Sydney Drinking Water Catchment Audit 2019 – Volume 2

WaterNSW

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Abbreviations

Abbreviation	Description
ABS	Australian Bureau of Statistics
ARRC	Australian River Restoration Centre
BC Act	NSW *Biodiversity Conservation Act 2016*
BLR	Basic landholder rights
BoM	Bureau of Meteorology
CLUM	Catchment Scale Land Use Mapping
CSP	Community Strategic Plan
DPE	NSW Department of Planning and Environment
DPI	NSW Department of Primary Industries
DPIE	NSW Department of Planning, Infrastructure and Environment
EPA	NSW Environment Protection Authority
EPL	Environment Protection Licence
ERP	Estimated residential population
FM Act	NSW *Fisheries Management Act 1994*
LCC	Lithgow City Council
LGA	Local Government Area
LLS	Local Land Services
LLS Act	NSW *Local Land Services Act 2013*
LTAAEL	Long term average annual extraction limit
NHMRC	National Health and Medical Research Council
NorBE	Neutral or beneficial effect

Abbreviation	Description
NRAR	NSW Natural Resources Access Regulator
NRM	Natural resource management
NV Act	NSW *Native Vegetation Act 2003*
PCT	Plant community type
POEO Act	NSW *Protection of the Environment Operations Act 1997*
OEH	NSW Office of Environment and Heritage
SA2	Statistical Area Level 2
SEED	Sharing and Enabling Environmental Data
TLGE	Total licensed groundwater entitlement
WAL	Water access licence
WFP	Water filtration plant
WMF	Water monitoring framework
WQMP	Water quality monitoring program
WSP	Water Sharing Plan
WSUD	Water sensitive urban design

1. Introduction

1.1 Themes and indicators of catchment health

This second volume of the Sydney Drinking Water Catchment Audit provides detailed analysis of each catchment health indicator under four themes, as listed in the NSW Government Gazette No.158 (19 December 2008) (see Table 1). In the chapters below, available information has been reviewed and analysed to determine the status of each indicator during the audit period (1 July 2016 to 30 June 2019). Longer term trends have been identified where there is available, comparative data. Case studies are provided to further illustrate some of the key issues, and these were prepared following field inspections by the auditor with relevant stakeholders (participants in field visits are listed in Volume 3 Appendix B).

Table 1: Indicators of catchment health

Theme	Indicators
Land use and human settlements	Community attitudes, aspirations and engagement Population settlements and patterns Land use Sites of pollution and potential contamination Soil erosion
Water quality	Ecosystem and raw water quality Nutrient load Cyanobacterial blooms
Water availability	Surface water flow Environmental flows Groundwater availability
Biodiversity and habitats	Macroinvertebrates Fish Riparian vegetation Native vegetation Fire Wetlands Physical form

1.2 Climate context

Climate, particularly rainfall, provides context for the audit analysis as it directly and indirectly affects the catchment health indicators. For example:

- Reduced rainfall results in reduced surface water flows and groundwater availability
- Fish, macroinvertebrates, riparian vegetation and wetlands are adversely affected by reduced water availability
- Hotter, drier conditions lead to an increased risk of bushfires.

Rainfall data records from the Bureau of Meteorology (BoM) were obtained by the auditor and analysed for the period of the summer 1938/39 to the end of the current audit period. Locations of BoM monitoring stations across the Catchment are shown in Figure 1. Data was unavailable for some parts of the Catchment (such as in the Kowmung, Lake Burragorang, Lower Coxs and Upper Nepean sub-catchments) as there are no BoM monitoring stations due to restricted access.

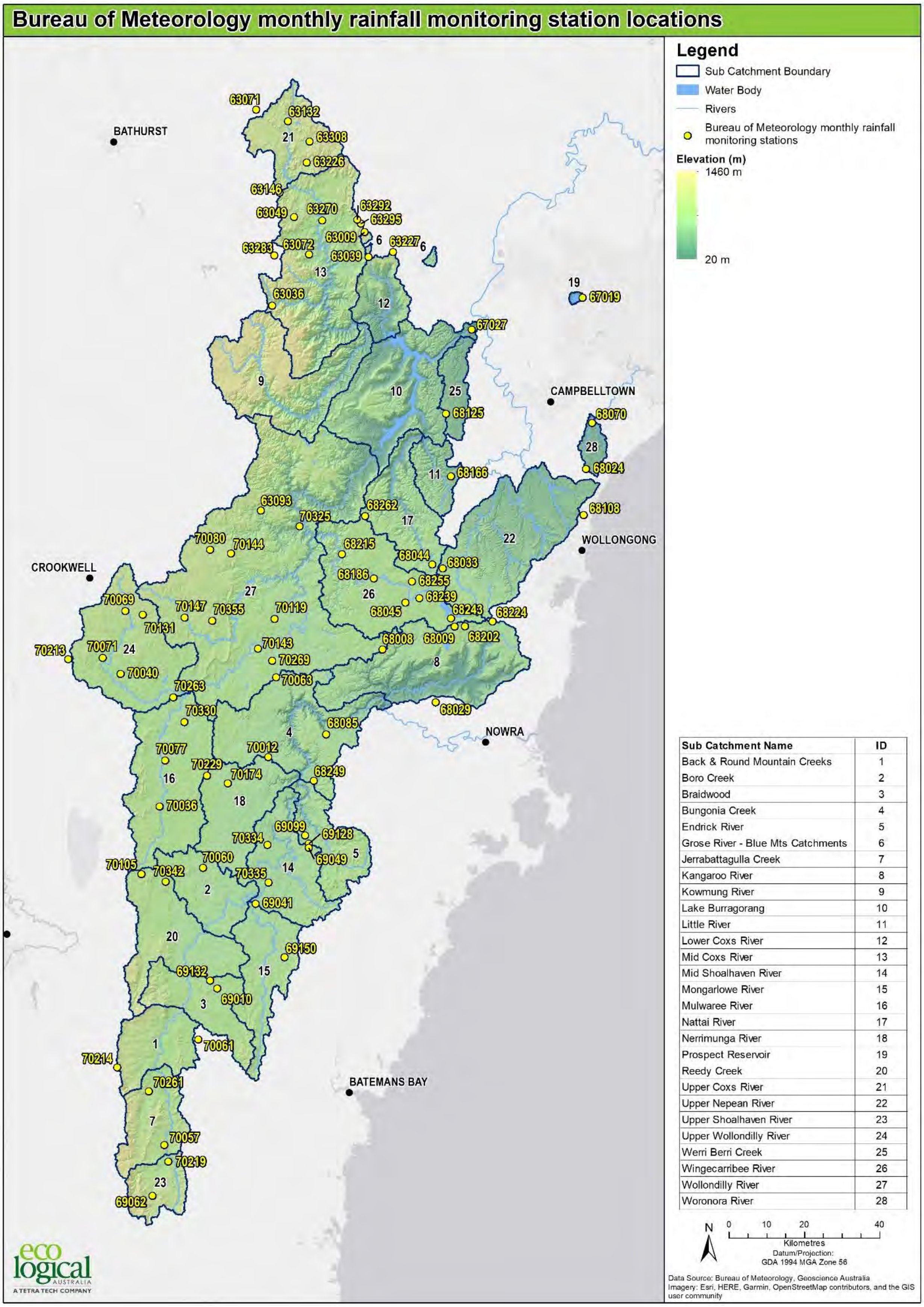
The methods to create climate graphs and maps for this audit were as follows:

- Total annual rainfall data from the BoM for each station across the Catchment was used to create the average annual rainfall graph (Figure 2). The BoM data was averaged by dividing the total annual rainfall value by the number of records for each year.
- Total monthly rainfall records from the BoM for each station were averaged to create maps (Figure 3 to Figure 8) to show long term and seasonal trends of interpolated rainfall distribution across the Catchment.

The analysis revealed the following important trends:

- Data collected since the 1930s indicates a long-term decline in wet years within the Catchment (Figure 2).
- The audit period (2016-19) was drier than the past two audit periods (2010-16) (Figure 3).
- The driest year during the audit period was 2017-18 (Figure 4).
- Greatest seasonal declines are seen in winter rainfall (Figure 5).

Seasonal rainfall has fluctuated across the Catchment during the audit period, as shown in Figure 5 to Figure 8.



Sub Catchment Name	ID
Back & Round Mountain Creeks	1
Boro Creek	2
Braidwood	3
Bungonia Creek	4
Endrick River	5
Grose River - Blue Mts Catchments	6
Jerrabattagulla Creek	7
Kangaroo River	8
Kowmung River	9
Lake Burragorang	10
Little River	11
Lower Coxs River	12
Mid Coxs River	13
Mid Shoalhaven River	14
Mongarlowe River	15
Mulwaree River	16
Nattai River	17
Nerrimunga River	18
Prospect Reservoir	19
Reedy Creek	20
Upper Coxs River	21
Upper Nepean River	22
Upper Shoalhaven River	23
Upper Wollondilly River	24
Werri Berri Creek	25
Wingecarribee River	26
Wollondilly River	27
Woronora River	28

Figure 1: Rainfall monitoring stations (Bureau of Meteorology)

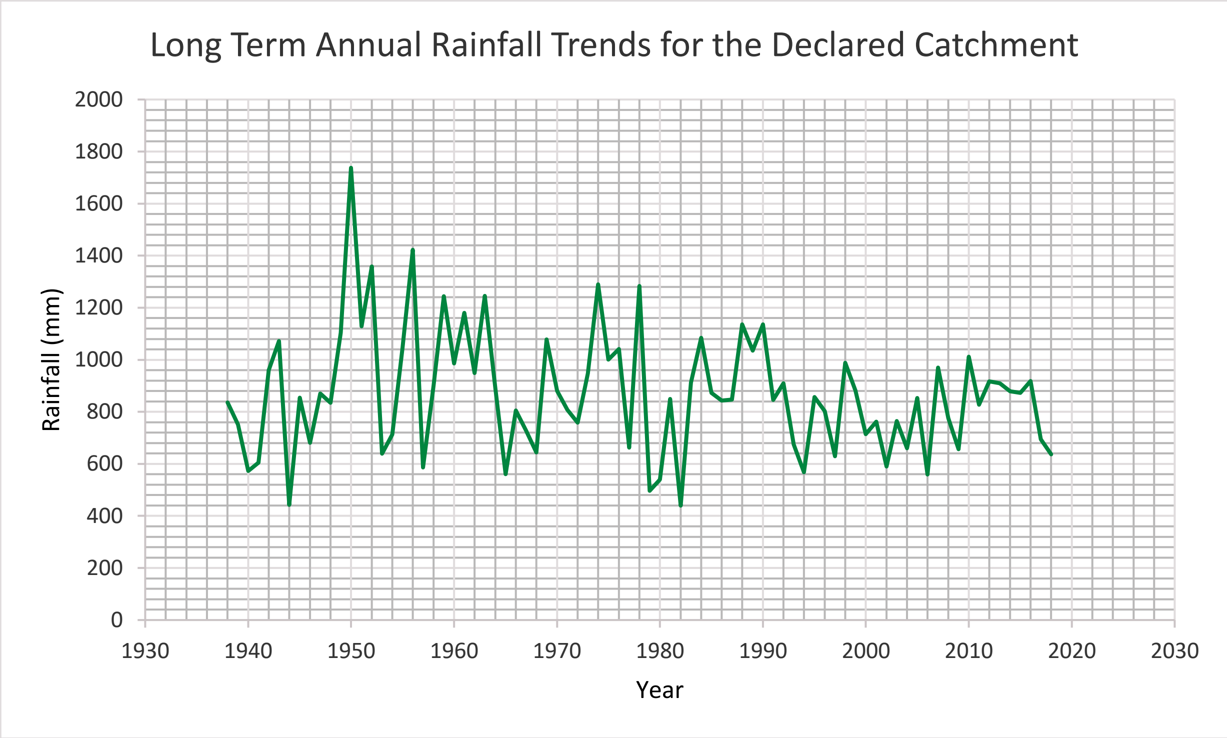


Figure 2: Long term average annual rainfall for the Catchment (Bureau of Meteorology)

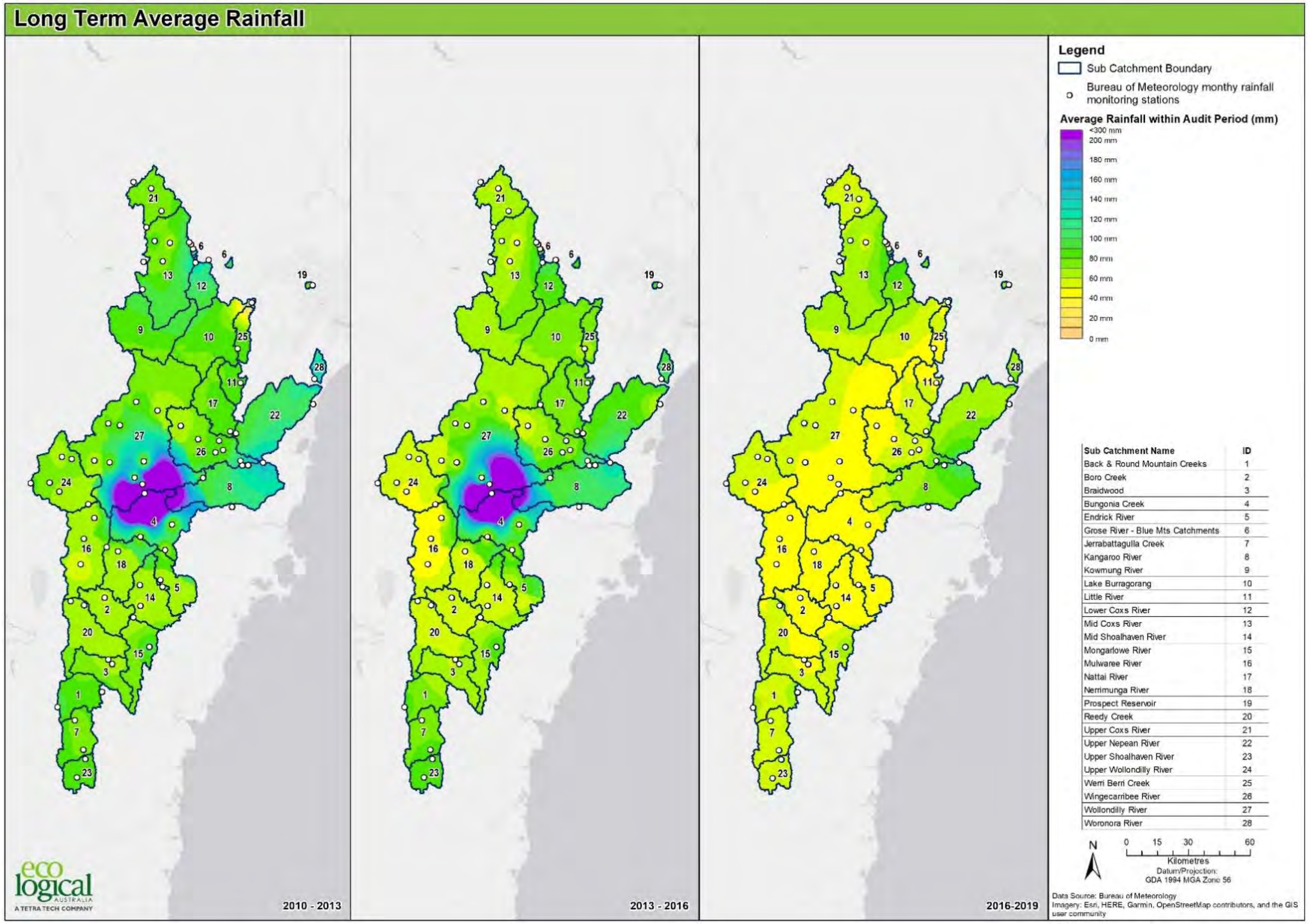


Figure 3: Long term average rainfall within three audit periods (Bureau of Meteorology)

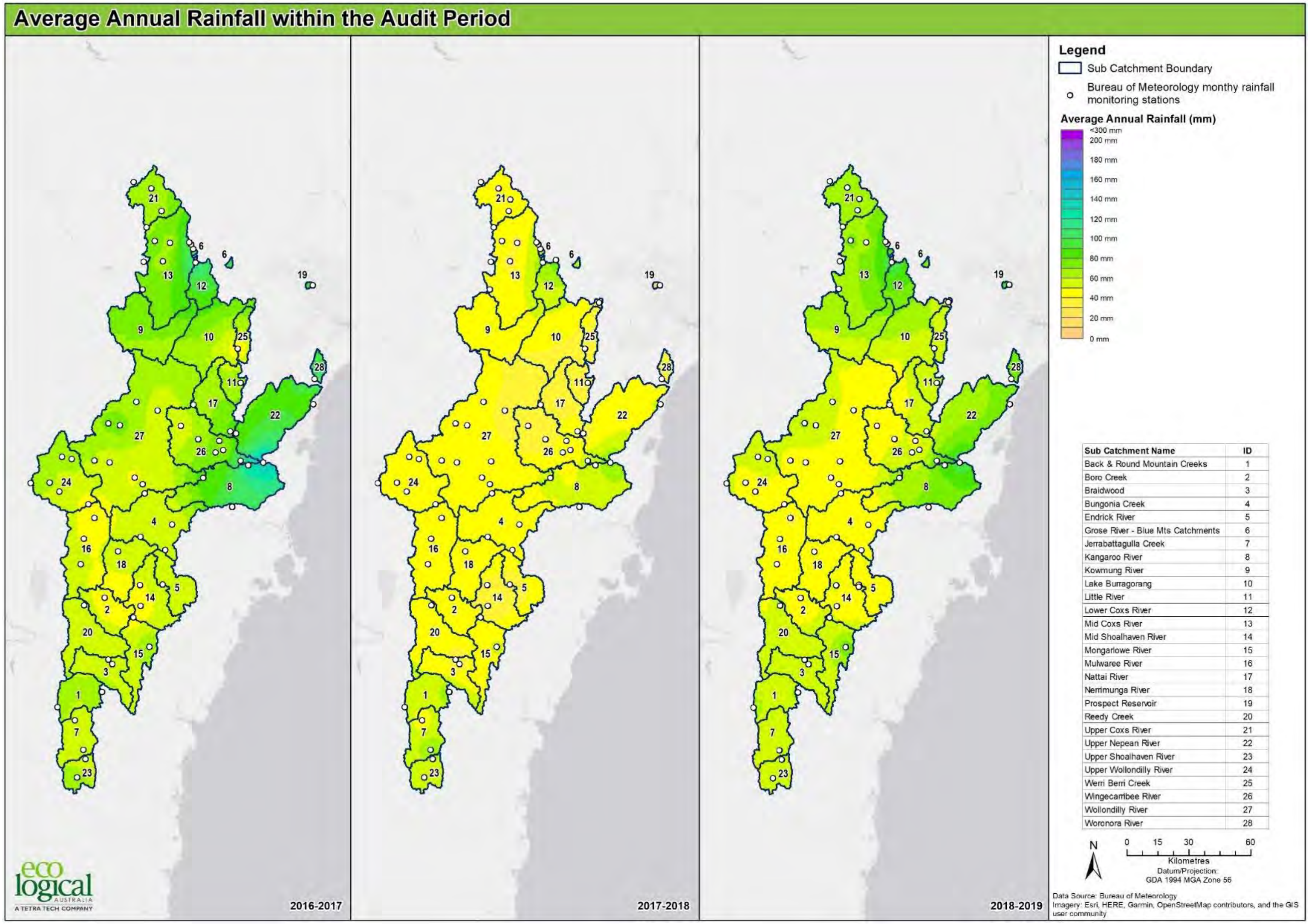


Figure 4: Average annual rainfall within the audit period 2016 -2019 (Bureau of Meteorology)

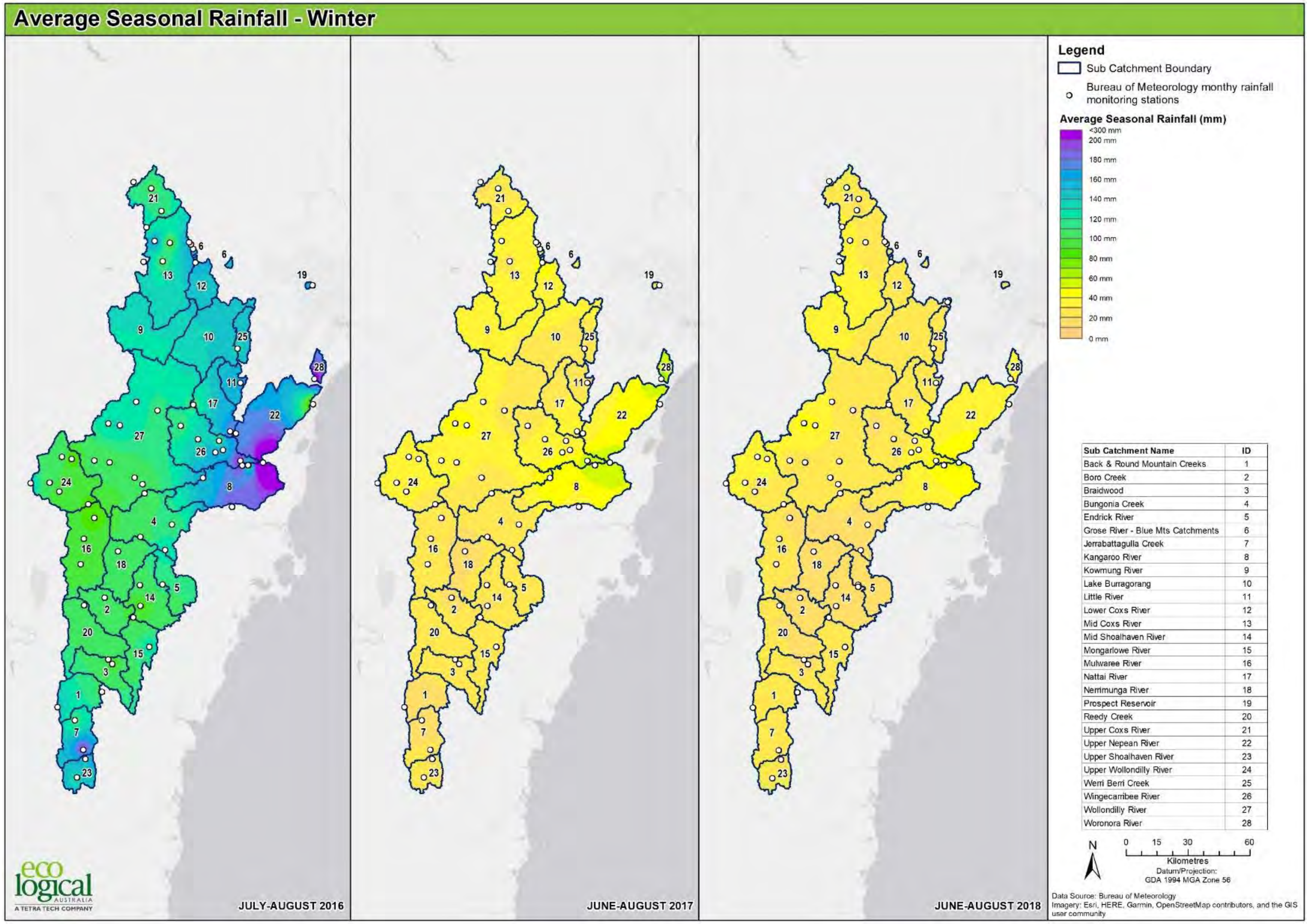


Figure 5: Average seasonal rainfall – Winter 2016 – 2018 (Bureau of Meteorology)

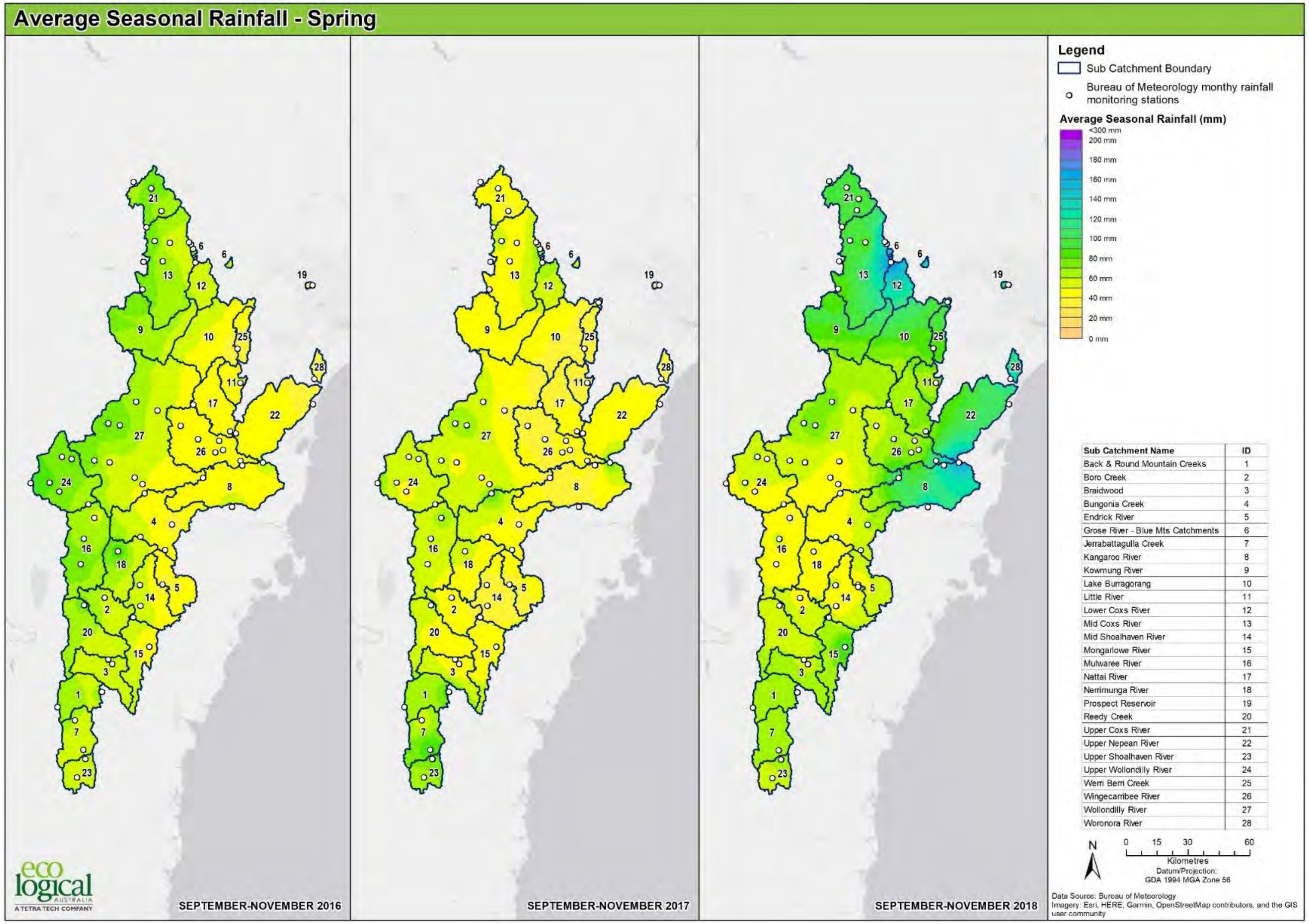


Figure 6: Average seasonal rainfall – Spring 2016 – 2018 (Bureau of Meteorology)

