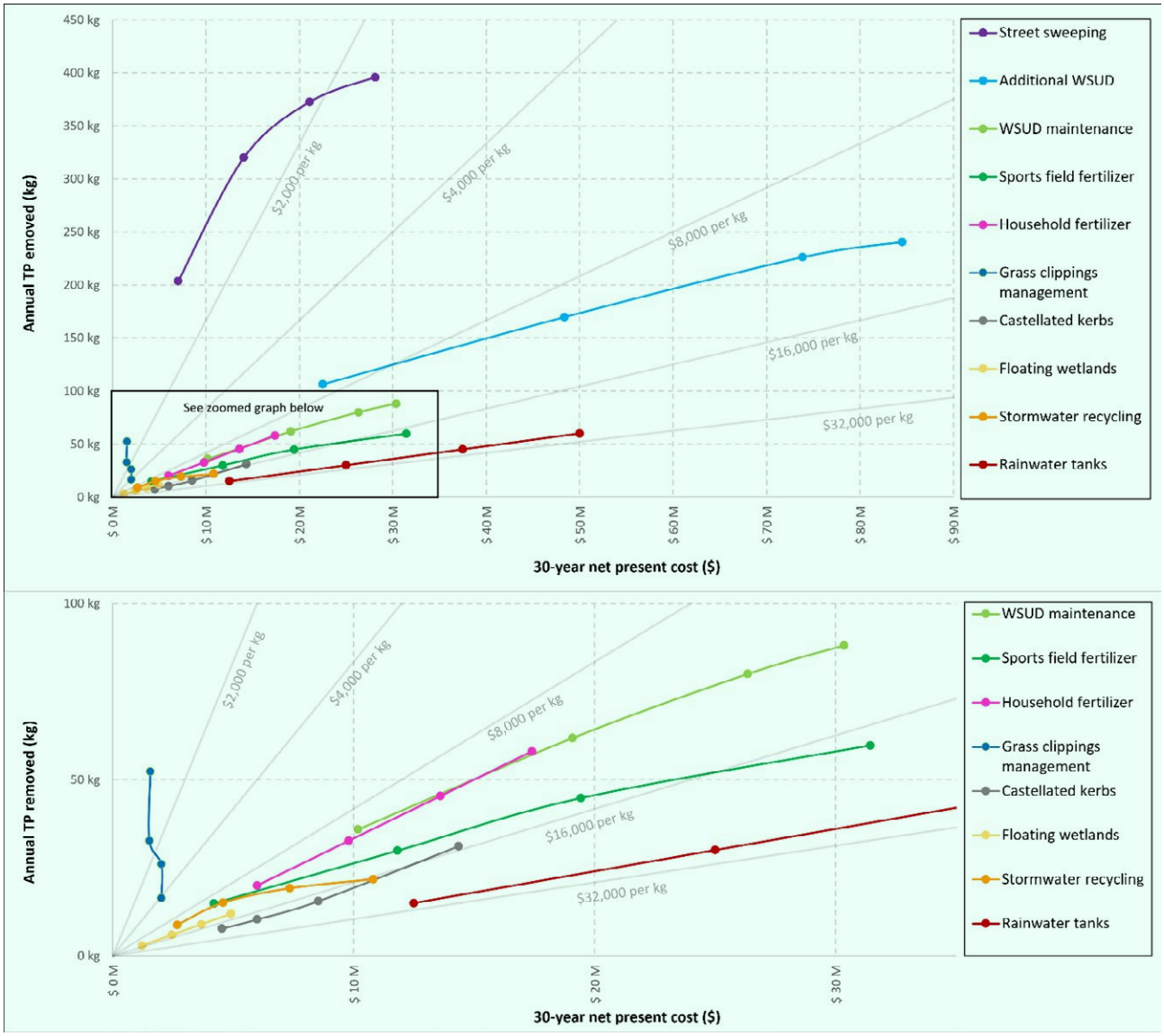


Figure 9. Annual total phosphorus load removed and 30-year lifecycle cost of each incremental investment level for the 10 assessed options for mitigating phosphorus pollution (Booksmythe et al., 2024). Coloured lines connect the four estimates for each option. Grey lines are a guide indicating the cost-effectiveness (cost per kg phosphorus removed) of the estimates. The top panel shows all estimates; the bottom panel shows a zoomed in view of the estimates within the inset box.

