ACT Government

Lake Tuggeranong Catchment Model

Technical Report: Configuration and Calibration of the Water Quantity and Quality Model

Water Information Services, ACT Office of Water

December 2024

Environment, Planning and Sustainable Development

Version History

Version	Revision Date	Author / Position
1.0	19/12/2024	Isobel Booksmythe

Document Location

File Name:	Lake Tuggeranong catchment model calibration report
Objective File No.:	A49730782
Objective Link:	https://objective.act.gov.au/#/documents/A49730782

© Australian Capital Territory, Canberra, 2024.

Contributors

Dr Sayani Dey

Dr Joel Stewart

Dr Andrew Kahn

Dr Isobel Booksmythe

Dr Danswell Starrs

This publication should be cited as:

Dey S, Stewart J, Kahn AT, Booksmythe I, Starrs D. 2024. Lake Tuggeranong Catchment Model Technical Report: Configuration and Calibration of the Water Quantity and Quality Model. Report to the ACT Healthy Waterways Program, ACT Government, Canberra.

ACT Government Disclaimer

The views and opinions expressed in this report are those of the author and do not necessarily represent the views, opinions or policy of funding bodies or participating member agencies or organisations.

Executive Summary

Lake Tuggeranong is a small (57 ha) urban lake in southern Canberra. Lake Tuggeranong was constructed in the late 1980s on Tuggeranong Creek, a 66 km^2 catchment that is predominantly (62%) urbanised. In recent decades, Lake Tuggeranong has been plagued by poor water quality. Since 2017, there has been a concerted effort to improve water quality in the lake through the construction of Water Sensitive Urban Design (WSUD) infrastructure throughout the catchment, and a major research program to understand the causes of poor water quality, and sources of pollutants entering the lake. This work has been undertaken as part of the ACT Healthy Waterways program.

In 2022, the ACT Government commited to developing Healthy Waterways Plans for priority catchments in the ACT. The Lake Tuggeranong catchment Healthy Waterways Plan aims to provide a suite of potential management options to Government to further improve water quality in Lake Tuggeranong. To acheive this, modelling and analyses have been undertaken to examine a broad range of management scenarios and identify cost-effective options to improve water quality in Lake Tuggeranong. To support these analyses, a catchment model was developed in the eWater model platform Source to support the testing of water quality management scenarios, and rank these scenarios based on cost-effectiveness.

This report presents an overview of the development, calibration and outputs of the Lake Tuggeranong catchment model. The underlying rainfall-runoff model chosen for this task was a Sacremento daily timestep model, implemented in Source. Fine-scale delineation of subcatchments, land use and imperviousness, flow regulation infrastructure and WSUD infrastructure were included in the model, to provide a complete, current assessment of the Lake Tuggeranong catchment. A total of 75 subcatchments were delineated to key infrastructure within the catchment, existing monitoring locations, and other features of interest. LIDAR data captured in 2020 was used to quantify surface imperviousness within subcatchments, facilitating an explicit representation of imperviousness in the model.

A comprehensive compilation of water quality data and streamflow data collected in the catchment from 2014 to the present was used to calibrate the Source model. The initial flow calibration is rated as suitable for estimating long-term catchment mean annual flow and long-term mean annual pollutant loads. The water quality model is parameterised against observed end-of-catchment median event concentrations of total phosphorus, total nitrogen, and total suspended solids, in the absence of load-based water quality data. The model estimates pollutant loads generated in the catchment based on land use and imperviousness data.

The parameterised model was used to simulate daily flows and pollutant loads generated in the Lake Tuggeranong catchment between 1889 and 2023, the period for which observed rainfall and climate data was available. Under current catchment land use and management conditions, the modelled average annual inflow to Lake Tuggeranong is 8.8 GL/year. The modelled mean annual loads of pollutants entering Lake Tuggeranong are 1,442 kg/year total phosphorus, 11,894 kg/year total nitrogen, and 397,064 kg/year total suspended solids.

The results provide a robust foundation for future catchment management plans and strategies.

Contents

List of figures

List of tables

1. Introduction

Lake Tuggeranong is a small (57 ha) urban lake in southern Canberra. The lake was constructed in the late 1980s on Tuggeranong Creek, a 66 km^2 catchment that is predominantly (62%) urbanised. In recent decades, Lake Tuggeranong has been plagued by poor water quality, with high loads of nutrients (phosphorus and nitrogen) and sediments entering the lake. Since 2017, there has been a concerted effort to improve water quality in the lake through the construction of Water Sensitive Urban Design (WSUD) infrastructure such as wetlands, swales and raingardens throughout the catchment, and a major research program to understand the causes of poor water quality, and sources of pollutants. This work has been undertaken as part of the ACT Healthy Waterways program.

In 2022, the ACT Government commited to developing Healthy Waterways Plans for priority catchments in the ACT. The Lake Tuggeranong catchment Healthy Waterways Plan aims to provide a suite of potential management options to Government to further improve water quality in Lake Tuggeranong. To acheive this, modelling and analyses have been undertaken to examine a broad range of management scenarios and identify cost-effective options to improve water quality in Lake Tuggeranong. To support these analyses, a catchment model was developed in the eWater model platform Source (Argent, et al., 2005) to support the testing of water quality management scenarios, and rank these scenarios based on cost-effectiveness.

This report documents the development of a new, daily timestep water quantity and quality model for the Lake Tuggeranong catchment. The purpose of the model is to simulate long-term mean annual flows and associated pollutant loads entering Lake Tuggeranong, to inform and support catchment improvement studies and associated management strategies.

The model builds upon and extends previous models describing the Lake Tuggeranong catchment by:

- Including long-term, gap-filled climate data to extend the time period over which simulated results are available (1889-2023);
- Incorporating and combining up-to-date spatial data on land use and land surface imperviousness in the catchment;
- Undertaking hydrological model calibration;
- Adopting a model structure delineated to
  - water quality monitoring points to facilitate water quality model parameterisation;
  - existing and potential water quality improvement infrastructure (i.e., WSUD infrastructure) to facilitate estimation of pollutant load reduction from this infrastructure.

1.1 Overview of previous modelling and monitoring studies in the catchment

The model presented in this report builds on several published and unpublished modelling and monitoring studies undertaken in the Lake Tuggeranong catchment to describe flows and water quality in Lake Tuggeranong. These studies are reviewed briefly below, highlighting how the data has been used to inform the current study.

1.1.1 Modelling studies

Lake Tuggeranong catchment MUSIC 6 model, GHD (2015)

To inform the early stages of the Basin Priority Project, GHD developed a model of the Lake Tuggeranong catchment using the software MUSIC (Model for Urban Stormwater Improvement Conceptualisation) to aid in identifying sources of pollutant loads entering Lake Tuggeranong (GHD, 2015). The Lake Tuggeranong catchment was delineated based on contour information and the ACT stormwater network. Existing WSUD infrastructure in the catchment at the time comprised only gross pollutant traps (GPTs) with or without sedimentation basins, as well as Lake Tuggeranong, Isabella Pond, and Upper Stranger Pond. These assets were each represented as GPT, sedimentation basin, or wetland nodes in the MUSIC model. Land use classification in the model was based on ACT Government land zoning data aggregated to six broad categories, and imperviousness was based on values for each land use category from the published literature. Likewise, water quality parameters (event mean concentration, EMC, and dry weather concentration, DWC, of pollutants) were taken from the literature, rather than derived from existing data in the Lake Tuggeranong catchment.

The MUSIC model simulated flows and pollutant loads in the catchment under rainfall and evaporation conditions for the 10-year period from 1968-1977. It predicted an annual flow volume of 20,600 ML in the Lake Tuggeranong catchment, with an annual average of 2.7 tonnes TP, 31.5 tonnes N, and 2230 tonnes TSS generated given the existing WSUD infrastructure in the catchment at the time.

Lake Tuggeranong catchment MUSIC X model, eWater Ltd (2022)

eWater developed another MUSIC model of the Lake Tuggeranong catchment to assess the potential pollutant load reductions associated with WSUD assets that were constructed up to June 2019 as part of the ACT Healthy Waterways project (eWater Ltd, 2022). The Lake Tuggeranong catchment was delineated to 11 subcatchments, 7 of which drained through WSUD assets. The model operated on a 6-minute time step for the period 2010-2015. Published or MUSIC default values for hydrology and water quality parameters were applied to the model, which adopted a land use -based stochastic EMC/DWC approach to water quality modelling.

Land use was derived from 0.5m LIDAR coverage mapping impervious surfaces in the catchment and was divided into 6 classes (roof, road, hardstand, pervious, bushland, and rural). WSUD assets were incorporated in the model by importing and combining the 7 existing MUSIC models representing the detailed design configurations of each asset. Design configurations are expected to differ slightly from works-as-executed configurations.

The MUSIC model predicted an annual flow volume of 14,284 ML, with an annual average of 4.8 tonnes P, 39.8 tonnes N, and 2320 tonnes TSS generated in the Lake Tuggeranong catchment. However, the model was uncalibrated and over the period 2010-2015 overestimated flows by 57.2%, compared to observed data from the gauge immediately downstream of Lake Tuggeranong (Tuggeranong Creek upstream of Sewer Crossing, gauge 410779). The model is therefore also likely to overestimate pollutant loads in the catchment. However, the percentage removal of pollutants associated with each WSUD asset may be used as a starting point in the current modelling study to represent the treatment performance of existing assets.

Upper Murrumbidgee catchment Source models, Alluvium (2017) and eWater Ltd (2019)

Alluvium (Alluvium, 2017) developed an Upper Murrumbidgee catchment model in Source with the best available data and methods as a part of a project to meet requirements for the Murray-Darlin Basin Plan and the ACT Water Resource Plan. Alluvium's model delineated the Upper Murrumbidgee catchment into 440 subcatchments, using a 20 m digital elevation model (DEM), water management and hydrological boundaries, and stream gauging locations. Current ACT and NSW land use classifications, consistent with the Australian Land Use Mapping (ALUM) codes, were combined into 20 functional units for use in the model. The model used climate data from 1980-2016 and a combination of SIMHYD and GR4J rainfall-runoff models, assigned to urban and agricultural subcatchments, respectively. Observed discharge and water quality data from storages (dams and lakes) and sewage treatment plants (STPs) were used to parameterise the model. The model calibration was moderate for most of the gauges, with missing data at both hydrology and water quality monitoring gauges constituting a major limitation of the model. Moreover, due to the large number of subcatchments, model performance was very slow.

Alluvium's Source catchment model did not estimate flows and pollutant loads entering Lake Tuggeranong, instead providing estimates for the outlet of the Lake Tuggeranong catchment, including the effect of the lake itself on these parameters. The model predicted an annual flow volume of 5,868 ML for the outflow from the Lake Tuggeranong catchment, with an annual average load of 0.29 tonnes P, 5.63 tonnes N and 128.9 tonnes TSS.

In 2019, eWater identified a number of potential improvements to Alluvium's Upper Murrumbidgee catchment model and rebuilt the model (eWater Ltd, 2019). Their updated catchment model defined fewer subcatchments outside the ACT, delineating a total of 163 subcatchments, to improve model performance. eWater's model retained the climate data, land use and functional unit classifications used in Alluvium's model, but used the LASCAM rainfall-runoff model across all subcatchments to enable assessment of the hydrological impacts of land use change. The updated catchment model also incorporated Canberra's water supply, with storages configured to operate, albeit without implementation of operating rules.

Water quality parameters (EMC and DWC) in this model used values taken from the literature, rather than being fitted to observed data. While flow parameters were calibrated to observed data from 32 gauges across the Upper Murrumbidgee catchment, the model did not calibrate end-of-catchment values for the Lake Tuggeranong catchment to the downstream gauge Tuggeranong Creek at Sewer Crossing (410779). Therefore this model configuration cannot provide reliable estimates of the total flow and loads generated from the Lake Tuggeranong catchment.

1.1.2 Monitoring studies

University of Canberra Lake Tuggeranong research project, Stage 3 report (2020)

The University of Canberra's Lake Tuggeranong research project has demonstrated the importance of external sources of nutrients to water quality in Lake Tuggeranong. Stage 3 of the Lake Tuggeranong research project analysed the nutrient contribution from different subcatchments, in order to understand the relative influence of different land uses on nutrient inputs to the lake (Ubrihien, et al., 2020). Water sampling during rainfall events was undertaken in the Kambah Creek and Village Creek subcatchments over two years (2018 – 2020), with more than 2000 grab samples collected and analysed. The monthly total phosphorus (TP), total nitrogen (TN) and total suspended solids (TSS) loads to Lake Tuggeranong were calculated for each subcatchment.

It was found that event discharge and loads of TP, TN, and TSS were much greater than those from baseflow. Event samples from urban areas of the subcatchments had high concentrations of nutrients with an unexpectedly high proportion in dissolved form. This study was constrained by extremely dry weather conditions over the spring and summer of 2019-20, which limited opportunities to collect event samples in a season of key interest. The movement of water and associated nutrients measured during these extreme conditions are unlikely to be representative of wetter years. Additionally, the lack of streamflow gauging at water quality sampling sites made it difficult to accurately estimate the nutrient loads entering the lake. Flow-weighted mean concentrations of nutrients from event samples were essential to calculate the load.

Despite these limitations, Stage 3 of the Lake Tuggeranong research project provides a significant water quality dataset including manual grab-sampling as well as data from 6 autosamplers at fixed locations on inflows to Lake Tuggeranong. The median measured concentrations of TP, TN and TSS from this work have been used in the parameterisation of our water quality model.

ACT Government water quality data

Several water quality monitoring programs supported or contracted by the ACT Government have measured pollutant (nutrient and sediment) concentrations at sampling sites across ACT waterways, including in the Lake Tuggeranong catchment. These have been collated into a single dataset and used in the parameterisation of our water quality model.

Waterwatch

This dataset includes water quality samples collected from eight different sampling sites in the Lake Tuggeranong catchment from 2017 to the present. The water quality parameters recorded include concentrations of TP and nitrates. Waterwatch data are publicly accessible at https://biocollect.ala.org.au/actwaterwatch. Following review and a focus on event flow water quality samples for model configuration, Waterwatch data were not used in the parameterisation of our water quality model.

Land Use Monitoring program (LUM)

Water quality data was collected from a single site in the Lake Tuggeranong catchment over 2018 and 2019. The water quality parameters recorded include concentrations of TP, TN and TSS.

Basin Plan Phase 1 (BPP1)

Under this program grab-samples were collected from 20 sampling sites in the Lake Tuggeranong catchment and analysed for water quality parameters including concentrations of TP, TN, and TSS.

ACT Lakes and Rivers water quality monitoring program

The ACT Lakes and Rivers water quality monitoring program has maintained two grab-sampling locations on Lake Tuggeranong. While these data were not used explicitly in the Source model calibration, they are relevant to the in-lake modelling described in the supplement to this report, *Predicting phosphorus concentration and trophic state of Lake Tuggeranong* (Kahn & Dey, 2024).

1.2 Key gaps addressed by this study

The brief review above highlights the considerable amount of new water quality data that is now available for the Lake Tuggeranong catchment, including some event-based concentration data. The new data can be used to refine model water quality parameters that were previously based on values derived from the published literature. The modelling studies described above are limited in their utility as catchment models in the current planning context, as they either did not have the tools or resources available to calibrate model hydrology or were calibrated over a spatial resolution too coarse to investigate detailed catchment management strategies. Additionally, these previous studies simulated results over relatively short timeframes (6 – 36 years).

This study therefore aims to address these gaps by:

1. Preparing a high spatial resolution catchment model that uses a long-term historical climate observations dataset to simulate results over the 133-year period 1889-2023.
2. Calibrating the catchment model to ensure that end-of-catchment observed flows match modelled flows over the long term, so that the model accurately represents long-term water yield.
3. Using available event-based and baseflow water quality data to parameterise land use -based water quality models and derive new estimates of mean annual pollutant loads to Lake Tuggeranong.

Section 2 of this report collates and summarises the input data used to build and parameterise the model including terrain models, land use, water quality assets, hydrological and water quality data. Section 3 describes the model construction and parameterisation procedures and associated results and limitations. Section 4 presents the results of long-term flow and load estimates for the catchment under the current conditions including spatial results and estimated loads to Lake Tuggeranong. Section 5 presents the predevelopment and current scenario analysis of the catchment. Section 6 provides the conclusions and recommendations for next steps to improve model performance through additional data collection or by upgrading the model techniques.

2. Model input data

The Source modelling framework allows the simulation of catchment hydrology and pollutant generation in response to rainfall and climatic processes, catchment characteristics, land use and imperviousness, and waterway management. This requires the input of data describing each of these elements, enabling the catchment to be represented as a connected patchwork of areas for which the conversion of rainfall to runoff, the generation of pollutants, and the flow of surface waters between areas, can be calculated. Dividing the catchment into subcatchments for which flow and water quality data are available allows finer-scale calibration of the model to observed data in the catchment.

This section describes the input data sets used for model creation and parameterisation including:

- Subcatchment delineation;
- Land use classification and imperviousness;
- Water quality data;
- Climate data;
- Lake configuration;
- Streamflow and storage level data;
- WSUD asset configuration.

2.1 Subcatchment delineation

The Lake Tuggeranong catchment is approximately 6,600 hectares and is mostly (62%) urbanised. The southeastern part of the catchment is rural and extends across the ACT border into NSW. Catchment development began in the 1980s (Beer, Young, Humphries, & Burgess, 1982) and continued into the early 1990s. The Lake Tuggeranong catchment is the smallest Water Management Area in the ACT, and also encompasses a small component of the Upper Murrumbidgee water management area due to diversion of the upper Stranger Pond catchment to Lake Tuggeranong at Isabella Pond.

Because the subcatchments delineated to WSUD assets for the eWater (2022) study contained some discrepancies with the ACT Government stormwater network map, a new subcatchment map was created using a pit-filled, 1 m DEM based on high-resolution LIDAR data (ACT Government, 2016) and the ACT Government stormwater network map. Subcatchments within the Lake Tuggeranong catchment were delineated to:

- known water quality monitoring locations;
- known streamflow monitoring locations;
- existing WSUD assets;
- ponds and storages.

This resulted in 75 subcatchments, shown in Figure 1. When identifying water quality monitoring sites for catchment delineation, University of Canberra water quality monitoring sites based on the stormwater network were prioritised.

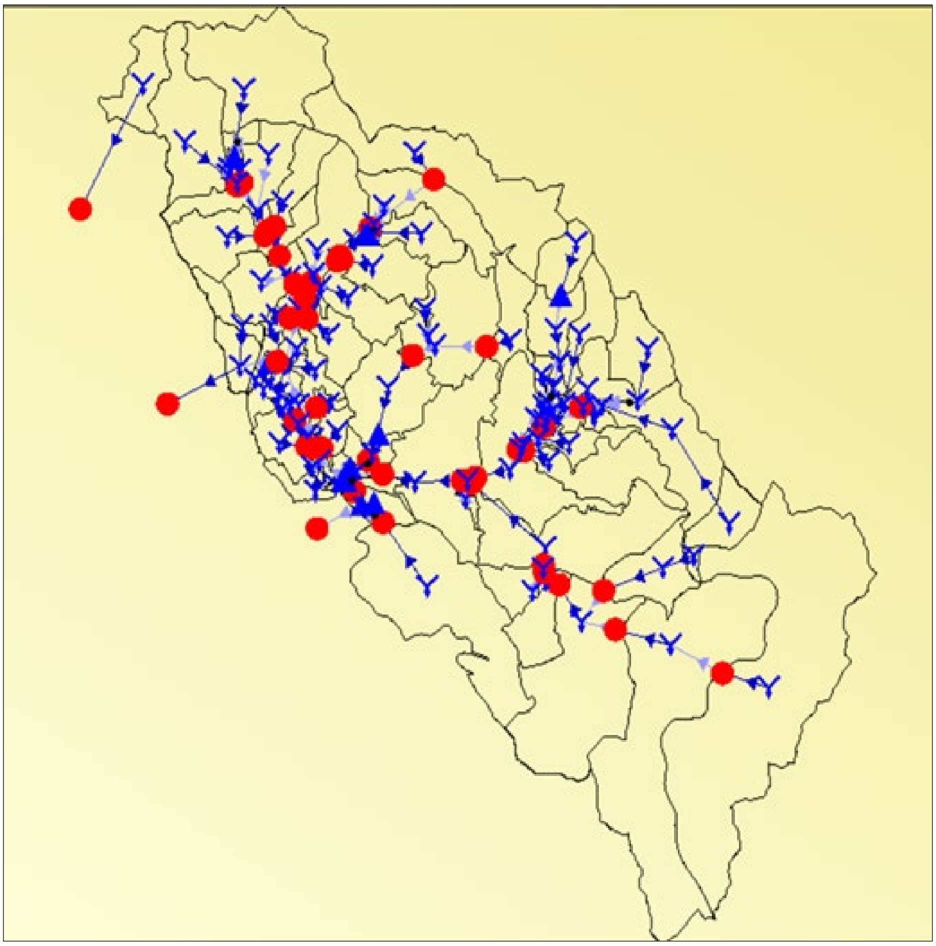

Figure 1. Screenshot of the Source model-generated Lake Tuggeranong subcatchment map, showing nodes defined by flow and water quality monitoring locations (large red points) and WSUD infrastructure (large blue triangles). Blue 'Y' symbols represent flow and pollutant generation within subcatchments and small blue arrows indicate the direction of flow.