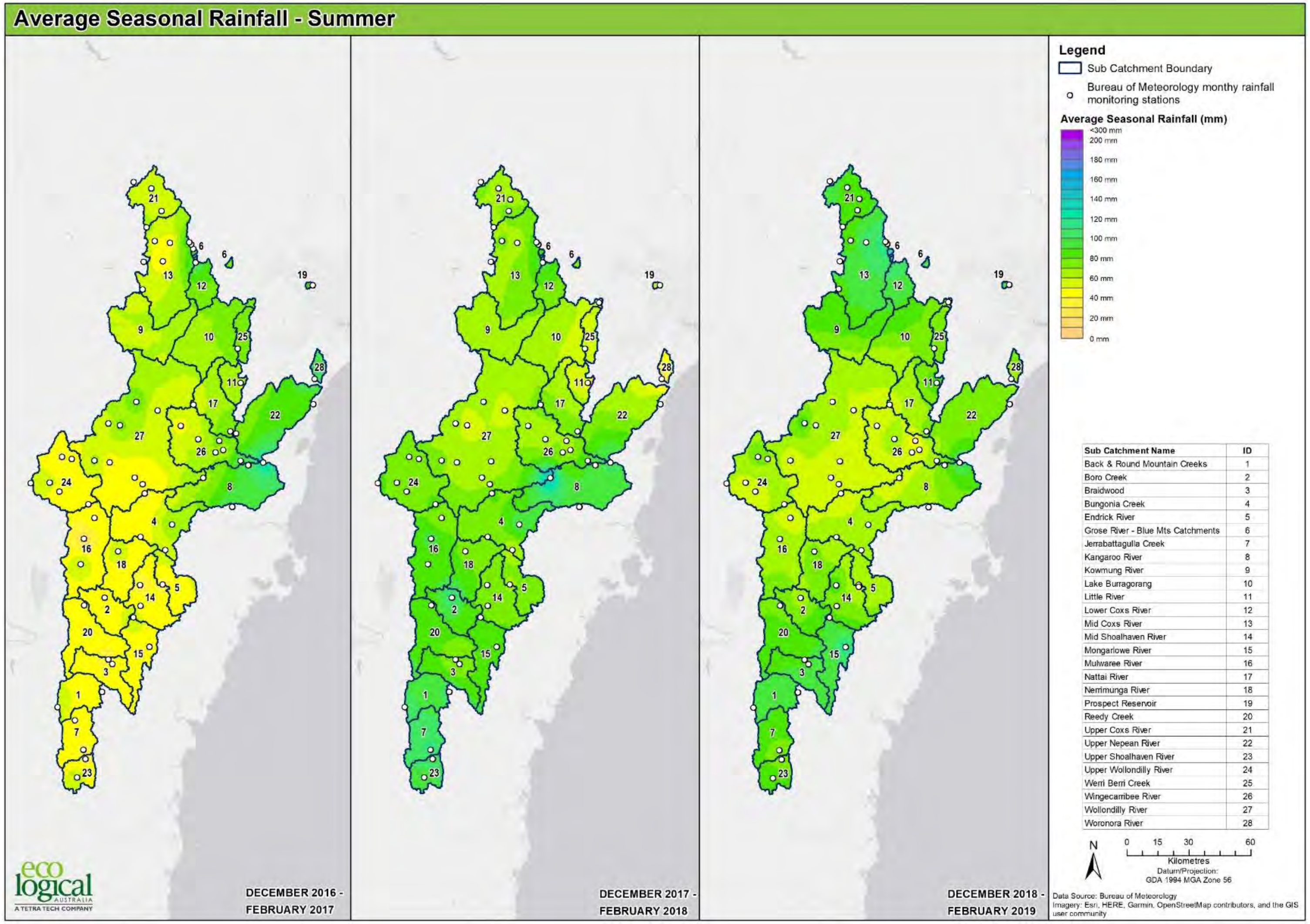


Figure 7: Average seasonal rainfall – Summer 2016 – 2019 (Bureau of Meteorology)

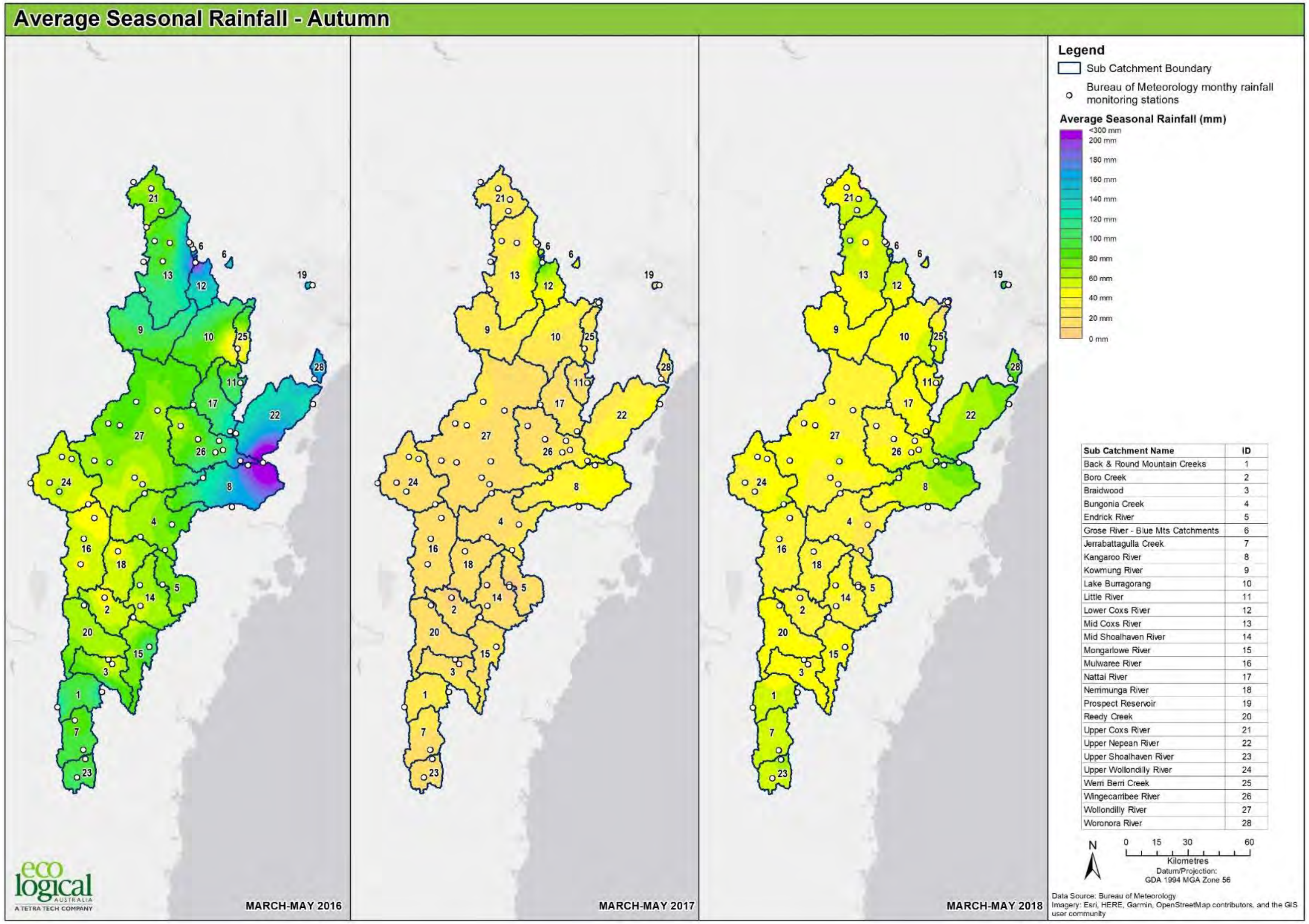


Figure 8: Average seasonal rainfall – Autumn 2016 – 2018 (Bureau of Meteorology)

LAND USE AND HUMAN SETTLEMENTS

Figure 9: Wingecarribee Shire Council signage expressing community sentiment

2. Community attitudes, aspirations and engagement

2.1 Definition and context

A positive and engaged community attitude to catchment health and the maintenance of quality waterways is essential for high standard catchment management. This indicator aims to gauge the attitudes of the community towards maintaining and improving catchment health, and the level of engagement within the community to bring this about.

2.2 Method

In the absence of previous catchment-wide community surveys, the methods for measuring community attitudes, aspirations and engagement are a mix of qualitative and output measures, using multiple sources of data to draw conclusions. Some interpretations of quantitative community surveys have also been accessed (Community Strategic Plans, Integrated Water Management Strategy surveys, and one Landcare survey). To be consistent with previous audits, community attitudes and levels of engagement were considered across these areas:

- community submissions to the audit
- active community natural resource management organisations
- funded community programs
- Community Strategic Plans for local councils.

2.3 Community submissions to the audit

As with previous audits, community groups have provided detailed submissions to the auditor to raise concerns about the health of the Catchment. Submissions have been made by the Blue Mountains Conservation Society, The Sutherland Shire Environmental Centre, fourteen local councils, Metropolitan Coal and Lithgow Oberon Landcare. The Environmental Defenders Office also provided a review of all cases mentioning the Catchment before the Land and Environment Court during the audit period. The matters raised in public submissions are addressed in Volume 3 Appendix B6 of the audit and relate specifically to:

- implementation of the 2016 audit recommendations
- mining in the Catchment
- Springvale water treatment plant
- neutral or beneficial effect (NorBE) test for development
- recreational activities
- erosion and weeds
- Warragamba dam wall.

Community submissions also request greater transparency and accountability for reporting actions arising from catchment audits. This should be extended to all agencies and presented in a platform that is easily accessible to the community.

2.4 Community natural resource management (NRM) organisations

Previous audits have referred to reports on the number of community NRM organisations, the number of active members and the number of landholders engaged in on-ground improvement works. Exact comparisons with previous audits are not possible because of database coding differences, including results from outside the Catchment. To counter data inaccuracies, local expert opinion regarding the number and vibrancy of these organisations was sought from discussion with the Local Land Services (LLS).

In general, some areas have experienced a reduction in on ground activities, such as a result of a stable rehabilitated site. Other areas are experiencing a surge of community activities. For example:

- South East LLS - On-ground works by community organisations have expanded, in particular in the Wingecarribee LGA where Bushcare and Rivercare are thriving, with 160 volunteers.
    - There are three active Landcare groups in the Wingecarribee area, and a further 19 Bushcare groups working exclusively on Council land supported by Wingecarribee Shire Council's Bushcare program. The active Landcare groups include Moss Vale Landcare Group Inc, Mount Gibraltar Landcare/Bushcare Inc, and Penrose Swamp Conservation Group.
    - There are nine active Landcare groups in the Goulburn area, including FROGS (Goulburn Wetlands); Mulwaree Ponds; Taralga; Tarlo / Middlearm; West Goulburn Bushland Reserve Group Inc; Arthursleigh (annual planting by Sydney University Landcare); Bungonia Trust; Windellema; and Tarago.
    - There are 20 active Landcare groups in the Upper Shoalhaven area, including Bombay; Boro Creek; Braidwood Rural; Braidwood Urban; Bungonia Park Trust; Bungendore; Flood Creek Non-Nativist Landcare Group; Friends of Mongarlowe River; Jacqua Creek; Majors Creek; Mongarlowe; Reedy Mulloon Creek; Sheep Station Creek; Snowball; Tomboye; Tallong Parke Estate; Taylor's Creek; Upper Deua; Windellama and Braidwood Garlic Growers.
    - Other organisations that undertake on-ground natural resource management activities include the Small Farms Network Capital Region and Rivers of Carbon.
- Central Tablelands LLS - There has been a decrease of active community organisations involved in on ground works, although the numbers submitted to the 2016 audit were described as 'ambitious'. Lithgow Oberon Landcare has expanded its influence with a new paid coordinator position. A total of 37 projects were completed in the Catchment during the audit period. These included riparian and wetland restoration involving weed and erosion control followed by native revegetation.
- Greater Sydney LLS – There have been ten projects in the Blue Mountains funded by Greater Sydney LLS during the audit period (value approximately $425,000). These relate to bush regeneration, weed control, revegetation, stormwater treatment and cultural activities with Traditional Owners.

2.5 Funded community programs

2.5.1 Rural Landscape Program

The Rural Landscape Program is the main incentive program used to encourage the grazier community to care for the Catchment. It targets priority pollutants by assisting land managers with a range of land and water management practices including erosion control, riparian management and grazing. It is a joint initiative between South East LLS and WaterNSW and is funded by WaterNSW and Catchment Action NSW. There were 95 projects under the Rural Landscape Program and Rivers of Carbon – Source Water Linkages Program during the audit period (compared to 118 in the previous audit period).

Trends in program funding are shown in Figure 10. All years except 2012/2013 exclude WaterNSW (and former Sydney Catchment Authority (SCA)) staff costs. Funding for this program was significantly lower in 2016/17 because it was a year of major restructuring in WaterNSW. During this time an agreement was reached with the Australian River Restoration Centre 'Rivers of Carbon' program. This partnership and the ongoing South East LLS partnership enabled significantly more investment in the program. The funding partners work with landholders who provide approximately 50% of the total funding (exact proportions change depending on the situation).

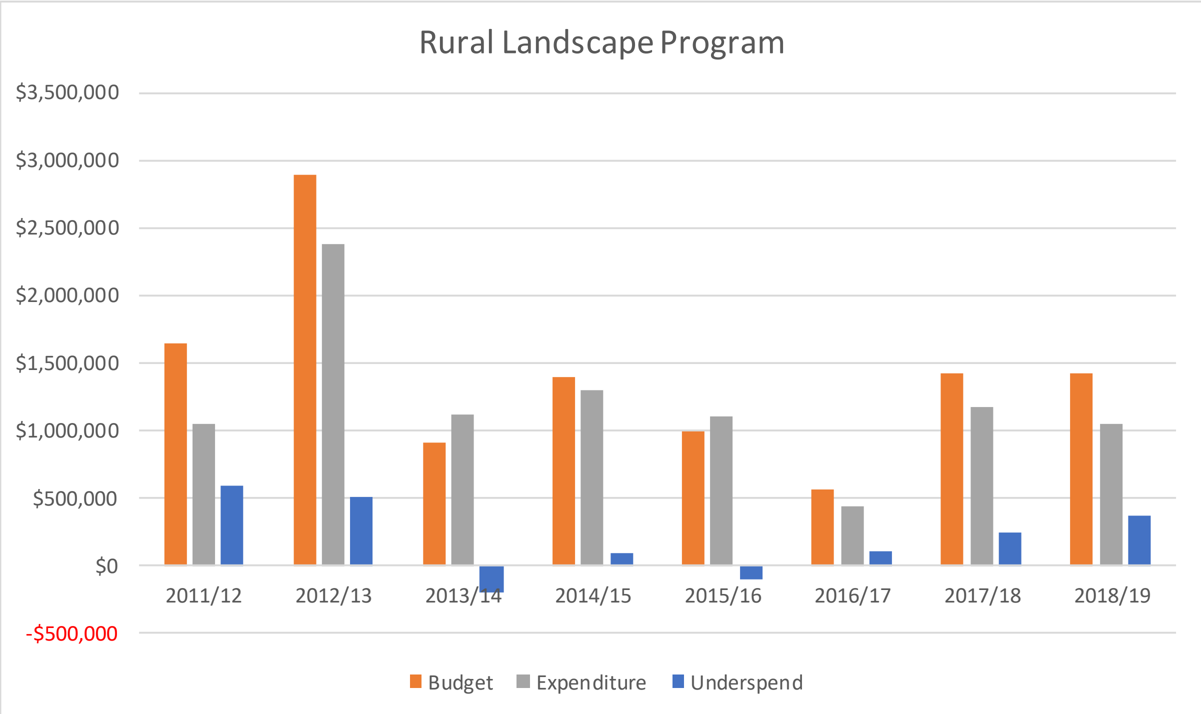


Figure 10: WaterNSW investment in Rural Landscape Program

The value of this program to the health of the Catchment over the long term is difficult to assess properly because of the paucity of the monitoring and evaluation data. The audit used benchmarking and case studies to evaluate short term outcomes.

Based on benchmarking, the program is implementing best practice riparian management in the sites reviewed. The standard project implementation processes were comprehensive, well thought out and supported by appropriate documentation. The implementation managers were able to exhibit impressive quality with the on-ground works.

The case studies (below) and landholder interviews show positive levels of community engagement that align different funding sources towards maintaining and improving catchment health. Landowners had a strong sense of project ownership, and their financial contribution was significant. These results were achieved during a period of drought in the Catchment which makes the landholders' contributions and the apparent short-term success of the program particularly significant.

However, there is a lack of long-term data to provide evidence to support this work. No five or ten-year program evaluations were completed during the audit period. Long term evaluations are essential in understanding the success or failure of natural resource management projects.

Case Study 1 – Rural Lands Program

Moss Vale

Investment:

WaterNSW – $12,974

South East LLS - $10,426

Landholder - $39,062

Protected riparian zone area – 6.08 ha

Riparian length – 1.56 km

Trees – 3000

Comment:

The original agreement for this work was 2000 trees. The owner supplemented this with another 1000 trees.

Case Study 2 – Rural Lands Program

Goulburn

Investment

WaterNSW - $34,833

Landholder - $11,242

Erosion treatment area – 0.46 ha

Protected riparian zone area – 2.6 ha

Trees – 240 shrubs and trees planted and maintained

Comment:

The landowner has since been inspired to create a new project further up the watercourse.

2.5.2 Engaged Communities Program

The audit considered the 'Engaged Communities' program which was subjected to analysis in the last audit. Figure 11 shows a decrease in expenditure since the previous audit period, with the largest decrease in the Community Education program due to the conclusion of a number of rural improvement education programs.

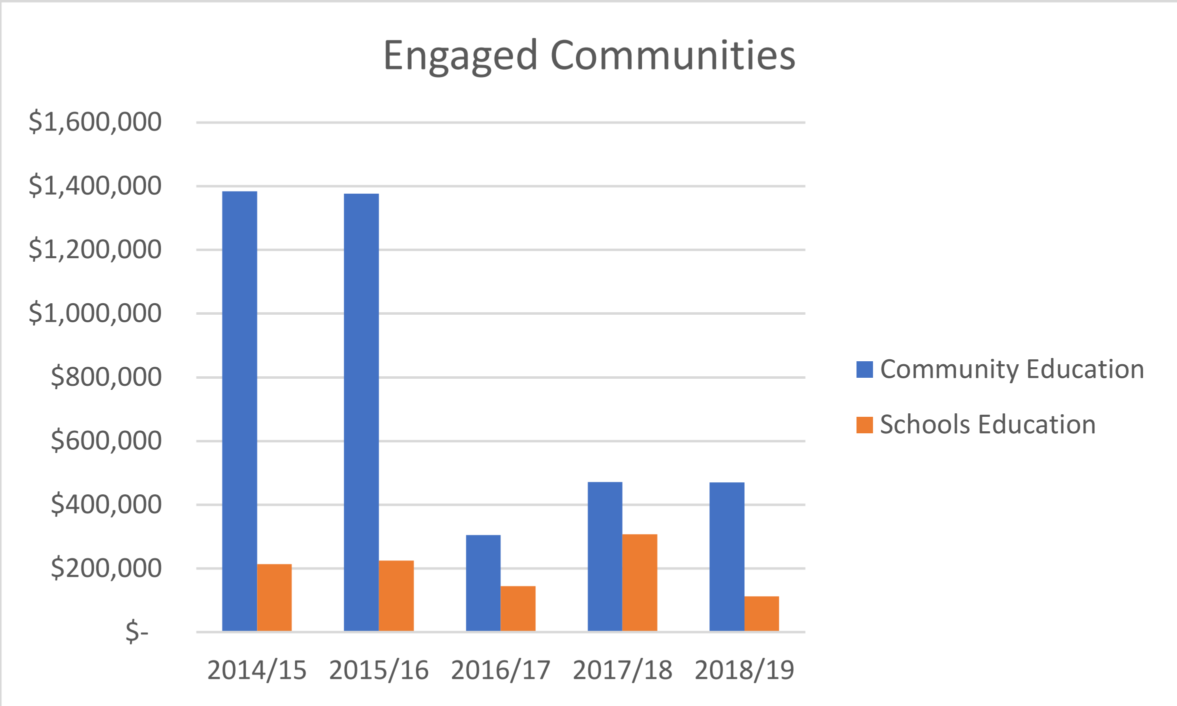


Figure 11: Engaged Communities Program funding (source: WaterNSW Annual Catchment Management Reports)

An activities analysis of this program (Figure 12) using data from the annual reports shows a decrease in visitation numbers by school groups and a decrease in visitation to the Warragamba Dam Visitors Centre. No data was available on the numbers of visitors to the grounds of dams in the Catchment.

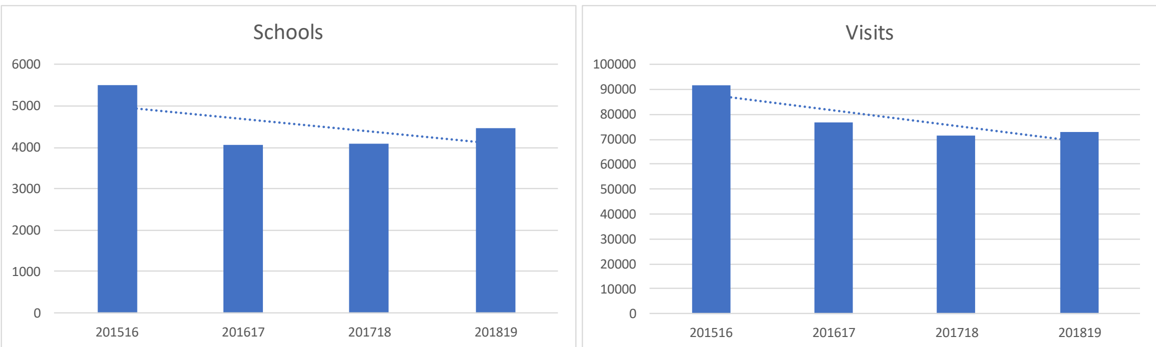


Figure 12: Decrease in excursions and visitors (left: school visits; right: Visitor Centre numbers)

Program evaluation is undertaken with teachers to determine the effectiveness of the school excursion program. WaterNSW reduced the Schools Education program target from 5000 students in 2015/16 to 3500 students in 2016/17 to focus on deeper engagement with smaller class sizes in line with ratios established by the NSW Department of Education and Training. These targets were exceeded in 2016/17, 2017/18 and 2018/19 by 15%, 17% and 28% respectively. Long-term program evaluation would assist in determining the effectiveness of revised levels of engagement.

2.6 Community strategic plans

The NSW Government's Integrated Planning and Reporting Framework is a strategic planning framework for local governments to determine and document their communities' aspirations and develop plans to achieve them. The Community Strategic Plan (CSP) is the highest level of strategic planning under the framework and sets a vision and strategic priorities for each of the councils.

All the councils in the Catchment renewed their CSPs during the audit period; a process that involved extensive community consultation. The plans are an interpretation of the large amount of information sought and received from the communities the various councils represent.

To duplicate the data from the last catchment audit, each CSP was reviewed to ascertain the stated community's priorities for water management. The word 'water' was used as the key word in a content search. The search included stemmed words (e.g. waterway) and synonyms (e.g river, stream, marine, aquatic). The context in which these were used on each occasion was evaluated, then classified into one of three priority categories:

- water supply and sewerage (community health)
- drainage and flooding (community safety)
- catchment and waterway protection (catchment health).

The dominant water management priority was assigned where more than 60% of the mentions of 'water' in the CSP related to each category. Figure 13 shows the water management priorities based on the CSPs.

To test this approach, councils were categorised in relation to population concentrations and percentage of waterway in the Catchment. This identified five councils where CSPs are likely to have the biggest impact on the Catchment (Goulburn, Wingecarribee, Wollondilly, Lithgow, Blue Mountains). The rating obtained from the CSP was cross-referenced with any other information available for that Council area. This included the Integrated Water Management Strategies and submissions made to public forums concerned with issues within the Catchment.

This cross-referencing changed Wingecarribee Council's rating. The CSP is mainly concerned with water supply and sewerage. However, this local government area has one of largest and most active Bushcare and Rivercare programs in the Catchment. This program is enabled by strong council support.

The analysis shows a significant improvement over this audit period in a focus on catchment health, extending into the Goulburn Mulwaree and Upper Lachlan Councils' CSPs.

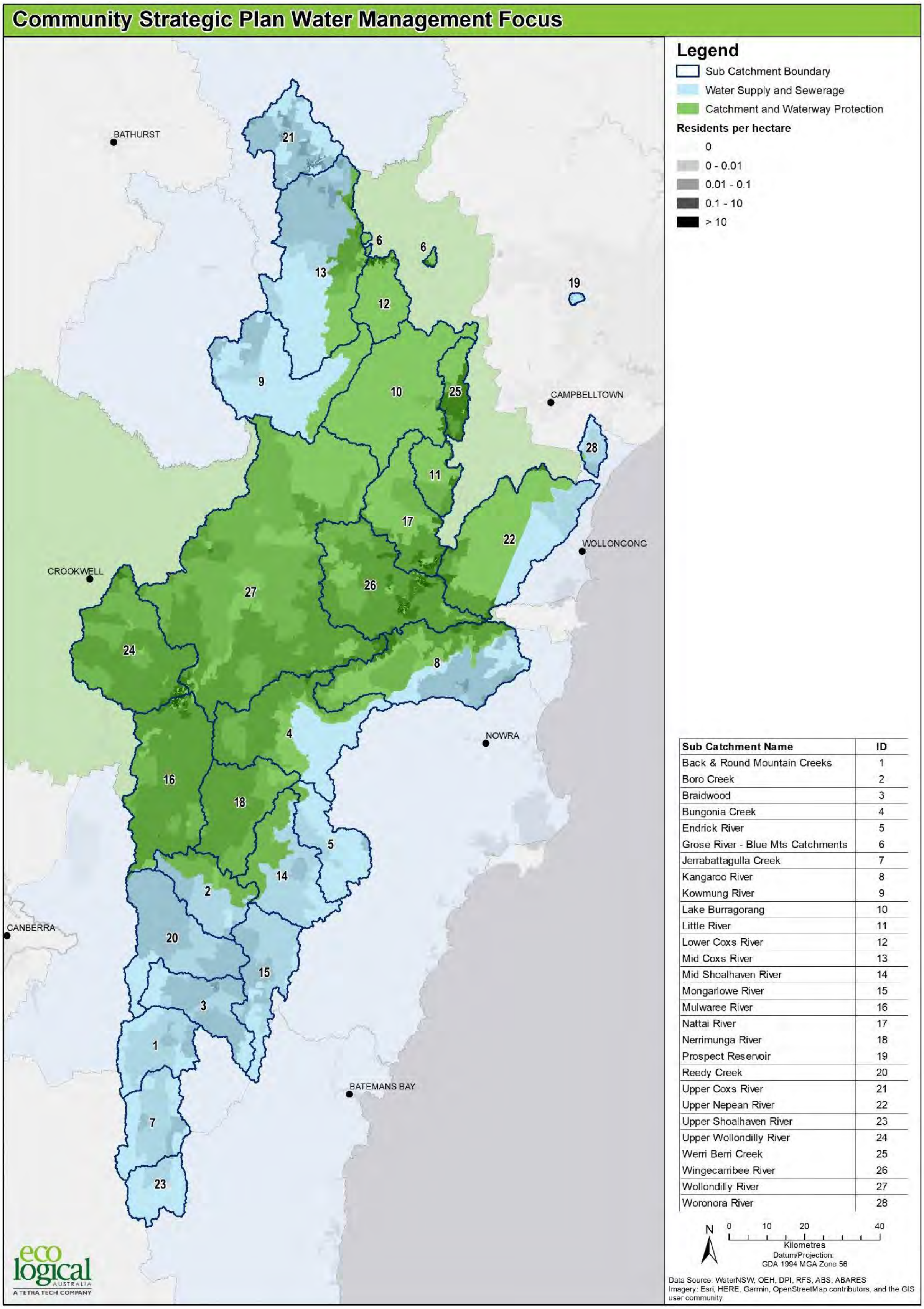


Figure 13: Community Strategic Plan Water Management Focus

2.7 Conclusion and recommendations

The data shows strong community involvement and advocacy within the Catchment. Concern in relation to coal mining continues to escalate, and so too do the communities' aspirations for catchment health, including the maintenance of quality water and sufficient water supply. As discussed elsewhere in this audit, there are a number of recommendations related to mining in the Catchment. It is further recommended that the community be informed of progress on all actions arising from the audit in a format that is easily accessible and posted annually.