Box 5. Street sweeping pilot

Based on the research findings that leaves contribute to stormwater pollution (see Part 3), a pilot street sweeping program was conducted over the summer of 2023–24 to better understand how much the leaves and other organic matter from streets contribute to the amount of nutrients in urban stormwater, and to begin to understand the efficacy of increasing the frequency of street sweeping as an option to mitigate pollution.

Over three months, two sub-catchments in the Lake Tuggeranong catchment were swept every fortnight and two sub-catchments were left unswept. Stormwater samples were collected during storm events to see if the fortnightly-swept catchments showed a reduction in nutrient concentrations. Samples of the material swept off the roads by the trucks were also taken to a lab for analysis.

The results indicate that leaves and other organic material on the roads are contributing significant amounts of phosphorus to stormwater in the catchment. Analysis of the material collected by street sweeping trucks (which included leaves, soil, grass clippings, gravel and road material) estimated that 39.2 kg of phosphorus was removed from the roads in the swept sub-catchments during the experiment. Scaled up to the Tuggeranong catchment, this pilot suggests that a fortnightly program of street sweeping could intercept around 300 kg a year of phosphorus, which is more than 40% of the target of 700 kg/year.

Analysis of the stormwater samples showed a modest decrease in phosphorus concentrations in stormwater from the swept sub-catchments over time, compared to the unswept sub-catchments. As there are many other factors that can influence nutrient concentrations in stormwater, the project was repeated in the summer of 2024–25 to strengthen our understanding of how much leaves contribute to phosphorus in the stormwater. Analysis of this second trial is underway.



The street sweeper used in the pilot program.

Can we reach the phosphorus reduction target?

The analyses of the effectiveness of individual pollution mitigation suggest that the ACT Government can succeed in curbing algal blooms in the lake if it implements a program to reduce phosphorus pollution. However, in practice, water managers will implement various pollution mitigation options concurrently, and this will affect their combined performance. This decrease arises because some pollution mitigation options partially offset the beneficial effects of others. For example, having a dedicated street sweeper follow mowers of road verges would diminish some of the effect of sweeping suburbs 36–48 times a year.

Dey et al. (2024) used the catchment water quality model to model this interactive effect. Their modelling indicates that the interactive effect reduces the total phosphorus removed by 25% and 34% for two different combinations of pollution mitigation options implemented concurrently, or ca. 30%. However, there are good reasons to argue that the 700 kg/year pollution reduction target can still be met.

Firstly, the management options to mitigate pollution are currently conceived in a simple way. Refinement of the options, both during implementation planning and in models, should both decrease their cost and increase their effectiveness. For example, street sweeping in winter, when cold temperatures limit algal growth, may have little impact on lake closures. Eliminating winter street sweeping will reduce costs. Targeting sweeping efforts in suburbs with a high density of street trees, and adding a complementary community program for collecting leaves, may intercept a greater amount of pollution from leaves and grass on verges, reducing the nutrient pollution from these sources beyond that predicted by Dey et al. (2024) for the most intense investment level of this option in the model. There are many nuances to the design of community partnerships and the design and siting of water quality assets that could increase their effectiveness above the average value used in the modelling.