2.2 Land use classification and imperviousness

Land use classification for the Lake Tuggeranong catchment model aims to represent a wide range of land uses that could be subject to different structural and non-structural catchment management actions, such as suburban street sweeping, construction of additional WSUD assets, or education around private household fertilizer use. To this end, broad land use classifications adopted for previous modelling studies (eWater Ltd, 2022) were disaggregated to a more granular set of classifications based on ACT Government land zoning. These were combined with data on land surface imperviousness to derive land use for the Lake Tuggeranong catchment model as follows:

1. Aerometrix (2020) LIDAR data at 0.5m pixel resolution was trimmed to the Lake Tuggeranong catchment, mapping 5 land surface imperviousness classes:
    - Impermeable ground level (i.e., roads and hardstand)
    - Impermeable above ground level (i.e., roofs)
    - Permeable ground level (i.e., pervious, unpaved ground)
    - Permeable above ground level (i.e., tree canopy)

- Water

2. The LIDAR data was converted to shapefile and intersected with the 2023 ACT Government land zoning GIS layer trimmed to the Lake Tuggeranong catchment, consisting of 17 land use zones consistent with ALUM codes:
   - Business zone
   - Community Facilities
   - Core zone
   - Leisure and accommodation
   - Local centre
   - Services
   - Services zone
   - Medium density residential
   - Suburban
   - Suburban core
   - Transport
   - Urban open space
   - Restricted access recreation zone
   - Hills ridges and buffer areas
   - Designated
   - River corridor
   - Rural

   The entire NSW portion of the catchment was classed as 'Rural' land use.
3. This cross-classified land use layer was intersected with the ACT Government road edges GIS layer, to identify road area within each land use zone. Areas classified as impermeable ground level that fell outside of the roads boundary were deemed hardstand, and areas classified as permeable above ground level that fell within the roads boundary (i.e. where trees overhung road) were reclassified as road (impermeable ground level). This approach yields a more precise classification of road area than the approach of eWater (eWater Ltd, 2022), where road centrelines buffered by 5m were used to estimate the area of impermeable road surface within the transport classification of the land zoning map, which includes the entire road corridor consisting of largely permeable open space.
4. Finally, visual inspection of aerial imagery was used to identify and manually delineate irrigated sports fields based on their "greenness" relative to nearby open spaces, and assign them a specific land use classification.
5. The land use and imperviousness layer was converted to a 0.5m grid, which was intersected with the Lake Tuggeranong subcatchment map to obtain the area of each land use - imperviousness combination within each subcatchment.
6. The detailed land use types were grouped into six major functional units for incorporation into the Source catchment model: suburban, commercial, open space, rural, bushland and sports field, each containing imperviousness classifications of road, hardstand, roof, permeable ground level, permeable above ground level, and water. The final land use and imperviousness classification schedule, and the area associated with each land use functional unit in the model domain is provided in Appendix C.

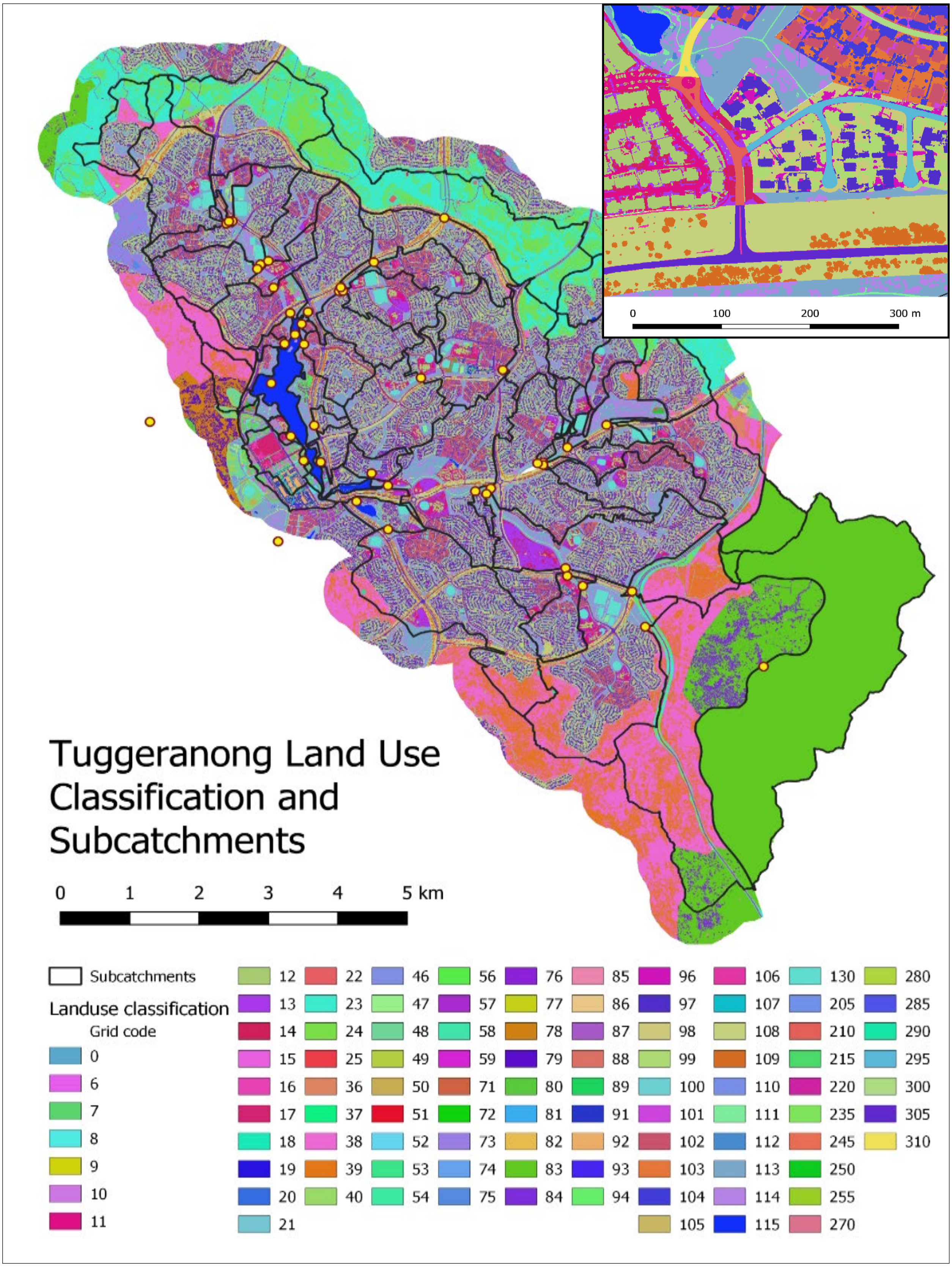

Figure 2. Land use map of the Lake Tuggeranong catchment with colours representing the unique code for each land use - imperviousness combination. Yellow dots indicate water quality or streamflow monitoring locations. **Inset:** close-up detail of a section of the map showing roads, rooftops and open space.

2.3 Water quality data

Water quality data from within the Lake Tuggeranong catchment was collected by a range of programs between 2014 and 2021 (Table 1). Some of the programs entailed event-based monitoring of specific land uses whilst others were focussed on grab sampling from many sites throughout the catchment to try and understand spatial variation of water quality and how it may relate to land use.

Table 1. The number of water quality samples collected across five monitoring programs and analysed for 3 pollutants used in model calibration. TP, total phosphorus; TN, total nitrogen; TSS, total suspended solids.

Monitoring program	Years active	Number of sites	TP	TN	TSS
Basin Plan Phase 1 (event sampling)	2014-2015	19	93	93	93
ACT Government Land Use Monitoring program (event sampling)	2018-2019	1	93	93	93
Lake Tuggeranong Research Project (event sampling)	2017-2018	7	1385	1376	1071
University of Canberra (grab sampling)	2018-2020	29	315	315	316
Upper Murrumbidgee Waterwatch (grab sampling)	2014-2021	8	585		
Total			2471	1877	1573

Table 1 shows there is a large amount of historical water quality data potentially available for use. However, no study in the catchment has converted the measured pollutant concentrations to loads, which requires simultaneously monitoring of flows in order to calculate flow-weighted mean concentrations.

Catchment models typically adopt a land use based EMC/DWC approach to estimate mean annual pollutant load, with model calibration achieved by matching observed loads to modelled loads. As no observed load data is currently available, we adopted the following model parameterisation approach:

1. All pollutant concentration data from the available water quality studies was compiled into a single data frame. For days where multiple samples were collected from a site, the mean of these samples was calculated as an approximation of the mean concentration occurring on that day.
2. Modelled daily flows and modelled pollutant concentrations were compiled into a single data frame and the event flow threshold, defined as the flow threshold that is exceeded in the top 10% of all modelled flow days, was identified.
3. For each day that observed pollutant concentration data was available, we retrieved the modelled flow and associated modelled concentration for the pollutant and monitoring site in question. We split this date-matched data between event and baseflow conditions and calculated the medians of the observed and modelled data for each site.

The median observed pollutant concentration value was compared to the median modelled pollutant concentration value for sites at the six major lake inlet points and a scaling factor estimated to scale the EMC values for that pollutant. The scaling factor was applied across all land uses for that pollutant.

Parameterisation steps 1-3 above were then re-run to test the model fit. This model parameterisation approach preserves the typical difference between land use-based EMC/DWC combinations whilst date-matching median observed lake inflow concentrations to the median modelled concentrations.

Figure 3 provides example plots and data for the monitoring point at the Village Creek inlet to Lake Tuggeranong. Modelled median event-based concentrations of TP exceed observed concentrations, however across all observed data (event and baseflow), median modelled concentrations match observations (n = 275). The time series of modelled concentrations can never attain the variability of observations due to the fixed nature of the EMC/DWC modelling method.

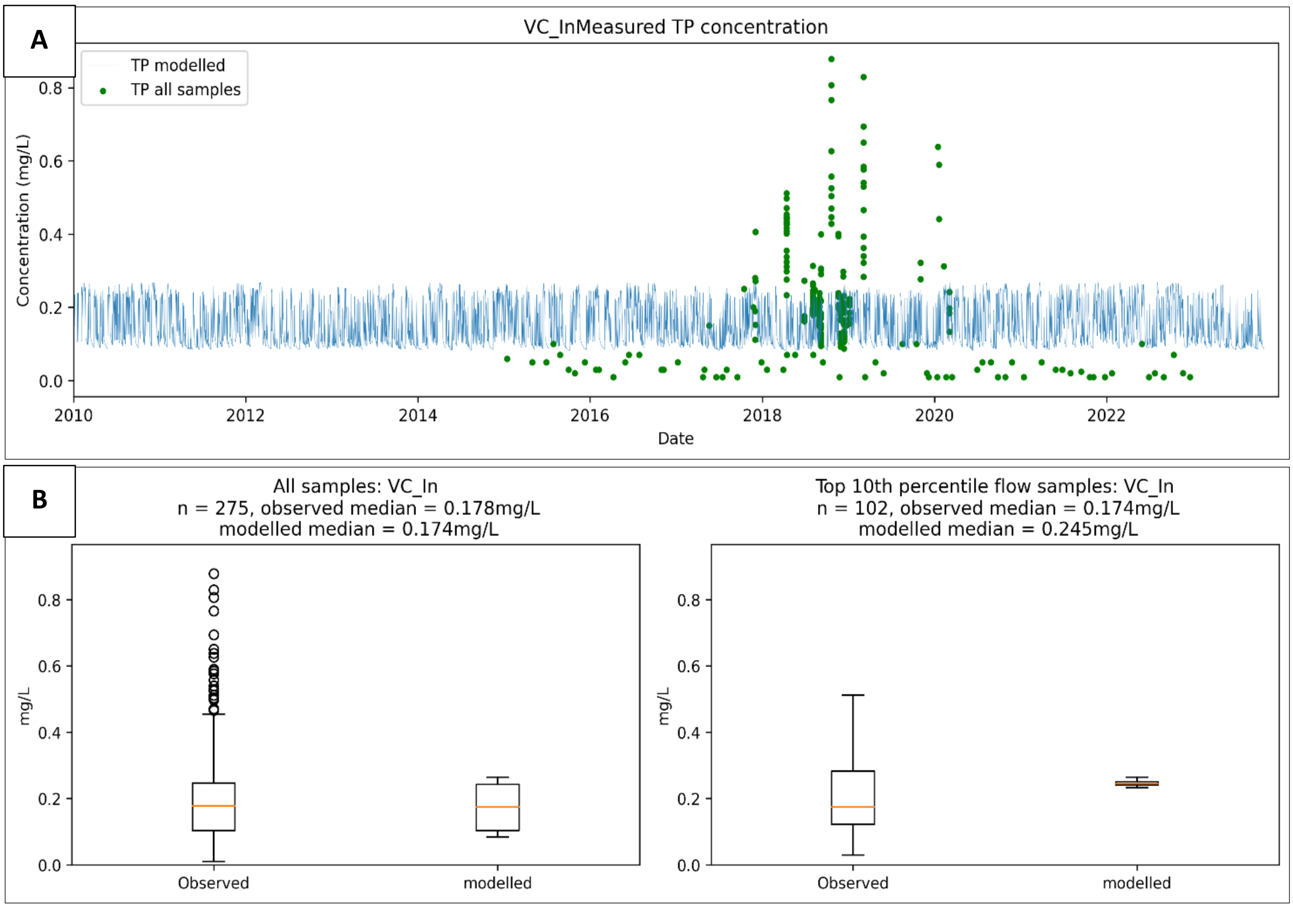

Figure 3. Example of the comparison of observed vs. modelled pollutant concentration data for a single water quality monitoring point. A) Time series of modelled total phosphorus (TP) concentrations (blue line) and date-matched observed median TP concentrations (green points) for the monitoring point at the Village Creek inlet to Lake Tuggeranong. B) Boxplots showing the distributions of modelled and observed median TP concentrations for all samples (left panel) and samples from the top 10th percentile of flow events (right panel) for the monitoring point at the Village Creek inlet to Lake Tuggeranong.

2.4 Climate data

Several climatological stations located within the Lake Tuggeranong catchment could provide data for sub-daily rainfall-runoff modelling. However, to meet the aims of the current model a long-term daily rainfall record without gaps is required. We therefore used patched daily data from the Tuggeranong (Isabella Plains) climatological station (Bureau of Meteorology station number 070339). This station is located within the Lake Tuggeranong catchment (Figure 4) and has been open since May 1996 - present with 99% completeness of the data record. For this post-1996 period we were able to provide complete observed climate data to the model. To cover the entire period 1889-2023, we used patched data for the pre-1996 period from the SILO (Scientific Information for Land Owners) patch point dataset for this station (https://www.longpaddock.qld.gov.au/silo/).

The following climate variable time series associated with this site were used for catchment modelling:

- Rainfall (mm/d) for rainfall-runoff modelling and water body water balance modelling;
- Morton's wet-environment areal evapotranspiration over land (mm/d) for rainfall-runoff modelling (MWet);
- Morton's shallow lake evaporation (mm/d) for water body water balance modelling (MLake);
- Maximum and minimum temperature for experimental stormwater and lake temperature modelling (Tmax and Tmin) ;
- Evapotranspiration (mm/d) of short crop for irrigation modelling.

2.5 Lake Tuggeranong storage configuration

Lake Tuggeranong is modelled as a completely mixed storage, taking inflows from the whole catchment and releasing flows according to the stage (water level) -discharge relationship of its outflow point at Lake Tuggeranong weir. The lake is also subject to daily rainfall and daily evaporation (MLake), modelled using the SILO daily time-series for the Tuggeranong (Isabella Plains) climatological station (station ID 070339). As Lake Tuggeranong does not have any water supply requirements, no water use is modelled for this storage.

To configure the Lake Tuggeranong storage node, a rating curve was derived from the bathymetry data and imported into the model. This was calculated from the observed water level measured at the Lake Tuggeranong weir (gauge 410784), using the level-volume-area (LVA) relationship for Lake Tuggeranong obtained from bathymetry data collected in 2015 by Steger and Associates Registered Land Surveyors under the Basin Priority Project (data provided in Appendix A).

The lake outlet was configured as an ungated spillway, using the stage-discharge rating table for the Lake Tuggeranong weir (gauge 410784) supplied by ALS Hydrographics via their HYDSTRA database. The stage-discharge data is provided in Appendix B.

2.6 Streamflow and storage level data

2.6.1 Gauge 410779: Tuggeranong Creek upstream of Sewer Crossing

The key streamflow data available for this catchment comes from the gauge at Tuggeranong Creek upstream of Sewer Crossing (gauge 410779; Figure 4) which is located a short distance below the Lake Tuggeranong outflow. Recorded streamflow data is available from 1986 and the gauge remains current. Gauge records show that the maximum recorded flow rate is approximately 200 cumecs, while the maximum rated flow is 108 cumecs or approximately 50% of the maximum recorded flow. Flows greater than 100 cumecs have occurred approximately 6 times since 1990. 216 gaugings (validating measurements) have been undertaken at the site since 1986, with the highest flows being gauged within the first few years of site establishment. Since 2000, the maximum gauged flow has been approximately 6.5 cumecs.

Consequently, higher recorded flows have higher associated uncertainty. However, the gauging record shows a stable relationship with little scatter, with gaugings covering the majority of observed flows at the site, indicating a reliable stage-discharge curve. The site is therefore rated as suitable for model calibration.

2.6.2 Additional short-term streamflow monitoring sites

Additional streamflow records collected by the ACT government for various short-term studies are included in the model:

- 410650 Upper Stranger Pond (1990-1990) Inflow to the pond at GPT
- 410651 Upper Stranger Pond (2017-2018) Outflow from Upper Stranger Pond
- ES1701 Tuggeranong Channel @ Clive Steele (2017-2018)
- ES1702 Monash Channel @ Charleston (2017-2018)

As validation gaugings are generally unavailable for these short-term monitoring sites, they are used for indicative comparison purposes rather than model calibration.

2.7 Water Sensitive Urban Design assets

Geographic location and pollutant reduction performance data were available for eight existing WSUD assets in the Lake Tuggeranong catchment, built under Stage 1 of the ACT Healthy Waterways program. eWater (eWater Ltd, 2022) modelled the flow and water quality performance of these assets using MUSIC (Table 2). Each of these eight WSUD assets is represented in the current Lake Tuggeranong catchment model as a splitter node that diverts flow to the asset, and a storage node that applies a water quality decay function, representing the percentage reduction in pollutant loads (TP, TN, and TSS) achieved by the asset. Splitter nodes are configured with a maximum flow rate that is diverted into the asset, and any flow above this bypasses the asset, based on the MUSIC modelled high-flow bypass threshold. Storage nodes are configured based on asset design information from their respective preliminary sketch plan (PSP) or design acceptance reports, and their pollutant load decay rate was initially set to match the MUSIC modelled percent reduction rate with a default half-life of 1 day. Field observations indicated that some assets are not currently performing to their full capacity, and the pollutant load decay rates were adjusted to reflect the reduced performance of these assets (Table 2).

Table 2. Adjusted efficiencies (% reduction) of water quality parameters for eight Healthy Waterways Stage 1 WSUD assets, matching the current observed working condition of assets. These values were implemented in the Lake Tuggeranong catchment model. Values in parentheses are the predicted efficiencies from MUSIC models in the technical reports for each asset *(eWater Ltd, 2022)*.

Asset	% Flow bypassed	% TP reduction	% TN reduction	% TSS reduction
TG008	41	27 (54)	25 (51)	41 (82)
TG010	28	54 (78)	51 (74)	66 (95)
TG011N	75	39 (66)	31 (53)	45 (75)
TG011S	75	39 (66)	31 (53)	45 (75)
TG012	29	20 (20)	9 (9)	24 (24)
TG017	52	60 (60)	47 (47)	65 (65)
TG029	49	10 (51)	9 (47)	14 (74)
TG030	66	28 (28)	15 (15)	32 (32)

3. Model build and parameterisation

3.1 Hydrology

3.1.1 Lake Tuggeranong catchment model build

A single catchment model representing the Lake Tuggeranong catchment was developed in Source version 5.3 (https://ewater.org.au/ewater-solutions/tools/source/). The model operated on a daily timestep using long-term, gap-filled climate observations from 01/01/1889 to 30/10/2023. Using a 1 m pit-filled DEM and the ACT Government stormwater network, the catchment was delineated into subcatchments based on flow gauging and water quality monitoring sites as well as WSUD asset locations. A node link network of the catchment model was established. Land use classifications and land surface imperviousness data were combined to define functional units implemented in the model.

The gauge downstream of Lake Tuggeranong (Tuggeranong Creek upstream of Sewer Crossing, gauge 410779) was identified as the node for flow calibration. For hydrologic parameterisation for this gauge, daily timestep streamflow data from 06/02/1986 to 30/10/2023 was input to the catchment model. The internal calibration tool using the objective functions square root daily, exceedance, and bias, was implemented to achieve a suitable fit between modelled and measured data. The daily Nash-Sutcliffe efficiency (NSE) coefficient (Nash & Sutcliffe, 1970) was used as the model performance criterion.

3.1.2 Model calibration

SIMHYD and Sacramento rainfall-runoff models were tested for their suitability for model calibration. The initial flow calibration was conducted for the Lake Tuggeranong catchment before delineation into subcatchments, for the period 01/01/1996 to 30/10/2023, with a warm-up period of 10 years (1986-1995). The permanent impervious fraction of the catchment (pctim) for roads, roofs and hardstand was set to 90% impervious in the Sacramento model as these land uses generate more runoff than permeable surfaces. The objective functions used in the calibration were square root daily, exceedance, and bias. Shuffled Complex Evolution (SCE) followed by Rosenbrock were chosen for optimisation, with 5 iterations and a population number of 500. The Sacramento rainfall-runoff model performed better than the SIMHYD model, providing a better fit with the recorded flow data (Table 3).