Catchment improvement programs that involve the community and private landholders are supported. The long-term effectiveness of these programs should be evaluated to inform future strategies. This should begin with an evaluation of projects that were completed five and ten years ago.

3. Population settlements and patterns

3.1 Definition and context

Population settlements and patterns refer to the number and distribution of people living within the Catchment. Increasing population size increases pressure on the natural resources required to sustain the population, including water quality and availability. Management controls and infrastructure need to be tailored to settlement patterns as well as population size. For example, a widely dispersed settlement pattern may have unsewered properties, whereas increasing population density in an urban area may trigger the need to upgrade a sewage treatment plant.

Assessment criteria for this indicator include:

- average annual population growth rate
- increase in population density.

3.2 Population data and method

The estimated resident population (ERP) is the official estimate of the Australian population. ERP links people to a usual place of residence within Australia. Usual place of residence data is collected by the Australian Bureau of Statistics (ABS) every five years during the census. The latest available ABS data is from the 2016 Census.

Statistical Areas Level 2 (SA2) are the base spatial units used to collect and disseminate statistics, and they are based on officially gazetted suburbs and localities. Local Government Area (LGA) populations are estimated as at 30 June each year from SA2 estimates. For post-census years, population is estimated using a mathematical model which is based on historical relationships between population and related indicator data. During census years, smaller 'mesh block' areas are used to provide detailed estimates of the spatial distribution of the population based on usual place of residence counts.

Data for ABS Category No. 3218.0 (Regional Population Growth, Australia) was adopted for this audit for the purposes of analysing changes in population that have occurred across the Catchment. Data for ABS Category No. 1270.0.55.004 (Significant Urban Areas, Urban Centres and Localities) was adopted for the purpose of analysing the distribution of the population across the Catchment and particularly areas where the population is concentrated.

The ABS population estimates are for the entire LGAs including areas inside and outside the Catchment. The population residing inside the Catchment is most relevant for assessing risks to the Catchments. As such, the 2016 census mesh block data was reviewed for this audit to estimate the total population in each sub-catchment, as this data is more representative of population trends than for the entire LGA.

For the previous catchment audit, the latest ABS census data available was from 2011 and therefore the population analysis for the entire audit period was based on estimates only. Following release of the 2016 census data these estimates have been adjusted in the current audit to reflect actual numbers.

NSW population projections for the 2016 to 2041 period were sourced from the NSW Department of Planning Industry and Environment (DPIE 2020) for each LGA. Whilst similarly based on the 2016 ABS Census data, different assumptions have been adopted by DPIE to estimate population growth (https://www.planningportal.nsw.gov.au/population/). Long-term population projections are based on LGAs rather than the smaller mesh blocks for the population census, so have less relevance.

3.3 Population density and distribution

The ABS population data (Table 2) indicates that density was highest in the Grose River-Blue Mountains, Lower Coxs River and Upper Coxs River sub-catchments in 2016. Changes in population density over two recent audit periods (2006-11 and 2011-16) were greatest in the Grose River-Blue Mountains sub-catchment. Population in the sub-catchments is typically concentrated in a few urban centres around the Blue Mountains, Lithgow, Southern Highlands and Goulburn, as shown in Figure 14**,** but generally is very low (less than 0.1 residents per hectare) across the Catchment.

3.4 Population growth rate

The estimated total residential population (number of persons) for each sub-catchment is summarised in Table 3 along with calculated population change rates (% change/year) for the current and recent audit periods. The total population within the Catchment was estimated to be 120,497 in 2016 based on ABS Census data. The population across all sub-catchments has increased by 1.73% between the 30 June 2011 and 2016 census based on ABS total residential population data for 2011 and 2016.

Table 3 indicates that the population has increased across almost all sub-catchments since the previous audit. Lake Burragorang and Upper Shoalhaven River have seen slight decreases in numbers. The decline in estimated population observed at Upper Shoalhaven River sub-catchment from 2011 to 2016 is a continuation of the decline observed in the 2006 to 2011 period. Overall, the population growth rate of 1.73% is similar to the previous audit period of 2.01%. An exception is the Woronora River sub-catchment, in which the annual population growth rate has significantly increased since the previous audit, where the total number of residents (147) has returned to a similar number to the 2006 estimate (refer Table 3).

3.5 Population projections

Population projections are not available at the same scale as the ABS census sub-catchment mesh block data. Population projections by the NSW Department of Planning and Environment (DPE) (Table 4) incorporate entire LGAs, including areas inside and outside the sub-catchments, and the data cannot be directly compared to the sub-catchment records. DPE has projected that the population will increase between 2016 and 2041 within all LGAs associated with the Catchment, except Lithgow LGA. The highest projected increase in population will occur in the Wollondilly LGA (2.04%), although most of this is expected to occur in the designated south-west Growth Centre of Sydney, which is outside the Catchment.

Table 2: Population density by sub-catchment (Australian Bureau of Statistics)

Sub-catchment	Area (km^2)	Population density (2016) (people/km^2)	Change in density (people/km^2/year)	
			2006-2011	2011-2016
Back & Round Mountain Creeks	345.3	0.6	0.06	0.01
Boro Creek	352.3	0.7	0.08	0.00
Braidwood	373.6	4.6	0.09	0.18
Bungonia Creek	802.8	1.6	0.05	0.01
Endrick River	339.3	0.2	-0.02	0.01
Grose River - Blue Mountains	21.3	120.7	1.71	1.10
Jerrabattagulla Creek	358.8	0.3	0.04	0.00
Kangaroo River	864.8	4.8	0.06	0.07
Kowmung River	769.7	0.1	0.01	0.00
Lake Burragorang	803.7	1.4	0.04	-0.01
Little River	184.0	5.9	-0.04	0.12
Lower Coxs River	246.1	45.0	0.63	0.28
Mid Coxs River	1069.3	4.3	0.05	0.07
Mid Shoalhaven River	498.5	0.4	0.02	0.04
Mongarlowe River	429.5	0.9	0.06	0.06
Mulwaree River	788.7	15.8	0.15	0.06
Nattai River	445.9	24.2	0.12	0.70
Nerrimunga River	483.7	1.3	0.08	0.03
Prospect Reservoir	9.7	0.0	0.08	-0.10
Reedy Creek	575.3	1.3	-0.04	0.10
Upper Coxs River	382.3	40.0	0.18	0.71
Upper Nepean River	892.6	1.5	0.02	0.02
Upper Shoalhaven River	217.4	0.1	-0.02	-0.02
Upper Wollondilly River	741.5	16.2	0.28	0.74
Werri Berri Creek	164.9	27.5	-0.04	0.16
Wingecarribee River	762.1	34.3	0.51	0.85
Wollondilly River	2701.3	2.8	0.06	0.06
Woronora River	74.2	2.0	-0.17	0.23

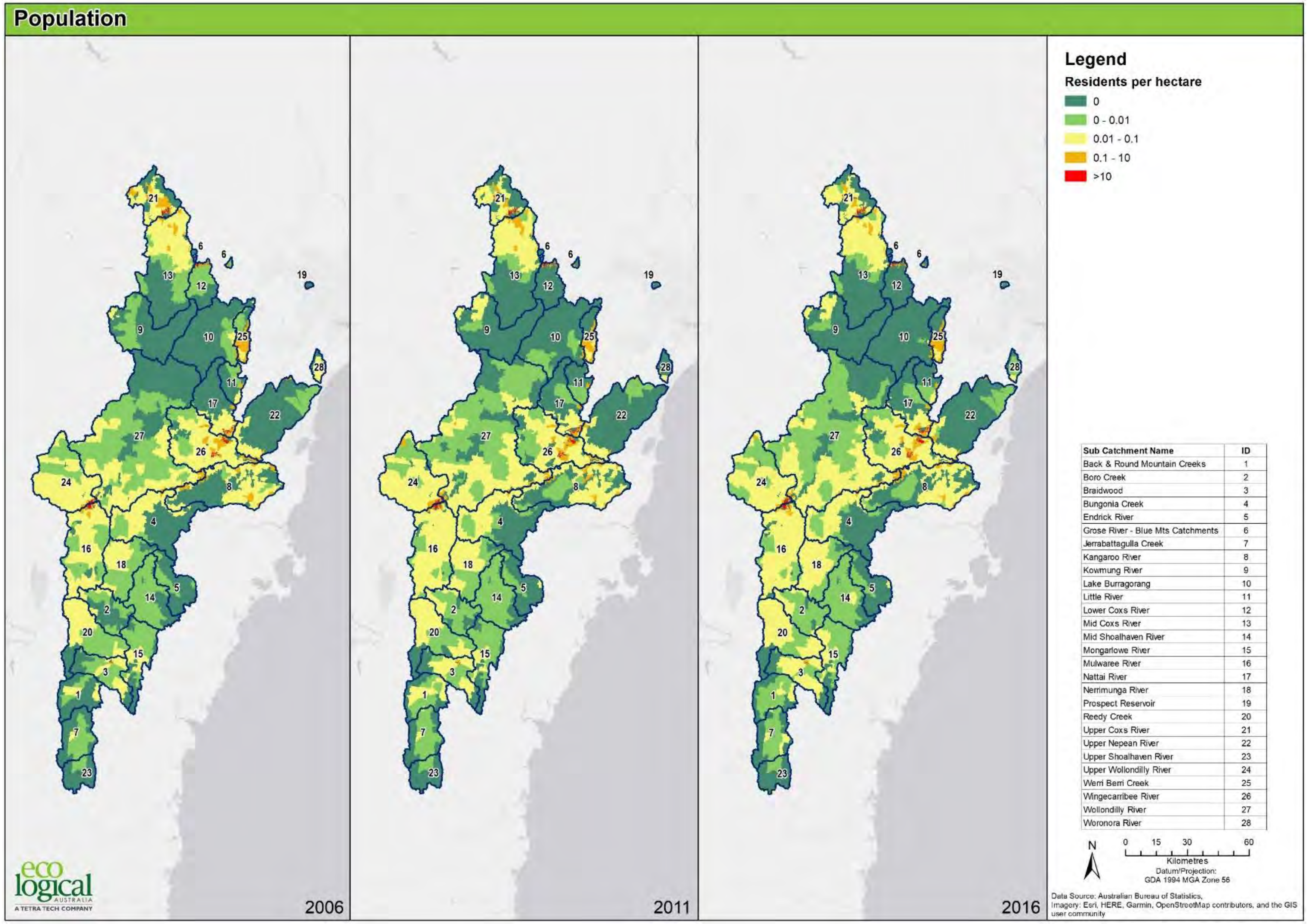


Figure 14: Population density during audit periods (Australian Bureau of Statistics data)

Table 3: Estimated residential population (persons) by sub-catchment (Australian Bureau of Statistics)

Sub-catchment	Total estimated population			Growth rate	
	2006	2011	2016	2006 to 2011	2011 to 2016
Back & Round Mountain Creeks	126	190	201	10.3%	1.1%
Boro Creek	156	237	238	10.3%	0.1%
Braidwood	1,424	1,523	1,727	1.4%	2.7%
Bungonia Creek	1,176	1,296	1,324	2.0%	0.4%
Endrick River	62	41	54	-6.7%	6.4%
Grose River - Blue Mts Catchments	2,387	2,497	2,567	0.9%	0.6%
Jerrabattagulla Creek	65	114	115	14.8%	0.3%
Kangaroo River	3,799	3,961	4,146	0.9%	0.9%
Kowmung River	78	109	115	8.1%	1.1%
Lake Burragorang	1,042	1,141	1,126	1.9%	-0.3%
Little River	1,050	1,029	1,093	-0.4%	1.2%
Lower Coxs River	10,384	10,852	11,062	0.9%	0.4%
Mid Coxs River	4,220	4,372	4,595	0.7%	1.0%
Mid Shoalhaven River	130	161	216	4.8%	6.9%
Mongarlowe River	225	303	377	7.0%	4.8%
Mulwaree River	11,923	12,284	12,426	0.6%	0.2%
Nattai River	9,713	9,872	10,811	0.3%	1.9%
Nerrimunga River	473	592	631	5.1%	1.3%
Prospect Reservoir	0	3	0	n/a	n/a
Reedy Creek	661	593	760	-2.1%	5.7%
Upper Coxs River	14,284	14,492	15,306	0.3%	1.1%
Upper Nepean River	1,227	1,280	1,338	0.9%	0.9%
Upper Shoalhaven River	38	26	15	-5.9%	-9.0%
Upper Wollondilly River	9,745	10,365	12,006	1.3%	3.2%
Werri Berri Creek	4,468	4,449	4,529	-0.1%	0.4%
Wingecarribee River	23,022	24,194	26,138	1.0%	1.6%
Wollondilly River	6,451	6,973	7,435	1.6%	1.3%
Woronora River	134	96	147	-5.7%	10.5%
Total residential population	108,464	113,047	120,497	2.01%	1.73%

Table 4: NSW State and Local Government Area population projections (Department of Planning & Environment)

Council name	Total estimated population		2016 to 2041		
	2016	2041	Total Change	Total % Change	% change / year
Blue Mountains City Council	78,850	83,600	4,750	6.0%	0.23%
City of Lithgow Council	21,500	20,800	-700	-3.3%	-0.13%
Goulburn Mulwaree Council	30,250	33,500	3,250	10.7%	0.41%
Kiama Council	22,100	26,100	4,000	18.1%	0.67%
Oberon Council	5,350	5,400	50	0.9%	0.04%
Queanbeyan-Palerang Council	57,800	65,350	7,550	13.1%	0.49%
Shoalhaven City Council	101,950	119,050	17,100	16.8%	0.62%
Upper Lachlan Shire Council	7,850	8,500	650	8.3%	0.32%
Wingecarribee Shire Council	49,000	51,500	2,500	5.1%	0.20%
Wollondilly Shire Council	49,850	82,500	32,650	65.5%	2.04%
Wollongong City Council	210,400	265,750	55,350	26.3%	0.94%

3.6 Conclusion

Government authorities continue to monitor and forecast population trends to inform strategic planning and infrastructure decisions that have the potential to affect catchment health. Population across the Catchment continues to be low, with increases in population concentrated in the main urban areas of the Southern Highlands, Goulburn, Lithgow and the Blue Mountains. Ongoing review of infrastructure capacity and development controls to protect catchment health in the context of population changes is supported.

4. Land use

4.1 Definition and context

Spatial and quantitative changes in land use across the Catchment indicate where risks to catchment health may be increasing or decreasing. Risks are greater where there are potential sources of pollution within the Catchment, such as those associated with the following land uses:

- intensive uses including sewage treatment plants
- urban activities
- stock grazing along riparian corridors
- mining / extractive industry.

In contrast, natural areas that have minimal human disturbance can improve or protect water quality in the Catchment.

4.2 Data sources and methods

Previous audits utilised land use maps of the Catchment prepared by WaterNSW and the former Sydney Catchment Authority. As there is no record of the methods and decision criteria used to classify and update land use (including for the most recent update in 2016), the process is unable to be replicated and therefore land use change in the current audit period cannot be accurately analysed against the previous method.

For the purposes of this audit, therefore, land use within the Catchment has been mapped and tabulated using the *Catchment Scale Land Use of Australia* (Catchment Scale Land Use Mapping (CLUM)) data (Department of Agriculture and Water Resources 2018). CLUM categories and sub-categories are as follows:

- Conservation and natural environments
    - Nature conservation
    - Managed resource protections
    - Other minimal use
- Production from relatively natural environments
    - Grazing native vegetation
    - Production forestry
- Production from dryland agriculture and plantations
    - Plantation forestry
    - Grazing modified pastures
    - Cropping
    - Perennial horticulture
    - Seasonal horticulture
    - Land in transition
- Production from irrigated agriculture and plantations
    - Irrigated plantation forestry
    - Grazing irrigated modified pastures

  - Irrigated cropping
  - Irrigated perennial horticulture
  - Irrigated seasonal horticulture
  - Irrigated land in transition
- Intensive uses
  - Intensive horticulture
  - Intensive animal husbandry
  - Manufacturing and industrial
  - Urban residential
  - Rural residential and farm infrastructure
  - Services
  - Utilities
  - Transport and communication
  - Mining
  - Waste treatment and disposal
- Water
  - Lake
  - Reservoir/dam
  - River
  - Channel/aqueduct
  - Marsh/wetland
  - Estuary/coastal water

4.3 Findings

All CLUM land uses within the Catchment are mapped by category in Figure 15, with detail of mining lease areas in Figure 16. Table 5 lists the dominant land uses within each sub-catchment and results can be summarised as follows:

- many sub-catchments, especially within the Special Areas, have land uses that are predominantly managed for conservation or resource protection purposes, although mining leases exist in many of these areas
- extensive areas within the Catchment are subject to grazing in native vegetation areas or modified pastures
- production native forests is a dominant land use in three sub-catchments (Black & Round Mountain Creek, Jerrabattagulla Creek and Upper Coxs River)
- many sub-catchments have areas of intensive land use (e.g. residential, transport), which have a relatively small extent (i.e. <15% of the sub-catchment area) but pose a higher risk to catchment health because they generate pollutants through sources such as sewage and urban stormwater discharges.

Coal mines and exploration leases are in the northern part of the Catchment; with mines in the Upper Coxs River, Upper Nepean River, Lake Burragorang, Woronora River and Wingecarribee River sub-catchments (Figure 16). Further detail of the extent of underground coal mines is in Table 5. Extensive areas of minerals exploration and small areas of minerals mining are in the southern part of the Catchment, as shown in Figure 16.

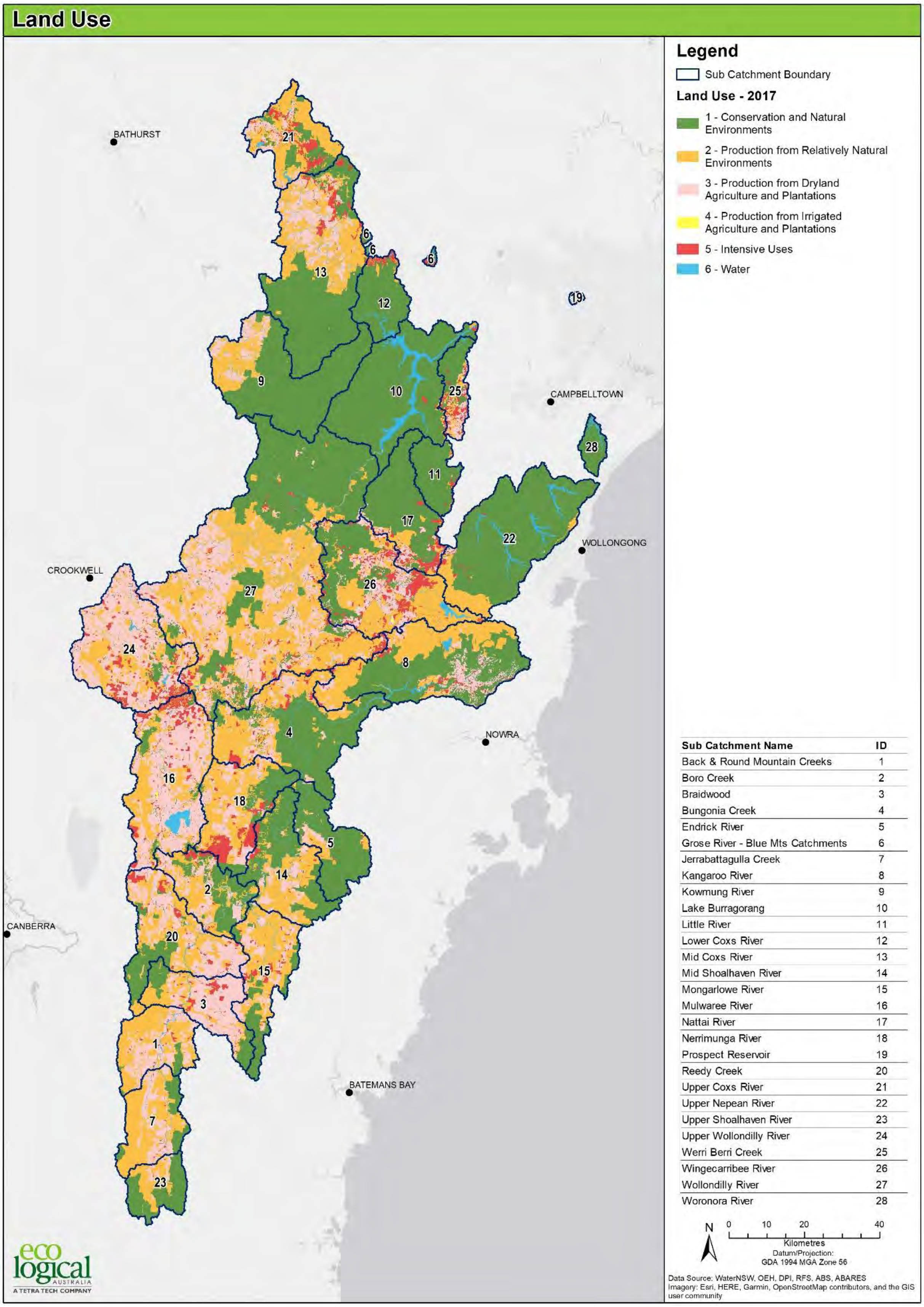


Figure 15: CLUM 2017 Land uses (Department of Agriculture)

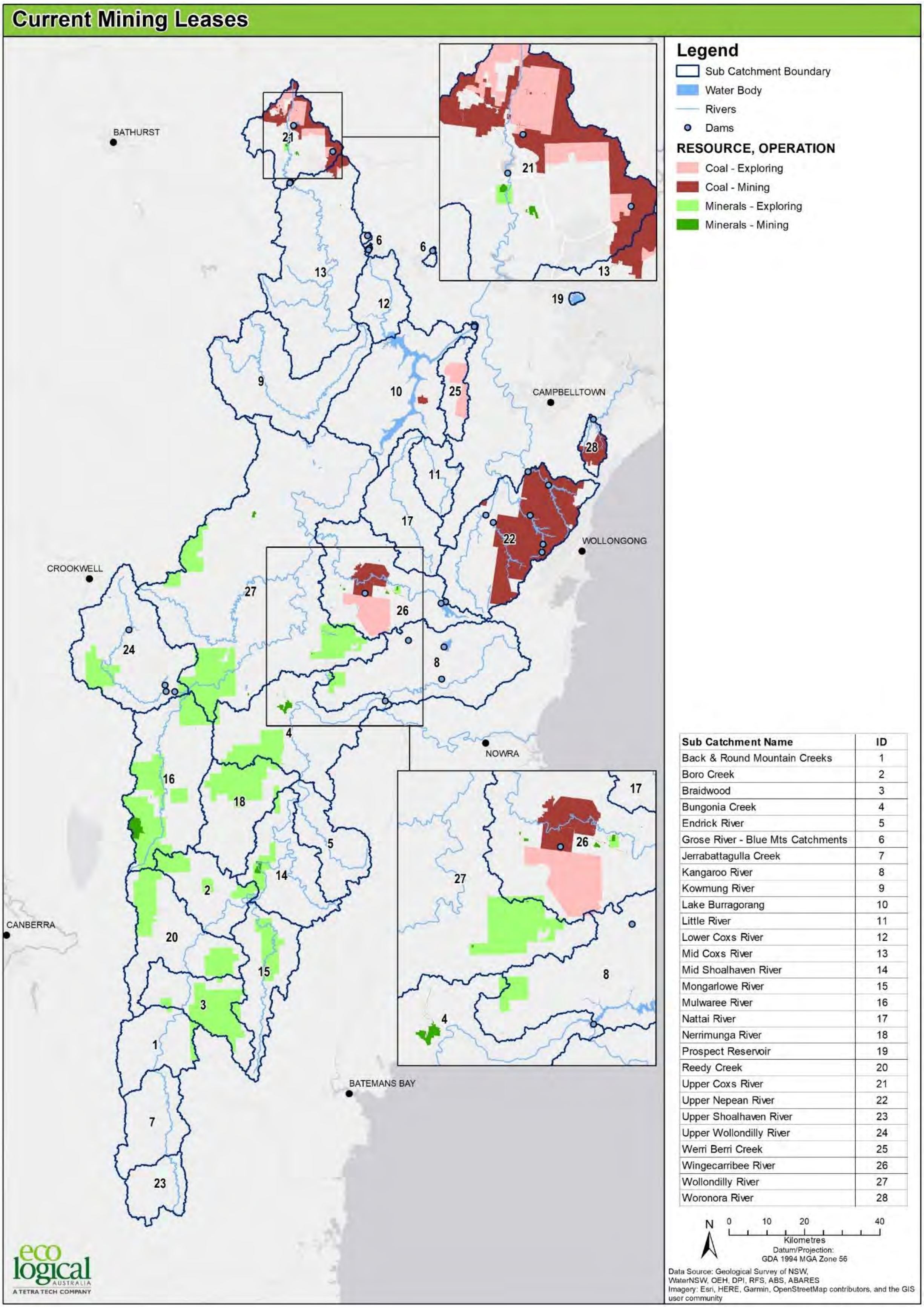


Figure 16: Mining leases in the Catchment

Table 5: Land use characteristics of sub-catchments (CLUM)

ID#	Sub-catchment	Land uses that are >20% of the sub-catchment area (from CLUM)	Coal mining lease area and underground % of sub-catchment#
1	Black & Round Mountain Creek	Grazing native vegetation (36%) Production native forests (22%) Grazing modified pastures (28%)	
2	Boro Creek	Other minimal use (27%) Grazing native vegetation (36%)	
3	Braidwood	Grazing modified pastures (49%)	
4	Bungonia Creek	Nature conservation (46%) Grazing native vegetation (31%)	
5	Endrick River	Nature conservation (66%)	
6	Grose River	Nature conservation (66%)	
7	Jerrabattagulla Creek	Grazing native vegetation (36%) Production native forests (24%) Grazing modified pastures (22%)	
8	Kangaroo River	Nature conservation (36%) Grazing native vegetation (25%)	
9	Kowmung River	Nature conservation (74%)	
10	Lake Burragorang	Nature conservation (87%)	456 ha (0.6%)
11	Little River	Nature conservation (92%)	47 ha (0.3%)
12	Lower Coxs River	Nature conservation (88%)	
13	Mid Coxs River	Nature conservation (45%) Grazing native vegetation (26%)	1601 ha (1.5%)
14	Mid Shoalhaven River	Nature conservation (20%) Other minimal use (30%) Grazing native vegetation (34%)	
15	Mongarlowe River	Nature conservation (22%) Grazing native vegetation (49%)	
16	Mulwaree River	Grazing native vegetation (29%) Grazing modified pastures (52%)	
17	Nattai River	Nature conservation (61%)	
18	Nerrimunga River	Grazing native vegetation (43%)	
19	Prospect Reservoir	n/a	
20	Reedy Creek	Grazing native vegetation (36%) Grazing modified pastures (35%)	
21	Upper Coxs River	Grazing native vegetation (22%) Production native forests (32%)	12,985 ha (33.9%)
22	Upper Nepean River	Nature conservation (29%) Managed resource protection (53%)	46,342 (51.9%)

ID#	Sub-catchment	Land uses that are >20% of the sub-catchment area (from CLUM)	Coal mining lease area and underground % of sub-catchment#
23	Upper Shoalhaven River	Nature conservation (61%) Grazing native vegetation (21%)	
24	Upper Wollondilly River	Grazing native vegetation (26%) Grazing modified pastures (41%)	
25	Werri Berri Creek	Nature conservation (42%)	
26	Wingecarribee River	Other minimal uses (25%) Grazing native vegetation (31%)	6270 (8.2%)
27	Wollondilly River	Nature conservation (23%) Grazing native vegetation (36%) Grazing modified pastures (20%)	
28	Woronora River	Managed resource protection (68%) Other minimal uses (21%)	3887 (52.4%)

Refer to Figure 16

4.4 Conclusions and recommendations

In 2019, WaterNSW proposed the CLUM product as the corporate land use dataset for the Catchment. CLUM is freely provided to all NSW agencies by the Department of Planning, Industry and Environment. The CLUM product is mapped to a very high accuracy and precision and will coincide with the ABS census five-year cycle discussed in Chapter 3. It is underpinned by national technical standards (e.g. ALUM classification system) and the mapping technique can be readily replicated. Moving to CLUM data from the previous WaterNSW method will provide a baseline dataset able to be monitored and evaluated over time. In future audits, it will be possible to use CLUM to assess land use changes across the Catchment. It is therefore recommended that WaterNSW adopts CLUM as the corporate land use dataset.