Secondly, several promising pollution mitigation options have yet to be explored that may help to meet the phosphorus mitigation target. Apart from floating wetlands, in-lake treatments have not been included in the modelled options, and these could contribute to further phosphorus reduction. For example, new products are emerging that draw and capture phosphorus out of stormwater, both in the catchment and in the lake itself. One potential intervention that has shown promising results in trials overseas is Poseidon PelletsTM. These pellets consist of porous granules that adsorb dissolved phosphorus from water. They promise a high rate of phosphorus adsorption at a relatively low cost but remain untested locally.

The uncertainty about the extent that fertilisers applied to residents' gardens contribute to stormwater pollution (Part 4) does not preclude taking action now. If it turns out from further research that the fraction of phosphorus attributed to fertiliser use is more than is currently estimated, and the fraction due to leaves and grass is less, there would be a shift in emphasis from options that target leaves to ones that target fertilisers. The same is true if sewer leaks turn out to be an important source of phosphorus; the leaks would need to be fixed but it would still be necessary to deal with leaves, grass and fertilisers.

The main cautionary note is about how quickly algae in Lake Tuggeranong will respond to reduced supplies of phosphorus from the catchment. Algal blooms may persist if the phosphorus in the sediments is able to sustain the blooms. This may mean it takes longer than the goal of a decade to fix the algal bloom problem. The long-term research focus should include investigations into in-lake treatments that reduce the supply of phosphorus from the sediments or compete with algae for phosphorus, such as Poseidon Pellets™.

Key conclusions can be drawn from the analyses in this report:

- There is sufficient knowledge to have confidence that a suite of actions can lead to a substantial reduction in the frequency of blue-green algal blooms in Lake Tuggeranong. Inflows of phosphorus pollution can be reduced by up to 700 kg/year within ten years, but whether this would significantly reduce algal blooms in the same time frame may depend on the development of in-lake treatments to deal with phosphorus stored in lake sediments.
- Algal blooms probably cannot be prevented from forming altogether. The analyses carried out for this report suggest the best that can be achieved is for algal blooms to be prevented in three out of four years on average.
- This means that the ACT Government may need to consider developing ways to treat algal blooms as they arise in the years where pollution levels may permit their formation. These may range from the promotion of algal competitors to the use of algicides (see Part 5).



Part 7
The path forward

- Research agenda
- Suggested priorities for restoration
- Next steps to finalise the Plan



Part 7: The path forward

The research findings and modelling work presented in this report provide confidence that the ACT Government can make real progress in addressing the problem of algal blooms in Lake Tuggeranong. The target level of phosphorus reduction is achievable, and this would reduce the impacts of blue-green algal blooms. Figure 10 shows a high-level plan for how this could be achieved, from which funding for implementation can be considered.