Table 3. Model performance statistics for the Sacramento and SIMHYD rainfall-runoff models.

Rainfall-runoff model	Daily Nash-Sutcliffe coefficient	% Volume bias
Sacramento	0.803	-0.85
SIMHYD	0.744	0.001

The initial calibration results confirmed the selection of the Sacramento rainfall-runoff model for the Lake Tuggeranong catchment. The calibrated hydrologic parameters for this model are provided in Table 4.

Table 4. Calibrated hydrologic parameters for the Lake Tuggeranong catchment model using a Sacramento rainfall-runoff model.

Parameter	Suburban	Open space	Commercial	Rural	Bushland	Sports field
Soil moisture store (Lztwm) (mm)	75	75	75	75	75	75
Soil moisture store (Lzfsm) (mm)	15	15	15	15	15	15
Soil moisture store (Lzfpm) (mm)	267.5	267.5	267.5	267.5	267.5	267.5
Rate of lateral outflows (Lzsk)	0.03	0.03	0.03	0.03	0.03	0.03
Rate of lateral outflows (Lzpk)	0.003	0.003	0.003	0.003	0.003	0.003
Rserv	0.346	0.346	0.346	0.346	0.346	0.346
Losses (Side)	0	0	0	0	0	0
Time delay in runoff (UH1)	0.88	0.88	0.88	0.88	0.88	0.88
Time delay in runoff (UH2)	0	0	0	0	0	0
Time delay in runoff (UH3)	0	0	0	0	0	0
Time delay in runoff (UH4)	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109
Time delay in runoff (UH5)	0.03	0.03	0.03	0.03	0.03	0.03
Soil moisture store (Uztwm) (mm)	75.44	75.44	75.44	75.44	75.44	75.44
Soil moisture store (Uzfwm) (mm)	75	75	75	75	75	75
Rate of lateral outflows (Uzk)	0.5	0.5	0.5	0.5	0.5	0.5
Water percolation (Zperc)	153.46	153.46	153.46	153.46	153.46	153.46
Water percolation (Rexp)	3.02	3.02	3.02	3.02	3.02	3.02

Parameter	Suburban	Open space	Commercial	Rural	Bushland	Sports field
Impervious runoff (Pctim)	0.5	0.5	0.5	0.5	0.5	0.5
Losses (Sarva)	0	0	0	0	0	0
Losses (Ssout) (mm)	0	0	0	0	0	0
Impervious runoff (Adimp)	0.30	0.30	0.30	0.30	0.30	0.30
Water percolation (Pfree)	0.19	0.19	0.19	0.19	0.19	0.19

Table 4 continued. See caption previous page.

3.1.3 Model verification

To verify the modelled flow generation of the Lake Tuggeranong catchment, a comparison was made with the Jerrabomberra catchment, which has similar geographic features and location.

A model of the Jerrabomberra catchment was set up in Source using the climate variables daily rainfall and Morton's wet-environment areal evapotranspiration over land (MWet). The rainfall data was obtained from SILO, using station ID 70066 for the NSW portion of the catchment, and station 70249 for the ACT portion. The MWet data was obtained from SILO station ID 70072. The gauged flow data used for calibrating this catchment came from Jerrabomberra at Hindmarsh (gauge 410790), obtained from ALS Pty Ltd. The model was calibrated using a Sacramento rainfall-runoff model, and the objective functions square root daily, exceedance, and bias. SCE followed by Rosenbrock were chosen for optimisation, with 5 iterations and a population number of 500. The calibration was a moderate fit with a daily Nash-Sutcliffe coefficient of 0.59 and volume bias of 0%.

The runoff coefficients of both the Lake Tuggeranong and Jerrabomberra catchments were calculated to compare their performance under predevelopment conditions, represented by 100% bushland land use. The runoff coefficient of the Lake Tuggeranong catchment was approximately 7%, and that of the Jerrabomberra catchment was approximately 8.5%. The two catchments performed similarly under pre-development conditions, verifying the flow generation of the Lake Tuggeranong catchment model.

3.1.4 Model uncertainty estimation

At this stage, model uncertainty estimation has not been undertaken.

3.1.5 Flow routing calibration

Due to the small catchment size and largely urban land use, flow routing was not undertaken in any reach in the Lake Tuggeranong catchment model.

3.1.6 Lake water balance

The lake water balance accounted for all inflows, outflows, rainfall, and evaporation from the lake.

3.2 Water quality

Source catchment models are best suited to estimating long-term mean annual catchment pollutant loads rather than daily concentrations. Ideally, empirical measurements of EMC and DWC from different land uses would be used to parameterise the model. However, as described in section 2.3, water quality data from the Lake Tuggeranong catchment has not been collected concurrently with quantitative flow data, precluding the calculation of EMC. As a result of these data limitations, and noting that long-term inflows and pollutant load into the lake are a key predictive output of the model, a simple approach was adopted to adjust land use -based model water quality parameters using available monitoring data:

1. For each water quality monitoring site, daily median event flow concentrations for each pollutant were calculated for all available dates, as described in section 2.3.
2. A baseline simulation run of the model was performed using EMC and DWC values adapted from the literature (Fletcher, Duncan, Poelsma, & Lloyd, 2004), (Witt, Mainwright, & Weber, 2015), (Melbourne Water, 2024), (Blacktown City Council, 2020), and the modelled daily flows and predicted pollutant concentrations for all monitoring sites were extracted.
3. Baseline modelled pollutant concentrations were date-matched with observed median flows and concentrations to allow for later flow stratification (if appropriate) and to account for sample population representativeness (dry periods or wet periods).
4. Median observed and modelled pollutant concentrations for six major lake inflow sites were then calculated, and used to estimate scaling factors to adjust the literature-derived EMC values for majority land uses (roads, roofs, hardstand, and pervious areas of suburban, commercial, and open space land use categories). Where data allowed, inflow-specific scaling factors were applied.
5. The model was re-run using the scaled EMC values (Appendix D), and modelled median concentrations were once again compared against observed median concentrations.
6. When median modelled and observed values were in agreement, the model parameters were checked against literature values to ensure that the model estimate remained in the anticipated range.

4. Results

4.1 Flow calibration

A hydrograph time series for flows in the Lake Tuggeranong catchment over the model calibration period, 1996-2023, is presented in Figure 4. The hydrograph demonstrates good agreement between the timing and magnitude of modelled and observed flows, which are highly correlated with a daily Nash-Sutcliffe coefficient of 0.88 indicating a very good fit (Moriasi, et al., 2007). There is acceptable peak flow matching with an overall low bias, suggesting the model is reliable in simulating high flow events (Table 5). This strong performance across flow magnitudes confirms the robustness of the model calibration and its suitability for simulating the hydrology of the Lake Tuggeranong catchment.

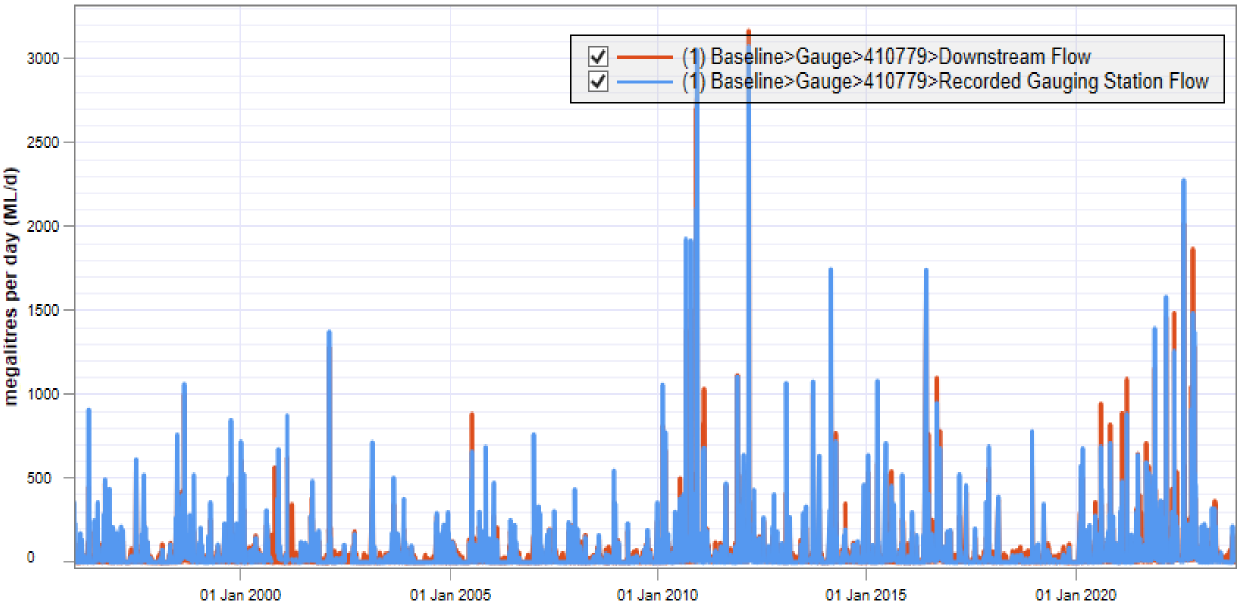

Figure 4. Modelled (red) and observed (blue) flows (daily discharge, ML/d) for Tuggeranong Creek upstream of Sewer Crossing (gauge 410779).

Table 5. Flow calibration model performance statistics for Tuggeranong Creek upstream of Sewer Crossing (gauge 410779).

Performance criterion	
Daily Nash-Sutcliffe Efficiency coefficient	0.88
Monthly Nash-Sutcliffe Efficiency coefficient	0.92
% Volume bias	-0.25

Figure 5 depicts the cumulative flow curve over the calibration period, demonstrating good agreement between modelled and observed flow over the entire period. This agreement indicates that the model accurately captures the total volume of water passing through the catchment, validating its performance in representing the overall hydrological processes.

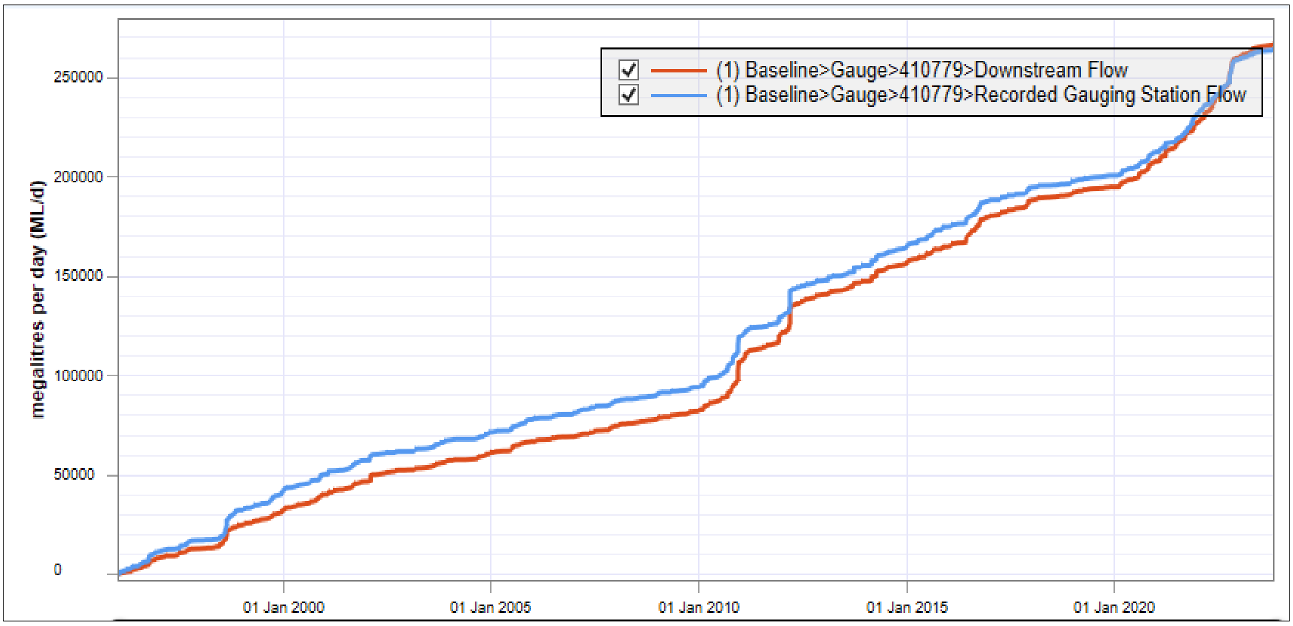

Figure 5. Modelled (red) and observed (blue) cumulative flow for Tuggeranong Creek upstream of Sewer Crossing (gauge 410779), 1996-2023.

Figure 6 illustrates the flow duration curve for flows in the calibration period, showing generally good agreement between modelled and observed flow across most flow conditions. However, discrepancies are noted particularly at low flows. This suggests that while the model performs well overall, there may be areas where the representation of low-flow conditions could be further refined or calibrated.

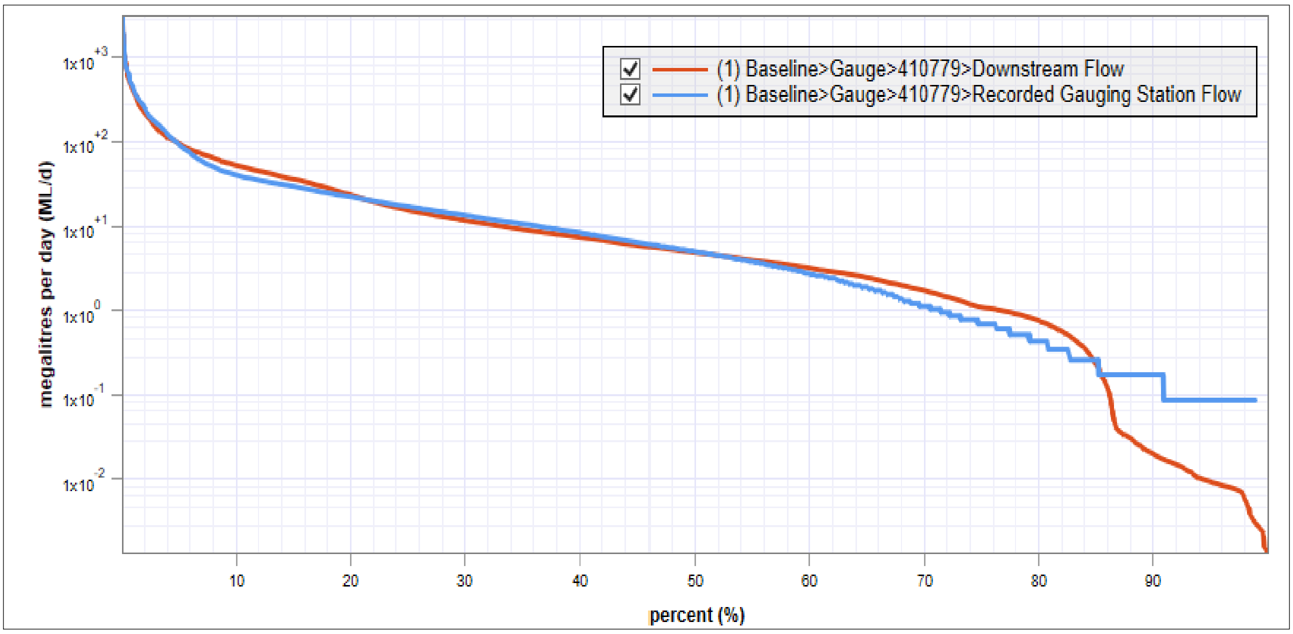

Figure 6. Modelled (red) and observed (blue) flow exceedance curve for Tuggeranong Creek upstream of Sewer Crossing (gauge 410779), 1996-2023.

Figure 7 presents the residual mass curves for observed and modelled flows over the calibration period. The difference between the curves indicates the cumulative difference between observed and modelled flows over time. Ideally, this difference should hover around zero, indicating minimal bias or systematic error in the model.

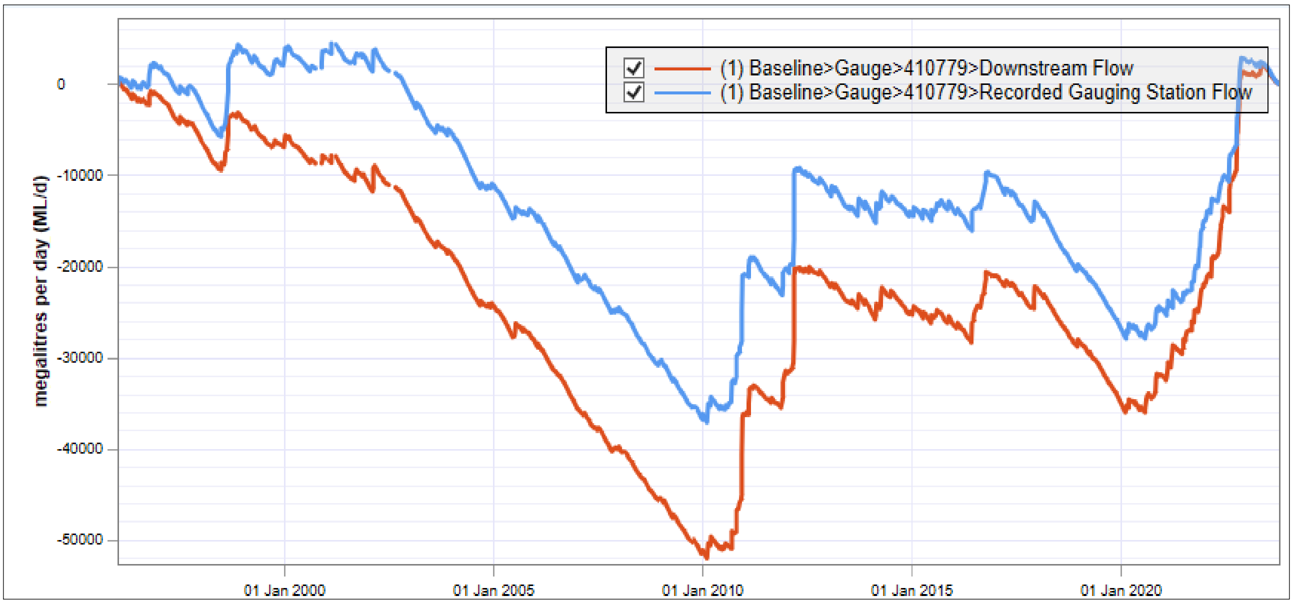

Figure 7. Modelled (red) and observed (blue) residual mass for Tuggeranong Creek upstream of Sewer Crossing (gauge 410779), 1996-2023.

The above plots collectively provide a comprehensive evaluation of the model's performance in simulating hydrological processes in the Lake Tuggeranong catchment, capturing overall flow patterns.

4.2 Water quality calibration

Figure 8 illustrates the comparisons between the median observed and modelled concentrations of TP, TN, and TSS for 34 sites across the Lake Tuggeranong catchment where water quality monitoring was undertaken. These comparisons provide a visual representation of the model's performance in simulating water quality across the catchment. At well-sampled sites, there is generally good agreement between the observed and modelled concentrations. Discrepancies at other sites are primarily due to insufficient sample numbers (Figure 9). Higher median TP concentrations are noted for sites in the Village Creek, Kambah Creek, and Wanniassa subcatchments (site codes beginning with VC, KC, WS respectively) compared to other areas within the Lake Tuggeranong catchment.

As there were multiple sampling locations across the catchment the mean of site medians can provide a robust central tendency measure. The mean of the median modelled concentration for TP is 0.17 mg/L, for TN is 1.33 mg/L, and for TSS is 49.7 mg/L.