Maintaining or increasing the total area of conservation and natural environments in the Catchment helps to protect drinking water. Consistent with existing legislation and policy framework, if impacts to biodiversity and natural heritage cannot be avoided, suitable private or public lands may be used to establish in-perpetuity conservation areas to offset loss or degradation associated with development. Further, the Special Areas should continue to be managed in accordance with the scheduled update of the Special Areas Strategic Plan of Management and long-term land management programs.

5. Sites of pollution and potential contamination

5.1 Definition and context

Catchment health is adversely affected by managed or uncontrolled pollution and contamination. An increase in pollution or contamination would constitute a worsening trend. There are a range of statutory instruments and agencies involved in regulation of pollution and contamination. Examples include:

- The NSW Environment Protection Authority (EPA) issues Environment Protection Licences (EPLs) under the *Protection of the Environment Operations Act 1997* (POEO Act). Holders of EPLs are required to publish environmental monitoring results (e.g. via a website) so the community is informed.

  The EPA introduced a risk-based licensing system in 2014 to consider day-to-day operations and the risk of a pollution incident in the context of:

  - Types and nature of emissions from the premises
  - What pollution control measure are in place
  - The proximity of the premises to sensitive environments and receivers
  - The level of sensitivity of those environments and receivers
  - Environmental management performance (enforcement history)
  - Environmental management systems and practices.

  The overall risk level is assessed as 1-3 (with 3 the highest risk). The environmental management performance is assessed as A – E (with E being the poorest environmental performers). Risk ratings are reviewed by the EPA every five years as a minimum and environmental management category is reviewed annually.

  The EPA, WaterNSW and local councils undertake compliance monitoring and enforcement under the POEO Act.

  Importantly, an EPL does not mean that discharges from licenced premises are benign or comply with ANZECC water quality guidelines.

- Landowners are required to notify the EPA of contaminated land in accordance with the *Contaminated Land Management Act 1997* (CLM Act).
- Development activities are regulated under the NSW *Environmental Planning and Assessment Act 1979*. This may include conditions of consent relevant to construction or operation.

5.2 Data source and method

Data has been sourced from the EPA's public registers of contaminated land and EPLs. Case studies were informed by field inspections and agency responses to queries by the auditor. The EPA has provided further context regarding actions it has taken during the audit period.

5.3 Findings

Figure 17 identifies locations of 79 premises with EPLs and 11 known contaminated sites in the Catchment. There has been an increase in the number of EPLs since the previous audit when there were

55 records. Table 6 lists the types and location of EPLs, and indicates that three sub-catchments (Mulwaree River, Upper Cox Creek and Wingecarribee River) have a high proportion of EPLs:

- Endrick River, Lake Burragorang, Mid Coxs River, Mid Shoalhaven River, Nerrimunga River, Prospect Reservoir, Reedy Creek (1 EPL each)
- Kangaroo River, Nattai River, Upper Wollondilly (2 each)
- Braidwood, Upper Nepean River, Wollondilly River (4 each)
- Bungonia Creek (6)
- Mulwaree River (14)
- Upper Coxs River (16)
- Wingecaribee River (17).

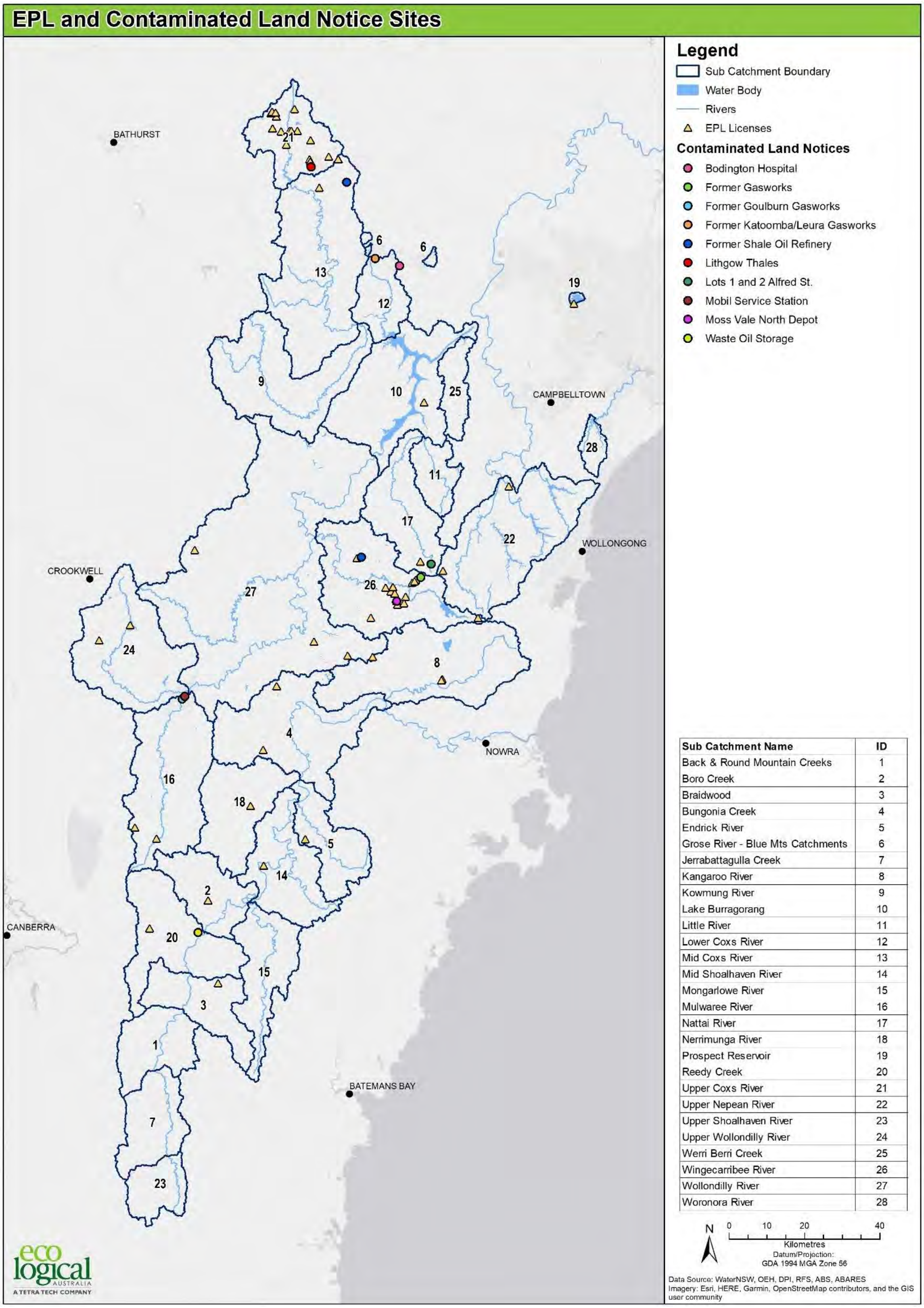
Wingecarribee River also has a high proportion of known contaminated sites compared to other sub-catchments.

Table 6: Environmental Protection Licences within the Catchment (EPA)

Sub-catchment	EPL reference*	Fee-based activity
Braidwood	1733	Sewage treatment processing by small plants
Braidwood	3517	Land-based extractive activity
Braidwood	4483	Crushing, grinding or separating
Braidwood	21131	Land-based extractive activity
Bungonia Creek	1371	Crushing, grinding or separating
Bungonia Creek	12939	Crushing, grinding or separating
Bungonia Creek	13012	Extractive activities
Bungonia Creek	13213	Crushing, grinding or separating
Bungonia Creek	20830	Bird accommodation
Bungonia Creek	21312	Mining for minerals
Endrick River	12725	Crushing, grinding or separating
Kangaroo River	10595	Generation of electrical power otherwise than from coal, diesel or gas
Kangaroo River	20244	Miscellaneous licensed discharge to waters (at any time)
Lake Burragorang	641	Coal works
Mid Coxs River	1852	Crushing, grinding or separating
Mid Coxs River	12323	Land-based extractive activity
Mid Shoalhaven River	12960	Land-based extractive activity
Mulwaree River	1649	Miscellaneous licensed discharge to waters (at any time)
Mulwaree River	1742	Sewage treatment processing by small plants
Mulwaree River	4047	General animal products production
Mulwaree River	6780	Composting
Mulwaree River	11436	Waste disposal by application to land
Mulwaree River	11455	Waste storage - hazardous, restricted solid, liquid, clinical and related waste and asbestos waste

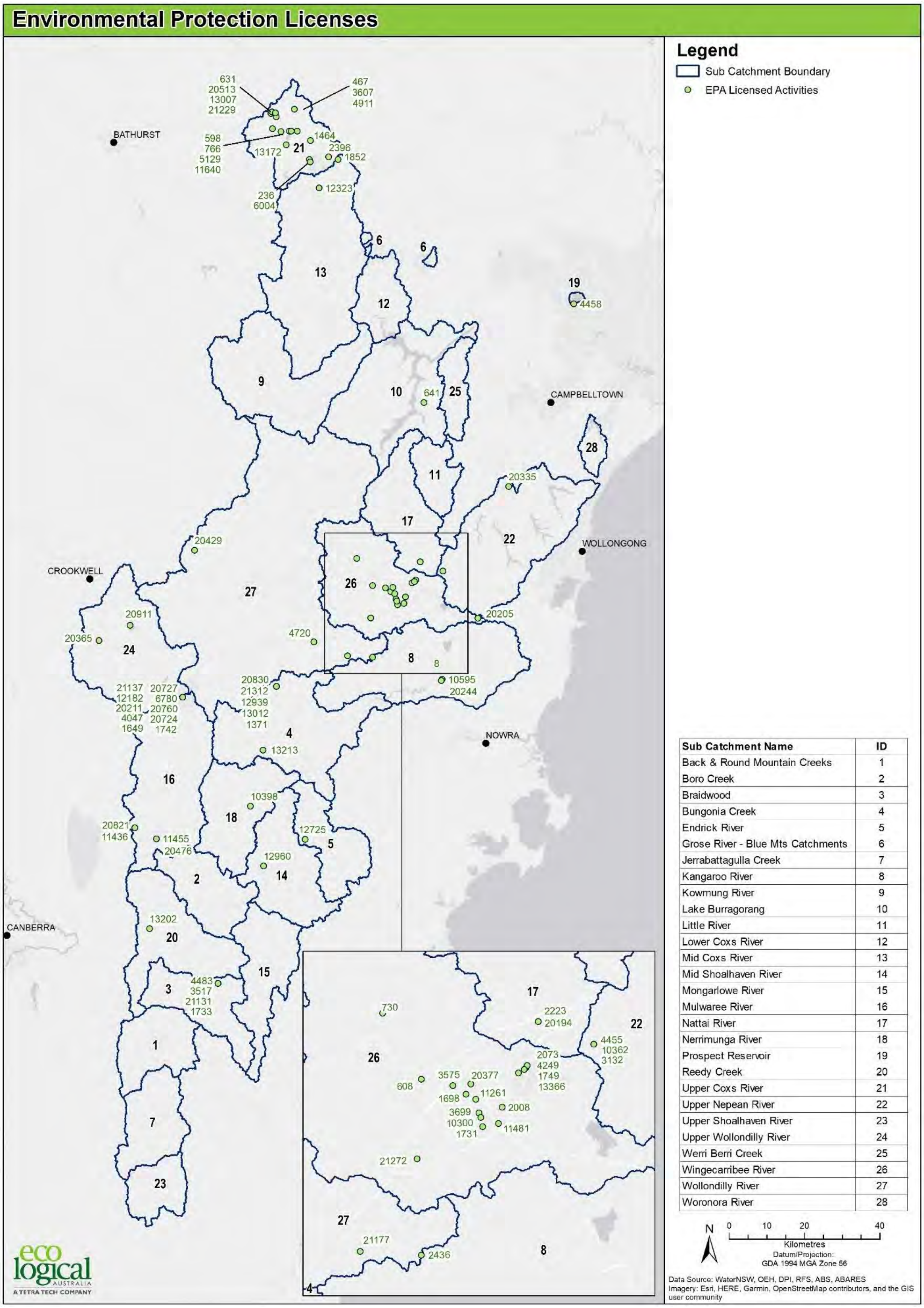
Sub-catchment	EPL reference*	Fee-based activity
Mulwaree River	12182	Non-thermal treatment of hazardous and other waste
Mulwaree River	20211	Crushing, grinding or separating
Mulwaree River	20476	Composting
Mulwaree River	20724	Non-thermal treatment of general waste
Mulwaree River	20727	Composting
Mulwaree River	20760	Wood preservation
Mulwaree River	20821	Concrete works
Mulwaree River	21137	Brewing and distilling
Nattai River	2223	Recovery of general waste
Nattai River	20194	Composting
Nerrimunga River	10398	Waste disposal by application to land
Prospect Reservoir	4458	Other activities
Reedy Creek	13202	Composting
Upper Coxs River	236	Sewage treatment processing by small plants
Upper Coxs River	467	Coal works
Upper Coxs River	598	Sewage treatment processing by small plants
Upper Coxs River	631	Coal works
Upper Coxs River	766	Waste disposal by application to land
Upper Coxs River	1464	Crushing, grinding or separating
Upper Coxs River	2396	Miscellaneous licensed discharge to waters (at any time)
Upper Coxs River	3607	Coal works
Upper Coxs River	4911	Coal works
Upper Coxs River	5129	Coal works
Upper Coxs River	6004	Waste disposal by application to land
Upper Coxs River	11640	Explosives production
Upper Coxs River	13007	Generation of electrical power from coal
Upper Coxs River	13172	Crushing, grinding or separating
Upper Coxs River	20513	Recovery of general waste
Upper Coxs River	21229	Coal works
Upper Nepean River	3132	Crushing, grinding or separating
Upper Nepean River	4455	Concrete works
Upper Nepean River	10362	Sewage treatment processing by small plants
Upper Nepean River	20335	Sewage treatment processing by small plants
Upper Wollondilly River	20365	Electricity works (wind farms)
Upper Wollondilly River	20911	Electricity works (wind farms)
Wingecarribee River	608	Coal works

Sub-catchment	EPL reference*	Fee-based activity
Wingecarribee River	730	Pig accommodation
Wingecarribee River	1698	Cement or lime production
Wingecarribee River	1731	Sewage treatment processing by small plants
Wingecarribee River	1749	Sewage treatment processing by small plants
Wingecarribee River	2008	Crushing, grinding or separating
Wingecarribee River	2073	Ceramics production
Wingecarribee River	3575	Sewage treatment processing by small plants
Wingecarribee River	3699	Animal accommodation
Wingecarribee River	4249	Land-based extractive activity
Wingecarribee River	10300	Composting
Wingecarribee River	11261	General agricultural processing
Wingecarribee River	11481	Metal waste generation
Wingecarribee River	13366	Non-thermal treatment of general waste
Wingecarribee River	20205	Miscellaneous licensed discharge to waters (wet weather only)
Wingecarribee River	20377	Extractive activities
Wingecarribee River	21272	Extractive activities
Wollondilly River	2436	Sewage treatment processing by small plants
Wollondilly River	4720	Crushing, grinding or separating
Wollondilly River	20429	Electricity works (wind farms)
Wollondilly River	21177	Wood or timber milling or processing
* Refer to Figure 18 for locations		



Sub Catchment Name	ID
Back & Round Mountain Creeks	1
Boro Creek	2
Braidwood	3
Bungonia Creek	4
Endrick River	5
Grose River - Blue Mts Catchments	6
Jerrabattagulla Creek	7
Kangaroo River	8
Kowmung River	9
Lake Burragorang	10
Little River	11
Lower Coxs River	12
Mid Coxs River	13
Mid Shoalhaven River	14
Mongarlowe River	15
Mulwaree River	16
Nattai River	17
Nerrimunga River	18
Prospect Reservoir	19
Reedy Creek	20
Upper Coxs River	21
Upper Nepean River	22
Upper Shoalhaven River	23
Upper Wollondilly River	24
Werri Berri Creek	25
Wingecarribee River	26
Wollondilly River	27
Woronora River	28

Figure 17: Sites with EPLs and known contamination in the Catchment (EPA data)



Sub Catchment Name	ID
Back & Round Mountain Creeks	1
Boro Creek	2
Braidwood	3
Bungonia Creek	4
Endrick River	5
Grose River - Blue Mts Catchments	6
Jerrabattagulla Creek	7
Kangaroo River	8
Kowmung River	9
Lake Burragorang	10
Little River	11
Lower Coxs River	12
Mid Coxs River	13
Mid Shoalhaven River	14
Mongarlowe River	15
Mulwaree River	16
Nattai River	17
Nerrimunga River	18
Prospect Reservoir	19
Reedy Creek	20
Upper Coxs River	21
Upper Nepean River	22
Upper Shoalhaven River	23
Upper Wollondilly River	24
Werri Berri Creek	25
Wingecarribee River	26
Wollondilly River	27
Woronora River	28

Figure 18: Locations and reference numbers for Environment Protection Licences (EPA)

5.4 Case studies

A series of case studies are presented below to highlight 'hot spot' areas and issues relevant to pollution within the Catchment within the audit period. Some of these issues were raised in the 2016 audit. Organisational leadership and staff retention were found to be key factors determining the effectiveness of achieving environmental objectives through infrastructure programs and compliance monitoring and enforcement.

5.4.1 Wingecarribee LGA sewerage services

There is potential for increased pollution as sewerage infrastructure nears capacity in the context of a growing population in the Wingecarribee LGA, as discussed in Chapter 3. Pollution incidents are managed in accordance with the Wingecarribee Shire Council Sewage Treatment Schemes Pollution Incident Response Management Plan (2015), which is reviewed annually. Wingecarribee Shire Council is progressively upgrading its sewage treatment plants (STPs) and sewerage network in accordance with its Integrated Water Cycle Management Strategy (Wingecarribee Shire Council & Public Works Advisory 2018), as summarised in Table 7. Further work is needed to obtain funding for design and construction of the STP upgrades.

Table 7: Wingecarribee Council sewerage infrastructure

Sewerage infrastructure	Status / comment
Sewerage network	Ongoing routine maintenance and repairs e.g. sewer blockages or overflows in pipes due to obstruction Sewer renewal program scheduled for 2019/20 and 2020/21 at priority sites across the Wingecarribee LGA
Berrima STP	Algal blooms were an issue in the tertiary pond due to the extended drought during the audit period. STP is nearing capacity and requires upgrade. Aquatic health monitoring and water quality modelling are being undertaken as part of the analysis for the STP upgrade.
Bowral STP at Burradoo	STP operated within licence conditions during the audit period. STP is nearing capacity and requires upgrade. Aquatic health monitoring and water quality modelling are being undertaken as part of the analysis for the STP upgrade. The NSW Safe and Secure funding for Bowral STP was approved (25% of total upgrade cost $6.6M).
Mittagong STP	STP operated within licence conditions during the audit period. STP is nearing capacity and requires upgrade. Aquatic health monitoring and water quality modelling are being undertaken as part of the analysis for the STP upgrade.
Moss Vale STP	STP operated within licence conditions during the audit period. STP is nearing capacity and requires upgrade. Aquatic health monitoring and water quality modelling are being undertaken as part of the analysis for the STP upgrade.

Figure 19 shows sites of EPLs and known contamination within the Wingecarribee River sub-catchment, including some of the STPs to be upgraded.

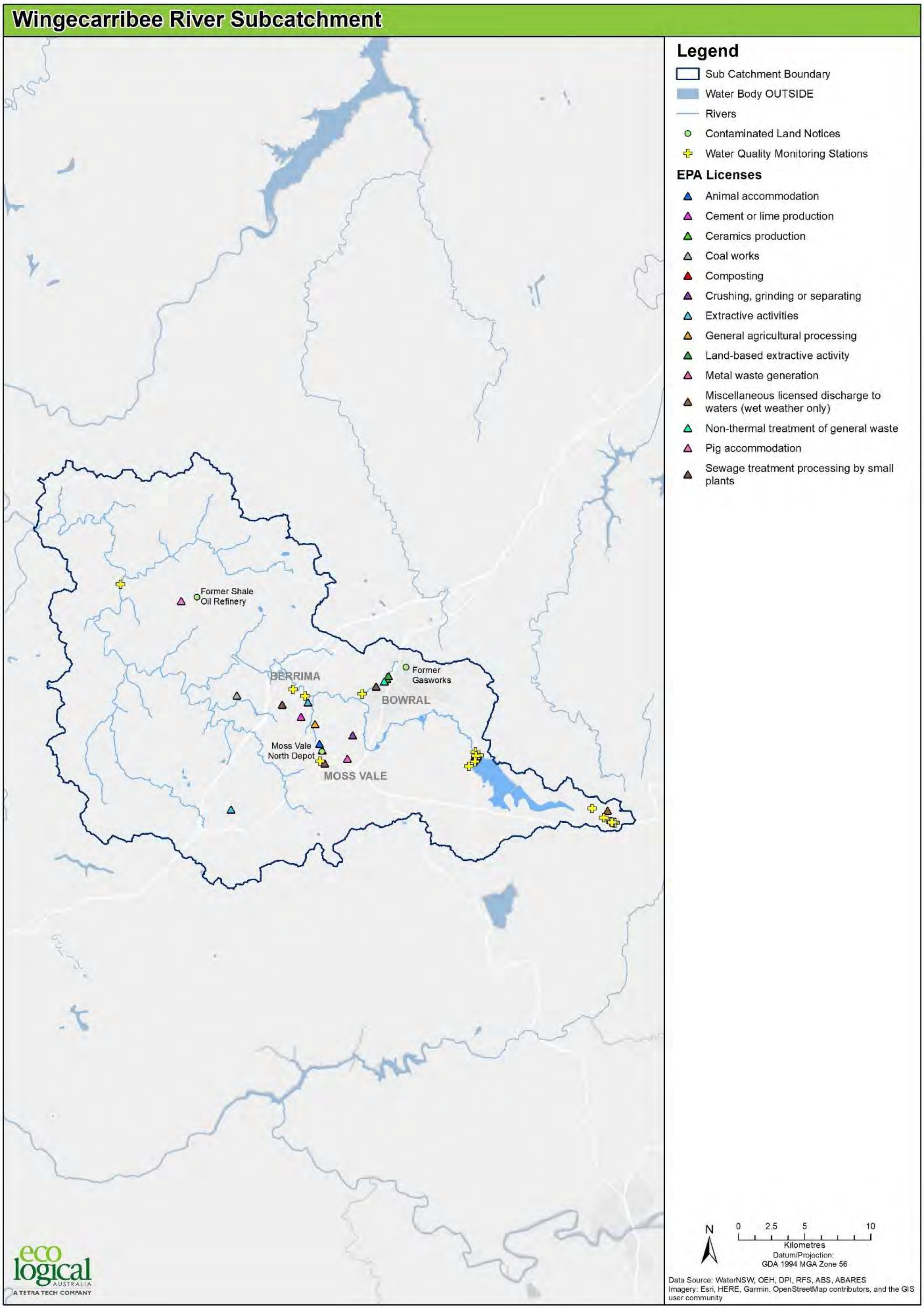


Figure 19: Wingecarribee sub-catchment – sites with EPLs or contaminated land (EPA)

5.4.2 Oil spill incidents in Special Areas

BACKGROUND

Three separate transformer oil spill incidents occurred during April and May 2017 on land managed by third party mining companies within the Cataract, Avon and Cordeaux Special Areas as a result of vandalism. Early remedial measures implemented included deployment and maintenance of oil absorbent booms, pillows and mats. On the Cataract Reservoir, a solid boom with skirt was installed and absorbent booms were secured to the upstream side of the solid boom. Under guidance from an expert panel, WaterNSW temporarily ceased supply of water from the Upper Canal to the Macarthur and Prospect Water Filtration Plants (WFPs) with the excess water transferred to Prospect Reservoir. The expert panel subsequently determined the risk to the quality of drinking water was low and WaterNSW recommenced supply from the Upper Canal to these WFPs.

WaterNSW conducted an investigation and prepared a report that detailed the factors that contributed to the incidents and its response to the incidents. WaterNSW kept key stakeholders, including its Board, Sydney Water, EPA and NSW Department of Health, informed of the incidents and the actions being taken and followed up on advice received from stakeholders (e.g. NSW Department of Health). WaterNSW issued Clean-up Notices to the respective mining companies requiring investigations and remediation of the oil spill sites.

A joint agency meeting in June 2017 attended by EPA, WaterNSW, DPE Compliance, NSW Resource Regulator and DPE - Division of Resources & Geoscience (DRG) was held to further discuss actions arising from these incidents. Although none of the incidents resulted in any oil migrating to WaterNSW storages or impacts for customers, recommendations and improvement actions were identified to reduce the future risk from mining company transformers, other transformers and chemical storages, and to improve incident response capability. The following key actions were agreed:

- To develop a coordinated whole of government response on identifying and reducing risks from chemical hazards in the Special Areas.
- As they are regulated under differing legislation, it was agreed that two separate programs were required to address the risks, one focusing on sites operated by mining companies and the other on non-mining organizations, including several utility, power and telecom companies.

ACTIONS TAKEN - SOUTH32 - CORRIMAL VENTILATION SHAFT 3 OIL SPILL, CATARACT CATCHMENT

WaterNSW issued Clean-up Notices to South32 requiring soil, sediment, surface water and groundwater investigations and implementation of remedial measures at the Corrimal Ventilation Shaft 3 Oil Spill site. An Investigation Completion report was prepared to address the Clean-up notice requirements which was accepted by the EPA appointed Independent Environmental Auditor and WaterNSW. The transformed yard site in the vicinity of the oil spill was remediated and a Remediation Validation Report was completed and reviewed by the EPA Independent Environmental Auditor and WaterNSW. A Water Quality Monitoring Program (WQMP) for the transformer yard and downstream swamp area was developed and implemented to monitor any oil that may migrate downstream from the swamp into the unnamed tributary flowing into Cataract Reservoir.