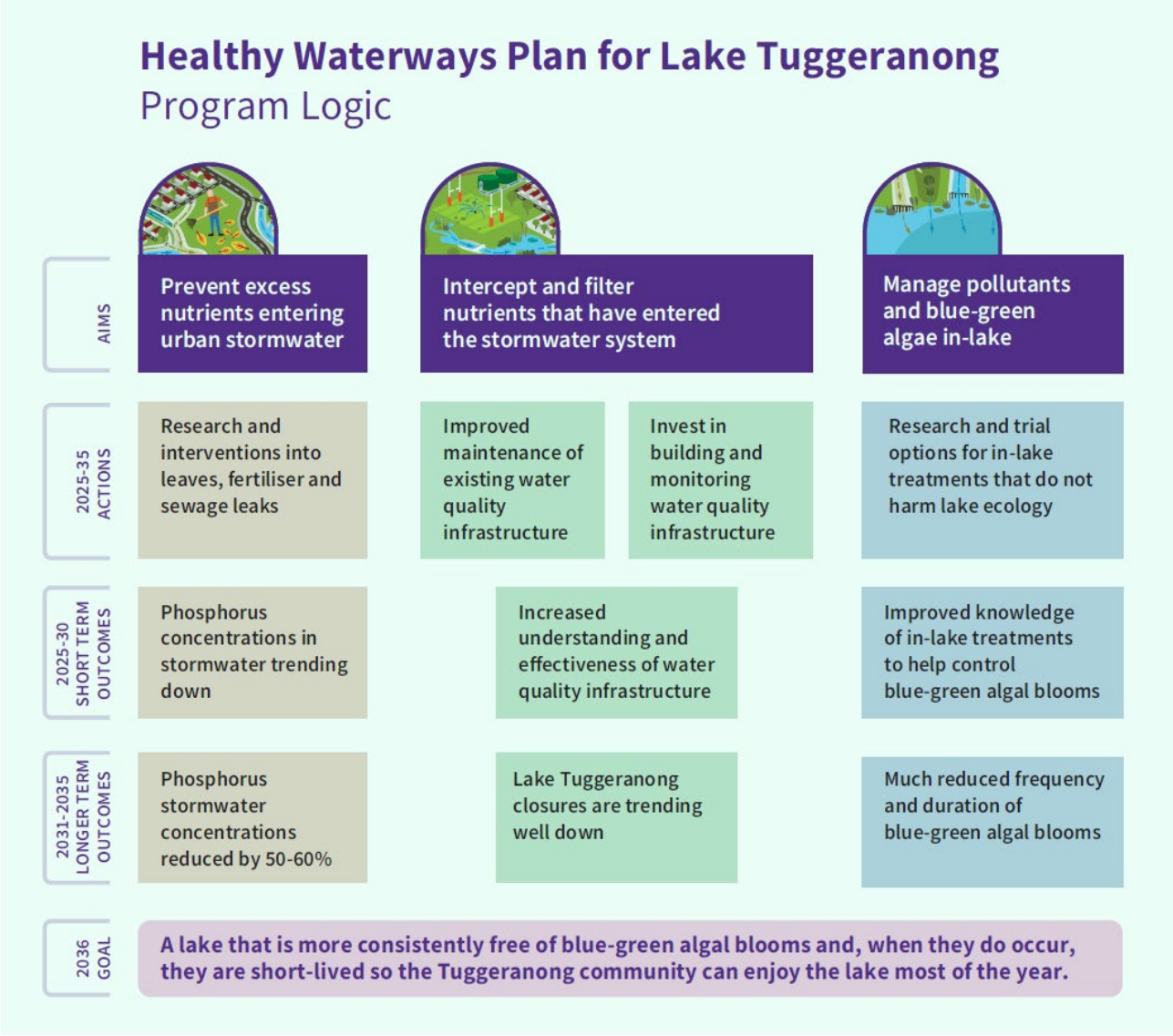


Figure 10. Draft program logic to guide more detailed implementation plan.

Research agenda

Ongoing research and monitoring is critical to refining options to mitigate pollution, to maximise their effectiveness and minimise their costs. The ACT is one of only a small number of jurisdictions in the world actively monitoring constructed wetlands. This is important for testing how well wetland assets perform against design model expectations (including as stormwater entering them becomes cleaner over time) and for informing how the assets are operated and maintained.

The highest priorities for research are to:

- trial promising pollution mitigation options
- investigate; to better understand, the fate of fertilisers applied to residents' blocks
- determine whether sewer cross-connections are a significant source of phosphorus in stormwater.

Table 14 describes the Healthy Waterways research program up to the summer of 2025–2026.

Refinement of various management options is also a priority but will occur as a matter of normal business in the implementation phase of a future Healthy Waterways plan for the lake.

Suggested priorities for restoration

Additional research will continue to refine knowledge and understanding of how to reduce phosphorus in the Lake Tuggeranong catchment, but there is enough evidence already to investigate funding for several priority actions.