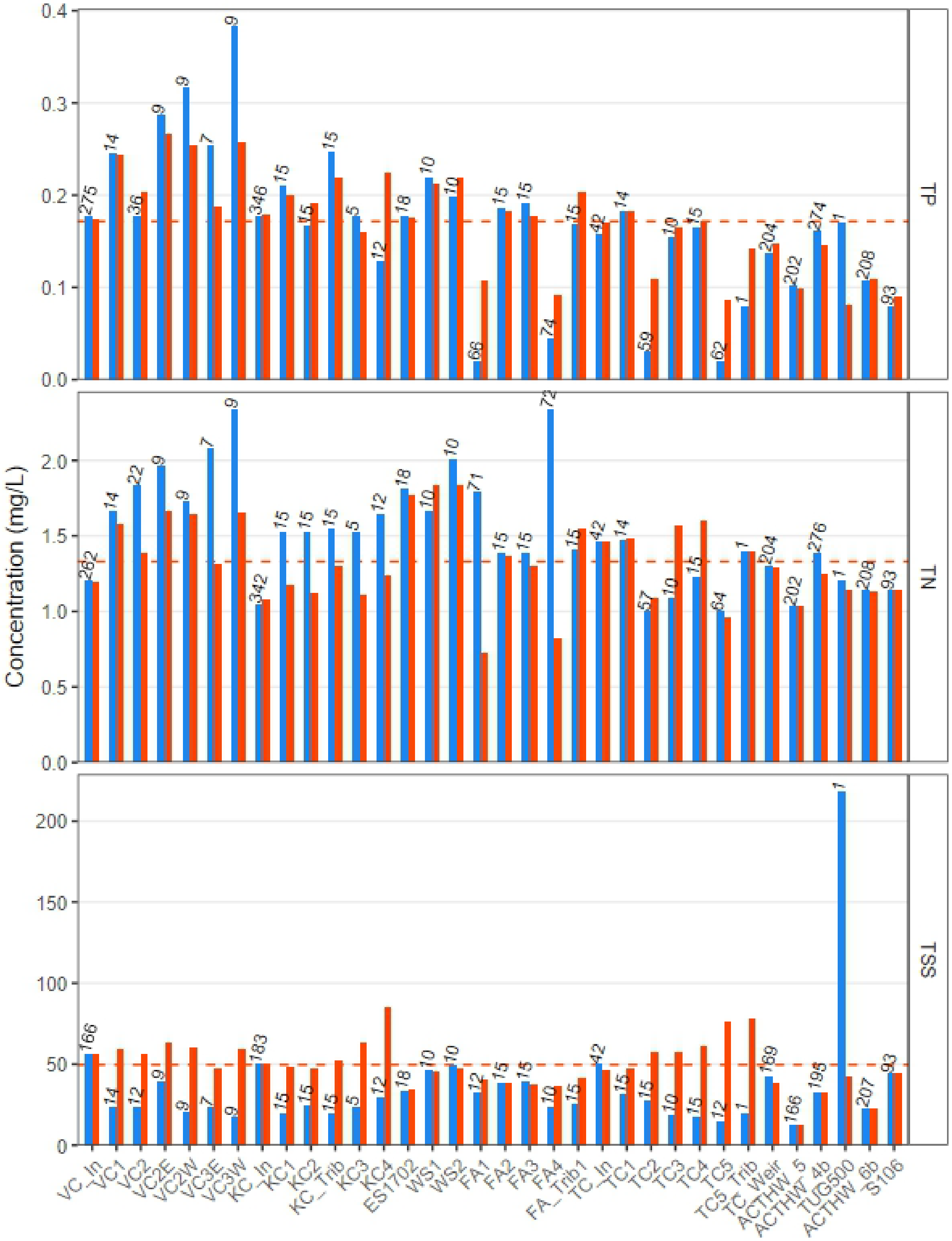

Figure 8. Observed (blue) and modelled (red) median concentrations of total phosphorus (TP; top panel), total nitrogen (TN; middle panel), and total suspended solids (TSS; bottom panel) for each water quality monitoring site in the Lake Tuggeranong catchment. Blue bars are labelled with the number of samples per site analysed for each parameter. The red dashed lines indicate the means of the median modelled concentrations of each pollutant (see text).

Figure 9 illustrates the deviations of modelled from observed site median concentrations for the three water quality parameters, as a function of the number of samples at the monitoring site. A value of zero indicates no bias in the model estimates for that site (i.e. no consistent over- or under-estimation of concentrations, compared to observed values). For all three parameters, deviations decline sharply with increasing sample size. The median deviation for TP is close to zero with a narrow interquartile range, indicating low overall bias. TN deviations are more spread out, with a slight overall positive bias indicated by the median just above zero. TSS deviations have a narrow interquartile range, with a median deviation below zero indicating an overall negative bias, and a notable positive outlier. As for TP and TN, the vast majority of substantial deviations for TSS occur for sites with very low sample sizes.

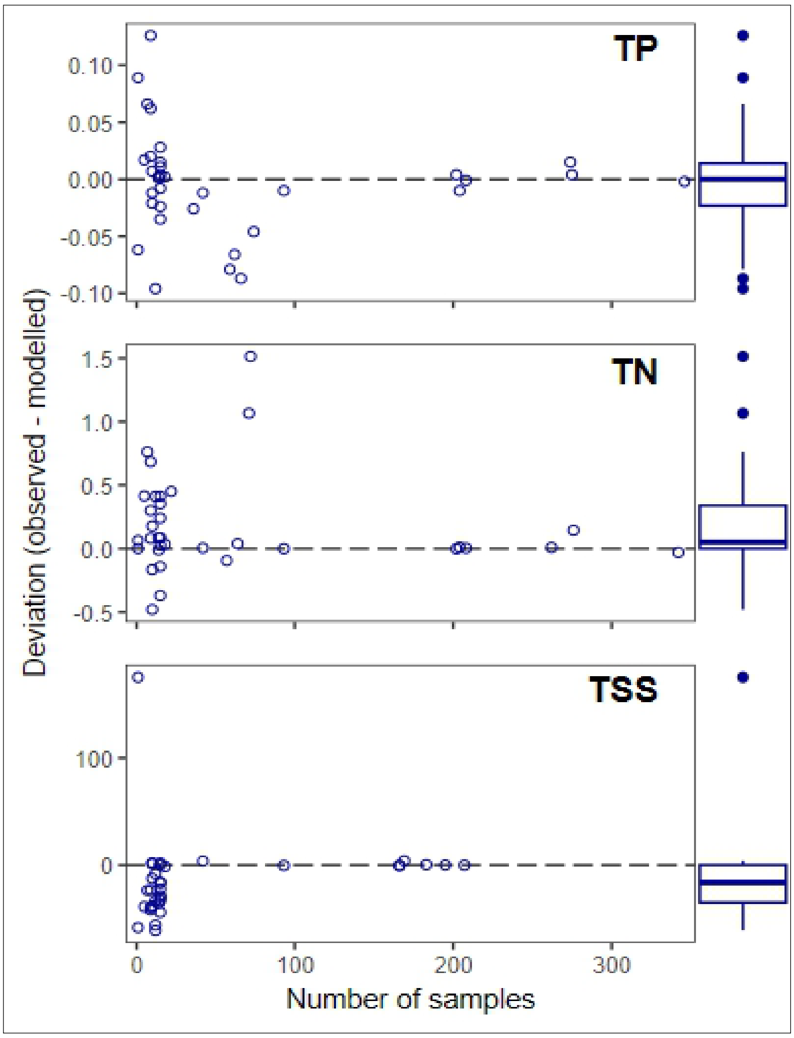

Figure 9. Scatter plots showing the deviation of modelled from observed median concentrations of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) as a function of sample size at 34 water quality monitoring sites in the Lake Tuggeranong catchment. The dashed grey line at zero indicates no bias in the model estimates for a given site. Box-and-whisker plots illustrate the spread of deviations.

4.3 Catchment modelling results

The calibrated catchment model was simulated over the climate period January 1889 – October 2023, and summaries of the total flow and pollutant loads were calculated for each complete year (1889-2022). Under current catchment land use and management conditions, the modelled mean annual inflow to Lake

Tuggeranong was 8.8 GL/year. The modelled mean annual loads of pollutants entering Lake Tuggeranong were 1,442 kg/year total phosphorus, 11,894 kg/year total nitrogen, and 397,064 kg/year total suspended solids.

Figure 10 presents a series of heat maps illustrating the modelled mean annual loads of TP, TN and TSS generated in different subcatchments of the Lake Tuggeranong catchment, with darker shading indicating a higher load. The pollutant load generated depends on the land uses within each subcatchment. The highest mean subcatchment TSS loads fall between 160 – 180 kg/ha/yr. The highest TN loads are between 3.5 – 4 kg/ha/yr, and the highest TP loads are between 0.6 – 0.7 kg/ha/yr. For all three pollutants, higher load generation occurs in more urbanised catchments. This broad visual representation can help in identifying the areas requiring critical attention to improve water quality in the catchment.

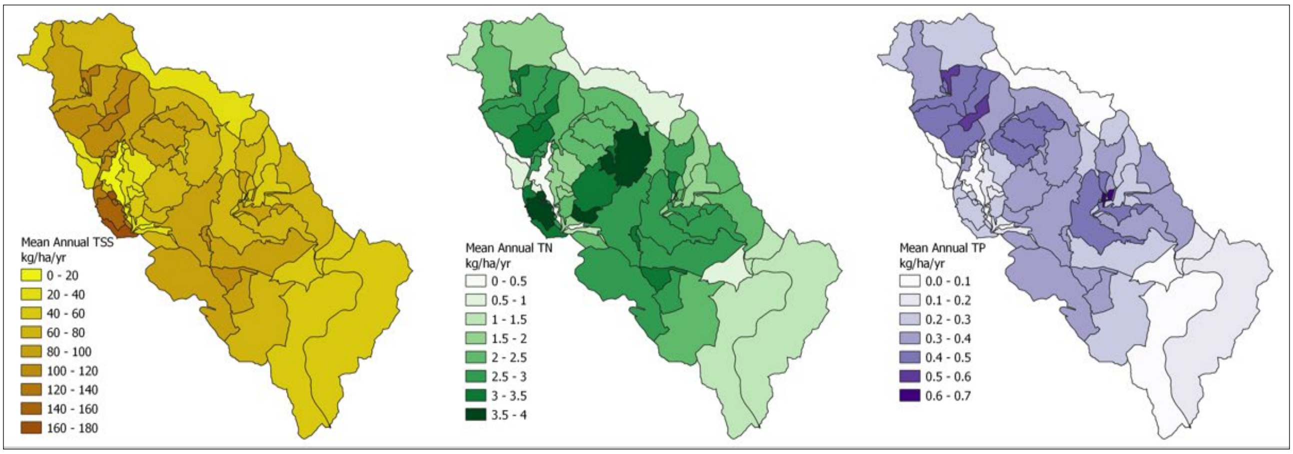

Figure 10. Heat maps of the Lake Tuggeranong catchment for mean annual loads of total suspended solids (TSS, left), total nitrogen (TN, centre) and total phosphorus (TP, right) generated in each subcatchment. Darker shading indicates higher mean annual concentrations.

Figures 11-13 show time-series of modelled daily inflows, pollutant concentrations, and pollutant loads entering Lake Tuggeranong in 2016, a year with a good spread of wet and dry periods. High flow events, likely driven by rainfall, lead to increased runoff, which carries higher concentrations and loads of phosphorus, nitrogen, and suspended solids into the lake. In 2016, the model estimates that the largest flow event saw over 1600 ML enter Lake Tuggeranong in a single day, representing 10% of the total annual inflow that year. This event carried loads of approximately 300 kg TP, 2,500 kg N, and 75,000 kg TSS to the lake, representing 12-13% of the total annual load of each pollutant entering Lake Tuggeranong in 2016. This pattern highlights the impact of storm events on water quality and the importance of managing runoff from the catchment to the lake.

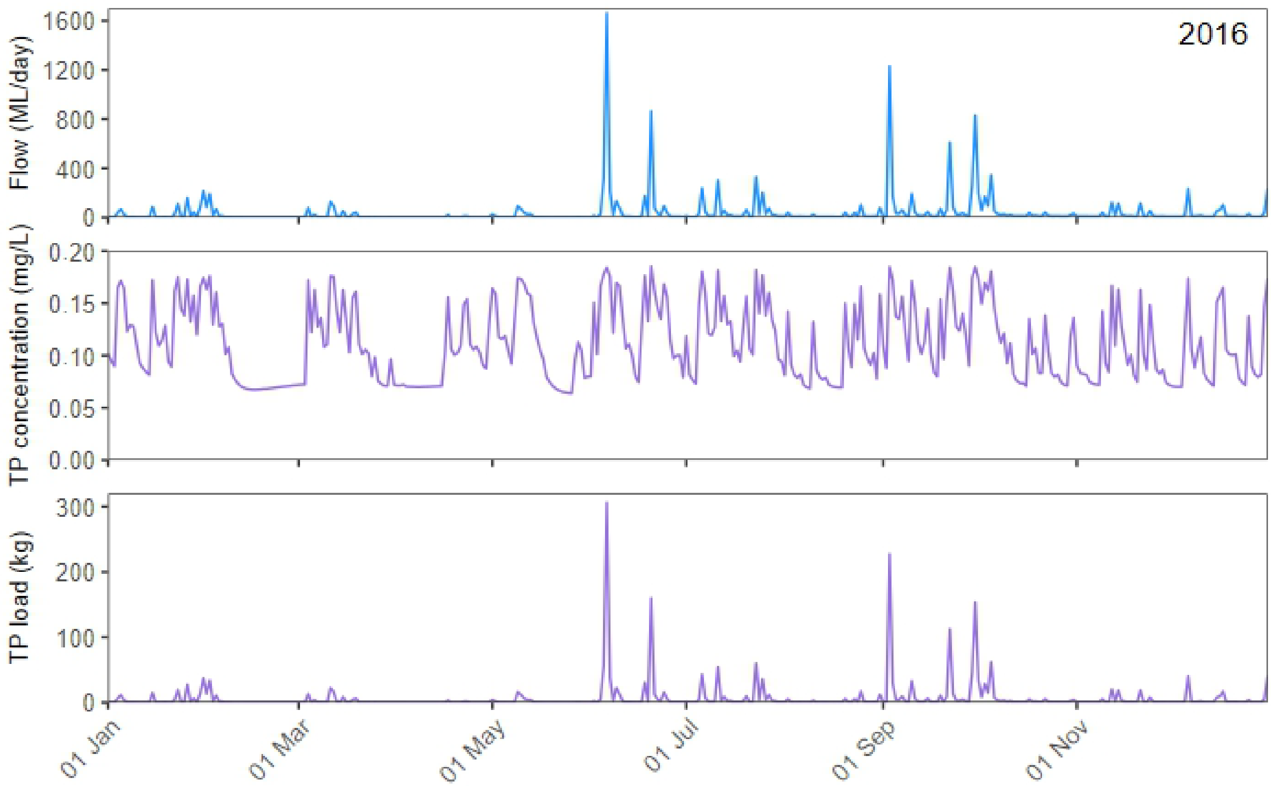

Figure 11. Modelled daily flow and total phosphorus (TP) concentration and load entering Lake Tuggeranong, 2016.

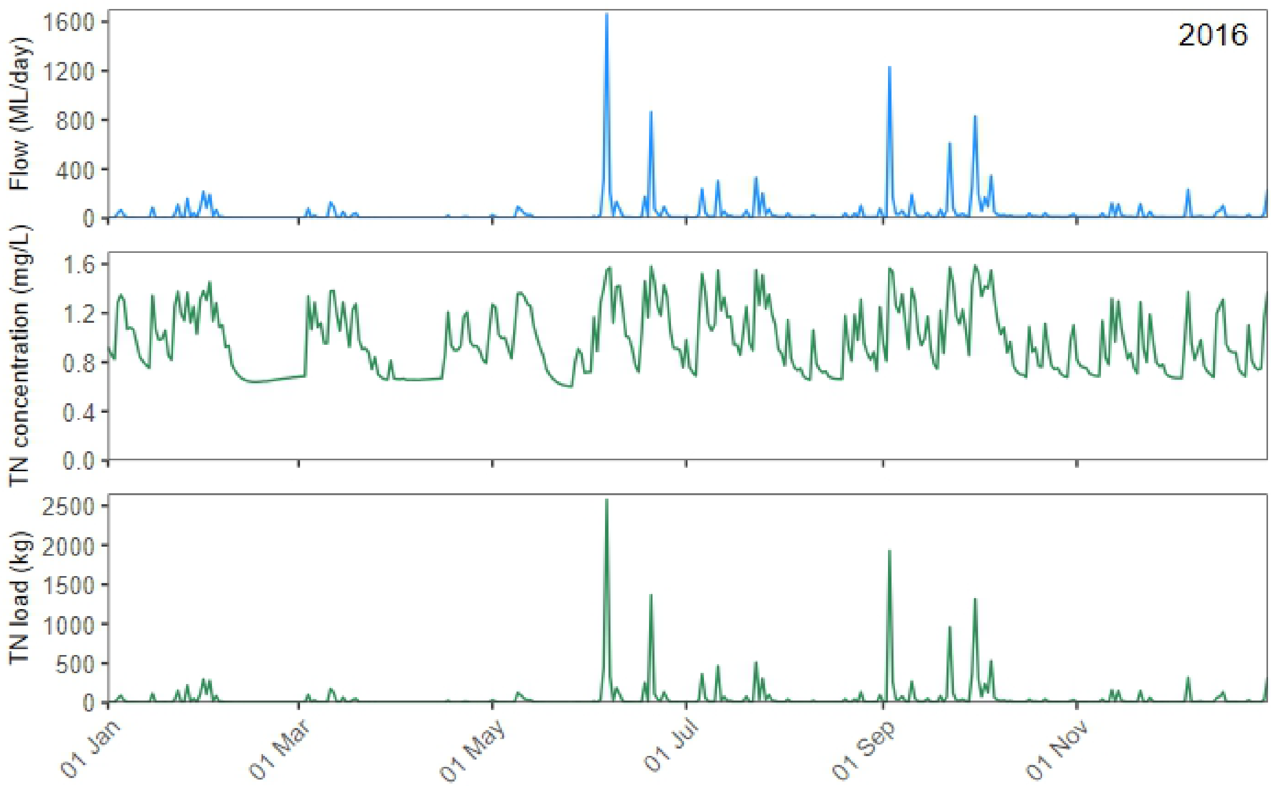

Figure 12. Modelled daily flow and total nitrogen (TN) concentration and load entering Lake Tuggeranong, 2016.

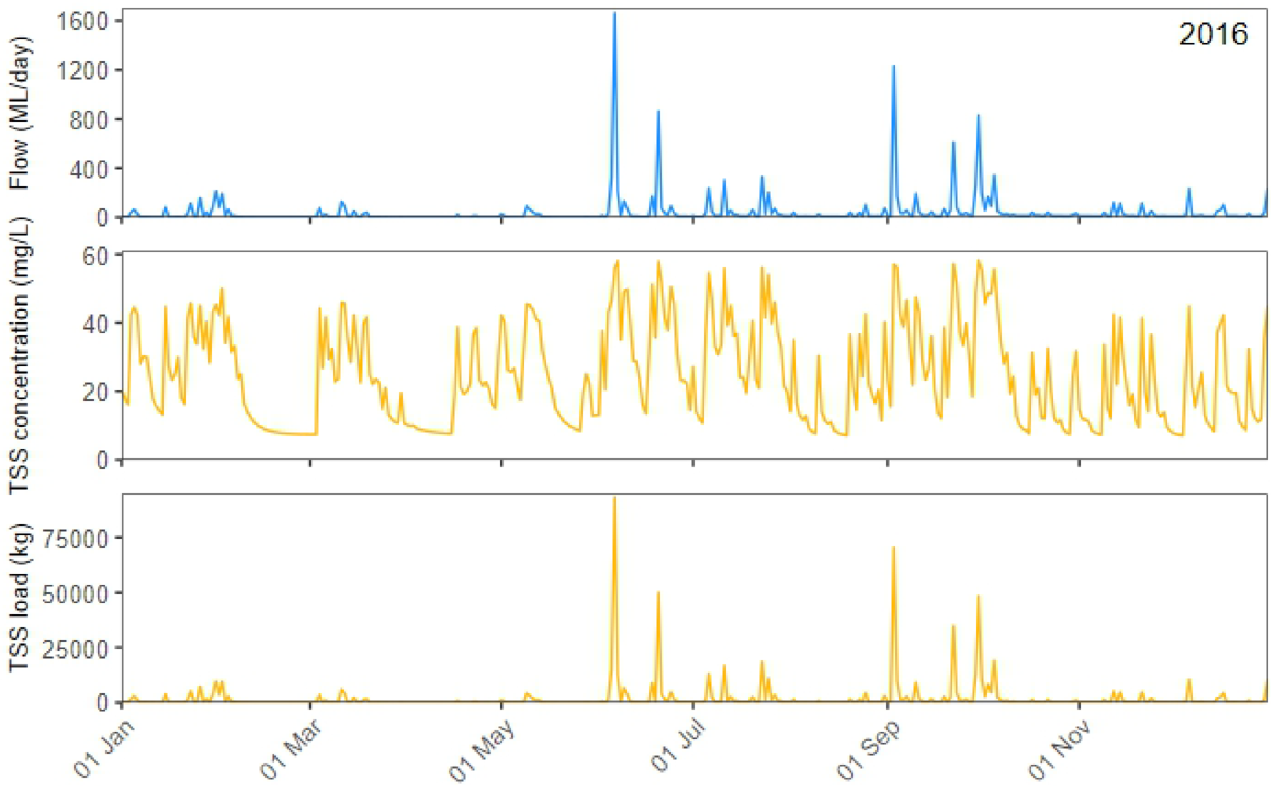

Figure 13. Modelled daily flow and total suspended solids (TSS) concentration and load entering Lake Tuggeranong, 2016.

Figure 14 shows the relationships between daily inflows, concentrations, and loads in 2016 for TP; TN and TSS showed the same patterns in the shape of these relationships.

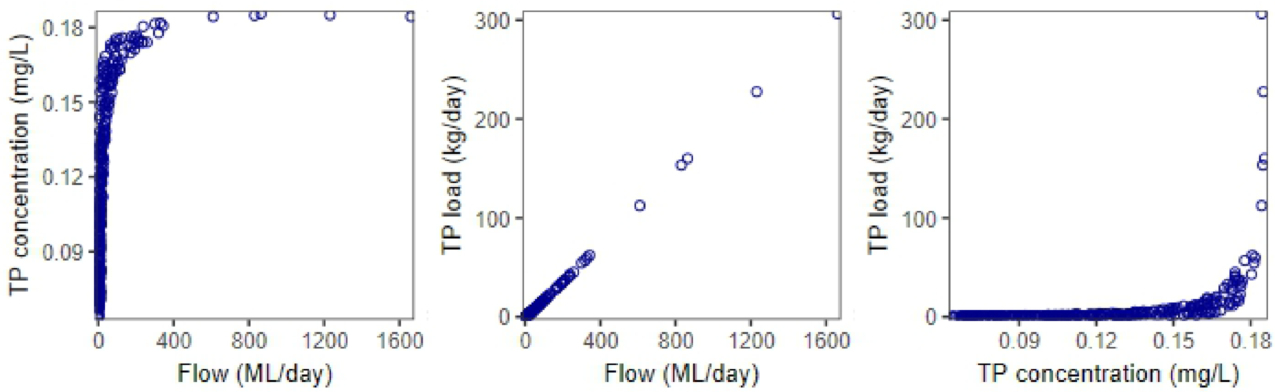

Figure 14. Relationships between the daily inflows and concentrations and loads of total phosphorus (TP) entering Lake Tuggeranong in 2016. The same relationships were seen for total nitrogen and total suspended solids.