The WQMP includes surface water, sediment/soil, groundwater sampling on a biannual six-monthly basis and provides a process for verifying that post remediation there are no unacceptable risks to human health or the environment. Weekly field observations indicate that oil sheen has not been observed downstream of Site 10 which is within the swamp area and weekly surface water sampling has not reported positive detections above the limit of detection for all analytes since a period prior to the November 2019 six monthly monitoring report. Inspections and water quality monitoring after the significant rainfall event in February 2020 did not detect any soil downstream of the swamp area in the unnamed tributary flowing into Cataract Reservoir.

ACTIONS TAKEN - WOLLONGONG COAL (RUSSELL VALE AND WONGAWILLI COLLIERIES) AVON AND NEBO OIL SPILLS

The two transformer oil spill sites (Wongawilli No 1 Shaft and Nebo No 3 Shaft) are in WaterNSW Metropolitan Special Areas within the Avon and Cordeaux Dam sub-catchments. Coffey on behalf of Wollongong Coal Ltd prepared and implemented a remediation methodology to address WaterNSW's Clean-up Notices for investigation and clean-up of the contamination at the sites. Remediation/validation work was carried out and completed in June 2018. The oil spills at these sites were contained by excavation of the soil, storing the excavated soil (initially onsite before relocating it to the Wongawilli Mine site), and backfilling the excavated sites. WaterNSW Catchment field staff have verified that the remediation excavation backfill works have been completed at both the spill sites as reported by Wollongong Coal Ltd.

CHEMICALS STORED AT NON-MINING SITES WITHIN SPECIAL AREAS

As part of a coordinated whole of government response to the spill incidents, the EPA and WaterNSW jointly undertook a review of the risks posed by stored chemicals at sites of non-mining organisations that have operations across sites located within the Special Areas. In Phase 1 of the project, a letter was sent by the EPA in October 2017 to the identified organizations, seeking information on liquid chemicals including transformer and fuel oils which are used or stored at the sites. Information requested included the type and quantities of stored chemicals, environmental controls like bunding, and security arrangements at each site. In Phase 2, a desktop review was undertaken and priority sites (including sites of Sydney Water, TransGrid, WaterNSW, Endeavour Energy and Appleshack Orchards) were selected for inspection and follow-up.

Key findings and actions based on the information received and the site inspections of the priority sites are given below. In general, the investigation found that chemicals stored at non-mining sites (primarily transformer oils and fuels) within the Special Areas are well secured and adequate management and response measures are in place to respond to any spill events.

It is considered that the Transgrid, Sydney Water and WaterNSW sites are all well secured with CCTV and/or regular security patrols. Chemicals stored at these sites including within transformers is appropriately stored in locked sheds or tanks with bunding. These sites have adequate environmental controls and incident response systems to address spill/fuel oil leakages and ensure there are no discharges offsite. Operational staff are adequately trained, and appropriate monitoring and early warning systems are in place.

Endeavour Energy has over 500 unmanned pole-mounted transformers with oil quantities ranging from 50L to 700L in active transmission substation systems within the Special Areas. Pole-mounted transformers near Cordeaux Dam and near Appin / Bulli Road (near Bureau of Meteorology Letterbox weather station) were inspected. Based on information provided by Endeavour Energy on the type of oils used in the transformers, low oil trigger device and remote auto notification to base station and adequate response teams and procedures, it was determined that Endeavour Energy is well prepared to manage any oil spills from the pole mounted transformers in a timely manner and the risk of transport offsite to receiving waters is negligible.

Environmental improvements in the form of improved bunding were considered necessary at one site. At Appleshack Orchards on Darkes Forest Road, the risk and adverse environmental consequences to the Woronora storage (approximately 8 km away) from a fuel or chemical spill at the site is very low. However, due to the potential for significant clean-up costs should a spill occur (any spill has the potential to drain to the onsite farm dam 220 m away), a high level of sound environmental practice and management around liquid chemicals at the site is required. WaterNSW therefore wrote to Appleshack seeking improvements in terms of adequate bunding for the above ground diesel tank and chemical storage shed. Appleshack implemented these improvements by late 2019.

MANAGEMENT OF MINING INFRASTRUCTURE IN SPECIAL AREAS

As part of a whole of government response to the three oil spill incidents, an audit program of mining company sites was developed and jointly implemented by DRG, Resources Regulator, DPE Compliance and WaterNSW. A total of 29 separate mining infrastructure sites were initially identified within the Special Areas across eight mining operations. From these sites, 12 individual sites across six mining operations were identified as being priority mine audit sites. A joint agency compliance audit program was developed and undertaken of these priority mining infrastructure sites within the Special Areas during late 2017 and early 2018. The key objective of the audit program was to assess the status and management of mining infrastructure in the Special Areas, including all transformers. The focus of the assessment at each site was the management of infrastructure to minimise the risk of pollution events occurring that could impact the water quality within the Special Areas.

Key findings and actions included:

- The audits identified a total of 5 non-compliances, 30 observations of concern and 7 suggestions for improvement. A Corrective Action Plan was prepared for the sites audited.
- Three of the six mining operations audited recorded no non-compliances with a total of only six observations of concern between them. Generally, these mining operations had good management practices, systems and processes in place to identify and control the risks associated with mining infrastructure in the Special Areas.
- The identified non-compliances primarily related to WaterNSW access consent requirements, including maintenance of a Special Area Key Register, inclusion of WaterNSW as an emergency contact, and no evidence of an adequate insurance policy detailing WaterNSW as an interested party with a liability equal to or greater than $25,000,000.
- WaterNSW has followed up and closed out all non-compliances and corrective actions identified in the Corrective Action Plan in its area of operations/responsibilities, and there are no pending actions from any of the mining entities.

5.4.3 Upper Coxs River sub-catchment

The waterways and landscapes of the Upper Coxs River sub-catchment have experienced substantial modification and pollution over decades associated with:

- urban development, including sewerage and stormwater infrastructure
- coal mining
- electricity generation at Mt Piper and Wallerawang.

Historical activities have a legacy of environmental damage that is expensive and challenging to repair. In recent years, including during the audit period, efforts have been made to tighten licencing and compliance on polluting activities and commence rehabilitation of degraded waterways such as Farmers Creek. Further work is needed to improve environmental conditions and catchment health in this sub-catchment.

Farmers Creek, Lithgow stormwater infrastructure

Discolouration at Springvale Mine outlet

Rehabilitation of stormwater channel bank by LCC

Rehabilitation of swamp by LLS

Figure 20: Photos of degraded sites within Upper Coxs River sub-catchment and sites subject to rehabilitation

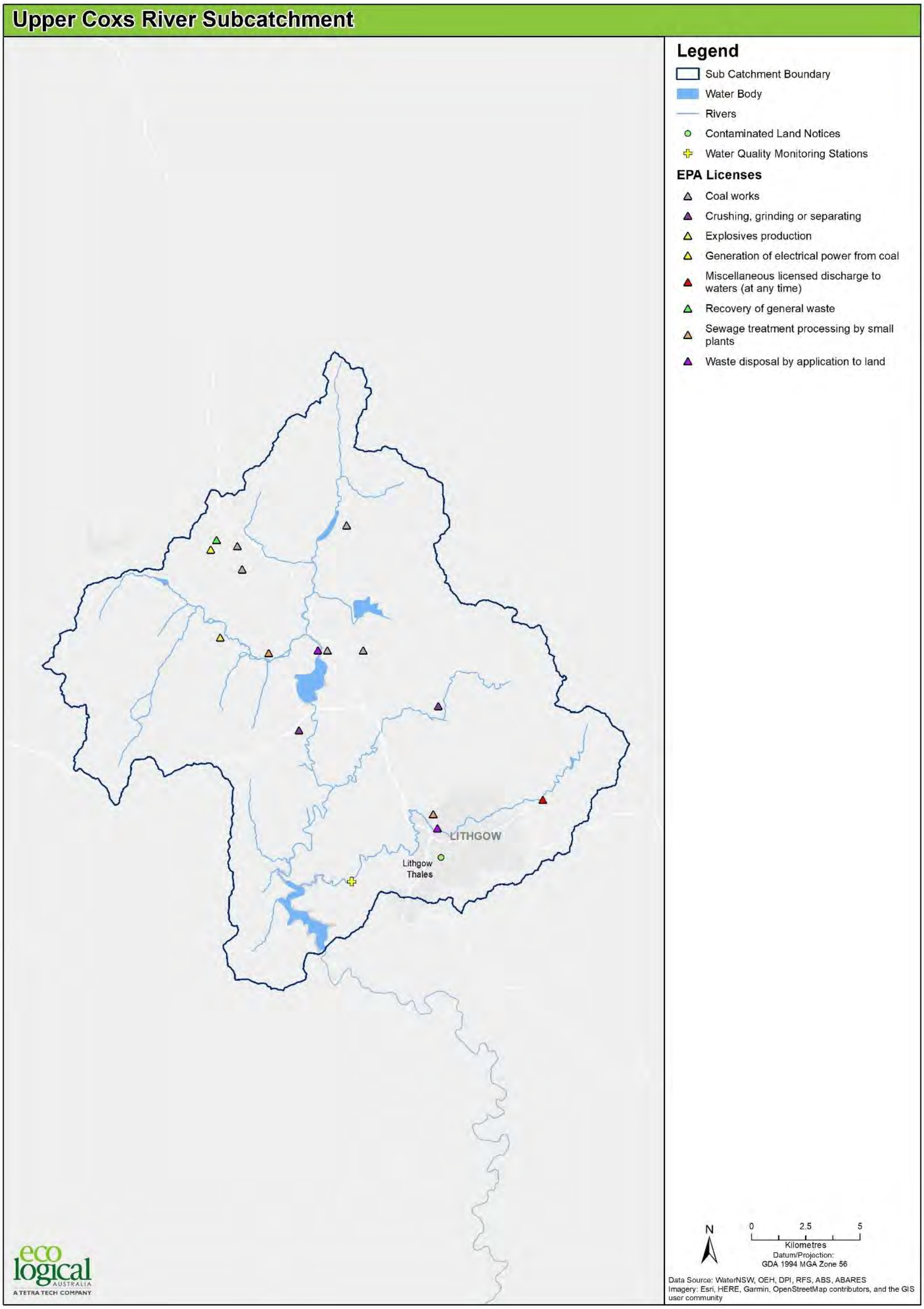


Figure 21: Uppers Cox's sub-catchment – sites with EPLs or known contamination (EPA)

5.4.4 Urban stormwater management

Stormwater pollution can be a diffuse or point source (end-of-pipe) and can occur during construction of a new development or as part of its ongoing operation. Best practice stormwater infrastructure incorporates features that improve the amenity and environment, as well as control stormwater flow.

WaterNSW has evaluated a range of stormwater management measures applied by local councils in the Catchment (see summary in Table 8). In late 2017, WaterNSW engaged the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) to undertake a stormwater program with priority councils (Blue Mountains City Council, Lithgow City Council, Goulburn Mulwaree Council and Wingecarribee Shire Council). Initially there was a positive interest in this program by multiple councils. At the end of the audit period, two councils (Blue Mountains and Goulburn Mulwaree) had engaged in the project. Outside the audit period, WaterNSW is setting up an internal benchmarking tool to measure council water management improvements.

Table 8: WaterNSW evaluation of local council stormwater management responses

Type	Council action	WaterNSW evaluation of action
Policies and strategies	Developing council policies and/or strategies that support a coordinated and integrated water management approach with the aim of incorporating water sensitive urban design and achieving Neutral or Beneficial Effect (NorBE) for developments across council practices. Leading actions by councils in the Catchment include the 2019 Blue Mountains Water Sensitive City Strategy and almost finalised Wollondilly Shire Council Integrated Water Management Policy and Strategy	WaterNSW engaged the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) to conduct a benchmarking, visioning and transition strategy process with target councils to assess current water management performance and set new targets for improvements against indicators. The project worked with multiple teams across Blue Mountains Council (approx. 30 staff). The benchmarking tool can be used for the ongoing evaluation of Council water management processes against set indications for water sensitive cities and see the results of other local government areas across Australia. WaterNSW is considering a desktop analysis of remaining councils interviewing a handful of staff WaterNSW works with councils to review and provide feedback on key documents.
Planning specifications	Reviewing council Development Control Plans (DCPs) and Local Environment Plans (LEPs) to incorporate specifications for improved stormwater management and NorBE e.g. Blue Mountains Development Control Plan, Chapter Part C6 Water Management. Including stormwater management as a focus in the Local Strategic Planning Statements. DPIE deadline for non-metropolitan councils' LSPS is late 2020.	WaterNSW is baselining the DCP content, definitions and references of councils in the Catchment against an internally developed DCP checklist standard WaterNSW is also evaluating councils' Local Environment Plans based on the presence of stormwater and other related clauses and content to monitor and work with councils to implement improvements over time. Assessment methods for DCP and LEP evaluation are draft only and not yet approved.
Education and training	Facilitating training to up-skill multiple teams across council to improve understanding of different management techniques e.g. training on bio-filtration systems was attended by staff of three councils (2019), DPIE Roadshow on NorBE	WaterNSW provides opportunities for NorBE training and has engaged a provider for Council stormwater education and training opportunities. Every training event incorporates mandatory post training evaluation and review.

Type	Council action	WaterNSW evaluation of action
	and the Controlled Area Guidelines (2019) and a Living Waterways Workshops were attended by 10 councils in 2017. WaterNSW NorBE training and phone support to undertake individual assessment if required has been taken up by Wingecarribee, Shoalhaven, Goulburn Mulwaree, Blue Mountains City, Queanbeyan Palerang Regional and Wollondilly Shire councils multiple times since 2016.	
Community consultation	Forming education programs focused on good stormwater management and pollution prevention, targeting varying audiences within the community e.g. providing and attending school programs. Wingecarribee Shire Council World Environment Day and Blue Mountains Shire Council School, Bushcare and community celebration events. Providing information on stormwater and water quality, its importance to environmental health and the role the community can play on its website e.g. Wingecarribee Shire Council Water Education, Wollondilly Shire Council Water and Blue Mountains City Council Waterways pages. In 2019, WaterNSW engaged the Cooperative Research Centre for Water Sensitive Cities to support the Blue Mountains City Council and include the communities' vision in the Water Sensitive Blue Mountains Strategy. Three community workshops were conducted as part of this process.	Engaging the Cooperative Research Centre for Water Sensitive Cities to conduct a community consultation and visioning process with partner council communities has assisted WaterNSW to monitor community values, awareness, understanding, concerns and priorities regarding stormwater management, assisting to inform future Council decisions.
Stormwater infrastructure and water quality monitoring	Monitoring the efficacy of custom designed WSUD devices e.g. Blue Mountains City Council in Leura Falls and Jamison Creeks. Partnering with WaterNSW to map, monitor and eliminate pollution sources related to stormwater and stream quality in key urban catchments	Improving the knowledge of the installed technologies, their functionality in location specific environments and sharing the outcomes with teams across council and other stakeholders. A dashboard is being finalised that provides a real-time interpretation of water monitoring results and identification of the areas to which they apply. Access will be available across council to enable evaluation of improvements in specific areas over time.

Urban development stormwater management case studies are provided below for locations in the Southern Highlands.

Case Study 1 – Renwick urban development

Renwick is the largest urban development subdivision in the Catchment except in Goulburn. WaterNSW contributed to water quality studies for the 2001 Masterplan and worked with Landcom to achieve NorBE in the design. This included riparian corridor restoration, bioretention basins for construction and long-term, and devices within each lot (e.g. rainwater tanks).

Comment – this is an example of best practice urban development in the Catchment and will require ongoing maintenance to continue to achieve water quality objectives.

Case Study 2 – Moss Vale commercial developments

Two recent commercial developments in Moss Vale have been subject to concurrence assessment and have required detailed stormwater quality modelling to demonstrate NorBE during construction and long-term operation. Stringent consent conditions were imposed, including the need for inclusion of water sensitive urban design features and ongoing compliance monitoring and reporting to Council.

Comment – there needs to be greater attention given to monitoring and adaptive management.

Post-approval responsibility for monitoring and maintenance should be determined during the planning approval process. Increasingly, responsibility is assigned to the developer and subsequent body corporate or equivalent, with council fulfilling a compliance role. Potential resources for ongoing maintenance, monitoring and compliance should be considered as part of the development proposal and approval.

5.4.5 EPA investigation of water quality in Lake Burragorang

In response to the 2018 NSW Auditor General's report into the EPA regulation of water pollution in drinking water catchments and illegal disposal of solid waste recommendations, the EPA reviewed the likely influence on the water quality in Lake Burragorang from premises with EPLs that have conditions allowing them to discharge into the Catchment. The review of licenced activities and the impact to water quality in the Lake Burragorang area was designed to provide information to target EPA regulatory activity where significant impact on Lake Burragorang might be anticipated. The review considered all 81 premises within the Catchment area that had an EPL, focusing on nutrient and salt load discharged from those premises. The review found that the impact of licensed activity on the Lake is negligible. The contribution from licensed premises to Lake Burragorang nutrient and salt loads was calculated to be less than 0.6% of total nitrogen, 0.1% of total phosphorous and 0.1% of the total salt load. Nutrient loads to Lake Burragorang also reduce as water travels downstream as they are assimilated e.g. through plant growth. This dilution further reduces any potential impacts from EPA licensed discharges.

5.4.6 Berrima Colliery closure

There was a deterioration in the quality of the mine water discharged to the Wingecarribee River following the closure of the Berrima Colliery (EPL No 608) in 2013. This included orange-yellow staining of the river due to the presence of iron and manganese, and increased levels of toxic dissolved metals such as nickel and zinc. The mine is subject to several pollution reduction programmes, which are conditions on the EPA licence. EPA actions have run in parallel with mine closure and rehabilitation requirements administered by the Resources Regulator.

Boral's Closure Working Group was put into effect during the current audit period. In 2016, Government authorities were notified of elevated mineral levels in water coming from the mine's adit (underground entrance). A passive treatment system, installed in 2018, effectively reduced mineral content and was replaced in 2019 by seven bulkheads as a long-term solution. As of the end of the audit period, groundwater at the site is recharging and discharging has reduced by 95% (Boral 2020).

5.5 Conclusions and recommendations

Sewerage infrastructure needs to be upgraded in the Wingecarribee River and Nattai River sub-catchment to support the growing population of the Wingecarribee LGA. Investigations are underway to progress these upgrades.

As discussed in other chapters of this audit report, there are multiple issues and community concerns regarding the relatively high numbers of sites of pollution and contamination in the Wingecarribee River and Upper Coxs River sub-catchments. Strategic investigation of cumulative environmental impacts in these two sub-catchments is recommended. This should consider point and diffuse pollutant sources, the adequacy of control measures and the capacity to effectively rehabilitate degraded sites.

More broadly, it is recommended that NorBE related consent / approval conditions for a range of development types across the Catchment are reviewed to determine if the objectives are being achieved as intended.

WaterNSW and LLS should continue to work with local councils to improve stormwater management practices.

6. Soil erosion

6.1 Definition and context

Soil erosion is one of the contributing components that increases risk to water quality within the Catchment. The water quality risk arises from the strong interdependency of fine sediment and nutrient loads i.e. nutrients are chemically bound to fine sediments, so liberation of sediment also results in liberation of nutrients. The liberation of nutrients from the soil profile can encourage excessive growth of algae and in-stream vegetation.

While there are numerous types of soil erosion, gully and streambank erosion are the main contributors in the Catchment (GHD 2013). Gully erosion is the focus of this chapter of the audit, whereas the impact of streambank erosion is considered in Chapter 18 Physical form.

6.2 Method

The understanding and quantification of gully erosion within the Catchment has varied across previous audits:

- The 2010 Audit quantified gully erosion using 1986 aerial photography (Emery 1986) and data from the 2005 Water Quality Risk Management Framework (SCA 2005). This provided an estimate of the total area of active gully erosion across the catchments (7.8 km^2).
- The 2013 Audit had no new quantitative gully erosion data available from across the Catchment and relied on the 1986 and 2005 datasets. However, it did report on outcomes from the Gully Erosion Evaluation Trial (GEET) that was initiated in 2011 to develop techniques to map the location, extent, and severity of gully erosion across the Catchment. By the time of the 2013 audit the GEET had only been implemented across three drainage units (Dixons Creek, Eden Forest and Oallen Ford).
- The 2016 audit was supported by results from implementation of the GEET method across a total of 45 drainage sites, identified by multiple government agencies as those units most likely to be experiencing gully erosion. The 2015 GEET implementation covered a significant portion of the non-forested catchment area and was (anecdotally) said to encompass the vast majority of areas within the Catchment likely to be prone to gully erosion (pers. comm., WaterNSW, January 2017).
- The data from implementation of GEET, which formed the basis of the previous audit assessment, is not available in the current audit period. Instead, the 2019 Audit focuses on the changes in gullying, as understood through active management of erosion within the Catchment.

6.3 Erosion management programs

For over 50 years, the NSW Government has implemented programs to address soil erosion in the Catchment. In 2013, WaterNSW developed the Rural Landscape Program in partnership with the South East Local Land Service to support better management of grazing from a land and soil health perspective. This holistic program replaced the Sustainable Grazing Program, Riparian Management Assistance Program, Catchment Protection Scheme and the Grazier Incentives Program. Further information about the Rural Landscape Program is in Section 2.5.1.

The Rivers of Carbon – Source Water Linkages (ROCSWL) is another program supported by WaterNSW focused on restoring and protecting river and riparian areas within the Catchment. The program has capacity to work with 60 landholders to better manage their waterways through bank stabilisation, revegetation, fencing and off-stream watering of livestock. Grants are only approved for projects that meet criteria in alignment with known and proven practices, and landholders also agree and sign off on managing the project to meet various targets (e.g. groundcover, stock management).

South East LLS and the Australian River Restoration Centre (ARRC) have partnership agreements with WaterNSW for the implementation of the Rural Landscape Program and the Rivers of Carbon – Source Water Linkages program. Staff from South East LLS and ARRC (in partnership with Greening Australia) work directly with landholders to plan and implement project activities. Some activities are undertaken by landholders, such as fencing and water supply set-up, other activities are undertaken by LLS and ARRC/Greening Australia, such as revegetation and erosion control treatments. Meetings are conducted with landholders throughout the project to assess and discuss progress and resolve any issues that arise. When projects are complete, an acquittal inspection is undertaken by the project supervisor and a concise report prepared that describes the work completed against the work planned and approved.

WaterNSW staff organise audits every year to inspect a selection of projects with LLS and ARRC/GA. The purpose of the audits is to inspect completed and acquitted projects, discuss safety procedures, and assess the effectiveness of the grant process from expression of interest to project completion. At the property and site scale, the overall effectiveness of infrastructure works at the point of completion is assessed and determined through the acquittal process. When works are considered vulnerable or at risk, such as freshly completed erosion treatments, follow up inspections are also undertaken.

MODIS satellite data has been tested by WaterNSW to determine the effectiveness of improved grazing practice on groundcover. This involved comparison of paddocks within study properties to similar (control) properties within 2 km of the study properties from two time periods (2000-2005 and 2009-2014), representing periods before and after the introduction of improved grazing practices. The results indicated that following improved grazing practices, pasture condition remained good for a significantly longer period, regardless of the different rainfall regimes. These methods of quantifying changes in pasture health proved useful, and the method can be used in the future to assess more properties in different areas. WaterNSW plans to repeat the MODIS condition assessment every five years and the next set of results will be available in the next audit period.

6.4 Conclusion and recommendations

Government programs that are jointly funded and implemented with private landholders appear to be effective in reducing soil erosion, not just at the program work site, but more broadly across the landscape as other landholders observe and implement the erosion control practices. In addition to the physical benefits to the health of the Catchment, these programs contribute positively to the social fabric of rural communities. The continuation of these types of erosion control programs is supported, and any changes to the programs should be informed by the results of robust long-term evaluation.

It is recommended that a catchment-wide analysis and mapping of gully erosion be updated, and this should include some on-ground validation of data.

WATER QUALITY

Figure 22: Wingecarribee Swamp

7. Ecosystem and raw water quality

7.1 Definition and context

Raw water quality is an important indicator of catchment health as it is the 'product' of multiple catchment processes, including climatic conditions, pollution controls, land management practices and vegetation cover. WaterNSW regularly monitors the quality of water in streams and storages at the locations depicted in Figure 23. Monitoring data is used by WaterNSW to identify and manage threats to water quality throughout the supply system.

Water quality monitoring is also undertaken by others in the Catchment for specific purposes, such as compliance with EPLs relevant to sewage treatment plants or mines.

7.2 Method

The auditors filtered water quality data from WaterNSW to 12 analytes consistent with those reviewed in previous audits, as listed in Table 9. Locations of WaterNSW water quality monitoring stations were mapped (Figure 23). Data was collated relevant to each storage or stream within each sub-catchment, then graphed for each analyte. The graphs also indicate the benchmark guideline for the analyte. (All graphs are presented in Volume 3 Appendix C.)

This audit sought to determine if the water quality in streams and storages complied with relevant guidelines during the audit period. Benchmark guidelines used in this audit are based on the Australian and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZG 2018) which refer to the ANZECC (2000) Ecosystem Water Quality Guidelines or the value applied in previous audits if ANZECC guidelines were not available. Table 9 identifies guidelines for streams and storages relevant to each analyte.

The criteria applied to this analysis refer to the quality of untreated or 'raw' water in 'natural' environments using generalised guidelines for healthy freshwater aquatic ecosystems, specifically for lowland rivers and freshwater lakes and reservoirs across south-east Australia. Use of ecosystem water quality guidelines are designed to trigger further investigation and the development of site-specific guidelines.

The auditors also compared data in the audit period to historic data to determine long term trends. The results were categorised for each analyte in streams and storages as follows:

- state of water quality during the audit period July 2016 to June 2019
  - A – fully compliant with guidelines (very good water quality)
  - B – mostly compliant with guidelines (good water quality)
  - C – mostly non-compliant with guidelines (poor water quality)
  - D – all non-compliant with guidelines (very poor water quality)
- trend for the audit period in the context of historic data
  - 1 – results during the audit period are generally better than historic records
  - 2 – results during the audit period are similar to historic records
  - 3 – results during the audit period are generally worse than historic records

For example, if water quality results for streams within a sub-catchment during the audit period were mostly compliant with the guidelines, and the data recorded during the audit period was similar to historic data, then the result for streams within that sub-catchment for that analyte would be ‘B2’.