Expand street sweeping program to be more often and seasonally optimised

Research by the University of Canberra (Ubrihien et al., 2019) plus the street sweeping pilot by the University of Canberra, Healthy Waterways and City Services demonstrated that leaves contribute a significant amount of phosphorus to catchment loads in the Tuggeranong catchment. Modelling by Booksmythe et al. (2024) indicates that an expanded street sweeping program would remove a significant amount of phosphorus from the catchment. If, for example, streets were to be swept 36 times a year, this would remove up to 316 kg/year or 53% of the target phosphorus reduction amount of 700 kg/year and cost up to around $1.4 million annually (Table 10, noting that the cost of investment level 3 has been annualised).

The Healthy Waterways team and ACT City Services ran a street sweeping pilot again in the summer of 2024–2025 to strengthen findings and inform how best to optimise a future street sweeping program to capture seasonal leaf fall.

New community pollution prevention programs

A successful community pollution prevention program that encourages communities to collect leaves and reduce fertiliser use will complement increased street sweeping by reducing the volume of leaves that make it onto roads. This will reduce the green waste going to landfill and disposal costs since, at present, all waste from streetsweeper trucks is deemed contaminated waste and goes to landfill.

The Leaf Collective and Love the Lakes pilot programs received positive feedback from the community and provide valuable insights into how to engage the community to change their practices around fertiliser use and leaves. In late 2024 a new program that builds upon the successes of the pilots was rolled out as the Waterways Friendly Gardening program.

Build new WSUD infrastructure

WSUD infrastructure cannot solve the problem of blue-green algal blooms on its own and is relatively costly to build and maintain (Table 10). However, there is value in building some additional water quality assets in the Tuggeranong catchment because there will always be some unavoidable pollution of stormwater, which these assets will help to intercept before the pollution reaches the lake. Constructed wetlands also provide other benefits to the community including habitat for native plants and animals, urban cooling (Tapsuwan et al., 2024), public amenity (NC Economics, 2023) and cultural value.

As with all existing suburbs, space constraints and underground services limit the locations where new water quality assets can be built. However, Healthy Waterways feasibility studies have identified several potential locations that could be investigated further.

Table 14. Healthy Waterways forward research agenda to 2026 for Lake Tuggeranong.

Area of research	Description	Estimated start date
Investigate potential leaks from sewerage—caffeine tracking study	Use caffeine in stormwater samples from across the catchment as an indicator of sewerage ingress.	Underway
Performance of constructed wetlands	Monitor the performance of four Stage 1 assets: two wetlands and two raingardens.	Underway
Street material content analysis	As part of the street sweeping project, run a study to understand what proportion of road matter phosphorus comes from non-leaf matter sources (e.g. from car tyres).	Summer 2024–2025
Maintenance of channel naturalisations	Develop methods to remove sediments accumulated in plant beds without destroying the plants.	Mid 2025
Investigate potential leaks from sewerage— Microbial Source Tracking	Test and compare the location, quantity and type of faecal matter (animal or human) found in different catchments after rain events, including Lake Tuggeranong.	Mid 2025
Investigate contribution of leaves on roofs to nutrient loads in stormwater	Examine how much leaves that fall on roofs are contributing to stormwater pollution given roofs are the biggest impervious area in the ACT.	Mid 2025
Circular economy—enhancing cost effectiveness of bioretention	Investigate income-generating potential from harvesting of vegetation from stormwater treatment ponds, floating wetlands etc., including when it's combined with swept material being used for biochar feedstock.	Mid 2025
Trial of Poseidon Pellets™	Run small-scale laboratory and field trials to test viability of Poseidon Pellets in the Lake Tuggeranong context.	Spring/Summer 2025–2026
Phosphorus content in leaves and soil	Investigate whether urban street trees of Tuggeranong shed unusually high levels of phosphorus in their leaves and where they access phosphorus from (soil or other sources such as the sewerage network).	Spring/Summer 2025–2026
Fertiliser leaching rates	Investigate runoff from residential blocks or gardens to estimate export rates of nutrients from fertiliser.	Spring/Summer 2025–2026
Maintenance of constructed wetlands	Develop approaches to harvesting macrophytes to increase the export of nutrients from wetlands and stimulate further uptake of nutrients.	Spring/Summer 2025–2026

Improve maintenance of existing water quality assets

The ongoing performance of all water quality assets relies on good operation and maintenance practices. Modelling by Booksmythe et al. (2024) indicates that improving the maintenance of existing Stage 1 and 2 water quality assets would deliver substantial phosphorus reduction benefits (Table 10). The Healthy Waterways and ACT City Services teams are exploring several ideas for facilitating the operation and maintenance of water quality assets to improve their performance.