4.4 Scenario analysis

4.4.1 Current and predevelopment scenarios

To understand the impact of changes to land use and urban development on the hydrology and water quality of the Lake Tuggeranong catchment, two contrasting land use scenarios were simulated using the calibrated catchment model. The first, 'current' scenario was the model of current land use and infrastructure conditions described in Section 4.3. Under the current scenario the modelled mean annual inflow to Lake Tuggeranong was approximately 8.8 GL, and the modelled mean annual pollutant loads were 1,442 kg TP, 11,894 kg TN, and 397,064 kg TSS. Figure 15 presents the long-term modelled annual inflow and pollutant loads entering Lake Tuggeranong under the current scenario, for the period 1889-2022.

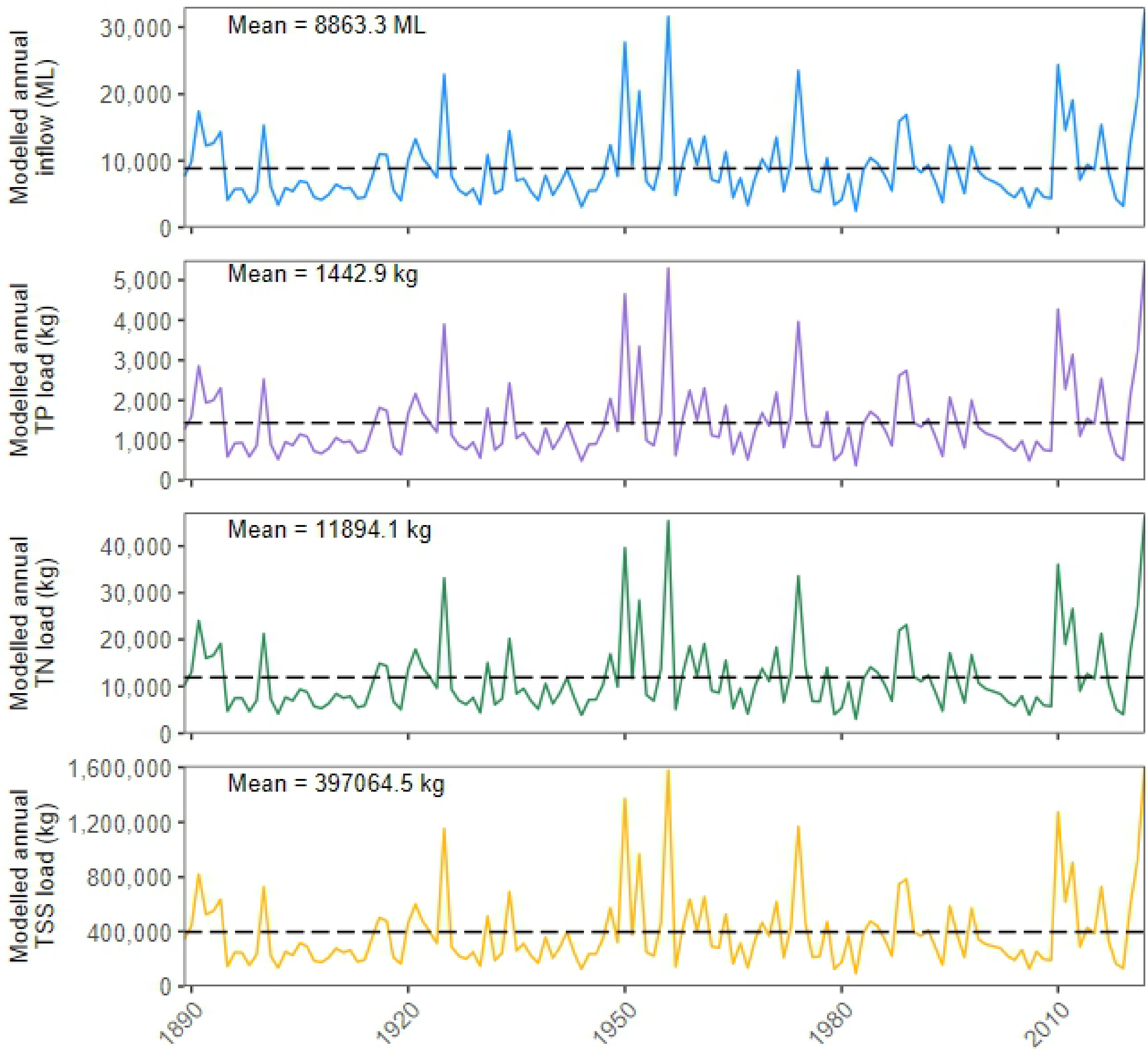

Figure 15. Long-term modelled annual inflows and annual loads of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) entering Lake Tuggeranong under current catchment conditions, for the period 1889 – 2022.

We compared this current scenario to a 'predevelopment' scenario, where all infrastructure (apart from Lake Tuggeranong itself) and developed land uses were removed from the model. Land use for all subcatchments was configured to be entirely bushland, to allow estimation of the runoff and pollutant generation under natural conditions. The results of the predevelopment scenario for the Lake Tuggeranong catchment were validated using the adjacent Jerrabomberra catchment, which has similar geographic conditions, for comparison (see Section 3.1.2). Figure 16 presents the long-term modelled annual inflow and pollutant loads entering Lake Tuggeranong under the predevelopment scenario, for the period 1889-

2022. The mean long-term annual inflow to the lake under predevelopment conditions was approximately 3,268 ML, and the modelled mean annual pollutant loads were 325 kg TP, 2470 kg TN, and 99,673 kg TSS.

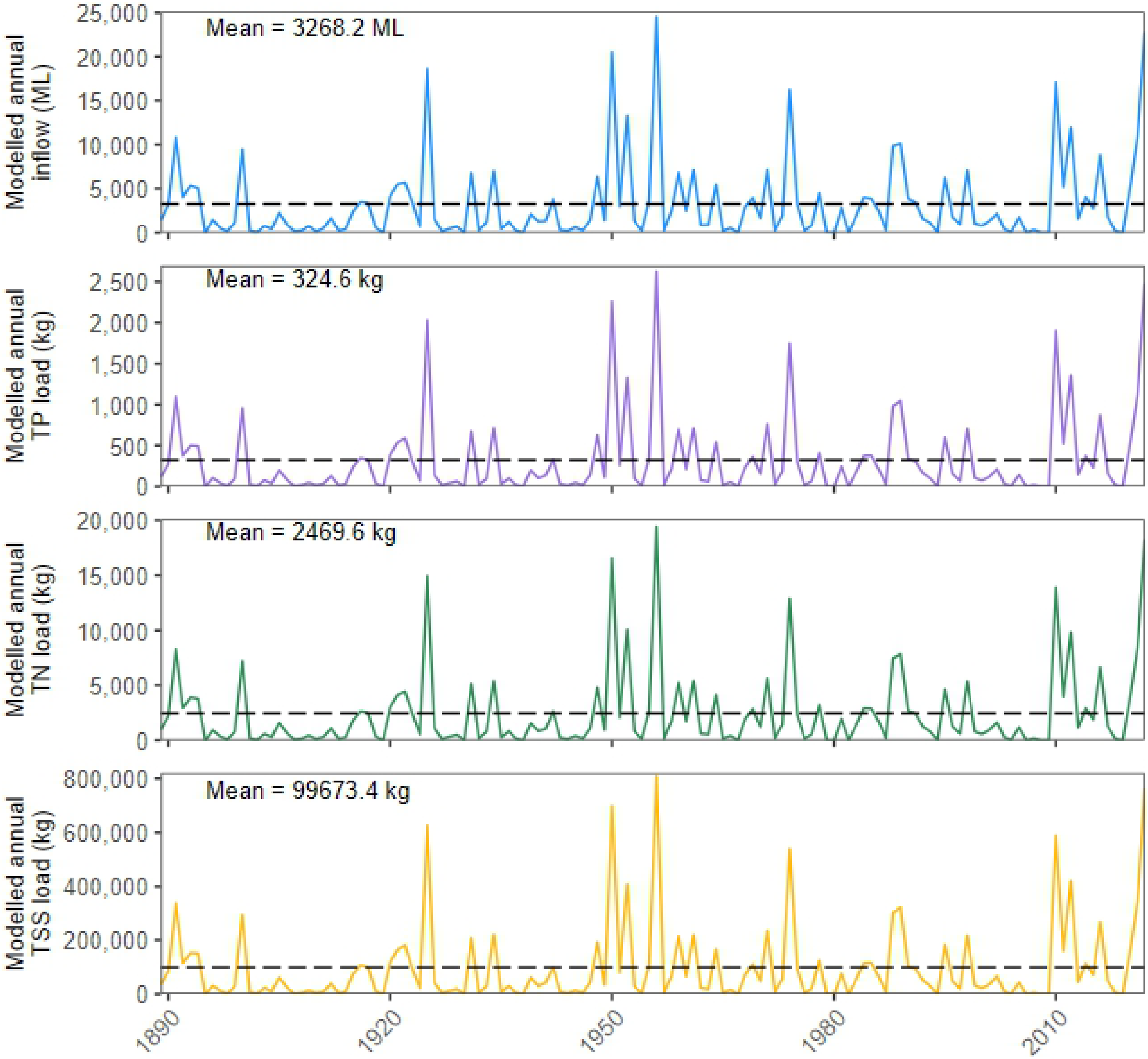

Figure 16. Long-term modelled annual inflows and annual loads of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) entering Lake Tuggeranong under predevelopment catchment conditions, for the period 1889 – 2022.

Table 6 and Figure 17 present comparisons of summary statistics for modelled annual inflows and pollutant loads generated under the current and predevelopment scenarios, for the period 1889-2022. On average, annual inflows to Lake Tuggeranong under predevelopment conditions were 25.5% of annual inflows under current conditions. The reduction in annual inflows, as well as reduced pollution generation modelled from the undeveloped catchment, meant that annual pollutant loads entering Lake Tuggeranong under predevelopment conditions were on average approximately 15% of annual pollutant loads under current conditions.

Table 6. Summary statistics describing modelled annual inflow volumes and loads of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) entering Lake Tuggeranong under the 'current' and 'predevelopment' model scenarios, for the period 1889-2022.

Parameter	Modelled scenario	Minimum	25th percentile	Median	Mean	75th percentile	Maximum
Annual inflow (GL)	Current scenario	2.50	5.39	7.39	8.86	10.37	32.3
Annual inflow (GL)	Predevelopment scenario	0	0.31	1.44	3.27	4.01	24.56
Annual TP load (kg)	Current scenario	377	857	1,176	1,442	1,705	5,412
Annual TP load (kg)	Predevelopment scenario	0	25	133	324	376	2,622
Annual TN load (kg)	Current scenario	3,019	6,893	9,508	11,894	14,100	46,236
Annual TN load (kg)	Predevelopment scenario	0	195	1,041	2,469	2,920	19,420
Annual TSS load (kg)	Current scenario	93,394	221,932	313,352	397,064	471,056	1,607,545
Annual TSS load (kg)	Predevelopment scenario	0	7,558	40,575	99,673	115,094	808,385

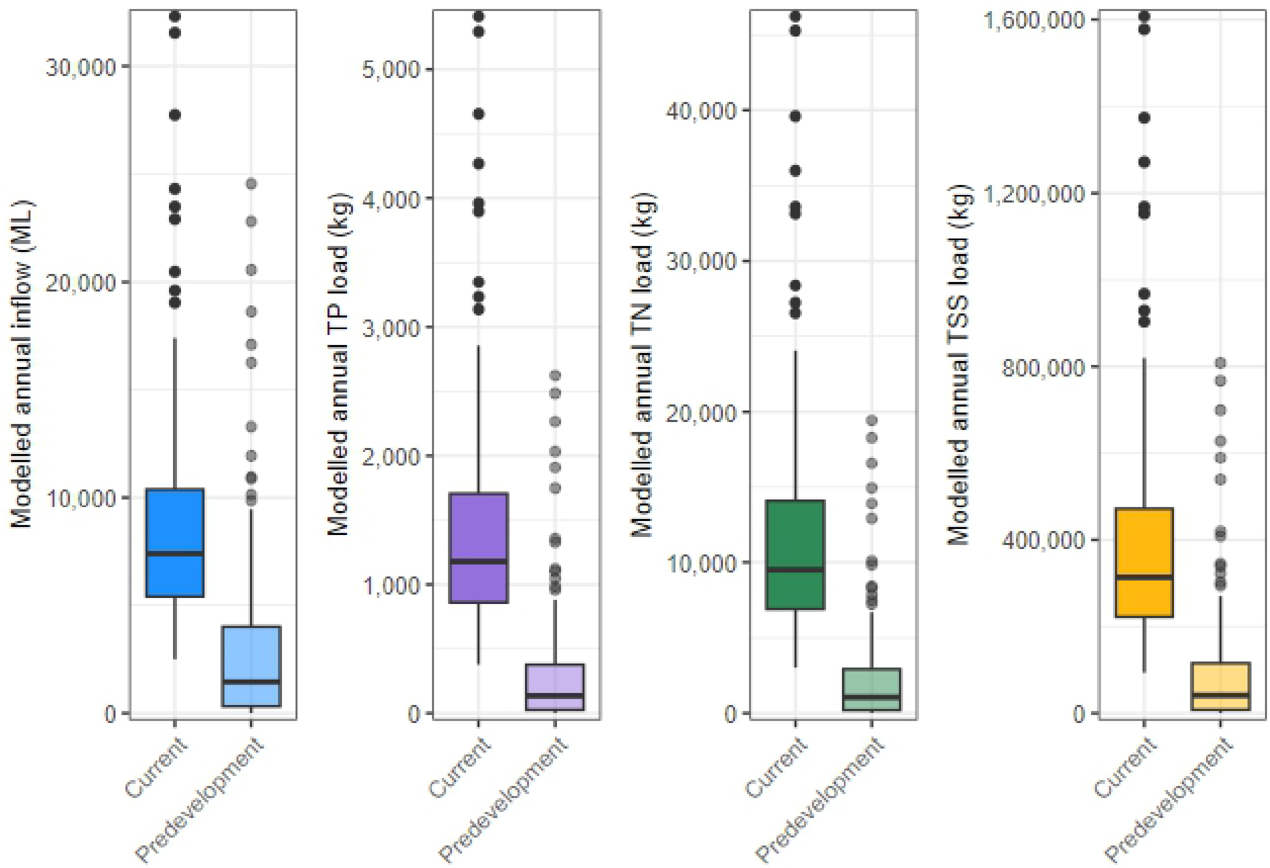

Figure 17. Box-and-whisker plots illustrating the distribution of modelled annual inflows and loads of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) entering Lake Tuggeranong under current and predevelopment catchment conditions, over the period 1889-2022.

Comparing the current and predevelopment scenarios is important for understanding catchment hydrology and pollutant generation before and after development, as well as the impacts of changes in hydrology and pollutant generation on trophic conditions in Lake Tuggeranong. The results from both modelled scenarios were used to parameterise a model of in-lake processes, which estimates the concentrations of phosphorous and chlorophyll a in the lake (Kahn & Dey, 2024). These concentrations were used to predict the distribution of trophic conditions in Lake Tuggeranong under the current and predevelopment scenarios. These analyses help to understand how conditions in the lake are predicted to respond under different inflow and pollutant conditions, and inform management decisions aimed at reducing the occurrence of blue-green algal blooms.

4.4.2 Catchment management option scenarios

The effects of specific management actions aimed at reducing pollutant inputs into the waterways and stormwater network of the Lake Tuggeranong catchment, or filtering or diverting water before it reaches the lake, were investigated in two additional scenarios implemented in the calibrated Source catchment model. Each scenario ('cost-effective' and 'broad benefits') consisted of a combination of different management actions, each with four possible levels of implementation, detailed in the companion to this report, *Lake Tuggeranong Catchment Management Options Assessment* (Booksmythe, Dey, Kahn, Stewart, & Starrs, 2024). The management options included in the two scenarios are detailed in Table 7.

Table 7. Details of the management options included in two scenarios…

Management option	Cost-effective scenario	Broad benefits scenario
Install additional WSUD infrastructure	Investment level 1: install 2 raingardens	Investment level 2: install 5 raingardens
Maintenance of existing WSUD infrastructure	Investment level 3: maintain 4 existing WSUD assets to their designed performance	Investment level 4: maintain 5 existing WSUD assets to their designed performance
Increase frequency of street sweeping	Investment level 4: 48 sweeps per year	Investment level 3: 36 sweeps per year
Manage grass clippings from municipal mowing	Investment level 3: designated street sweeping truck to follow mowers	Investment level 3: designated street sweeping truck to follow mowers
Sports field fertilizer management	Investment level 1: install bioretention swales to intercept 25% of total sports field P	Investment level 3: install bioretention swales to intercept 75% of total sports field P
Household fertilizer management	Investment level 4: very high implementation of community partnership programs aimed at reducing household fertilizer P inputs	Investment level 1: low implementation of community partnership programs aimed at reducing household fertilizer P inputs
Install castellated kerbs	n/a	Investment level 1: install castellated kerb outlets at a rate of 1 per 4 stormwater sumps adjacent to urban open space
Install floating wetlands	n/a	Investment level 4: install 4000 m^2 of floating wetlands
Stormwater recycling for sports field irrigation	Investment level 2: install stormwater recycling infrastructure at 4 sports field sites	Investment level 3: install stormwater recycling infrastructure at 6 sports field sites

Different management actions are implemented in different ways in the catchment model. Some options are explicitly represented by the addition or modification of specified links and nodes in the model:

- **Additional WSUD infrastructure** Proposed raingardens were represented in the catchment model by new storage nodes placed at the locations indicated in the original plans for the raingardens. As for existing assets, each proposed asset was modelled as a splitter node that diverts flow to the asset, and a storage node that applies a water quality decay function, representing the percentage reduction in pollutant loads (TP, TN, and TSS) achieved by the asset. Splitter nodes are configured with a maximum flow rate that is diverted into the asset, and any flow above this bypasses the asset, based on the MUSIC modelled high-flow bypass threshold. The proposed raingarden storage nodes were configured using the size indicated in the original plans, and the performance details of similar existing WSUD assets.

- **Maintenance of existing WSUD infrastructure** The catchment model includes storage nodes representing each WSUD asset in the Lake Tuggeranong catchment, with the performance of each asset configured to reflect its current phosphorus removal efficiency (Table 2). To represent maintenance of these assets to their designed performance, the performance details were reconfigured to the phosphorus removal rates given in the detailed design reports for each asset.
- **Sports field fertilizer management** For each scenario, we modelled sufficient bioretention swales to intercept the required amount of sports field generated phosphorus (i.e., 25% or 75% of all sports field generated phosphorus, Table 7). We modelled one bioretention swale per subcatchment, starting with the subcatchment containing the largest sports field area, and divided the total swale area across the number of swales included in each scenario, proportionally to the area of sports field in each subcatchment.
    - Each bioretention swale was represented by a storage node configured based on the detailed design of a similar, existing WSUD asset.The percentage removal of TP, TN, and TSS were calculated for each bioretention swale using a MUSIC model consisting of a source, GPT, bioretention, and receiving node.
        - The source node was configured to have the size of the subcatchment's sports field area, and land use set at 100% pervious; remaining parameters used default values.
        - The GPT node was configured with high flow bypass.
        - The bioretention node was configured with size proportional to the subcatchment's sports field area, filter area set to 90% of total swale area, and an extended detention depth of 0.3 m based on recommended MIS08 guidelines; remaining parameters used default values.
        - The MUSIC model for each bioretention swale was run on a 6-minute timestep.
    - As the scale of the catchment model does not delineate sports fields from their subcatchments, a controlled splitter node was added to divert water to the storage node. Because sports fields typically generate higher TP concentrations than the catchment average, but splitters do not allow the adjustment of concentration in the diverted water, we instead increased the load of TP treated by bioretention swales by diverting more water to each sports field storage node. We divided the sports field TP concentration by the subcatchment TP concentration and multiplied this ratio by the proportion of sports field area in the subcatchment, to find the proportion of runoff volume to divert to the storage node.
- **Stormwater recycling infrastructure for sports field irrigation** Each sports field with stormwater recycling infrastructure was represented by a storage node and an irrigator node. A maximum of 1 ML water was diverted to the storage node via a controlled splitter during event flows. The irrigator node was configured as a perennial pasture crop using the crop coefficient from the NSW Environmental Guidelines on the used of effluent by irrigation (NSW Department of Environment and Conservation, 2004), with soil moisture capacity set at 20% and default soil configuration. The subcatchment's sports field area was used to set the size of the irrigated area, determining the water demand for irrigation. Daily rainfall and evapotranspiration (short crop) were obtained from SILO (https://www.longpaddock.qld.gov.au/silo/), covering the climatic period represented in the model (1899 – 2023). During dry periods the irrigation demand specified by the irrigator node was met by the water in the storage node, while in wet periods the demand is first met by rainfall. Excess water was

returned to the stormwater system downstream of the sports field via a link, maintaining water and mass balance.