Table 9: Water quality guidelines for storages and catchments

Water quality analyte	Storages		Catchments	
	Guideline	Justification	Guideline	Justification
Chlorophyll-*a* (*Chl-a*)	<5.0 µg/L	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	<5.0 µg/L	In ANZECC guidelines for lowland rivers. ANZECC does not provide any guideline for upland rivers
pH	6.5 – 8.0 pH units	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	6.5 – 8.0 pH units	Guideline range was given in ANZECC for upland rivers
Electrical Conductivity	0.15 mS/cm	Selected by the Dr Ian Wright in the 2016 audit. The ANZECC (2000) guideline value for south-eastern Australia lakes and reservoirs was 0.02-0.03 mS/cm, from Tasmanian lakes, and was not considered to be realistic or representative for freshwater lakes of the Sydney region.	0.35 mS/cm	Given as the maximum default value in ANZECC for upland rivers
Dissolved Oxygen (DO)	90 - 110% Saturation	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	90 - 110% Saturation	In ANZECC guidelines for upland rivers
Turbidity	<5.0 NTU	Selected from lower end of range (1-20 NTU) given in the ANZECC guidelines for freshwater lakes and reservoirs	<5.0 NTU	Selected from lower end of ANZECC upland stream range 2 to 25 NTU
Ammonium-Nitrogen (NH_4)	<0.01 mg/L	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	<0.013 mg/L	In ANZECC guidelines for upland streams
Oxidised Nitrogen (NO_x)	<0.01 mg/L	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	<.015 mg/L	In ANZECC guidelines for upland streams
Total Nitrogen (TN)	<0.35 mg/L	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	<0.250 mg/L	In ANZECC guidelines for upland streams
Soluble Reactive Phosphorus (SRP)	<0.005 mg/L	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	<0.015 mg/L	In ANZECC guidelines for upland streams
Total Phosphorus (TP)	<0.01 mg/L	In ANZECC guidelines for south-eastern Australia lakes and reservoirs	<0.020 mg/L	In ANZECC guidelines for upland streams
Total Aluminium (TAl)	<0.055 (if pH>6.5) mg/L	In ANZECC for protection of 95% of freshwater species.	<0.055 (if pH>6.5) mg/L	In ANZECC for protection of 95% of freshwater species
Total Iron (TFe)	3.5 mg/L	Selected by Dr Ian Wright in the 2016 audit based on raw water treatability because ANZECC doesn’t set benchmark for ecosystem health	3.5 mg/L	Selected by Dr Ian Wright in the 2016 audit based on raw water treatability because ANZECC doesn’t set benchmark for ecosystem health

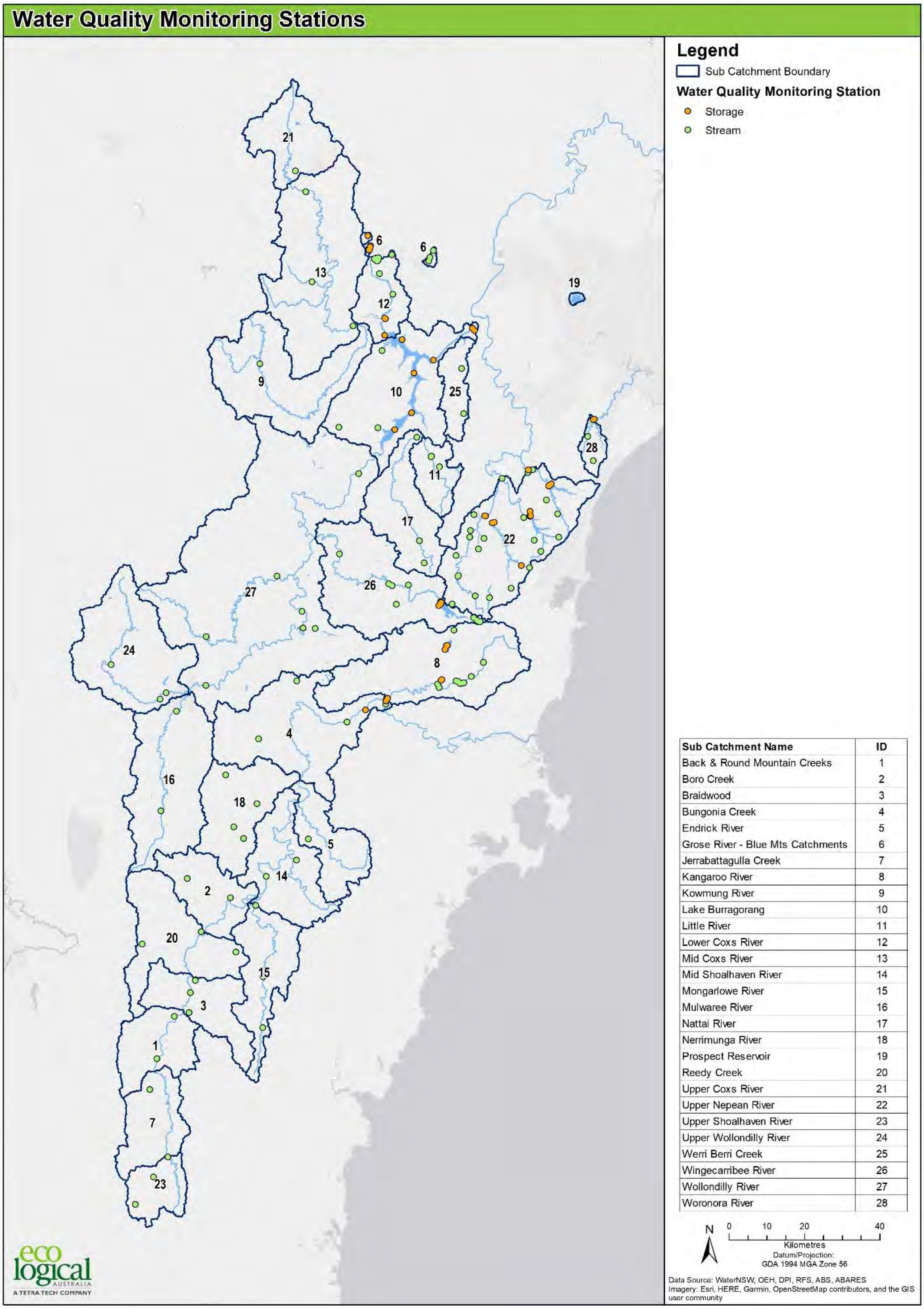


Figure 23: WaterNSW water quality monitoring stations

7.3 Findings

Water quality 'report cards' are presented in Volume C Appendix C for storages and streams in each sub-catchment. These comprise a map of monitoring stations with graphs of recorded data. Results of the analysis are presented in Table 10 and Table 11 below, with key findings summarised as follows:

- Water quality in most streams and storages in the Catchment during the audit period was stable based on long term data. This finding is consistent with the conclusion in the 2017-18 Annual Water Quality Monitoring Report by WaterNSW, which stated:

  Warm weather and ongoing drought conditions have been favourable to algal growth in some storages but generally the lack of large inflow events has resulted in good, stable water quality.
- Stream water quality in the Little River sub-catchment, which is in the Special Areas, is consistently good and could be used as a benchmark for other streams.
- Streams in the Endrick Creek, Kowmung River and Nerrimunga River subcatchments have a paucity of data and very poor results for the limited data collected. WaterNSW has advised that samples were not collected due to lack of flow during the drought.
- There is ongoing very poor Dissolved Oxygen, Turbidity and Total Aluminium results in streams in the Boro Creek catchment (station E890).
- Dissolved Oxygen tends to be poor at lower depths in deep storages such as Bungonia Creek, Kangaroo River (Tallowa Dam), Lake Burragorang and Lower Coxs River. It is normal for a stratified, deep, unmixed lake to be anoxic in the hypolimnion in the months prior to it becoming thermally homogenous in the winter when it naturally mixes. Lake Fitzroy is shallow and has relatively good Dissolved Oxygen.
- Total Iron concentrations in storages were ranked as 'good' or 'very good' (generally below the 3.5 mg/L benchmark) in all storages except DLM1 in the Blue Mountains.
- Results for Total Aluminium tend to be ranked as 'poor' or 'very poor' (generally more than 0.055 mg/L) than Total Iron for most storages and streams, which may reflect natural differences in the Catchment landscape.
- Water quality in Wingecarribee Dam is stable but has relatively poor results across multiple analytes. This dam is positioned upstream of known pollutant sources within the sub-catchment, so the shallow configuration of the dam and transfers of water to the Shoalhaven system during the drought may have contributed to the results. Raw water from the dam is subject to treatment for drinking water purposes.
- Conductivity on smaller tributaries is often worse than in main streams, due to dilution effects.
- Water quality downstream of major urban areas tends to be relatively poor (e.g. monitoring station R1 in the Lower Coxs River sub-catchment; station E203 in the Nattai sub-catchment is downstream of Mittagong).
- The monitoring station in the Upper Coxs River sub-catchment (E046) is positioned in part of the Catchment unaffected by many of the pollutant sources (e.g. urban centres, mines, power station), and has relatively good water quality.
- Streams in the Mulwaree River sub-catchment recorded high nutrient concentrations, which may be a result of agricultural activities (e.g. over-application of fertiliser).

- Records in the Braidwood sub-catchment at monitoring station E891 (tributary downstream of Braidwood) are worse than at E860 (Shoalhaven River), and there was a notable improvement in multiple indicators at E891 due to upgrades to the sewerage network in 2017.

7.4 Recommendations

Recommendations are as follows:

- Further investigation is recommended in response to ongoing very poor Dissolved Oxygen, Turbidity and Total Aluminium results in streams in the Boro Creek catchment (station E890).
- Factors that affect water quality in Wingecarribee Dam should be considered as part of the strategic investigation of cumulative impacts in the Wingecarribee River sub-catchment.
- Strategic investigation of cumulative impacts is recommended within the Upper Coxs River sub-catchment that considers WaterNSW monitoring results together with results of EPL compliance monitoring.

Table 10: Water quality analysis for storages in each sub-catchment

Sub-catchments	pH	Conductivity	DO	Turbidity	NH_4	NO_x	TN	Chl-a	TP	PSR	TAl	TFe
Blue Mountains - DLC1	A2	A2	B2	A1	C1	C2	B2	B2	B2	B2	A1	A2
Blue Mountains - DLM1	C1	A2		A1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	C3
Blue Mountains - DTC1	n/a	A2		A1	B1	C2	C2	B2	B2	B2	A1	A2
Bungonia Creek	B2	B2	C2	B2	C2	C2	C2	C2	C2	B2	C2	A1
Kangaroo River (Tallowa Dam)	B2	B2	C2	B2	C2	C2	B2	B2	C2	B2	C2	B2
Kangaroo River (Lake Fitzroy)	B2	A2	B2	C2	C2	C2	C2	C2	C2	A1	C2	A2
Lake Burragorang	B1	C2	C2	B2	B2	C2	B2	B2	B2	B2	C2	A2
Lower Coxs River	B2	C3	C2	B2	C2	C2	B2	B2	B1	B2	B1	A2
Upper Nepean River - Avon Dam	B2	B2	B2	B2	C2	C1	B2	B2	B2	B2	B2	A2
Upper Nepean River - Lake Cataract	C2	A2	B2	B2	C2	C2	B2	B2	B2	A2	C2	B2
Upper Nepean River - Lake Cordeaux	B2	A2	B2	B2	C2	C2	B2	B2	B2	B2	B2	B2
Upper Nepean River - Lake Nepean	B2	A2	B2	B2	C2	C2	B2	B2	C2	B2	C2	A2
Wingecarribee Dam	B2	B2	B2	C2	C2	C2	C2	C2	C2	B2	C2	B2
Woronora Dam	B2	A2	B2	B2	B2	C2	B2	B2	B2	B2	B2	A2

Table 11: Water quality analysis for streams in each sub-catchment

Sub-catchments	pH	Conductivity	DO	Turbidity	NH_4	NO_x	TN	Chl-a	TP	PSR	TAl	TFe
Back & Round Mountain Creeks	C2	A2	n/a	B2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Blue Mountains	B2	A2	C2	B2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Boro Creek	B2	A2	D2	D2	B2	B2	B2	C3	B2	A2	D2	A2
Braidwood	B2	B2	C2	B2	B2	B2	C2	C2	C2	B2	C2	B2
Bungonia Creek	B2	B2	A1	B2	B2	B2	C2	B2	B2	A2	C2	B2
Endrick River	D2	D2	n/a	D2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Jerrabattagulla Creek	C2	A2	n/a	A2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Kangaroo River	B2	A2	C2	B2	C2	C2	C2	B2	B2	B3	C2	B2
Kowmung River	D2	D2	A1	D2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Lake Burragorang	B2	B2	C3	A1	B1	B1	B1	B2	B1	A2	B1	A2
Little River	B2	A2	B2	A1	B1	B1	A1	B2	A1	A2	B1	A2
Lower Coxs River	B2	A2	B2	B2	B2	C2	C2	B2	B2	A2	C2	B2
Mid Coxs River	C2	C3	B2	B2	B2	B2	B2	B2	B2	B2	C2	B2
Mid Shoalhaven River	C2	A2	B2	B2	B2	B2	B2	B2	A1	A2	C2	A2
Mongarlowe River	C2	B2	C2	B2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mulwaree River	C2	D2	C2	B2	C2	B2	C2	C2	C2	C2	C2	A2
Nattai River	C2	C2	B2	B2	C2	C2	C2	B2	B1	B2	C2	A2
Nerrimunga River	B2	B2	D2	D2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Reedy Creek	A2	B2	n/a	B2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Upper Coxs River	C2	B2	B2	B2	B2	C2	C2	B2	C2	C2	C2	B2
Upper Nepean River	B2	B2	C2	C2	B2	C2	B2	B2	B2	A2	C2	B2
Upper Shoalhaven River	B2	A2	n/a	check	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Sub-catchments	pH	Conductivity	DO	Turbidity	NH_4	NO_x	TN	Chl-a	TP	PSR	TAl	TFe
Upper Wollondilly River	D2	C2	C2	B2	B2	B2	C2	C2	B2	B2	B2	A2
Werri Berri Creek	B2	B2	C2	B2	B2	B2	B2	B2	B2	A2	C2	B2
Wingecarribee River	B2	B2	C2	C2	C2	C2	C2	C2	B2	B2	C2	B2
Wollondilly River	C2	C2	B2	B2	B2	B2	C2	C2	B2	B2	C2	B2
Woronora River	C2	A2	C3	B2	B2	B2	B2	B2	A1	A2	C2	B2

8. Nutrient loads

Nitrogen and phosphorus are nutrients that are regarded by WaterNSW as ‘priority pollutants’ because of the potentially adverse impact they can have on waterways. Nutrients in waters, particularly the impounded waters of lakes and reservoirs, can accumulate over time in the water column and sediment. A lake or reservoir with high nutrient levels, which is often linked to higher levels of plant and algae growth, is termed ‘eutrophic’. At the other end of the scale, lakes with very low levels of nutrients, and plant and algae growth, are classed as ‘oligotrophic’. A major objective of water management is to promote low nutrient levels and maintain ‘oligotrophic’ lakes and reservoirs.

Nutrient loads entering waterways can be via:

- Point sources – such as sewage treatment plants (STPs) and urban development stormwater infrastructure. These include waste discharges that are regulated by the EPA under the *Protection of the Environment Operations Act 1997.*
- Diffuse sources - such as associated with agricultural and forestry activities.

Once the nutrient enters a stream or storage, it can be measured and expressed as a concentration value (such as mg/L), as discussed in the water quality results in Chapter 7. However, before the nutrient enters the waterway it is measured as a load value, which is often in mass (kilograms or tonnes per year) but can also be expressed in area terms (e.g. as kg per km^2). Chapter 5 identifies pollution sources in the Catchment and Chapter 7 provides results of nutrient monitoring in streams and storages. This chapter reviews information about nutrient loads entering waterways in the Catchment.

Best practice requires nutrients to be controlled so that the load discharged to the environment is minimised. Increasing loads of nutrients entering streams and storages is a worsening trend, whereas decreasing loads represents an improving trend.

Previous audits considered results of the WaterNSW ‘Pollution Source Assessment Tool’ (PSAT) and discharges to water and land from premises under an EPL (such as from STPs). The PSAT has not been updated during the audit period and results of nutrients discharged under EPLs gives an incomplete picture of nutrient loads to the Catchment because they don’t consider diffuse sources or unlicensed point sources. It is therefore concluded that there is inadequate information about the load of nutrients entering the Catchment from multiple sources. However, a robust water quality monitoring regime is considered an adequate indicator of nutrients in the streams and storages of the Catchment.

9. Cyanobacterial blooms

9.1 Definition and context

Cyanobacteria are a microscopic form of plant life found in water, commonly known as blue-green algae. Under some conditions, certain species of cyanobacteria can produce toxins that can be hazardous to human health, to fish and any animals that contact it. Cyanobacteria is often a cumulative problem that is closely associated with the nutrient enrichment status of water impoundments. It is also one of the most important biological measures of performance for storage and supply of potable water.

The proliferation of some species can cause mild water quality problems (such as taste and odour issues) ranging through to severe water quality problems that can cause illness and death of human and animals. A combination of natural and human factors can influence the abundance and types of cyanobacteria, with temperature, slow water flow, and availability of nitrogen and phosphorus well understood triggers. Increasing cyanobacteria alerts (described below) in the Catchment are a worsening trend, whereas fewer alerts indicates an improving trend.

9.2 Data and methods

The data assessed during this audit was provided by the WaterNSW water quality monitoring program, which includes collection of cyanobacteria data from streams and storages in the Catchment. Historic and current data was provided in the form of cyanobacteria cell counts, bio-volumes and toxic cyanobacteria cell counts and biovolumes. Information on toxic cyanobacteria alerts was also provided by the WaterNSW Metropolitan & South Coast Regional Algal Coordinating Committee, for four sites that are currently operated by Energy Australia.

The cyanobacteria data (cell counts and biovolumes) was provided by WaterNSW for 35 sites across 13 sub-catchments for all years of the current reporting period, except for between 1 July 2016 and 30 June 2017. This data was not available at the time of the audit. The data records received were slightly less than the previous audit, where a full dataset for 40 sites was provided and assessed.

The water bodies that were sampled by WaterNSW within the Catchment are used for community based recreation purposes, hence the data received was based on notifications of cyanobacterial results and public alerts issued relevant to NHMRC (2008) recreational alert levels for cyanobacteria:

- **Good**: the biovolumes of potentially toxic cyanobacteria was greater than 0.04 mm^3/L but less than 0.4 mm^3/L
- **Moderate**: the biovolumes of potentially toxic cyanobacteria was greater than 0.4 mm^3/L but less than 4.0 mm^3/L
- **Poor**: the biovolumes of potentially toxic cyanobacteria was greater than 4.0 mm^3/L. The red trigger of greater than 4.0 mm^3/L applies when known toxic species dominate (contributing more than 75% of the biovolume). When cyanobacteria species not thought to produce toxins are dominant, the threshold between Amber and Red is 10 mm^3/L.

This audit uses the alert levels above to provide an assessment on the status of each site in terms of potential cyanobacteria blooms and trends between 2016-2019.

9.3 Cyanobacteria alerts

A total of 1266 alerts were reported during the 2016-2019 audit period, consisting of 553 green alerts, 490 amber alerts and 223 red alerts. Time series plots showing the records of toxic cyanobacteria biovolumes (historic and current) against the NHMRC (2008) guidelines are provided in Volume 3 Appendix D of this audit.

Table 12 below provides a yearly summary of weeks of cyanobacteria alerts at all water bodies monitored by WaterNSW in the Catchment, for the current and previous audit period. The majority of alerts (73%) reported for the 2016-2019 reporting period were recorded at the Lake Wallace and Lake Lyell sites (N1158, N1159 and N1160) currently operated by Energy Australia. The Lake Wallace sites consist of an impoundment used for recreation and power station cooling water on the Upper Coxs River, near Wallerawang, upstream from Lithgow. The Lake Lyell site is located in a similar area associated with thermal power station cooling of water, however it is located downstream from Lithgow (see map showing locations of monitoring stations in Volume 3 Appendix D).

Table 12: Summary of annual cyanobacteria alerts*

	Year	NHMRC (2008) recreational guidelines			Total alerts
		Green	Amber	Red	
Previous audit	2013-2014	139	32	4	175
	2014-2015	125	50	8	183
	2015-2016	143	44	11	198
Current audit	2016-2017	82	20	0	102
	2017-2018	171	263	184	618
	2018-2019	300	207	39	546

NOTES: *Dataset between 1 July 2016 to 30 June 2017 was incomplete.

The assessment indicated a 56% increase in cyanobacteria alerts compared to the 2013-2016 audit. This increase is due to ongoing drought conditions experienced within the region in 2017-19, which generally promotes favourable conditions for algal bloom growth including reduction of flow and high water temperatures. The following presents a breakdown of the alerts summarised in Table 12.

- Red alerts: Cyanobacterial blooms resulted in the issuing of a total of 223 red alerts (cumulative weeks under red alert) over the current audit period, with 184 of the 223 alerts occurring during 2017-2018. The number of weeks under red alert has increased since the previous 2013-2016 audit period (23 red alerts), which is due to drought conditions within the region. Only two sites reported red alerts during the reporting period; Lake Wallace and Lake Lyell (202 and 21 alerts recorded respectively).
- Amber alerts: A total of 490 weeks of amber alerts was issued during 2016-2019. The number of alerts initially decreased during 2016-2017 before showing a significant increase to 263 alerts during 2017-2018, followed by a slight decrease to 207 alerts during 2018-2019. A similar trend was observed during the previous audit period (2013-2016).
- Green alerts: A total of 553 green alerts (weeks under alert) was identified by the Committee during the reporting period. The total number of alerts for this reporting period has shown a

75% increase in comparison to the previous audit period (139 green alerts recorded). As previously discussed, this is likely to be drought driven.

9.4 Discussion

The following seven sites present notable trends in cyanobacteria levels that were identified during this audit and in comparison to the 2013-2016 audit. These have been discussed in the section below.

- Lake Wallace (N1159 and N1160)
- Lake Lyell (N1158)
- Wingecarribee Lake (DWI1)
- Wingecarribee River (E303 and E332)
- Lake Yarrunga
- Fitzroy Falls
- Farmers Creek D/S STP (E046)

Councils have treatment systems in place to achieve drinking water quality guidelines. However, costs for treatment could be reduced if there are lower levels of cyanobacterial in the (pre-treated) raw water from rivers and storages.

LAKE WALLACE & LAKE LYELL

Lake Wallace (sites N1159 and N1160) showed the largest number of weeks (343 weeks for each site) recorded under cyanobacteria alert during the current audit period. This comprised a total of 120 weeks under red alert, 130 weeks under amber alert and 93 green alerts for site N1159. Site N1160 showed 82 weeks under red alert, 168 weeks under amber alert and 93 under green alert. These results show an increase since the previous audit when 10 weeks under red alert, 25 weeks under amber alert and an additional 27 weeks under green alert (a total of 62 weeks under alert) was reported.

Lake Lyell (N1158) showed the second highest alert count at 232 weeks under alert (21 red, 132 amber and 79 green).

WINGECARRIBEE, FITZROY FALLS & LAKE YARRUNGA

Wingecarribee Lake at outlet (site DWI1) also showed a notable number of weeks (139) recorded under cyanobacteria alert, comprising 29 weeks under amber alert and 110 under green alert, with no red alerts declared during the audit period. This site has historically shown poor water quality in terms of cyanobacteria cell counts and biovolumes and is linked to Fitzroy Falls and Lake Yarrunga, which have also previously shown issues related to cyanobacteria. During the previous audit, Fitzroy Falls reported the highest alert count at a total of 100 weeks; however, improvement has been observed during 2016-2019 with a decrease to 43 weeks under alert (39 green and 4 amber). Lake Yarrunga has also decreased from 121 weeks under cyanobacteria alert recorded during 2013-2016 to 16 weeks under alert during this audit.

Further linked to the Wingecarribee Lake, the Wingecarribee River (sites E303 and E332) located immediately downstream of the lake showed problematic cyanobacteria results during the previous audit. Similarly to Fitzroy Falls, this site (E332) has shown improvement during this audit, with total alerts decreasing from 41 weeks during 2013-2016 to 7 weeks under alert.

FARMERS CREEK

The Farmers Creek site located downstream of Lithgow STP (site E046) has historically contained serious and protracted cyanobacteria blooms that regularly cause red alerts. The site has a chronic history of blooms occurring in Farmers Creek that are linked to algal blooms in the tertiary treatment ponds at the Lithgow STP, with cyanobacterial contaminated effluent released to Farmers Creek causing high cyanobacterial numbers in the creek. Upgrades to the STP took place several years ago, which has since resulted in no cyanobacteria-contaminated effluent being released to the creek since that time. The STP upgrade also reduced the nitrogen and phosphorus loads released to Farmers Creek. As a result, no alerts were identified during the previous audit and only one amber alert occurred during the start of the 2016-2019 audit, therefore continuing the improved trend.

9.5 Conclusion

The review of cyanobacteria data provided by WaterNSW for the 2016-2019 audit suggests a worsening trend in cyanobacteria alerts for water storages within the Sydney Catchment. This was due to drought conditions contributing to promotion of cyanobacteria bloom growth in streams and storages.

Some sites that previously showed elevated cyanobacteria alerts during 2013-2016, including Wingecarribee Lake and River, Fitzroy Falls and Lake Yarrunga, show an improving trend during this audit. Farmers Creek downstream of the STP (site E046) also continued to show notable improvement with only one amber alert for cyanobacteria occuring.

Lake Wallace and Lake Lyell sites showed the highest number of weeks under cyanobacteria alert, with a total of 343 alerts at each of the two Lake Wallace sites and 232 alerts at Lake Lyell. Of these, 120 and 82 red alerts were recorded at the two Lake Wallace sites and 21 red alerts were identified at Lake Lyell. These results suggest remedial action may be required at these sites, in addition to Wingecarribee Lake which showed the third highest alert count during the audit period.

9.6 Recommendation

It is recommended that options to reduce high numbers of cyanobacterial alerts at Lake Wallace and Lake Lyell (in the Upper Coxs sub-catchment) and Wingecarribee Lake (in the Wingecarribee sub-catchment) are developed as part of a strategic investigation of cumulative environmental impacts in these two sub-catchments. Development of options to manage cyanobacteria in Lake Wallace and Lake Lyell should be in consultation with the owner of these lakes, Energy Australia.

WATER AVAILABILITY

Figure 24: Restricted access to protect a drying swamp in the Upper Coxs River sub-catchment

10. Surface water flows

10.1 Definition

Surface water flow refers to the volume and rate at which water moves in creeks or rivers within the Catchment. The availability of surface water flow was assessed for this audit by considering:

- the level and variability of streamflow at stream gauge locations throughout the Catchment
- compliance with surface water extraction licences within each sub-catchment.

10.2 Context and method

WaterNSW operates a network of river gauging stations that measure the streamflow levels. Data from stream gauges is published each week by WaterNSW to provide information that can be compared to information about how much rainfall has been recorded, how full the dams are, and how much raw water they have supplied to their customers.

The availability of surface water in the Catchment has been determined by assessment of daily mean streamflow data from 67 river gauging stations. Gauging station locations are mapped in Figure 25, noting that not every sub-catchment has a station. The median streamflow level data (ML/day) for the audit period was calculated and compared with long-term data. For the purpose of this audit, streamflow level was categorised as significantly reduced if the median value of streamflow during the audit period was found to be less than 50% of the long-term median flow.