Next steps to finalise the Plan

The Government will create Version 1 of the Healthy Waterways Plan for Lake Tuggeranong based on this report, incorporating further inputs from First Nations people and feedback from the community. An implementation plan will then be developed and funded to set out how the vision will be achieved over the next 10 years, including how it will be monitored and evaluated.

Glossary & References



Glossary

Term	As defined in the Plan
Adsorption, adsorbed	The adhesion of a substance (e.g. charged phosphorus ions) to a surface (such as charged clay particles in soil or Poseidon Pellets™).
Bacterial pathogen	Bacteria that can lead to illness.
Baseflow	Streamflow continues between rain events.
Bioavailable	(for plant nutrient–algae relationship) Plant nutrients that are in a form that can be absorbed and used by algae to support growth and metabolism.
Bioretention	Infrastructure (for example, swales or raingardens) comprised of soil, plants and microbes to treat and filter stormwater. Stormwater is spread through the surface of the infrastructure, percolates vertically and is collected in outlet pipes at the base of the asset, leaving behind filtered pollutants.
Bioretention basin	Landscaped depression to manage and treat runoff. See 'Bioretention'
Bioretention swale	Type of bioretention system using linear, vegetated drains in a landscape to capture and filter runoff.
Blue-green algae	A group of photosynthesising, algae-like bacteria that live in freshwater, estuarine and marine environments. Also known as cyanobacteria.
Calibrate, calibration (models)	Adjusting water quality models so they provide a good description of the water quality in Tuggeranong's waterways. This is achieved by comparing model predictions with actual measurements of water quality in the stormwater system and making adjustments to the model to minimise its differences with the observed data.
Catchment	Area of land where precipitation collects and drains to a common outlet (for example, a river or waterbody). May also be known as a drainage basin.
Chlorophyll *a*	A pigment in many plants and algae that helps them absorb light energy and convert it to chemical energy in a process called photosynthesis. Chlorophyll *a* is often used as a proxy to assess algae biomass as it is easier to measure than biomass.
Constructed wetlands	Both a general term for water quality assets comprised of soil, plants and microbes to treat and filter urban runoff, and a reference to a specific type of asset where stormwater that is diverted to the wetland flows laterally to an outlet at its downstream end (as compared to 'bioretention'; see definition above).
Cyanobacteria	See blue-green algae.
Diffuse source	A non-point source, where pollutants are generated from many sources across the catchment.
Deposition rate	(for leaves) The volume of leaves that fall from trees for a given area/time.
Enterococci	Bacteria commonly found in the intestines of humans and animals, used to indicate faecal pollution in waterbodies.
Eutrophic	Water bodies in a eutrophic state are nutrient rich, with highly productive plant growth and high turbidity. They are seasonally deficient in oxygen, which may lead to fish kills. Eutrophic lakes may experience regular algal blooms.