- **Floating wetlands** To represent floating wetlands in the catchment model, a storage routing link was added just upstream of the Lake Tuggeranong storage node. This was configured using a decay model to reduce the phosphorus concentration in the water passing through the routing link, without affecting water volume. The percentage removal of phosphorus was calculated based on the estimated annual load of TP removed per square metre of floating wetland.

The remaining options cannot be explicitly modelled, and their effects were incorporated in the model by calculating the percentage phosphorus removal attained by each option, compared to the current load of phosphorus available to be intercepted by that option, and adjusting phosphorus concentrations within the catchment model based on these percentage reductions:

- **Household fertilizer management** The percentage reduction in phosphorus concentration due to management of household fertilizer use was applied to all area classified as suburban pervious, and calculated based on the difference in total phosphorus load generated from suburban pervious land across the catchment with and without household fertilizer management.
- **Increase street sweeping frequency | Manage grass clippings from municipal mowing | Install castellated kerbs** The percentage reduction in phosphorus concentration due to these options was applied to all area classified as road. As street sweeping, grass clipping management, and castellated kerbs all act to reduce the load of phosphorus generated from roads, the combined effects of these management options were modelled using a build-up wash-off model (Booksmythe, Dey, Kahn, Stewart, & Starrs, 2024) to predict the total percentage reduction in the phosphorus load from roads for the selected combination of these options in each scenario.

Table 8 presents summary statistics for modelled annual inflows and pollutant loads generated under the cost-effective and broad benefits catchment management scenarios, for the period 1889-2022. The management actions included in these scenarios are not predicted to have a large impact on runoff generation or inflows into Lake Tuggeranong; on average, annual inflows to Lake Tuggeranong under the catchment management scenarios were 97-98% of annual inflows under current conditions. However, the annual TP loads entering Lake Tuggeranong were substantially reduced under the catchment management scenarios. Under the cost-effective scenario annual TP loads were on average approximately 67% of annual TP loads under current conditions, and under the broad benefits scenario annual TP loads were on average approximately 56% of annual TP loads under current conditions.

Table 8. Summary statistics describing modelled annual inflow volumes and loads of total phosphorus (TP) entering Lake Tuggeranong under the 'cost-effective and 'broad benefits' catchment management model scenarios, for the period 1889-2022. Compare to the 'current' scenario, Table 6.

Parameter	Modelled scenario	Minimum	25th percentile	Median	Mean	75th percentile	Maximum
Annual inflow (GL)	Cost-effective scenario	2.36	5.29	7.31	8.76	10.27	32.30
Annual inflow (GL)	Broad benefits scenario	2.31	5.22	7.22	8.64	10.15	31.93
Annual TP load (kg)	Cost-effective scenario	236	551	771	992	1,179	4,076
Annual TP load (kg)	Broad benefits scenario	173	441	639	868	1,041	3,877

5. Summary and future model refinements

5.1 Summary

This report has described the data and methods used to parameterise, configure and calibrate the Lake Tuggeranong catchment model. The model was used to explore four scenarios of different catchment land use and management actions, providing long-term mean annual inflows and pollutant loads to Lake Tuggeranong under each scenario.

The catchment model improves on previous modelling work for the Lake Tuggeranong catchment:

- The model simulates flows and pollutant loads across the Lake Tuggeranong catchment on a daily timestep over 133 years of climate data from 1889-2023.
- The model incorporates updated land use and imperviousness layers to simulate runoff and pollutant generation across six functional land use classes.
- The model is delineated to water quality monitoring locations to facilitate parameterisation with concentrations of three pollutants – total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS).
- The model is delineated to existing stormwater treatment infrastructure to facilitate estimates of pollutant load reduction after treatment.
- The model hydrology is calibrated to a gauge immediately downstream of Lake Tuggeranong, with a very good fit between observed and modelled flow.
- The model incorporates recently constructed WSUD infrastructure in the Lake Tuggeranong catchment.
- The model incorporates a storage node representing Lake Tuggeranong, simulating flow and pollutant loads entering and leaving the storage.

Key results of the model include:

- Under current catchment land use and management, the model estimates a mean annual inflow to Lake Tuggeranong of approximately 8.8 GL for the period 1889-2022. Under predevelopment conditions, annual flows are on average 75% lower, with an estimated mean annual flow of approximately 3.3 GL.
- Under current catchment land use and management, the model estimates mean annual pollutant loads entering Lake Tuggeranong of 1,442 kg TP, 11,894 kg TN, and 397,064 kg TSS. Under predevelopment conditions, annual pollutant loads to the lake are on average 85% lower.
- By implementing combinations of catchment management options chosen by the ACT Healthy Waterways program, the model estimates that average annual TP loads to Lake Tuggeranong would be reduced to 868-992 kg, a 33-44% decrease compared to current catchment conditions.
- Land use is the major determinant of simulated subcatchment pollutant loads.

5.2 Future model refinements

The reliability and information provided by the Lake Tuggeranong catchment model could be enhanced by improvements to the data used for subcatchment delineation and calibration, and by undertaking assessments of model uncertainty:

- The calibration of water quality (pollutant) estimates in the model was based on observed median concentrations during event flows, which were the only available water quality data. However, observed pollutant loads provide a more robust framework for calibration in Source. Collecting data on pollutant loads requires simultaneous measures of concentration and flow volume and represents a significant change to the water quality and quantity monitoring currently undertaken in the ACT.
- Incorporating observed flow data from additional gauging stations within the Lake Tuggeranong catchment would enhance model reliability by broadening the data available for hydrological calibration.
- Undertaking an uncertainty estimation for the flows and pollutant loads estimated by the catchment model would provide a quantitative assessment of model reliability. Understanding model uncertainty is important when comparing across modelled scenarios, to ensure that differences are explained by modelled management options rather than measurement/estimation error.
- Understanding uncertainty in the model would also allow identification of areas where more hydrological and/or water quality data could improve the reliability of model estimates.

6. References

ACT Government. (2016). Digital Elevation Model - ACT Elevation Acquisition 2015. Canberra.

Alluvium. (2017). *Development of Source models for the ACT and Region.* Prepared for Environment, Planning and Sustainable Development Directorate, ACT Government, Canberra.

Argent, R. M., Grayson, R. B., Podger, G. M., Rahman, J. M., Seaton, S., & Perraud, J.-M. (2005). E2 - A flexible framework for catchment modelling. In A. Zerger, & R. Argent, *MODSIM 2005 International Congress on Modelling and Simulation* (pp. 594-600). Melbourne, Victoria: Modelling and Simulation Society of Australia and New Zealand.

Beer, T., Young, P. C., Humphries, R. B., & Burgess, J. S. (1982). *Environmental water quality - a systems study in Tuggeranong Creek and Kambah Pool.* Canberra: ANU Press.

Blacktown City Council. (2020). *Water sensitive urban design (WSUD) developer handbook - MUSIC modelling and design guide.* Blacktown, NSW.

Booksmythe, I., Dey, S., Kahn, A., Stewart, J., & Starrs, D. (2024). *Lake Tuggeranong Catchment Management Options Assessment: Technical report supporting the Lake Tuggeranong Healthy Waterways Plan.* Report to the ACT Healthy Waterways Program, ACT Government, Canberra.

eWater Ltd. (2019). *The rebuilding and calibration of Source model for the ACT and upper Murrumbidgee.* Prepared for Environment, Planning and Sustainable Development Directorate, ACT Government, Canberra.

eWater Ltd. (2022). *Lake Tuggeranong Modelling v1.0.* Prepared for Environment, Planning and Sustainable Development Directorate, ACT Government, Canberra.

Fletcher, T., Duncan, H., Poelsma, P., & Lloyd, S. (2004). *Stormwater flow and quality, and the effectiveness of non-proprietary stormwater treatment measures - A review and gap analysis.* Melbourne: Cooperative Research Centre for Catchment Hydrology, Monash University.

GHD. (2015). *Basin Priority Project water quality monitoring framework - Lake Tuggeranong catchment.* Prepared for Environment, Planning and Sustainable Development Directorate, ACT Government, Canberra.

Kahn, A., & Dey, S. (2024). *Predicting phosphorus concentration and trophic state of Lake Tuggeranong: Technical report supplement to the Lake Tuggeranong Catchment Model.* Report to the ACT Healthy Waterways Program, ACT Government, Canberra.

Melbourne Water. (2024). *MUSIC (Model for Urban Stormwater Improvement Conceptualisation) Guideline.* Report to Victorian State Government, Melbourne.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the American Society of Agricultural and Biological Engineers, 50*, 885-900.

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part 1 - a discussion of principles. *Journal of Hydrology, 10*, 282-290.

NSW Department of Environment and Conservation. (2004). *Environmental Guidelines: Use of effluent by irrigation.* Sydney: NSW Government.

Ubrihien, R., Dyer, F., O'Connell, J., Tschierschke, A., Morcom, R., Cross, Y., . . . Clear, R. (2020). *Lake Tuggeranong Research Project Report: Stage 3.* Prepared for Environment, Planning and Sustainable Development Directorate, ACT Government, Canberra.

Witt, C., Mainwright, M., & Weber, T. (2015). *NSW MUSIC Modelling Guidelines.* Report to NSW Government Local Land Services, Sydney: BMT WBM Pty Ltd.

Appendices

Appendix A: Level-volume-area data for Lake Tuggeranong

To configure the Lake Tuggeranong storage node in the catchment model requires information on the relationship between the water level and volume of the lake. Figure A1 shows the stage-volume rating curve used in configuring the Lake Tuggeranong storage node in the model. The level-volume-area (LVA) relationship for Lake Tuggeranong was derived from bathymetry data collected by Steger and Associates Registered Land Surveyors in 2015, presented in Table A1.

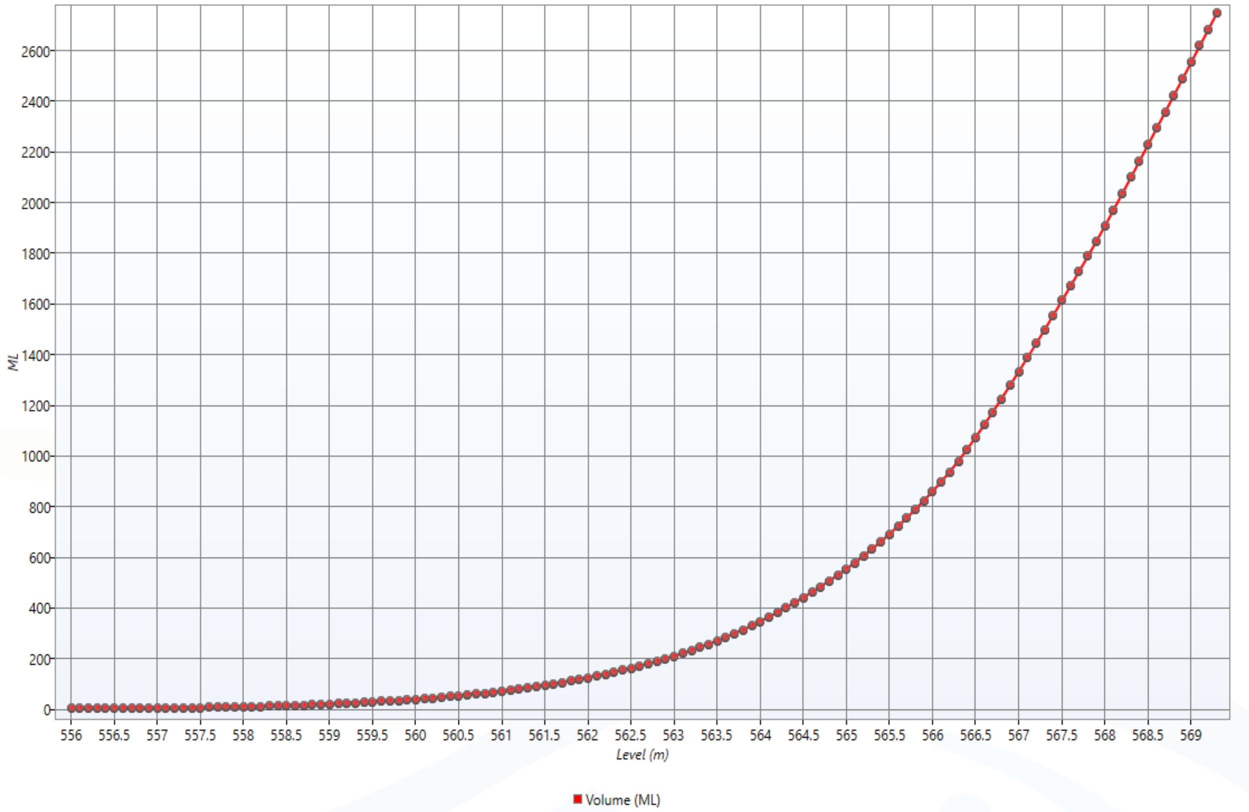

Figure A1. Water level - volume ratings curve for Lake Tuggeranong (gauge 410784) derived from bathymetry data (see Table A1). Source: Steger and Associates Registered Land Surveyors, 2015.

Table A1. Lake Tuggeranong water level, volume, and surface area data. Source: Steger and Associates Registered Land Surveyors, 2015.

Level (m)	Volume (ML)	Surface area (km^2)	Level (m)	Volume (ML)	Surface area (km^2)	Level (m)	Volume (ML)	Surface area (km^2)
556.0	0	0	558.4	10.1361	0.009721	560.8	60.19836	0.035167
556.1	0.014874	0.000119	558.5	11.18874	0.010526	560.9	63.92854	0.037302
556.2	0.036423	0.000215	558.6	12.31101	0.011223	561.0	67.9121	0.039836
556.3	0.072831	0.000364	558.7	13.49978	0.011888	561.1	72.14851	0.042364
556.4	0.122048	0.000492	558.8	14.76326	0.012635	561.2	76.63992	0.044914
556.5	0.222146	0.001001	558.9	16.10082	0.013376	561.3	81.38454	0.047446
556.6	0.374086	0.001519	559.0	17.52169	0.014209	561.4	86.36409	0.049795
556.7	0.570277	0.001962	559.1	19.02266	0.01501	561.5	91.56732	0.052032
556.8	0.808589	0.002383	559.2	20.60679	0.015841	561.6	97.00797	0.054406
556.9	1.104417	0.002958	559.3	22.27321	0.016664	561.7	102.6982	0.056902
557.0	1.442882	0.003385	559.4	24.02014	0.017469	561.8	108.6627	0.059645
557.1	1.824143	0.003813	559.5	25.84861	0.018285	561.9	114.8979	0.062353
557.2	2.241786	0.004176	559.6	27.79639	0.019478	562.0	121.405	0.065071
557.3	2.690724	0.004489	559.7	29.85126	0.020549	562.1	128.2425	0.068375
557.4	3.16953	0.004788	559.8	32.00766	0.021564	562.2	135.4093	0.071668
557.5	3.677818	0.005083	559.9	34.26355	0.022559	562.3	142.8931	0.074838
557.6	4.218615	0.005408	560.0	36.62414	0.023606	562.4	150.7054	0.078123
557.7	4.79095	0.005723	560.1	39.09346	0.024693	562.5	158.8814	0.08176
557.8	5.397505	0.006066	560.2	41.67477	0.025813	562.6	167.4558	0.085744
557.9	6.045165	0.006477	560.3	44.38028	0.027055	562.7	176.4338	0.08978
558.0	6.744306	0.006991	560.4	47.21816	0.028379	562.8	185.8594	0.094256
558.1	7.488318	0.00744	560.5	50.20973	0.029916	562.9	195.7887	0.099293
558.2	8.290076	0.008018	560.6	53.35829	0.031486	563.0	206.241	0.104523
558.3	9.164035	0.00874	560.7	56.6817	0.033234	563.1	217.2403	0.109993

Level (m)	Volume (ML)	Surface area (km²)
563.2	228.7825	0.115422
563.3	240.9099	0.121274
563.4	253.6379	0.12728
563.5	266.9702	0.133322
563.6	280.9174	0.139472
563.7	295.4839	0.145666
563.8	310.6996	0.152156
563.9	326.6404	0.159409
564.0	343.3933	0.167529
564.1	360.9095	0.175162
564.2	379.1175	0.18208
564.3	398.0267	0.189093
564.4	417.6585	0.196317
564.5	437.9539	0.202954
564.6	458.8675	0.209136
564.7	480.4328	0.215652
564.8	502.7146	0.222818
564.9	525.8767	0.231621
565.0	549.963	0.240863
565.1	575.1935	0.252304
565.2	601.5961	0.264027

Level (m)	Volume (ML)	Surface area (km²)
565.3	629.1803	0.275842
565.4	657.9845	0.288043
565.5	687.9878	0.300033
565.6	719.1112	0.311234
565.7	751.5013	0.323901
565.8	785.1463	0.336449
565.9	820.0771	0.349308
566.0	856.4557	0.363786
566.1	894.2724	0.378167
566.2	934.0697	0.397974
566.3	976.8441	0.427744
566.4	1022.38	0.455357
566.5	1070.137	0.477574
566.6	1119.482	0.493452
566.7	1170.426	0.509434
566.8	1222.593	0.521672
566.9	1275.738	0.531451
567.0	1329.908	0.541698
567.1	1384.869	0.549609
567.2	1440.435	0.555666
567.3	1496.534	0.56099

Level (m)	Volume (ML)	Surface area (km²)
567.4	1553.159	0.566248
567.5	1610.312	0.571526
567.6	1668.006	0.576945
567.7	1726.277	0.582703
567.8	1785.19	0.589135
567.9	1844.844	0.596536
568.0	1906.38	0.615362
568.1	1968.905	0.625256
568.2	2032.357	0.634518
568.3	2096.546	0.641889
568.4	2161.172	0.646257
568.5	2226.008	0.648362
568.5	2226.008	0.648362
568.6	2290.955	0.649472
568.7	2355.947	0.649921
568.8	2420.965	0.650178
568.9	2485.993	0.650283
569.0	2551.028	0.650344
569.1	2616.068	0.650402
569.2	2681.113	0.650454
569.3	2746.163	0.650495

Appendix B: Level – discharge data for Lake Tuggeranong outflow

The Lake Tuggeranong outflow was configured as an ungated spillway in the Source model, using the level-discharge relationship from Lake Tuggeranong weir (gauge 410784), presented in Table B1.

Table B1. Lake Tuggeranong weir rating table. *Source: ALS Pty Ltd.*

Level (m)	Discharge (ML/d)	Level (m)	Discharge (ML/d)	Level (m)	Discharge (ML/d)	Level (m)	Discharge (ML/d)
0	0	568.14	740.448	568.43	3957.12	568.72	9072
567.86	0	568.15	809.568	568.44	4121.28	568.73	9244.8
567.87	1.08	568.16	881.28	568.45	4285.44	568.74	9417.6
567.88	6.10848	568.17	959.04	568.46	4458.24	568.75	9676.8
567.89	16.848	568.18	1036.8	568.47	4631.04	568.76	9849.6
567.90	34.56	568.19	1123.2	568.48	4812.48	568.77	10022.4
567.91	41.2992	568.20	1209.6	568.49	4993.92	568.78	10281.6
567.92	48.816	568.21	1296	568.50	5184	568.79	10454.4
567.93	57.1104	568.22	1382.4	568.51	5339.52	568.80	10713.6
567.94	66.096	568.23	1468.8	568.52	5503.68	568.81	10886.4
567.95	76.032	568.24	1563.84	568.53	5667.84	568.82	11059.2
567.96	86.4	568.25	1667.52	568.54	5840.64	568.83	11318.4
567.97	98.496	568.26	1771.2	568.55	6013.44	568.84	11491.2
567.98	110.592	568.27	1874.88	568.56	6186.24	568.85	11664
567.99	124.416	568.28	1978.56	568.57	6359.04	568.86	11923.2
568.00	138.24	568.29	2090.88	568.58	6540.48	568.87	12096
568.01	162.432	568.30	2211.84	568.59	6721.92	568.88	12355.2
568.02	189.216	568.31	2324.16	568.60	6912	568.89	12528
568.03	219.456	568.32	2436.48	568.61	7076.16	568.90	12700.8
568.04	251.424	568.33	2557.44	568.62	7240.32	568.91	12960
568.05	285.984	568.34	2678.4	568.63	7404.48	568.92	13132.8
568.06	323.136	568.35	2808	568.64	7577.28	568.93	13392
568.07	362.88	568.36	2937.6	568.65	7750.08	568.94	13564.8
568.08	406.08	568.37	3067.2	568.66	7922.88	568.95	13824
568.09	451.872	568.38	3205.44	568.67	8095.68	568.96	13996.8
568.10	501.12	568.39	3343.68	568.68	8277.12	568.97	14256
568.11	555.552	568.40	3490.56	568.69	8458.56	568.98	14428.8
568.12	613.44	568.41	3646.08	568.70	8640	568.99	14601.6
568.13	675.648	568.42	3801.6	568.71	8812.8		

Appendix C: Land use and imperviousness classification

Table C1 lists the detailed land use classifications included in each of the six functional land use units defined for the Lake Tuggeranong catchment. Table C2 provides a breakdown of the major and minor subcatchments delineated in the Source catchment model, and Figure C1 shows a map of the major subcatchments. Table C3 provides the subcatchment area breakdown in hectares and area ratio based on land use functional units used in the catchment model.

Table C1. Detailed land use classifications based on ACT Government land zoning grouped into 6 functional units for use in the catchment model.