10.3 Findings

Results in Table 13 indicate that more than half (52%) of the monitoring stations had significantly reduced streamflow levels compared to the long term. This reflects the relatively low rainfall experienced during the audit period. Sites with significantly reduced streamflow were in the following 15 sub-catchments:

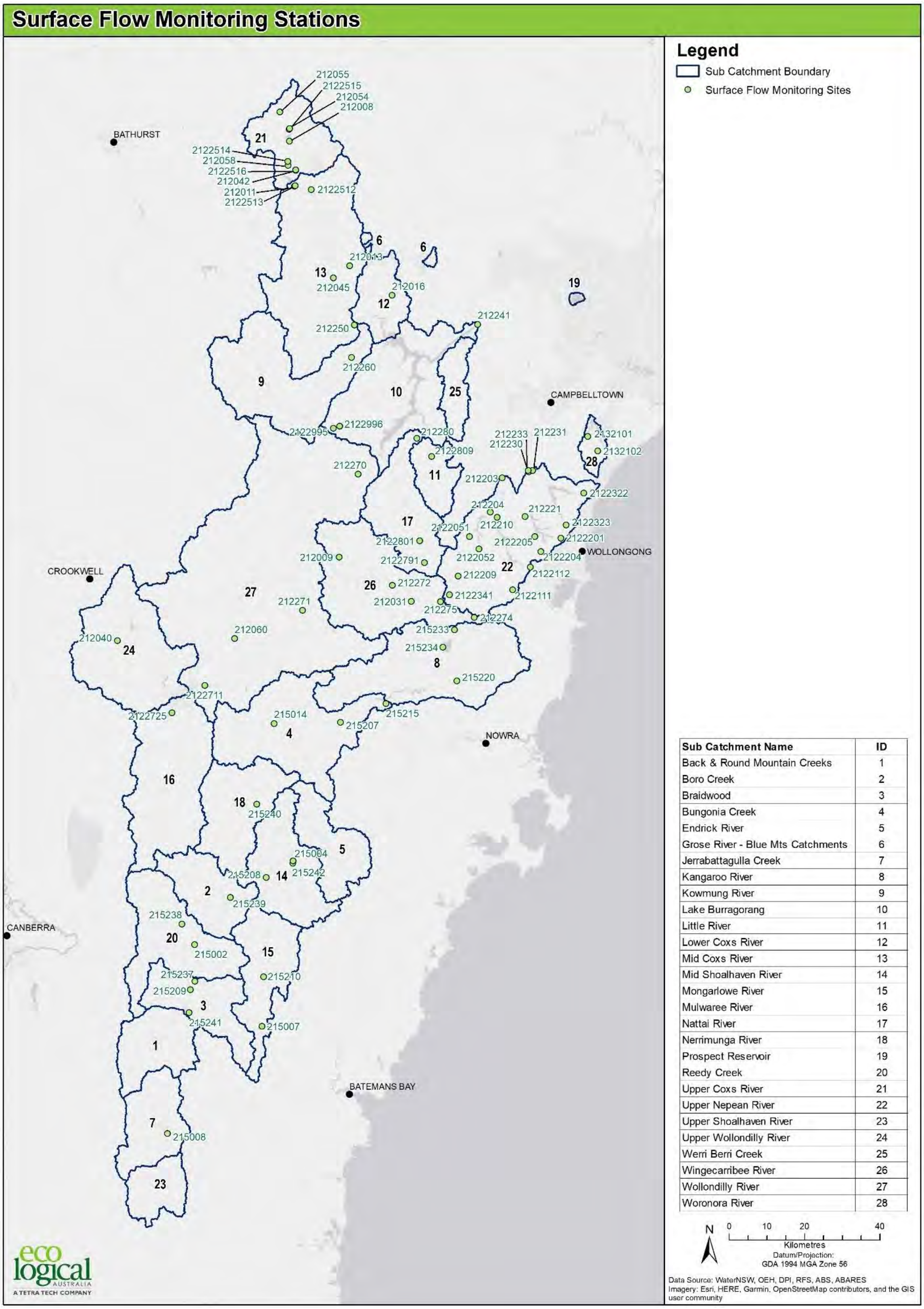
- Boro Creek
- Braidwood
- Bungonia Creek
- Kangaroo River
- Kowmung River
- Mid Coxs River
- Mid Shoalhaven River
- Mongarlowe River
- Nattai River
- Reedy Creek
- Upper Nepean River
- Werriberri Creek
- Wingecarribee River
- Wollondilly River
- Woronora River

Some stations experienced substantially higher median flows during the audit period compared to long term records. These sites were in the Upper Coxs River and Upper Nepean River sub-catchments and are associated with controlled releases such as those associated with the Wallerawang Power Station.

10.4 Recommendations

Recommendations from the Audit of the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 (Alluvium and Vista Advisory 2019) should be implemented as relevant to the Sydney Drinking Water Catchment. In particular, the water licenses need to be reviewed so that long-term average annual extraction limit (LTAAEL) levels are sustainable in the context of climate change, as well as maintaining compliance with Part 2 (clause 12) and Part 7 (clauses 42 to 44) of the Water Sharing Plan (WSP), which specifies the assessment of performance indicators such as changes in low flow regime, moderate to high flow regime as well as changes in annual surface water extraction relative to the LTAAEL for each extraction management unit.

It is recommended that the Water Sharing Plans for the Greater Metropolitan Region Unregulated River Water Sources 2011 and the Greater Metropolitan Region Groundwater Sources 2011 are reviewed and updated. This should include review and revision of surface water / groundwater interactions, with an assessment of the consequences of the (likely) higher proportion of total licensed groundwater entitlement (TLGE) and basic landholder rights (BLR) of the LTAAELs. (Further information to support this recommendation is in Chapter 12.)



Sub Catchment Name	ID
Back & Round Mountain Creeks	1
Boro Creek	2
Braidwood	3
Bungonia Creek	4
Endrick River	5
Grose River - Blue Mts Catchments	6
Jerrabattagulla Creek	7
Kangaroo River	8
Kowmung River	9
Lake Burragorang	10
Little River	11
Lower Coxs River	12
Mid Coxs River	13
Mid Shoalhaven River	14
Mongarlowe River	15
Mulwaree River	16
Nattai River	17
Nerrimunga River	18
Prospect Reservoir	19
Reedy Creek	20
Upper Coxs River	21
Upper Nepean River	22
Upper Shoalhaven River	23
Upper Wollondilly River	24
Werri Berri Creek	25
Wingecarribee River	26
Wollondilly River	27
Woronora River	28

Figure 25: Surface water flow gauging stations

Table 13: Streamflow during the audit period compared to long term records (poor results in bold) (WaterNSW)

Subcatchment	Station #	Site name	First record	Long term median	2016-19 median	% difference
Boro Creek	215239	Boro Creek at Marlowe	25-02-94	3.24	1.25	**38.41**
Braidwood	215241	Jembaicumbene Creek At Bendoura	30-08-94	11.55	3.53	**30.54**
Braidwood	215209	Shoalhaven River at Mount View	09-11-73	144.80	50.43	**34.83**
Braidwood	215237	Gillamatong Creek at Braidwood No. 2	14-03-94	3.10	5.09	164.25
Bungonia Creek	215014	Bungonia Creek at Bungonia	15-04-81	0.88	0.53	60.91
Bungonia Creek	215207	Shoalhaven River at Fossickers Flat	16-07-77	349.06	162.14	**46.45**
Bungonia Creek	215215	Shoalhaven River D/S Tallowa Dam	20-07-91	385.02	262.84	68.27
Jerrabattagulla Creek	215008	Shoalhaven River at Kadona	18-09-50	45.00	19.48	**43.29**
Kangaroo River	215220	Kangaroo River at Hampden Bridge	08-11-73	160.80	78.95	**49.10**
Kangaroo River	215234	Yarrunga Creek at Fitzroy Falls	02-03-83	12.00	4.56	**38.00**
Kangaroo River	215233	Yarrunga Creek at Wildes Meadow	16-11-73	6.39	2.99	**46.86**
Kowmung River	212260	Kowmung River @ Cedar Ford	19-05-68	123.52	36.07	**29.20**
Lake Burragorang	2122996	Tonalli No 2	20-07-03	2.68	2.15	80.26
Little River	2122809	Little river @ fire road (W4I)	22-08-90	3.03	1.79	59.14
Lower Coxs River	212016	Kedumba River @ Kedumba Crossing	03-06-90	19.50	10.33	52.95
Mid Coxs River	212250	Coxs River @ Kelpie Point	02-11-66	154.85	55.58	**35.89**
Mid Coxs River	212045	Coxs River at Island Hill	19-08-81	49.05	37.70	76.86
Mid Coxs River	212013	Megalong Creek at Narrow Neck	21-11-68	4.99	2.35	**47.09**
Mid Coxs River	2122512	Coxs River @ Glenroy Bridge	02-05-99	16.60	27.39	165.00
Mid Coxs River	2122513	Cox's River @ Downstream Lake Lyell	27-07-14	26.20	27.62	105.42
Mid Coxs River	212011	Coxs River at Lithgow	28-05-60	28.83	24.95	86.54
Mid Shoalhaven River	215208	Shoalhaven River at Hillview	08-11-73	287.29	120.29	**41.87**
Mid Shoalhaven River	215242	Corang River at Meangora	04-12-94	19.27	8.72	**45.27**
Mid Shoalhaven River	215004	Corang River at Hockeys	09-09-24	25.07	8.09	**32.28**

Subcatchment	Station #	Site name	First record	Long term median	2016-19 median	% difference
Mongarlowe River	215007	Mongarlowe River at Monga	09-08-03	17.51	13.59	77.60
Mongarlowe River	215210	Mongarlowe River at Mongarlowe	09-11-73	46.90	20.58	**43.89**
Nattai River	2122801	Nattai River @ The Crags	13-07-90	5.46	4.27	78.17
Nattai River	212280	Nattai River @ Smallwoods	08-07-65	17.40	5.47	**31.47**
Reedy Creek	215002	Shoalhaven River at Warri	03-09-14	169.10	53.47	**31.62**
Reedy Creek	215238	Reedy Creek at Manar	19-02-94	4.85	0.69	**14.23**
Upper Coxs River	2122516	Farmers Creek	02-11-14	10.02	10.67	106.53
Upper Coxs River	212042	Farmers Creek at Mt Walker	25-09-80	14.62	8.90	60.84
Upper Coxs River	2122514	Cox's River @ Upstream Lake Lyell	08-02-14	39.53	41.37	104.66
Upper Coxs River	212058	Coxs River at u/s Lake Lyell	15-12-00	25.17	39.58	157.27
Upper Coxs River	212008	Coxs River at Bathurst Rd	10-02-51	15.22	29.00	190.54
Upper Coxs River	2122515	Cox's River@ Powerstations	07-06-14	32.20	32.30	100.31
Upper Coxs River	212054	Coxs River at Wallerawang	19-01-92	16.39	32.47	198.18
Upper Coxs River	212055	Neubecks Creek at u/s Walwang	08-12-91	0.52	0.27	52.69
Upper Nepean River	2122341	Glenquarry Creek at Alcorns	06-04-03	7.01	0.39	**5.56**
Upper Nepean River	2122111	Avon River at Summit Tank	30-03-90	4.29	1.84	**42.82**
Upper Nepean River	212209	Nepean River at Maguires Crossing	06-02-70	35.77	9.73	**27.20**
Upper Nepean River	2122112	Flying Fox No3 Creek at Upper Avon	27-06-90	0.53	0.31	59.79
Upper Nepean River	2122052	Burke River at Nepean Dam Inflow	20-02-90	10.73	5.32	**49.60**
Upper Nepean River	2122201	Goondarrin Creek at Kemira 'D' Cast	04-08-90	0.76	0.26	**33.73**
Upper Nepean River	2122051	Nepean River at Nepean Dam Inflow	18-02-90	29.37	10.62	**36.15**
Upper Nepean River	2122323	Cataract River at Angels Creek	04-06-90	4.58	1.81	**39.54**
Upper Nepean River	212210	Avon River at Avon Weir	28-06-69	2.36	5.31	224.85
Upper Nepean River	212221	Cordeaux River at Cordeaux Weir	23-06-90	32.30	71.65	221.82
Upper Nepean River	212204	Nepean River at Avon Dam Road	24-07-86	92.16	99.22	107.65

Subcatchment	Station #	Site name	First record	Long term median	2016-19 median	% difference
Upper Nepean River	2122322	Loddon River at Bulli Appin Road	10-03-90	5.24	2.46	**46.84**
Upper Nepean River	212203	Nepean River at Pheasants Nest	17-11-83	5.17	32.79	634.24
Upper Nepean River	212231	Cataract River at Jordans Crossing	10-11-67	115.40	103.25	89.47
Upper Wollondilly River	212040	Kialla Creek at Pomeroy	02-01-90	3.07	2.88	93.71
Werriberri Creek	212244	Werrberri Ck @ Werombi	01-07-88	2.51	0.97	**38.72**
Wingecarribee River	212274	Caalang Creek at Maugers	27-11-86	6.87	3.19	**46.50**
Wingecarribee River	212275	Wingecarribee River At Sheepwash Bridge	10-10-86	8.28	4.80	58.01
Wingecarribee River	212031	Wingecarribe River @ Bong Bong Weir	08-06-89	18.87	8.41	**44.56**
Wingecarribee River	212272	Wingercarribee River @ Berrima	23-08-75	26.57	8.83	**33.24**
Wingecarribee River	212009	Wingecarribee River at Greenstead	27-10-89	43.63	13.77	**31.56**
Wollondilly River	2122711	Wollondilly River @ Murrays Flat	18-08-90	10.56	7.92	75.01
Wollondilly River	212060	Tarlo River at Willowbank	11-02-11	4.33	4.40	101.62
Wollondilly River	212271	Wollondilly River @ Golden Valley	03-01-74	35.37	16.76	**47.38**
Wollondilly River	212270	Wollondily River @ Jooriland	16-12-61	211.24	46.56	**22.04**
Woronora River	2132102	Waratah River at Fire Rd No 95	21-02-07	5.86	1.50	**25.67**
Woronora River	2132101	Woronora River at Fire Rd 9F	21-02-07	1.75	0.04	**2.11**

11. Environmental flows

11.1 Definition and context

Dams and weirs, such as those within the Sydney Catchment, affect the natural flow of water through waterways and can impact the shape and structure of the river channels, their water quality and the ecological communities that depend on them (Poff et al. 2010). Environmental flows are commonly released from dams to reinstate a more natural flow regime within rivers to improve their overall ecological health.

Environmental flow rules in the Catchment for all dams, except Tallowa and Warragamba, were developed by scientific investigations by the Independent Expert Panel of the Hawkesbury-Nepean River Management Forum. Tallowa's environmental flow rule was developed by DPI Water, based on scientific analysis and community consultation. Warragamba Dam does not currently have an environmental flow rule as the fixed releases from Warragamba are for dilution and drinking water purposes only. The Government has approved a variable environmental flow rule for Warragamba Dam that is likely to commence in 2024.

All environmental flow releases aim to balance water supply and ecological benefits downstream. The dams release a proportion of the inflows and retain a portion in the dam for water supply. While the dams have release works that have a maximum volume (e.g. Avon Dam, with a maximum release of 1400 ML/d), these are generally in the moderate to high flow range.

Provisions for the release of environmental flows are included in the Water Sharing Plan (WSP) for the Greater Metropolitan Region Unregulated River Water Sources 2011 (NSW Office of Water 2011). Environmental flow releases are defined in the WSP for storages within the Shoalhaven, Upper Nepean and Upstream Warragamba, Hawkesbury and Lower Nepean Rivers and the Southern Sydney Rivers water sources. The calculation of the environmental flow releases is defined in the Water Licences and Approvals Package (NSW Office of Water 2012). Environmental flows released within the Catchment typically focus on maintaining the base flow or low flow component of the flow regime. They are defined as either a specified quantity of water over a set period for some storages (e.g. Warragamba Dam), or as a proportion of inflows for others (e.g. storages within the Nepean catchment). Environmental releases are not usually required when the storage is spilling at a rate equal to or greater than the defined environmental release (NSW Office of Water 2011).

11.2 Data source

WaterNSW operates a series of hydrometric gauging stations across the Catchment. Daily data from a selection of sites in the form of annual compliance reports was provided by WaterNSW for the audit over the period 2013-2019. This data was used in the audit analysis and included:

- daily inflows into target storages
- daily spill data from target storages
- daily environmental releases from target storages.

11.3 Method

Environmental flows were assessed by measuring the degree of compliance of the environmental water deliveries during the audit period with the environmental flow rules defined in the WSP. Eleven locations were assessed for environmental flows (Table 14; Figure 26). These cover the Warragamba, Shoalhaven, Upper Nepean and Woronora systems, and are consistent with the sites used for the environmental flows assessment in the 2013 and 2016 audits.

Table 15 summarises the environmental flow rules and exceptions for each of the storages assessed. Calculations of the environmental flow releases defined in the Water Licences and Approvals Package (NSW Office of Water 2012) were used to assess the percentage of time that these flow rules were achieved.

Table 14: Dams and weirs assessed in the environmental flow's analysis

Dam/Weir	Sub-catchment	Major river system
Warragamba Dam	Lake Burragorang	Warragamba System
Wingecarribee Dam	Wingecarribee River	Shoalhaven System
Tallowa Dam	Kangaroo River	Shoalhaven System
Fitzroy Falls	Kangaroo River	Shoalhaven System
Cataract Dam	Upper Nepean	Upper Nepean System
Cordeaux Dam	Upper Nepean	Upper Nepean System
Avon Dam	Upper Nepean	Upper Nepean System
Nepean Dam	Upper Nepean	Upper Nepean System
Broughtons Pass Weir	Upper Nepean	Upper Nepean System
Pheasants Nest Weir	Upper Nepean	Upper Nepean System
Woronora Dam	Woronora River	Woronora System

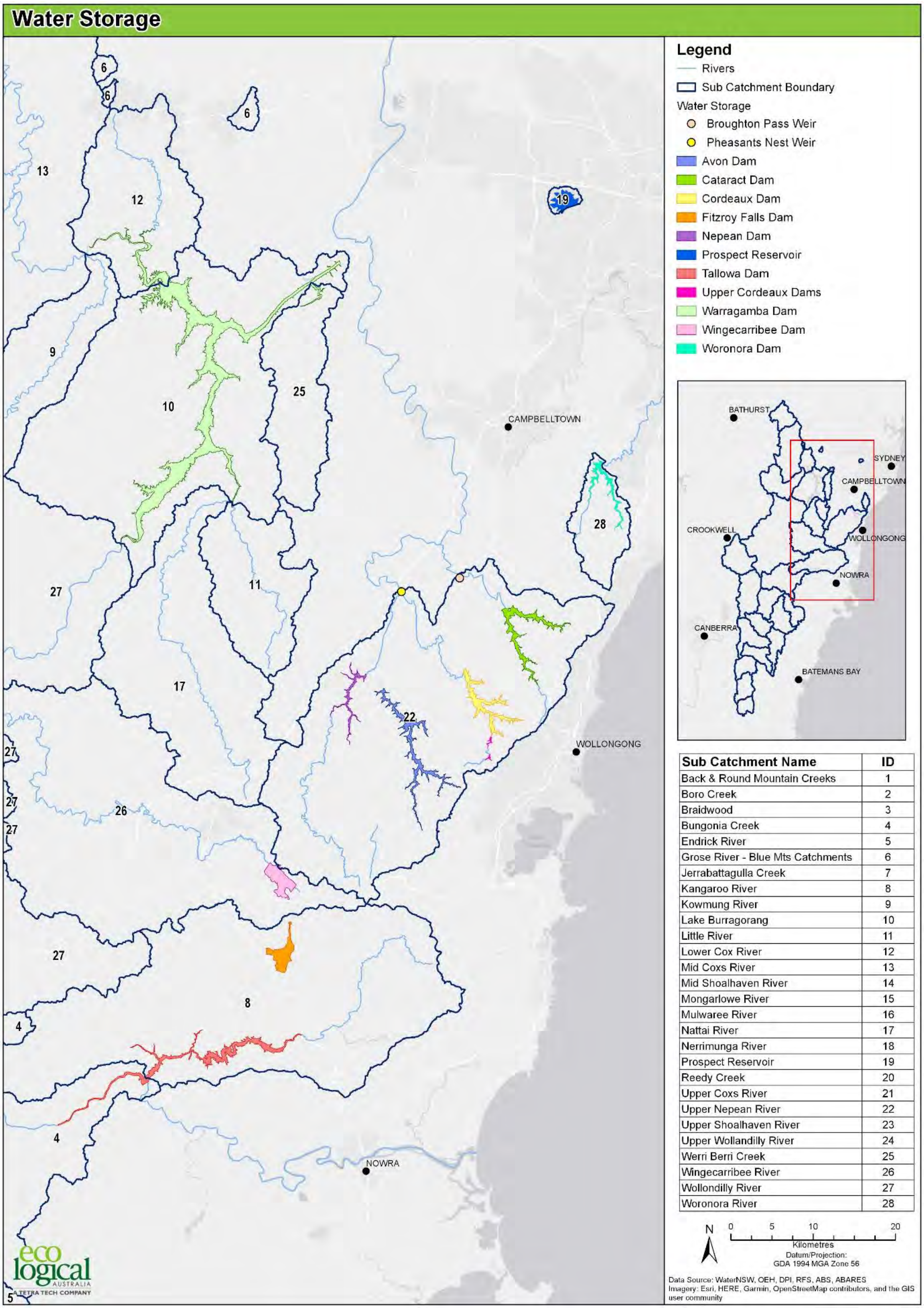


Figure 26: Location of storages within the Catchment used in the environmental flow indicator analysis

Table 15: Environmental flow rules and exemptions for storages used in the audit analysis

Storage	Environmental flow rules	Exemptions
Warragamba Dam	- 5 ML/d from Warragamba pipeline to Megarritys creek all year - 17 ML/d from 1 April to 31 October from Warragamba pipeline to Warragamba River - 25 ML/d from 1 November to 31 March from Warragamba pipeline to Warragamba River	- The storage is spilling at a rate that equals or exceeds the release requirement - The release cannot be met due to an emergency situation - The release cannot be met due to capacity constraints or maintenance
Wingecarribee Dam	- Daily release = 3 ML/d measured at Sheepwash bridge (212275)	
Tallowa Dam	- When inflows to Lake Yarrunga are <= 80^{th} percentile daily flow* daily release equal to inflows must be made. - When inflows into Lake Yarrunga are >80^{th} percentile daily flow* then daily release of 80^{th} percentile + 20% of inflows must be released. - Inflows measured at Kangaroo River at Hampden Bridge gauge (215220) and the Shoalhaven River at Fossickers Flat gauge (215207)	
Fitzroy Falls	- By the end of each month, five thirds of the month's inflow from Wildes Meadow Creek to Fitzroy Falls Reservoir has been released or met - Inflows measured at Yarrunga Creek at Wildes Meadow gauge (215233)	- The storage is spilling at a rate that equals or exceeds the release requirement
Cataract Dam	- When inflows to Cataract Dam are <= 80^{th} percentile daily flow (14 ML/d) daily release equal to inflows must be made. - When inflows into Cataract Dam are >80^{th} percentile daily flow (14 ML/d) then daily release of 14 ML/d + 20% of inflows must be released. - Inflows measured at Loddon River at Bulli Appin Road gauge (2122322) and the Cataract River at Corrimal No. 1 gauge (2122323)	- The storage is spilling at a rate that equals or exceeds the release requirement - The release cannot be met due to an emergency situation - The release cannot be met due to capacity constraints or maintenance
Cordeaux Dam	- When inflows to Cordeaux Dam are <= 80^{th} percentile daily flow (4.5 ML/d) daily release equal to inflows must be made. - When inflows into Cordeaux Dam are >80^{th} percentile daily flow (4.5 ML/d) then daily release of 6.8 ML/d + 20% of inflows must be released. - Inflows measured at Goondarrin Creek at Kemira "D" Cast gauge (2122201) and the Sandy Creek at Cordeaux River gauge (2122205)	
Avon Dam	- When inflows to Avon Dam are <= 80^{th} percentile daily flow (6.8 ML/d) daily release equal to inflows must be made. - When inflows into Avon Dam are >80^{th} percentile daily flow (6.8 ML/d) then daily release of 6.8 ML/d + 20% of inflows must be released. - Inflows measured at the Avon River at Summit Tank gauge (2122111) and the Flying Fox No. 3 Creek at Fire Road gauge (2122112)	
Nepean Dam	- When inflows to Nepean Dam are <= 80^{th} percentile daily flow (20.1 ML/d) daily release equal to inflows must be made. - When inflows into Nepean Dam are >80^{th} percentile daily flow (20.1 ML/d) then daily release of 20.1 ML/d + 20% of inflows must be released. - Inflows measured at the Nepean River at Nepean Dam gauge (2122051) and the Burke River at Nepean Dam gauge (2122052)	- The storage is spilling at a rate that equals or exceeds the release requirement - The release cannot be met due to an emergency situation - The release cannot be met due to capacity constraints or maintenance
Broughtons Pass Weir	- Environmental flow released out of Cataract dam that day **PLUS** - Inflows into catchment between Broughtons pass weir and cataract dam when inflow is <= 80^{th} percentile daily flow (4.4 ML/d) - Flows into catchment between Broughtons pass weir and cataract dam are >80^{th} percentile daily flow (4.4 ML/d) then daily release of 4.4 ML/d + 20% of inflows must be released. - Inflows equal 0.24 x Inflows to Cataract Dam (NSW Office of Water, 2012)	

Storage	Environmental flow rules	Exemptions
Pheasants Nest Weir	- Environmental flow released out of Avon, Nepean and Cordeaux dam that day **PLUS** - Inflows into catchment between Pheasants nest weir and Avon, Nepean and Cordeaux dam when inflow is <= 80^{th} percentile daily flow (4.5 ML/d) - Flows into catchment between Pheasants nest weir and Avon, Nepean and Cordeaux dam are >80^{th} percentile then daily release of 4.5 ML/d + 20% of inflows must be released. - Inflows equal 0.38 x Inflows to Avon Dam (NSW Office of Water, 2012)	
Woronora Dam	- When inflows to Avon Dam are <= 80^{th} percentile daily flow (20.1 ML/d) daily release equal to inflows must be made. - When inflows into Woronora Dam are >80^{th} percentile daily flow (20.1 ML/d) then daily release of 20.1 ML/d + 20% of inflows must be released. - Inflows measured at Waratah Rivulet gauge (2132102) and the Woronora River (upstream of Woronora Dam) gauge (2132101)	

* 80^{th} percentile inflows for Tallowa Dam are presented in **Table 16**

Source: Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011

Table 16: 80th percentile inflows threshold to Tallowa Dam (to be read in conjunction with Table 15)

Month	Monthly flow threshold (ML/d)
January	150
February	161
March	182
April	259
May	298
June	334
July	371
August	332
September	299
October	281
November	256
December	179

The analysis included comparing, on a daily time step, the required environmental flow requirement for each storage (as defined by the rules set out in Table 15) with the actual environmental flow release time series provided by WaterNSW. This was then compared to the time series of storage spill to account for days where the requirement was achieved with spills and hence a release wasn't required. The result was expressed as a percentage of days where the actual release met the environmental requirement.

11.3.1 Status

The status of the environmental flows shows the degree of achievement of the environmental flow rules for each declared storage outlined in the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011. The categories used to determine status were:

- **Good** - Environmental flow rules were achieved more than 95% of the time.
- **Moderate** - Environmental flow rules were achieved between 85-95% of the time.
- **Poor** – Environmental flow rules were achieved less than 85% of the time.

11.3.2 Trend

To assess the trend in environmental flow delivery at each declared storage, the degree of achievement of the environmental flow rules were compared between the 2013-2016 audit period and the 2016-2019 audit period. These periods were considered as they cover the duration of the current Water Sharing Plan for the Catchment and hence the current environmental rules. The categories used to determine the trend were:

- **Improving**: Proportion of time environmental flow rules were achieved increased by 5% or more from 2013-2016 to 2016-2019.
- **Stable**: Proportion of time environmental flow rules were achieved in 2016-2019 was within 5% of the 2013-2016 result
- **Worsening**: Proportion of time environmental flow rules were achieved reduced by 5% or more from 2013-2016 to 2016-2019.

11.3.3 Data quality

The data provided for this audit was considered good quality and was complete over the years assessed for all stations. Therefore, for assessing compliance with environmental rules, the data was assessed as fit-for-purpose.

11.4 Findings

A total of 742,279 ML of environmental water was released from the 11 storages analysed during the 2016-2019 audit period. This is 14% less than the previous audit period, during which time 861,740 ML was delivered. This reduction is consistent with the reduced water availability across the Catchment in 2016-2019 compared to the previous audit period (as discussed in Chapter 10). Releases from Tallowa Dam constituted around 77% of the environmental water released in 2016-2019 (Figure 27), with Pheasants Nest Weir, which passes environmental flows out of Avon, Nepean and Cordeaux, being the next largest contributor of environmental water in the Catchment.