Term	As defined in the Plan
Export rate	% of nutrient (in this case phosphorus) in applied fertilisers lost to runoff.
Hydrograph	A way to display the flow of water over time.
Impervious surface	Water-resistant surface that is a partial or total barrier to water, such as concrete, roofs, roads.
Management scenarios	Packages of phosphorus pollution mitigation options that together are intended to achieve a desirable water quality outcome.
Mesocosm	Enclosure set up in the lake to study aquatic responses under controlled conditions.
Mesotrophic	Water bodies in a mesotrophic state have a moderate amount of nutrients, moderately clear water, some algal blooms in late summer and oxygen depletion at bottom of lake as biomass decomposes. If they do experience algal blooms, it is typically in late summer.
Microbial Source Tracking	Method to identify the sources of faecal contamination in water bodies; that is, whether it comes from humans or animals (domestic pets, wildlife, livestock).
Net Present Value (NPV)	The difference between the present value of cash inflows and outflows over time.
Nitrogen	Key nutrient essential for the growth of aquatic plants and algae. Excess nitrogen can lead to nutrient pollution which can cause algal blooms.
Nutrient load	Refers to the amount of nutrients entering a waterbody in a given time period; for example, kg phosphorus entering Lake Tuggeranong per year.
Oligotrophic	Water bodies in an oligotrophic state have very low nutrient concentrations and tend to have very clear water with little plant or algal growth. High oxygen concentrations depress the release of algal nutrients stored in lake-bottom sediments. Hence, oligotrophic lakes are not prone to algal blooms.
Phosphorus	Key nutrient essential for the growth of aquatic plants and algae. Excess phosphorus can lead to nutrient pollution which can cause algal blooms. Can be either particulate (sediment-bound) or present in dissolved forms. Total phosphorus (TP) is the sum of all forms of phosphorus present in a sample. In this report, phosphorus refers to total phosphorus unless otherwise stated and these terms are used interchangeably.
Phytoplankton	Photosynthesising microscopic organisms that live suspended in water. Blue-green algae/ cyanobacteria are a type of phytoplankton.
Point-source	Where pollutants are generated from specific sources in the catchment such as nutrients from a sewage treatment plant outlet.
Pollutant, Pollution (of water)	A substance (like phosphorus) that is present at levels that can cause harm to life. Phosphorus is not directly harmful but is a pollutant at high concentrations or supply because it promotes the growth of harmful algae.
Pollution mitigation options	Individual approaches to reducing the level of phosphorus in stormwater such as increasing the frequency of street sweeping or building water quality assets.
Raingarden	A water quality asset using bioretention technology in a shallow, landscaped depression to capture and filter urban runoff.
Runoff	Water that flows over the surface of the ground when it cannot sink into the ground.
Runoff infrastructure	Infrastructure or landscaping that holds, redirects and/or slows runoff to allow it to sink into the landscape.

Term	As defined in the Plan
Sediments	In this context, sediments are bits of soil and organic matter eroded from the catchment into stormwater and lake water. Sediments may become deposited in the bottom of lakes.
Stormwater	Water generated through rain that has made its way into the stormwater system.
Stormwater runoff	Rain that isn't absorbed into the ground and flows over the landscape.
Stormwater system	Concrete channels and pipes designed to direct stormwater away from built up areas to reduce flood risk.
Stratification	Formation of distinct thermal layers in the water column, which affect the distribution of oxygen and nutrients within the lake.
Suspended solids	Small particles that remain suspended in water, affecting water quality and aquatic life by reducing light penetration and temperature.
Total dissolved solids	The inorganic and organic substances dissolved in water. They are used as an indicator of water quality.
Treatment train	Water quality infrastructure working in sequence to remove pollutants and manage water flow to a target level.
Trophic state	Describes the biological productivity of a water body and depends on factors such as the concentration of nutrients like phosphorus and nitrogen (see oligotrophic, mesotrophic, eutrophic).
Turnover	Seasonal process where water layers mix resulting in the redistribution of oxygen and nutrients throughout the lake.
Water Sensitive Urban Design (WSUD)	WSUD seeks to minimise impacts of urban development on the natural water cycle by integrating developments with a site's natural features and promoting the integration of stormwater, water supply and sewage management.
Water quality assets	Infrastructure solutions that aim to filter water of pollutants, such as constructed wetlands, raingardens and ponds. Water quality assets are also commonly referred to as 'WSUD infrastructure'.

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