ACT land zoning	Functional unit
Business zone	commercial
Community Facilities	commercial
Core zone	commercial
Leisure and accommodation	commercial
Local centre	commercial
Services	commercial
Services zone	commercial
Medium density residential	suburban
Suburban	suburban
Suburban core	suburban
Transport	open space
Urban open space	open space
Restricted access recreation zone	open space
Hills ridges and buffer areas	bushland
Designated	bushland
River corridor	bushland
Rural	rural
Sports field (estimated)	sports field

Table C2. Major subcatchments of the Lake Tuggeranong catchment and their component minor subcatchments delineated in the Source catchment model.

Major subcatchment	Minor subcatchments
Village Creek (VC)	VC0, VC1, VC2, VC3, VC4, VC6, VC7, VC8, VC9, VC10, VC11
Kambah Creek (KC)	KC0, KC1, KC2, KC3, KC4, KC5, KC6, KC7
Tuggeranong Creek (TC)	TC0, TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC6_NSW, TC8_NSW
Lake Tuggeranong (Lake T)	
East Lake (EL)	EL1, EL2
West Lake (WL)	WL0, WL1, WL2, WL3, WL4, WL5, WL6, WL7, WL8, WL9, WL10, WL11
Downstream of Lake Tuggeranong (DSL)	DSL1, DSL2
Drakeford Drive South (DDS)	DDS1, DDS2
(DLC)	DLC_N, DLC_S
Stranger Pond (SP)	SP1, SP2
Wanniassa (WS)	WS0, WS1, WS2, WS3, WS4
Fadden stormwater (FA)	FA0, FA1, FA2, FA3, FA5, FA6, FA7, FA8, FA9, FA10, FA11, FA12, FA13, FA14, FA15, FA16, FA17, FA9_NSW

Fig. C1. Map of Lake Tuggeranong catchment showing major subcatchment boundaries. VC, Village Creek; KC, Kambah Creek; WS, Wanniassa; FA, Fadden stormwater; TC, Tuggeranong Creek; DSL, Downstream of Lake Tuggeranong; Lake T, Lake Tuggeranong; DLC, XXX; WL, West Lake; EL, East Lake; DDS, Drakeford Drive South; SP, Stranger Pond.

Table C3. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	VC0 (ha)	VC0 (%)	VC1 (ha)	VC1 (%)	VC2 (ha)	VC2 (%)	VC3 (ha)	VC3 (%)	VC4 (ha)	VC4 (%)	VC6 (ha)	VC6 (%)
Commercial road	1.16654	1.28342	0.55272	1.45670	0.06191	0.06184	0.00053	0.00081	0.00000	0.00000	0.52402	2.40107
Commercial hardstand	2.96745	3.26478	3.54531	9.34381	0.09628	0.09617	0.75895	1.17555	0.72954	0.59131	1.30516	5.98024
Commercial roof	3.62099	3.98381	3.96793	10.45763	0.40466	0.40420	0.96058	1.48785	0.96820	0.78476	1.85026	8.47786
Commercial pervious	3.42116	3.76396	2.91630	7.68602	0.33240	0.33202	2.63463	4.08081	1.87153	1.51694	1.60472	7.35280
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	3.73592	4.11026	1.45375	3.83141	5.77357	5.76696	3.69303	5.72018	6.43127	5.21276	0.40714	1.86552
Suburban hardstand	5.17332	5.69168	1.37583	3.62604	5.56696	5.56059	2.89318	4.48128	5.92845	4.80520	0.73999	3.39064
Suburban roof	17.15034	18.86877	4.56512	12.03155	22.63823	22.61229	11.73104	18.17036	22.69013	18.39110	2.30035	10.54015
Suburban pervious	29.87385	32.86716	7.64501	20.14873	38.47253	38.42845	20.42040	31.62942	36.44461	29.53956	2.69231	12.33615
Suburban water	0	0	0	0	0.01395	0.01393	2.50E-05	3.87E-05	0.00095	0.00077	0	0
Open space road	4.47567	4.92413	2.24256	5.91036	4.15447	4.14971	2.77265	4.29460	4.04727	3.28044	1.83831	8.42312
Open space hardstand	1.61398	1.77570	0.76704	2.02155	2.45150	2.44869	1.30548	2.02207	3.76469	3.05140	0.72845	3.33773
Open space roof	0.20061	0.22071	0.07460	0.19661	0.48495	0.48439	0.25650	0.39730	0.80075	0.64903	0.14520	0.66532
Open space pervious	14.24994	15.67776	8.83674	23.28958	12.97204	12.95718	16.26664	25.19562	29.51479	23.92272	7.48905	34.31473
Open space water	0.03960	0.04357	0	0	0	0	0	0	0	0	0.19962	0.91466
Bushland road	0	0	0	0	0	0	0	0	0	0	0	0
Bushland hardstand	0.04743	0.05218	0	0	0.24205	0.24177	0	0	0	0	0	0
Bushland roof	0.00363	0.00399	0	0	0.00097	0.00097	0	0	0	0	0	0
Bushland pervious	3.15228	3.46813	0	0	6.44823	6.44084	0	0	0	0	0	0
Bushland water	0	0	0	0	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	0	0	0.86778	1.34411	10.18341	8.25399	0	0
Total subcatchment area	90.89270	100	37.94290	100	100.11470	100	64.56140	100	123.37560	100	21.82460	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	VC7 (ha)	VC7 (%)	VC8 (ha)	VC8 (%)	VC9 (ha)	VC9 (%)	VC10 (ha)	VC10 (%)	VC11 (ha)	VC11 (%)	Lake T (ha)	Lake T (%)
Commercial road	0	0	0	0	0.01835	0.00688	0	0	0	0	0	0
Commercial hardstand	0	0	0	0	1.02446	0.38388	1.19452	0.64653	0	0	0	0
Commercial roof	0	0	0	0	0.62828	0.23543	1.79132	0.96955	0	0	0	0
Commercial pervious	0	0	0	0	2.96747	1.11196	4.26940	2.31081	0	0	0	0
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	0.31054	9.59627	0.00158	0.03398	5.07906	1.90321	10.61841	5.74720	2.75089	3.36567	0	0
Suburban hardstand	0.24232	7.48839	0.00455	0.09815	3.93032	1.47275	6.24872	3.38211	1.53092	1.87306	0	0
Suburban roof	0.71997	22.24891	0.00000	0.00000	17.65425	6.61534	29.89265	16.17935	8.30131	10.15654	0	0
Suburban pervious	1.00224	30.97160	0.09433	2.03477	29.37379	11.00684	51.34650	27.79122	16.30805	19.95268	0	0
Suburban water	0	0	0	0	0	0	0	0	2.50E-05	3.06E-05	0	0
Open space road	0.01912	0.59088	0.73261	15.80361	9.13640	3.42356	3.42844	1.85564	0.08557	0.10470	0.16068	0.22103
Open space hardstand	0.07169	2.21524	0.14298	3.08425	4.31557	1.61712	2.79452	1.51253	0.16162	0.19775	0.31379	0.43165
Open space roof	0.01592	0.49202	0.02103	0.45355	0.45775	0.17152	0.31814	0.17220	0.01235	0.01511	0.30226	0.41579
Open space pervious	0.85420	26.39669	3.63864	78.49169	44.29813	16.59923	34.55149	18.70095	5.38125	6.58389	2.76054	3.79745
Open space water	0	0	0	0	0.17846	0.06687	0	0	0	0	69.15733	95.13407
Bushland road	0	0	0	0	3.77569	1.41481	0.43221	0.23393	1.15907	1.41811	0	0
Bushland hardstand	0	0	0	0	1.75254	0.65671	0.10256	0.05551	0.23837	0.29165	0	0
Bushland roof	0	0	0	0	0.24923	0.09339	0.00665	0.00360	0.11275	0.13795	0	0
Bushland pervious	0	0	0	0	142.00602	53.21198	30.50463	16.51058	45.69143	55.90287	0	0
Bushland water	0	0	0	0	0.02273	0.00852	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	0	0	7.25782	3.92829	0	0	0	0
Total subcatchment area	3.23600	100	4.63570	100	266.86850	100	184.75800	100	81.73360	100	72.69460	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	KC0 (ha)	KC0 (%)	KC1 (ha)	KC1 (%)	KC2 (ha)	KC2 (%)	KC3 (ha)	KC3 (%)	KC4 (ha)	KC4 (%)	KC5 (ha)	KC5 (%)
Commercial road	0	0	0	0	0	0	0	0	0	0	0.22272	0.32619
Commercial hardstand	0.23590	0.18352	0.10135	0.12613	0.11103	0.12613	0.00800	0.12613	0.00045	0.02089	1.68770	2.47178
Commercial roof	0.46683	0.36317	0.10200	0.12693	0.11174	0.12693	0.00805	0.12693	0.00003	0.00116	1.91152	2.79958
Commercial pervious	0.80327	0.62490	0.02740	0.03410	0.03002	0.03410	0.00216	0.03410	0.01793	0.83192	2.24089	3.28197
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	7.27826	5.66213	6.20275	7.71915	6.79539	7.71915	0.48981	7.71915	0.00000	0.00000	4.54340	6.65420
Suburban hardstand	7.37201	5.73507	5.85418	7.28537	6.41351	7.28537	0.46229	7.28537	0.02456	1.13940	4.10095	6.00621
Suburban roof	28.02338	21.80082	19.67904	24.49003	21.55926	24.49003	1.55399	24.49003	0.15034	6.97445	14.86127	21.76563
Suburban pervious	45.12123	35.10210	33.59659	41.81005	36.80656	41.81005	2.65302	41.81005	0.19061	8.84250	26.44537	38.73156
Suburban water	0	0	0	0	0	0	0	0	5.00E-05	0.00232	2.50E-05	3.66E-05
Open space road	6.75730	5.25685	2.59264	3.22647	2.84036	3.22647	0.20473	3.22647	0.00375	0.17404	2.08079	3.04750
Open space hardstand	2.98208	2.31991	1.45161	1.80649	1.59030	1.80649	0.11463	1.80649	0.41023	19.03093	1.24580	1.82459
Open space roof	0.23348	0.18164	0.19942	0.24818	0.21848	0.24818	0.01575	0.24818	0.06228	2.88910	0.11700	0.17135
Open space pervious	29.18828	22.70705	10.54832	13.12710	11.55616	13.12710	0.83297	13.12710	1.29149	59.91344	8.08024	11.83421
Open space water	0.01618	0.01258	0	0	0	0	0	0	0	0	0	0
Bushland road	0	0	0	0	0	0	0	0	0	0	0	0
Bushland hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Bushland roof	0	0	0	0	0	0	0	0	0	0	0	0
Bushland pervious	0	0	0	0	0	0	0	0	0	0	0	0
Bushland water	0	0	0	0	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	0	0	0	0	0.00388	0.17984	0.74094	1.08517
Total subcatchment area	128.54280	100	80.35530	100	88.03280	100	6.34540	100	2.15560	100	68.27860	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	KC6 (ha)	KC6 (%)	KC7 (ha)	KC7 (%)	SP1 (ha)	SP1 (%)	SP2 (ha)	SP2 (%)	EL1 (ha)	EL1 (%)	EL2 (ha)	EL2 (%)
Commercial road	0	0	0	0	0.34455	0.09473	0.25623	0.65596	0	0	0.1566	0.8058
Commercial hardstand	0.06448	0.04990	0	0	2.55082	0.70133	0.34418	0.88112	0	0	0.7782	4.0044
Commercial roof	0.08659	0.06701	0	0	2.85592	0.78521	1.33480	3.41714	0	0	1.1017	5.6688
Commercial pervious	0.00426	0.00329	0	0	8.95477	2.46205	1.59170	4.07482	0	0	1.6979	8.7366
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	6.73670	5.21343	0	0	16.71164	4.59474	0.75529	1.93357	1.96217	3.10053	0	0
Suburban hardstand	6.08694	4.71059	0	0	21.71844	5.97132	2.18503	5.59379	5.25066	8.29684	0	0
Suburban roof	23.68161	18.32684	0	0	73.29687	20.15242	5.26468	13.47782	7.70244	12.17103	0.00198	0.01016
Suburban pervious	41.86302	32.39716	0	0	102.74356	28.24856	5.68414	14.55165	10.69712	16.90309	0.03886	0.19994
Suburban water	0	0	0	0	0.00210	0.00058	0	0	0	0	0	0
Open space road	5.30084	4.10224	2.16018	0.69905	12.17165	3.34650	1.47995	3.78873	1.76602	2.79058	1.38581	7.13058
Open space hardstand	2.65729	2.05644	2.24234	0.72564	5.34020	1.46825	1.23752	3.16811	2.27993	3.60263	0.97812	5.03284
Open space roof	0.16133	0.12485	0.10101	0.03269	0.58110	0.15977	0.09868	0.25262	0.39105	0.61793	0.08547	0.43977
Open space pervious	38.37112	29.69483	13.61355	4.40542	58.24083	16.01287	12.63747	32.35250	32.93501	52.04237	12.78198	65.76885
Open space water	0	0	0	0	0	0	4.32094	11.06181	0.30060	0.47500	0.06847	0.35228
Bushland road	0	0	6.17691	1.99888	0.86652	0.23824	0	0	0	0	0	0
Bushland hardstand	0.00225	0.00174	2.42975	0.78628	0.74172	0.20393	0	0	0	0	0	0
Bushland roof	0.00093	0.00072	1.47904	0.47863	0.70985	0.19517	0	0	0	0	0	0
Bushland pervious	4.20082	3.25095	280.72872	90.84543	52.08091	14.31925	0	0	0	0	0	0
Bushland water	0	0	0.08650	0.02799	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	3.80112	1.04509	1.87120	4.79037	0	0	0.35953	1.84994
Total subcatchment area	129.21820	100	309.01800	100	363.71260	100	39.06180	100	63.28500	100	19.43470	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	WL0 (ha)	WL0 (%)	WL1 (ha)	WL1 (%)	WL2 (ha)	WL2 (%)	WL3 (ha)	WL3 (%)	WL4 (ha)	WL4 (%)	WL5 (ha)	WL5 (%)
Commercial road	4.3703	7.9703	0.8347	3.1681	1.0011	6.7299	0	0	0.62984	11.02963	0	0
Commercial hardstand	11.5970	21.1500	6.8472	25.9884	1.2159	8.1740	0.00085	0.01072	2.13908	37.45934	0	0
Commercial roof	25.6801	46.8340	5.6090	21.2888	4.2901	28.8403	0.00085	0.01072	1.99816	34.99153	0	0
Commercial pervious	4.4233	8.0669	3.4839	13.2230	2.1629	14.5404	0.00355	0.04478	0.60119	10.52793	0.13435	2.80000
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	0	0	0.01252	0.04754	0	0	0	0	0	0	0	0
Suburban hardstand	0	0	0.10727	0.40713	0	0	0	0	0	0	0	0
Suburban roof	0	0	0.09979	0.37877	0	0	0	0	0	0	0	0
Suburban pervious	0	0	0.23981	0.91019	0	0	0	0	0	0	0	0
Suburban water	0	0	0	0	0	0	0	0	0	0	0	0
Open space road	3.84955	7.02060	3.52733	13.38791	2.07414	13.94361	0.01007	0.12708	0.00397	0.06961	0.76260	15.89337
Open space hardstand	2.01038	3.66643	0.97456	3.69894	1.33538	8.97721	0.81178	10.24202	0.06327	1.10804	0.59875	12.47873
Open space roof	0.65246	1.18991	0.17189	0.65240	0.72916	4.90187	0.14906	1.88065	0.04205	0.73636	0.43773	9.12289
Open space pervious	2.24307	4.09078	4.41994	16.77583	2.06527	13.88395	6.94281	87.59543	0.22977	4.02371	2.82017	58.77550
Open space water	0.00605	0.01103	0.01925	0.07306	0	0	0.00702	0.08861	0.00307	0.05385	0.00874	0.18216
Bushland road	0	0	0	0	0	0	0	0	0	0	0	0
Bushland hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Bushland roof	0	0	0	0	0	0	0	0	0	0	0	0
Bushland pervious	0	0	0	0	0.00130	0.00874	0	0	0	0	0.03586	0.74736
Bushland water	0	0	0	0	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	0	0	0	0	0	0	0	0
Total subcatchment area	54.83220	100	26.34710	100	14.87520	100	7.92600	100	5.71040	100	4.79820	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	WL6 (ha)	WL6 (%)	WL7 (ha)	WL7 (%)	WL8 (ha)	WL8 (%)	WL9 (ha)	WL9 (%)	WL10 (ha)	WL10 (%)	WL11 (ha)	WL11 (%)
Commercial road	0.22090	9.12689	0.48320	9.59071	0.10770	9.94735	0	0	0.00152	0.00688	0.00052	0.00688
Commercial hardstand	0.75873	31.34842	0.70091	13.91191	0.09505	8.77898	0.09312	8.05055	0.08472	0.38388	0.02891	0.38388
Commercial roof	1.34172	55.43604	1.17561	23.33390	0.22848	21.10234	0.28581	24.70893	0.05195	0.23543	0.01773	0.23543
Commercial pervious	0.07700	3.18144	0.66586	13.21619	0.21683	20.02632	0.09627	8.32271	0.24539	1.11196	0.08373	1.11196
Commercial water	0.00003	0.00103	0.01950	0.38706	0	0	0	0	0	0	0	0
Suburban road	0	0	0	0	0	0	0	0	0.42001	1.90321	0.14331	1.90321
Suburban hardstand	0	0	0	0	0	0	0	0	0.32501	1.47275	0.11090	1.47275
Suburban roof	0	0	0	0	0	0	0	0	1.45989	6.61534	0.49813	6.61534
Suburban pervious	0	0	0	0	0	0	0	0	2.42902	11.00684	0.82882	11.00684
Suburban water	0	0	0	0	0	0	0	0	0	0	0	0
Open space road	0	0	0.00018	0.00347	0.09565	8.83440	0	0	0.75552	3.42356	0.25779	3.42356
Open space hardstand	0.01015	0.41951	0.59345	11.77910	0.07803	7.20652	0.22165	19.16190	0.35687	1.61712	0.12177	1.61712
Open space roof	0.00730	0.30172	0.15618	3.09997	0.03780	3.49127	0.12877	11.13295	0.03785	0.17152	0.01292	0.17152
Open space pervious	0.00448	0.18496	1.22931	24.39981	0.19978	18.45156	0.30532	26.39594	3.66317	16.59923	1.24992	16.59923
Open space water	0	0	0.01400	0.27789	0.02340	2.16126	0.02576	2.22702	0.01476	0.06687	0.00504	0.06687
Bushland road	0	0	0	0	0	0	0	0	0.31222	1.41481	0.10654	1.41481
Bushland hardstand	0	0	0	0	0	0	0	0	0.14492	0.65671	0.04945	0.65671
Bushland roof	0	0	0	0	0	0	0	0	0.02061	0.09339	0.00703	0.09339
Bushland pervious	0	0	0	0	0	0	0	0	11.74298	53.21198	4.00686	53.21198
Bushland water	0	0	0	0	0	0	0	0	0.00188	0.00852	0.00064	0.00852
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	0	0	0	0	0	0	0	0
Total subcatchment area	2.42030	100	5.03820	100	1.08270	100	1.15670	100	22.06830	100	7.53000	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	DDS1 (ha)	DDS1 (%)	DDS2 (ha)	DDS2 (%)	DSL1 (ha)	DSL1 (%)	DSL2 (ha)	DSL2 (%)	DLC N (ha)	DLC N (%)	DLC S (ha)	DLC S (%)
Commercial road	0	0	0	0	0	0	0	0	0	0	0	0
Commercial hardstand	0	0	0	0	0.00817	0.01807	0	0	0	0	0.08175	0.12357
Commercial roof	0	0	0	0	0.00840	0.01857	0	0	0	0	0.14145	0.21382
Commercial pervious	0	0	0	0	6.11195	13.52072	0	0	0	0	0.03060	0.04626
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	0.89352	7.67025	1.04632	3.69542	0	0	0	0	0.25714	8.61201	3.97777	6.01283
Suburban hardstand	0.63470	5.44849	2.06447	7.29133	0	0	0	0	0.35156	11.77441	5.04227	7.62195
Suburban roof	1.85668	15.93838	4.99336	17.63565	0	0	0	0	1.31517	44.04747	15.13896	22.88422
Suburban pervious	3.18648	27.35385	5.69499	20.11369	0	0	0	0	0.74893	25.08312	22.82264	34.49895
Suburban water	0	0	0	0	0	0	0	0	0	0	0	0
Open space road	0.74070	6.35840	3.08179	10.88433	0	0	0	0	0	0	3.06436	4.63212
Open space hardstand	0.10360	0.88930	1.21974	4.30791	0.00737	0.01631	0.00040	0.00118	0.02711	0.90785	1.28473	1.94201
Open space roof	0.02935	0.25194	0.11342	0.40059	0.00070	0.00155	0	0	0.00355	0.11892	0.17930	0.27103
Open space pervious	4.20409	36.08938	10.09991	35.67110	0.25166	0.55672	0.09442	0.27857	0.28234	9.45621	14.39076	21.75323
Open space water	0	0	0	0	0	0	0	0	0	0	0	0
Bushland road	0	0	0	0	0	0	0	0	0	0	0	0
Bushland hardstand	0	0	0	0	0.65479	1.44850	0.28300	0.83498	0	0	0	0
Bushland roof	0	0	0	0	0.05969	0.13205	0.00107	0.00317	0	0	0	0
Bushland pervious	0	0	0	0	37.96401	83.98318	33.51431	98.88211	0	0	0	0
Bushland water	0	0	0	0	0.13757	0.30434	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	0	0	0	0	0	0	0	0
Total subcatchment area	11.64910	100	28.31400	100	45.20430	100	33.89320	100	2.98580	100	66.15460	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	TC0 (ha)	TC0 (%)	TC1 (ha)	TC1 (%)	TC2 (ha)	TC2 (%)	TC3 (ha)	TC3 (%)	TC4 (ha)	TC4 (%)	TC5 (ha)	TC5 (%)
Commercial road	0.58272	0.22654	0	0	0.32153	0.12952	0.06495	0.12948	0.06495	0.12948	0.33632	0.09282
Commercial hardstand	6.51431	2.53251	0	0	1.28484	0.51756	0.77034	1.53569	0.77034	1.53569	3.38792	0.93498
Commercial roof	7.38043	2.86922	0	0	1.32700	0.53454	0.64949	1.29477	0.64949	1.29477	3.90561	1.07785
Commercial pervious	17.78314	6.91338	0	0	32.92973	13.26479	2.22145	4.42849	2.22145	4.42849	9.11530	2.51558
Commercial water	0	0	0	0	0.05460	0.02199	0	0	0	0	0	0
Suburban road	10.77831	4.19018	0.73186	6.26525	12.30299	4.95590	2.64384	5.27054	2.64384	5.27054	12.01325	3.31534
Suburban hardstand	13.56212	5.27241	1.15220	9.86371	14.49177	5.83759	3.18411	6.34758	3.18411	6.34758	12.88176	3.55503
Suburban roof	49.75319	19.34207	3.12461	26.74904	46.70982	18.81570	11.68760	23.29944	11.68760	23.29944	47.17029	13.01776
Suburban pervious	55.40174	21.53800	3.50165	29.97680	72.67577	29.27533	14.37982	28.66642	14.37982	28.66642	77.11695	21.28225
Suburban water	7.51E-05	2.92E-05	0	0	2.51E-05	1.01E-05	0	0	0	0	0.00033	8.97E-05
Open space road	10.01014	3.89155	0	0	5.67404	2.28562	2.44259	4.86935	2.44259	4.86935	6.28860	1.73549
Open space hardstand	6.52754	2.53765	0.53100	4.54575	4.94635	1.99249	1.51306	3.01630	1.51306	3.01630	5.23212	1.44393
Open space roof	0.72237	0.28083	0.00733	0.06271	0.39423	0.15880	0.12290	0.24500	0.12290	0.24500	0.85361	0.23557
Open space pervious	46.04883	17.90196	2.63256	22.53675	49.70804	20.02344	10.34895	20.63080	10.34895	20.63080	50.24425	13.86609
Open space water	0.52547	0.20428	0	0	0	0	0	0	0	0	0	0
Bushland road	0	0	0	0	0	0	0	0	0	0	3.29003	0.90796
Bushland hardstand	0	0	0	0	0	0	0	0	0	0	0.86734	0.23936
Bushland roof	0	0	0	0	0	0	0	0	0	0	0.11853	0.03271
Bushland pervious	0	0	0	0	4	2	0	0	0	0	116.54473	32.16329
Bushland water	0	0	0	0	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	30.00000	11.66281	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	1.63753	0.63661	0	0	1.16687	0.47004	0.13350	0.26613	0.13350	0.26613	12.98638	3.58390
Total subcatchment area	257.22790	100	11.68120	100	248.24920	100	50.16260	100	50.16260	100	362.35330	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	TC6 (ha)	TC6 (%)	TC7 (ha)	TC7 (%)	TC6 NSW (ha)	TC6 NSW (%)	TC8 NSW (ha)	TC8 NSW (%)
Commercial road	0	0	0	0	0	0	0	0
Commercial hardstand	0	0	0	0	0	0	0	0
Commercial roof	0	0	0	0	0	0	0	0
Commercial pervious	0	0	0	0	0	0	0	0
Commercial water	0	0	0	0	0	0	0	0
Suburban road	0	0	0	0	0	0	0	0
Suburban hardstand	0.00375	0.00369	0	0	0	0	0	0
Suburban roof	0.00153	0.00150	0	0	0	0	0	0
Suburban pervious	0.00685	0.00674	0	0	0	0	0	0
Suburban water	0	0	0	0	0	0	0	0
Open space road	0.20877	0.20533	0.04334	0.00706	0	0	0	0
Open space hardstand	0.07513	0.07389	0.03677	0.00599	0	0	0	0
Open space roof	0.01225	0.01205	0.00597	0.00097	0	0	0	0
Open space pervious	4.06725	4.00025	0.25709	0.04191	0.00258	0.02625	2.64149	0.31220
Open space water	0	0	0	0	0	0	0	0
Bushland road	6.02788	5.92859	6.56298	1.06977	0	0	0	0
Bushland hardstand	0.71094	0.69923	1.62155	0.26431	0	0	0	0
Bushland roof	0.27050	0.26604	0.35840	0.05842	0	0	0	0
Bushland pervious	90.27019	88.78316	298.69189	48.68689	0.00055	0.00561	0.00130	0.00015
Bushland water	0.01985	0.01952	0.10036	0.01636	0	0	0	0
Rural road	0	0	0.24039	0.03918	0	0	0	0
Rural hardstand	0	0	0.53294	0.08687	0	0	5.00E-05	5.91E-06
Rural roof	0	0	0.64118	0.10451	0	0	7.50E-05	8.87E-06
Rural pervious	0	0	304.00698	49.55325	9.82337	99.96815	843.45908	99.68764
Rural water	0	0	0.39566	0.06449	0	0	0	0
Sports field	0	0	0	0	0	0	0	0
Total subcatchment area	101.67490	100	613.49550	100	9.82650	100	846.10200	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	WS0 (ha)	WS0 (%)	WS1 (ha)	WS1 (%)	WS2 (ha)	WS2 (%)	WS3 (ha)	WS3 (%)	WS4 (ha)	WS4 (%)
Commercial road	0	0	0	0	1.54112	0.82442	0	0	0	0
Commercial hardstand	0.22877	0.74891	1.55212	1.03660	6.70734	3.58810	0	0	0.01836	0.02462
Commercial roof	0.36464	1.19371	2.44706	1.63431	8.64741	4.62595	0	0	0.00633	0.00849
Commercial pervious	1.71141	5.60254	3.03841	2.02924	8.14436	4.35684	0	0	0.07058	0.09467
Commercial water	0	0	0	0	0	0	0	0	0	0
Suburban road	1.18540	3.88057	9.03820	6.03629	7.84594	4.19720	0.67185	6.88093	1.71359	2.29845
Suburban hardstand	2.50062	8.18613	9.28827	6.20331	8.99315	4.81090	0.51682	5.29313	2.21056	2.96504
Suburban roof	8.63839	28.27903	32.95523	22.00964	32.99276	17.64954	2.46192	25.21422	8.27366	11.09754
Suburban pervious	8.11016	26.54977	49.31735	32.93733	54.74475	29.28581	4.14976	42.50066	12.91723	17.32601
Suburban water	0	0	2.50E-05	1.67E-05	0.00105	0.00056	0	0	0.00045	0.00060
Open space road	1.26220	4.13198	4.93795	3.29788	9.44718	5.05379	0.16886	1.72939	5.19069	6.96232
Open space hardstand	0.97098	3.17863	3.53733	2.36246	5.75370	3.07795	0.07289	0.74654	1.88015	2.52187
Open space roof	0.11025	0.36091	0.46175	0.30838	1.12409	0.60134	0.00465	0.04762	0.24454	0.32801
Open space pervious	5.43135	17.78029	31.69643	21.16893	35.70274	19.09925	1.71724	17.58751	15.71887	21.08387
Open space water	0.03285	0.10754	0.00560	0.00374	0	0	0	0	0	0
Bushland road	0	0	0	0	0	0	0	0	0.51420	0.68970
Bushland hardstand	0	0	0	0	0.00187	0.00100	0	0	0.06840	0.09175
Bushland roof	0	0	0	0	0	0	0	0	0.02153	0.02888
Bushland pervious	0	0	0	0	0.32207	0.17229	0	0	25.70486	34.47818
Bushland water	0	0	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	1.45519	0.97187	4.96317	2.65506	0	0	0	0
Total subcatchment area	30.547	100	149.7309	100	186.9327	100	9.764	100	74.554	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	FA0 (ha)	FA0 (%)	FA1 (ha)	FA1 (%)	FA2 (ha)	FA2 (%)	FA3 (ha)	FA3 (%)	FA5 (ha)	FA5 (%)	FA6 (ha)	FA6 (%)
Commercial road	0.00155	0.00077	0.00178	0.00390	0	0	0	0	0	0	0	0
Commercial hardstand	0.68547	0.33986	1.27610	2.80488	0	0	0.56164	0.42239	0	0	0	0
Commercial roof	1.04842	0.51982	1.47323	3.23817	0	0	0.68604	0.51595	0	0	0	0
Commercial pervious	3.23227	1.60258	6.71763	14.76535	0	0	4.86537	3.65908	0	0	0	0
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	12.21125	6.05443	3.05012	6.70417	0.26349	3.19399	8.76270	6.59013	0	0	1.31484	1.83693
Suburban hardstand	12.72037	6.30686	2.42518	5.33055	0.25484	3.08907	9.77361	7.35040	0.00222	0.03223	1.43267	2.00154
Suburban roof	48.91619	24.25304	7.39270	16.24915	1.04438	12.65981	33.22342	24.98620	0.05123	0.74231	5.36633	7.49712
Suburban pervious	74.69462	37.03419	11.53219	25.34776	1.75898	21.32205	50.77288	38.18454	0.10458	1.51540	8.99825	12.57116
Suburban water	0.00150	0.00074	0	0	0	0	0.00090	0.00068	0	0	0	0
Open space road	8.37676	4.15327	2.07507	4.56101	0.00935	0.11339	2.20094	1.65525	0.33517	4.85688	1.70013	2.37520
Open space hardstand	4.42618	2.19454	1.77967	3.91171	0.03974	0.48167	1.71507	1.28985	0.20396	2.95548	2.54351	3.55345
Open space roof	0.47688	0.23644	0.10978	0.24129	0.00427	0.05176	0.20312	0.15276	0.04800	0.69560	1.01666	1.42034
Open space pervious	34.29041	17.00146	6.51373	14.31717	0.42130	5.10688	18.91811	14.22766	2.77117	40.15607	40.27044	56.26052
Open space water	0	0	0	0	0.04402	0.53359	0	0	0	0	5.00E-05	6.99E-05
Bushland road	0	0	0	0	0.15460	1.87402	0	0	0	0	0.00000	0.00000
Bushland hardstand	0	0	0	0	0.01489	0.18053	0	0	0	0	0.00713	0.00995
Bushland roof	0	0	0	0	0.01464	0.17746	0	0	0	0	0.01075	0.01502
Bushland pervious	0	0	0	0	4.22510	51.21578	0	0	0	0	8.91775	12.45869
Bushland water	0	0	0	0	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0.60912	0.30201	1.14873	2.52490	0	0	1.28330	0.96513	3.38467	49.04604	0	0
Total subcatchment area	201.69100	100	45.49590	100	8.24960	100	132.96710	100	6.90100	100	71.57845	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	FA7 (ha)	FA7 (%)	FA8 (ha)	FA8 (%)	FA9 (ha)	FA9 (%)	FA10 (ha)	FA10 (%)	FA11 (ha)	FA11 (%)	FA12 (ha)	FA12 (%)
Commercial road	0	0	0	0	0.96626	0.58898	0	0	0.15920	0.21730	0	0
Commercial hardstand	0	0	0.09825	0.09336	2.87939	1.75511	0.01547	0.62058	0.81899	1.11787	0.84147	7.30903
Commercial roof	0	0	0.28170	0.26767	2.81759	1.71744	0.01910	0.76595	0.99322	1.35568	1.03335	8.97575
Commercial pervious	0	0	1.17809	1.11941	3.34845	2.04102	0.12335	4.94762	2.15616	2.94302	2.27579	19.76764
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	0.24393	1.83693	3.40824	3.23849	7.53109	4.59051	0	0	2.25456	3.07734	0.05280	0.45865
Suburban hardstand	0.26579	2.00154	4.42791	4.20736	8.06460	4.91570	0	0	2.19261	2.99278	0.08285	0.71968
Suburban roof	0.99555	7.49712	18.40574	17.48898	28.53998	17.39629	0	0	9.76619	13.33023	0.71281	6.19152
Suburban pervious	1.66934	12.57116	29.18282	27.72928	45.86605	27.95723	0	0	14.57372	19.89220	1.08328	9.40943
Suburban water	0	0	0	0	2.49E-05	1.52E-05	0	0	2.50E-05	3.41E-05	0	0
Open space road	0.31540	2.37520	4.65181	4.42011	3.14482	1.91690	0.41795	16.76375	1.63615	2.23324	0.58038	5.04121
Open space hardstand	0.47187	3.55345	2.44401	2.32228	1.98188	1.20804	0.17292	6.93569	1.13037	1.54288	0.57485	4.99321
Open space roof	0.18861	1.42034	0.20423	0.19406	0.18810	0.11466	0.00655	0.26267	0.17858	0.24375	0.09548	0.82934
Open space pervious	7.47089	56.26052	15.52775	14.75434	17.56257	10.70510	1.50429	60.33586	10.68431	14.58340	4.16896	36.21182
Open space water	9.28E-06	6.99E-05	0.01460	0.01387	0	0	0	0	0	0	0.01068	0.09273
Bushland road	0.00000	0.00000	0.14620	0.13892	2.44566	1.49073	0	0	0.18495	0.25245	0	0
Bushland hardstand	0.00132	0.00995	0.74621	0.70904	0.57236	0.34888	0	0	0.12498	0.17059	0	0
Bushland roof	0.00199	0.01502	0.21660	0.20581	0.06938	0.04229	0	0	0.00813	0.01109	0	0
Bushland pervious	1.65440	12.45869	24.30774	23.09701	34.67503	21.13585	0	0	25.02885	34.16279	0	0
Bushland water	0	0	0	0	0.01220	0.00744	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	0	0
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	0	0	0	0	3.39245	2.06784	0.23356	9.36789	1.37250	1.87337	0	0
Total subcatchment area	13.27909	100	105.24190	100	164.05787	100	2.49320	100	73.26347	100	11.51270	100

Table C3 cont. Area of land use functional units within Lake Tuggeranong subcatchments (see Table C2), in hectares (ha) and as a percentage of subcatchment area (%).

Functional unit	FA13 (ha)	FA13 (%)	FA14 (ha)	FA14 (%)	FA15 (ha)	FA15 (%)	FA16 (ha)	FA16 (%)	FA17 (ha)	FA17 (%)	FA9 NSW (ha)	FA9 NSW (%)
Commercial road	0	0	0	0	0	0	0	0	0	0	0	0
Commercial hardstand	0	0	0	0	0	0	0.00048	0.00069	0	0	0	0
Commercial roof	0	0	0	0	0	0	0.01188	0.01718	0	0	0	0
Commercial pervious	0.02585	1.29481	0	0	0	0	0.04275	0.06184	0	0	0	0
Commercial water	0	0	0	0	0	0	0	0	0	0	0	0
Suburban road	0	0	0	0	0.99534	6.47445	4.91072	7.10386	2.05614	3.19399	0	0
Suburban hardstand	0	0	0	0	0.98473	6.40548	4.14411	5.99488	1.98860	3.08907	0	0
Suburban roof	0	0	0	0	4.20349	27.34277	16.32055	23.60934	8.14979	12.65981	0	0
Suburban pervious	0	0	0	0	5.84599	38.02693	24.30567	35.16064	13.72613	21.32205	0	0
Suburban water	0	0	0	0	0	0	0	0	0	0	0	0
Open space road	0.02215	1.10948	0	0	0.84631	5.50505	1.22231	1.76820	0.07299	0.11339	0	0
Open space hardstand	0.01945	0.97424	0.01723	4.25808	0.46344	3.01456	1.04693	1.51450	0.31008	0.48167	0	0
Open space roof	0.02070	1.03685	0.00050	0.12360	0.07351	0.47819	0.07243	0.10477	0.03332	0.05176	0	0
Open space pervious	0.62372	31.24084	0.38697	95.61832	1.84850	12.02407	7.92437	11.46341	3.28757	5.10688	0.02229	0.03109
Open space water	0	0	0	0	0	0	0.00198	0.00286	0.34350	0.53359	0	0
Bushland road	0	0	0	0	0	0	0.04578	0.06622	1.20641	1.87402	0	0
Bushland hardstand	0	0	0	0	0	0	0.00348	0.00503	0.11622	0.18053	0	0
Bushland roof	0	0	0	0	0	0	0.00023	0.00033	0.11424	0.17746	2.50E-05	3.49E-05
Bushland pervious	0	0	0	0	0	0	9.02073	13.04941	32.97031	51.21578	0.00283	0.00394
Bushland water	0	0	0	0	0	0	0	0	0	0	0	0
Rural road	0	0	0	0	0	0	0	0	0	0	0	0
Rural hardstand	0	0	0	0	0	0	0	0	0	0	0	0
Rural roof	0	0	0	0	0	0	0	0	0	0	0	0
Rural pervious	0	0	0	0	0	0	0	0	0	0	71.66356	99.96493
Rural water	0	0	0	0	0	0	0	0	0	0	0	0
Sports field	1.28462	64.34376	0	0	0.11200	0.72851	0.05313	0.07685	0	0	0	0
Total subcatchment area	1.99650	100	0.40470	100	15.37330	100	69.12750	100	64.37530	100	71.68867	100

Appendix D: Literature-derived EMC and DWC values

Baseline values of the event mean concentrations (EMC) and dry weather concentrations (DWC) of total phosphorus (TP), total nitrogen (TN) and total suspended solids (TSS) generated by functional land use units were derived from the literature for initial parameterisation of the model. The EMC values were then scaled based on date-matched observations. Tables D1-D3 present the baseline EMC and DWC values for each functional unit.

Table D1: Baseline total phosphorus (TP) EMC and DWC values (mg/L) derived from the literature for each combination of functional land use and surface imperviousness.

Land surface imperviousness	Suburban	Commercial	Open space	Rural	Bushland	Sports field
Road	EMC: 0.501 DWC: 0.015	EMC: 0.501 DWC: 0.015	EMC: 0.501 DWC: 0.015	EMC: 0.251 DWC: 0.015	EMC: 0.251 DWC: 0.015	
Hardstand	EMC: 0.251 DWC: 0.015	EMC: 0.251 DWC: 0.015	EMC: 0.251 DWC: 0.015	EMC: 0.251 DWC: 0.015	EMC: 0.251 DWC: 0.015	
Roof	EMC: 0.128 DWC: 0.015	EMC: 0.128 DWC: 0.015	EMC: 0.128 DWC: 0.015	EMC: 0.251 DWC: 0.015	EMC: 0.251 DWC: 0.015	
Pervious	EMC: 0.251 DWC: 0.04	EMC: 0.251 DWC: 0.04	EMC: 0.251 DWC: 0.04	EMC: 0.218 DWC: 0.04	EMC: 0.079 DWC: 0.04	EMC: 0.251 DWC: 0.015
Water	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	

Table D2: Baseline total nitrogen (TN) EMC and DWC values (mg/L) derived from the literature for each combination of functional land use and surface imperviousness.

Land surface imperviousness	Suburban	Commercial	Open space	Rural	Bushland	Sports field
Road	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	
Hardstand	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	EMC: 2.187 DWC: 1.0	
Roof	EMC: 1.995 DWC: 1.0	EMC: 1.995 DWC: 1.0	EMC: 1.995 DWC: 1.0	EMC: 1.995 DWC: 1.0	EMC: 1.995 DWC: 1.0	
Pervious	EMC: 1.995 DWC: 0.4	EMC: 1.995 DWC: 0.4	EMC: 1.995 DWC: 0.4	EMC: 1.995 DWC: 0.4	EMC: 1.995 DWC: 0.4	EMC: 1.995 DWC: 1.0
Water	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	

Table D3: Baseline total suspended solids (TSS) EMC and DWC values (mg/L) derived from the literature for each combination of functional land use and surface imperviousness.

Land surface imperviousness	Suburban	Commercial	Open space	Rural	Bushland	Sports field
Road	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	
Hardstand	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	EMC: 269.15 DWC: 15.849	
Roof	EMC: 19.95 DWC: 15.849	EMC: 19.95 DWC: 15.849	EMC: 19.95 DWC: 15.849	EMC: 19.95 DWC: 15.849	EMC: 19.95 DWC: 15.849	
Pervious	EMC: 141.25 DWC: 15.849	EMC: 141.25 DWC: 15.849	EMC: 141.25 DWC: 15.849	EMC: 89.12 DWC: 15.849	EMC: 39.81 DWC: 15.849	EMC: 141.25 DWC: 15.849
Water	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	EMC: 0 DWC: 0	

Appendix E: Modelled annual load of total phosphorous

The table below provides total phosphorous generated for each combination of functional land use and surface imperviousness annually.

Table E1: Modelled annual total phosphorus (TP) load (kg/yr) generated for each combination of functional land use and surface imperviousness.

Land surface imperviousness	Road TP (kg/yr)	Hardstand TP (kg/yr)	Roof TP (kg/yr)	Pervious TP (kg/yr)	Water TP (kg/yr)
Suburban	322	169	314	140	0
Commercial	17	45	30	16	0
Open space	243	76	5	88	0
Rural	0	0	1	132	0
Sports field	0	0	0	58	0
Total annual load (kg/yr)	582	290	350	434	0