11.4.1 Status

During the 2016-2019 audit period the environmental flow indicator achieved an overall 'Good' status rating, with nine of the storages obtaining a 'Good' rating and two storages a 'Moderate' rating (Table 17). Storages in the Warragamba and Woronora systems were 98% or more compliant with the environmental flow requirement set out in the WSP. In the Shoalhaven system, Wingecarribee Dam and Fitzroy Falls Dam received a 'Good' rating, with Tallowa achieving 93% compliance, i.e. 'Moderate' rating.

Interrogation of the data revealed that where the Tallowa flow requirement was not met, the flow delivery was within 5-10 ML/d of the required flow. Therefore, only small improvements in environmental flow delivery would increase the storage at Tallowa to a 'Good' rating.

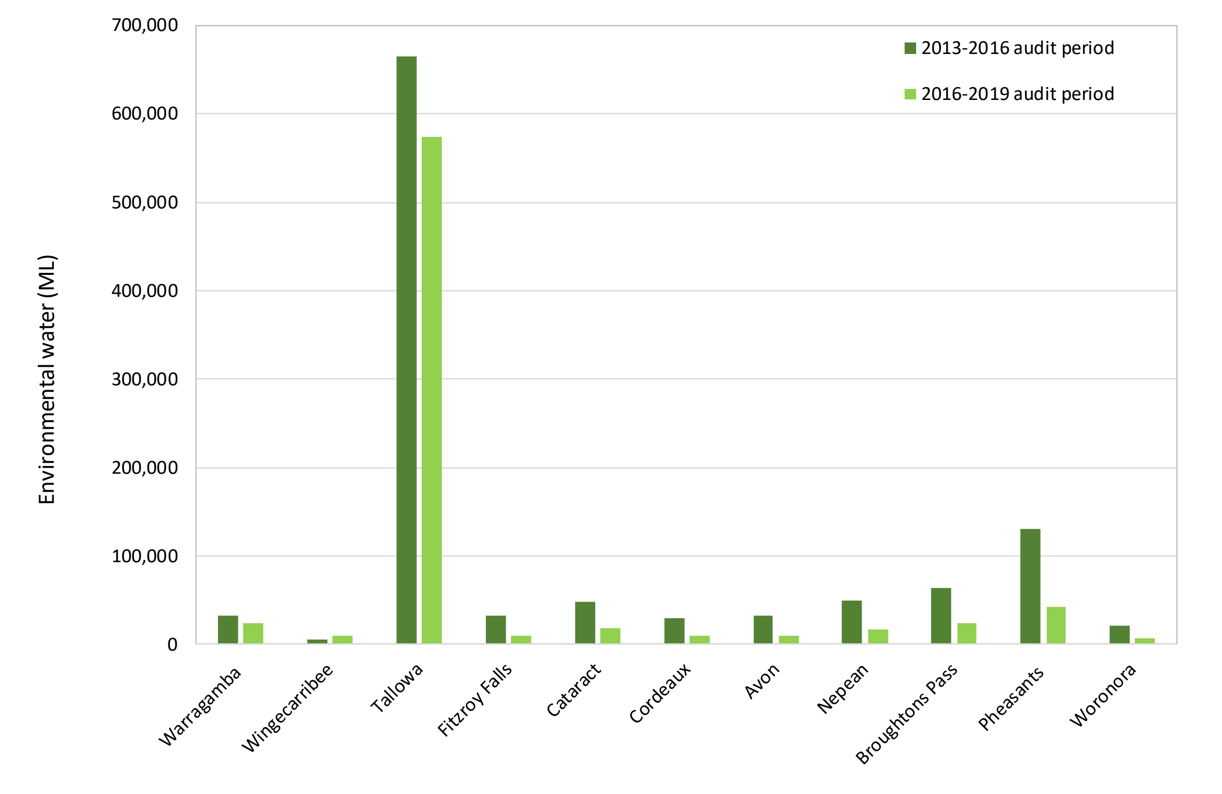


Figure 27: Flow releases from the storages assessed in this audit (WaterNSW)

Table 17: Status results for the environmental flows indicator during 2016-2019

Dam/Weir	Sub-catchment	River System	% Compliance	Status
Warragamba Dam	Lake Burragorang	Warragamba System	100%	**Good**
Wingecarribee Dam	Wingecarribee River	Shoalhaven System	100%	**Good**
Tallowa Dam	Kangaroo River	Shoalhaven System	93%	**Moderate**
Fitzroy Falls	Kangaroo River	Shoalhaven System	100%	**Good**
Cataract Dam	Upper Nepean	Upper Nepean System	100%	**Good**
Cordeaux Dam	Upper Nepean	Upper Nepean System	99%	**Good**
Avon Dam	Upper Nepean	Upper Nepean System	99%	**Good**
Nepean Dam	Upper Nepean	Upper Nepean System	94%	**Moderate**
Broughton Pass Weir	Upper Nepean	Upper Nepean System	100%	**Good**
Pheasants Nest Weir	Upper Nepean	Upper Nepean System	99%	**Good**
Woronora Dam	Woronora River	Woronora System	100%	**Good**
		Average	98%	**Good**

11.4.2 Trend

Comparison between the previous 2013-2016 and current 2016-2019 audit periods (Table 18) indicates an overall 'Stable' trend; with most storages remaining compliant with their environmental flow requirements. The Nepean Dam shows a minor decrease from 99% in 2013-2016 to 94% compliance during 2016-2019.

Table 18: Trend results for the environmental flows indicator

Dam/Weir	Sub-catchment	River System	% Compliance		Trend
			2013-2016	2016-2019	
Warragamba Dam	Lake Burragorang	Warragamba System	99%	100%	**Stable**
Wingecarribee Dam	Wingecarribee River	Shoalhaven System	100%	100%	**Stable**
Tallowa Dam	Kangaroo River	Shoalhaven System	93%	93%	**Stable**
Fitzroy Falls	Kangaroo River	Shoalhaven System	92%	100%	**Stable**
Cataract Dam	Upper Nepean	Upper Nepean System	99%	100%	**Stable**
Cordeaux Dam	Upper Nepean	Upper Nepean System	100%	99%	**Stable**
Avon Dam	Upper Nepean	Upper Nepean System	98%	99%	**Stable**
Nepean Dam	Upper Nepean	Upper Nepean System	99%	94%	**Worsening**
Broughton Pass Weir	Upper Nepean	Upper Nepean System	100%	100%	**Stable**
Pheasants Nest Weir	Upper Nepean	Upper Nepean System	100%	99%	**Stable**
Woronora Dam	Woronora River	Woronora System	100%	100%	**Stable**
		Average	98%	98%	**Stable**

11.5 Conclusion

The analysis considered the degree of compliance with the environmental flow rules outlined within the relevant resource plan and concluded that there are high levels of compliance. However, as part of the Water Sharing Plan update, the suitability of current environmental flow management practices should be reviewed in the context of increasing pressures associated with climate change. For example, during the audit period, there were times when the environmental releases from the Wingecarribee Dam were not flowing past Bong Bong weir, with little or no flow over Berrima weir and sections of the river were completely dry. The impact of the environmental flow releases were negligible further downstream potentially because of river bed / soil moisture dryness or licenced / unlicenced extractions.

12. Groundwater availability

12.1 Definition and context

Groundwater is an important environmental and economic resource. Extraction of groundwater for human consumption, such as for drinking water, agriculture or industrial use can reduce the water that is available to the environment. Environmental water requirements include maintaining surface water base flow, wetlands and other Groundwater Dependent Ecosystems (GDEs).

Groundwater use within the Catchment is managed by the WSP for the Greater Metropolitan Region Groundwater Sources 2011. The following nine groundwater sources are relevant to the Sydney Drinking Water Catchment (Figure 28):

- Coxs River Fractured Rock
- Goulburn Fractured Rock
- Sydney Basin North
- Sydney Basin South
- Sydney Basin Nepean
- Sydney Basin Richmond
- Sydney Basin Blue Mountains
- Sydney Basin Central
- Sydney Basin Coxs River.

WSPs provide a legislative basis for sharing water between the environment and other purposes, and address licensing of the take and the use of groundwater. The take of groundwater by consumptive uses and aquifer interference activities is required to be accounted for by a Water Access Licence unless an exemption applies. WSPs also provide opportunities to trade water within a defined water source in accordance with the rules of the plan.

12.2 Sustainable extraction limits

Sustainable water trading requires a solid understanding of the volumes of groundwater recharge received by each water source as the available volume for licenced take is calculated as a proportion of the annual recharge. The WSP includes recharge volumes that are estimated based on a percentage of infiltration of average annual rainfall across the intake beds of each groundwater source (currently 6%). Initially the average rainfall for the time period between 1921 and 1995 was used to estimate recharge (NOW 2011), though the rainfall period has recently been extended up to 2012, which has resulted in the current recharge estimates in the Plan and reported in the 2016 audit (Table 19).

The part of the recharge that is not reserved as environmental water is included in the volume of water that is potentially available for extraction, which is termed the long-term average annual extraction limit (LTAAEL). Changes in the rainfall period used for recharge estimates have resulted in one small change in the LTAAEL in recent updates (2015) of the plan (Table 19).

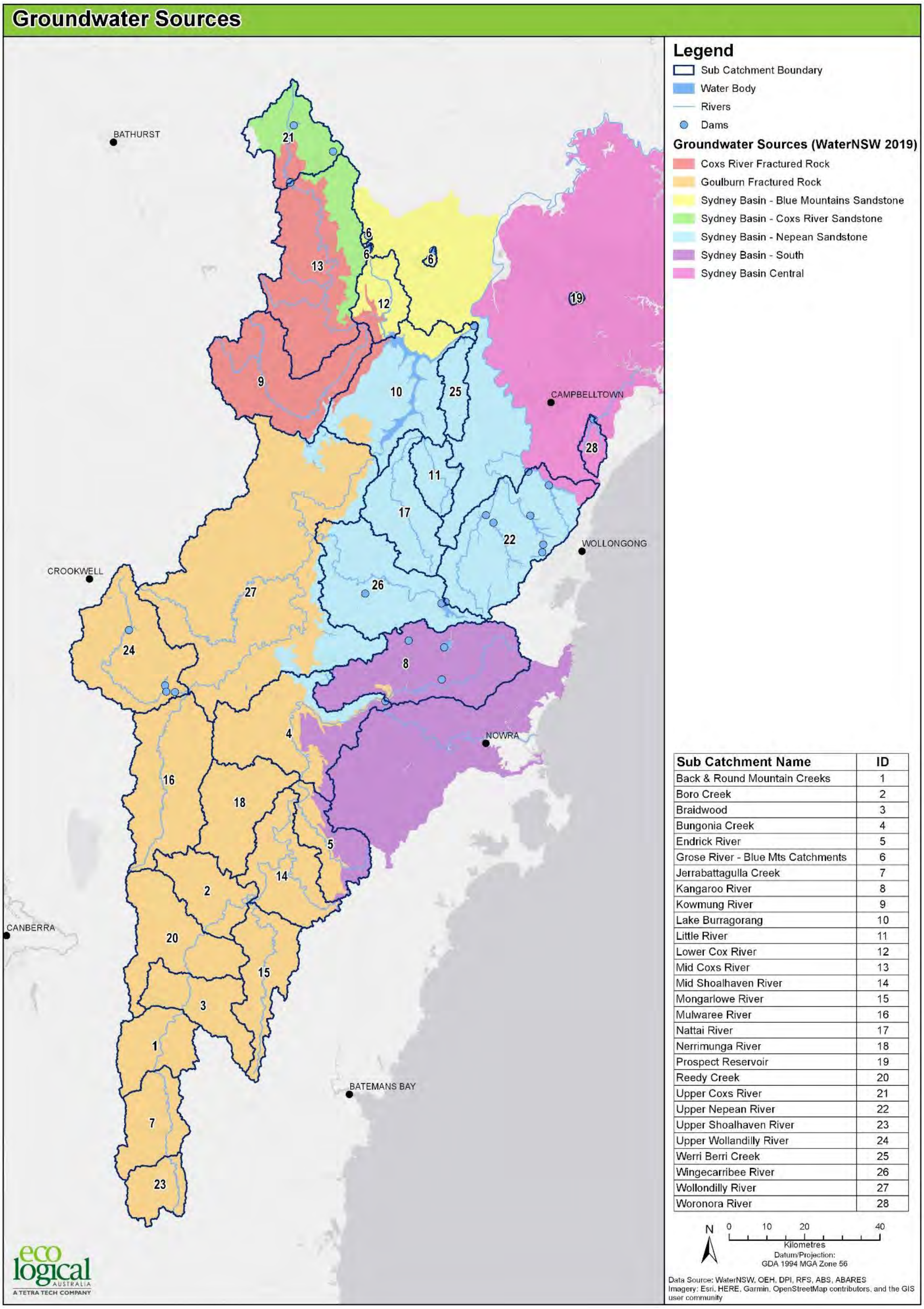


Figure 28: Groundwater sources and the Catchment

Table 19: Recharge and LTAAELs groundwater sources relevant to the Catchment

Source	Recharge infiltration rate (%)		Recharge (ML/year)		LTAAEL (ML/year)	
	2016 audit[a]	Current audit[b]	2016 audit[a]	Current audit[b]	2016 audit[a]	Current audit[b]
Sydney Basin North	6	5	269,187	224,322	19,682	16,402
Sydney Basin South	6	5	225,326	187,772	69,892	58,243
Sydney Basin Nepean	6	5	224,483	187,069	99,568	82,973
Sydney Basin Richmond	6	5	127,878	106,565	21,103	17,586
Sydney Basin Blue Mountains	6	5	78,474	65,395	7,039	3,245
Sydney Basin Central	6	5	229,223	191,019	45,915	38,263
Sydney Basin Coxs River	6	5	31,312	26,094	17,108	14,257
Coxs River Fractured Rock	4	1	67,087	16,574	7,005	1,702
Goulbourn Fractured Rock	4	1	259,784	64,946	53,074	13,269

NOTES: [a] NOW (2011), with update as recorded in the 2015 update to the WSP, [b] EMM (2015)

There have been no significant changes to the recharge estimates since the previous 2016 audit, with the planned review of groundwater recharge and LTAAELs to be undertaken for the issue of the updated WSP in 2021.

As part of the five-year WSP review, DPI Water commissioned a review of rainfall recharge rates for coastal porous rock groundwater sources. This review identified recharge rates that were used for coastal porous rock aquifers might be overestimating true recharge to the system (EMM 2015). This is relevant for the nine Sydney Basin groundwater sources. Rather than a 6% infiltration rate as used in the WSP, EMM (2015) recommended use of a 1% infiltration rate for Permian and 5% infiltration rate for Triassic sandstone in the Sydney Basin. The recharge and LTAAEL volumes using the original infiltration rate from the WSP (NOW 2011) and the updated infiltration rates from EMM (2015) are those presented in Table 19.

Sustainable groundwater volumes beneath high value conservation areas (such as national parks, nature reserves and historic and Aboriginal sites) are treated separately to the rest of the water source in that 95 or 100% of the estimated recharge is reserved as planned environmental water and is therefore not available for water trading. Across the remainder of the water source the percentage of recharge that is reserved as environmental water is determined by the sustainability factor, which weighs the environmental values in each groundwater source against the socio-economic dependence on groundwater. The sustainability factors used in the plan are determined based on a risk matrix and vary from 40 to 70% (Table 20).

Table 20: Groundwater recharge allocation for sustainable extraction limit estimation

	Low socio-economic risk	Moderate socio-economic risk	High socio-economic risk
High environmental risk	95%	75% Goulburn Fractured Rock Coxs River Fractured Rock	50%
Moderate environmental risk	75% Sydney Basin North Sydney Basin Blue Mountains Sydney Basin Central	50% Sydney Basin South Metropolitan Coastal Sands Botany Sands Hawkesbury Alluvium	40% Sydney Basin Richmond Sydney Basin Nepean Maroota Tertiary Sands
Low environmental risk	50%	40% Sydney Basin Cox River	30%

Source: Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources – Background document

12.3 Water allocations

Part of the LTAAEL is reserved for basic landholder rights (BLR), which includes water for domestic and stock purposes that is extracted from an aquifer underlying the landholder's property. Under section 52 of the *Water Management Act 2000*, groundwater may be extracted to meet defined domestic and stock purposes without a licence, although the work (usually a bore) must still be approved by WaterNSW. The *Water Management Act 2000* requires that water sharing must protect BLR, which is achieved by reserving a water volume for the water requirements for domestic and stock users.

The total licensed groundwater entitlement (TLGE) therefore includes the volumes assigned (or estimated) to all current groundwater access licenses (WAL) under the *Water Management Act 2000*. These are licenses for local water utilities; for aquifer interference; for stock and domestic water use (other than BLR), as well as for general purpose water access for consumptive purposes, which includes industrial, irrigation and recreation use. The TLGE does not include unresolved water licence applications and current aquifer interference activities that have not yet been assigned a volume (i.e. for which a WAL has yet to be issued).

Due to the separation of land and water, the WALs are not assigned to a specific location, but to an entire groundwater source. During this audit process the water volumes are therefore compared by groundwater source, rather than by the boundary of the Sydney Drinking Water Catchment. This is carried out for the nine groundwater sources that were assessed during the 2016 audit to enable long-term comparison (Table 21). The volume reserved for BLR has remained the same since the previous audit for all groundwater sources, except the Coxs River Fractured Rock, which has increased from 179 ML/year to 190 ML/year. This increase is likely drought driven. The changes observed in TLGE since the previous audit are attributed to ongoing adjustments in groundwater licenses that have been reassigned from the *Water Act 1912* to the *Water Management Act 2000*. At the time of the previous audit the transition of some licenses was pending. Now complete, these have been assigned to the year of application.

Table 21: Water allocations for basic landholder rights and total licensed groundwater entitlement

Groundwater source	Volume reserved for BLR (ML/yr)		TLGE (ML/yr)			
	2013 Audit[a]	2016 & 2019 Audits[b]	2015/16[d]	2016/17[d]	2017/2018 [d]	2018/19[d]
Coxs River Fractured Rock	179	190	125.5	125.5	125.5	255.5
Goulburn Fractured Rock	3114	3114	4344	4532	4633	6433
SB Blue Mountains	421	421	113.7	113.7	113.7	113.7
SB Central	2601	2601	2947.5	2947.5	3265.5	3621.5
SB Coxs River	454	454	7421.5	7421.5	9987.5	9987.5
SB Nepean	5971	5971	26562.4	27144.4	27933.4	34195.4
SB North	722	722	912	2912	2917	3027
SB Richmond	1623	1623	16652.5	16652.5	16652.5	16652.5
SB South	2098	2098	3087	3087	3330	3525

[a] GHD (2013), [b] WSP (version 1/1/2015, accessed 5/2/2020), [c] ELA (2016),
[d] WaterNSW Water Registry

The percentage of LTAAEL that is allocated either as BLR or as TLGE is shown in Figure 29. These percentages do not include any water allocations that are still managed under the *Water Act 1912*.

Figure 29 suggests the current groundwater allocations for all nine groundwater sources in the Catchment remain within the limits set by the current water plan, particularly when the LTAAEL is calculated using a 6% infiltration / recharge rate (consistent with previous audits). For this audit, the LTAAEL has also been calculated using the EMM (2015) infiltration rates (5% and 10% for Permian strata and Triassic sandstones respectively) for the 2018/2019 water year. This was recommended during the 2016 audit based on the EMM (2015) study, which suggests the current 6% infiltration rate is likely to provide an overestimate. Calculations using the EMM (2015) rates suggest the Sydney Basin Richmond groundwater source may exceed the LTAAEL by approximately 3%. The Sydney Basin Coxs River groundwater source and Goulburn Fractured Rock groundwater source also show significant increases in percentage allocated water in comparison to previous estimates.

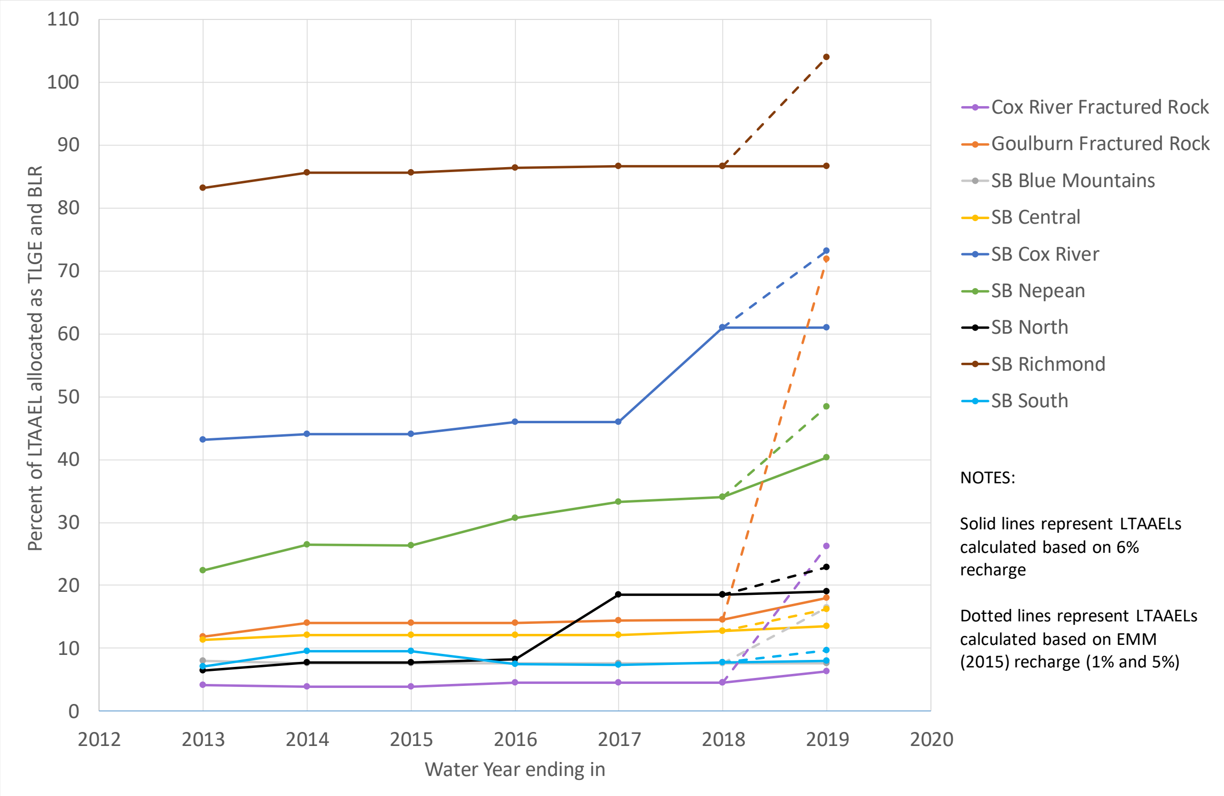


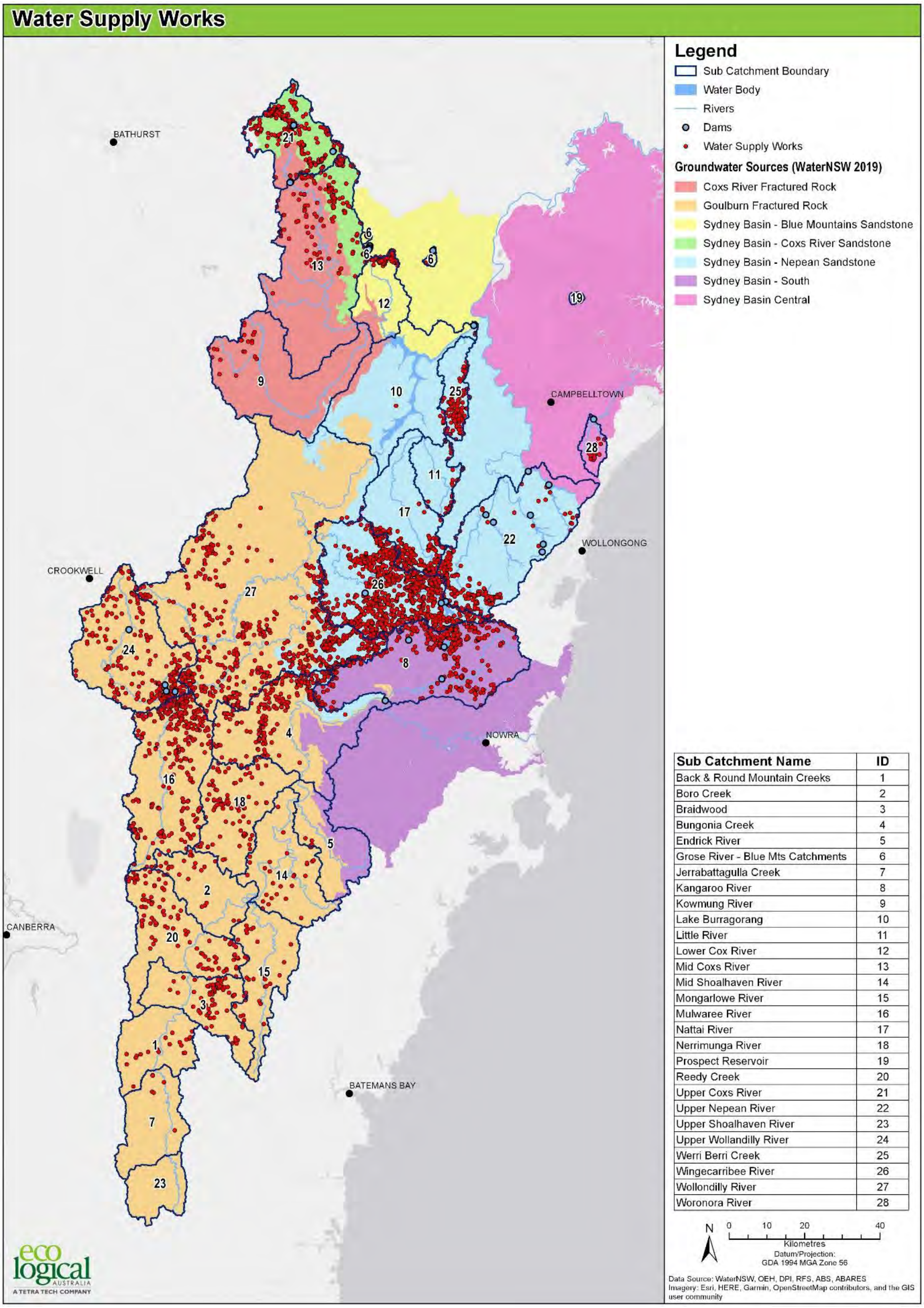
Figure 29: Percent of LTAAEL allocated as TLGE and BLR

The observed increases are not unexpected considering the lower estimated infiltration rate of 1% recommended by EMM (2015) for sandstone formations, which is particularly relevant for the Sydney Basin Coxs River groundwater source. The increases in groundwater extraction observed in relation to the LTAAELs defined for each groundwater source, further highlights the need to review actual recharge estimates as part of the ten-year review of the Water Sharing Plan scheduled in 2021.

12.4 Water supply works

Water supply work approvals authorise a holder to construct and use a specific water supply work at a specific location. Water supply works are either linked to a WAL, which specifies the volumetric extraction limits they entitle the holder to extract, or link to water access as part of BLR. Water supply works include installation works such as wells, excavations, bores or spear points.

After removal of duplicates from the data, a total of 5364 licensed water supply works were identified in the Catchment at the end of June 2019. A total of 401 of these were licensed during the current audit period (July 2016 to July 2019) (Table 22**;** Figure 30).



Sub Catchment Name	ID
Back & Round Mountain Creeks	1
Boro Creek	2
Braidwood	3
Bungonia Creek	4
Endrick River	5
Grose River - Blue Mts Catchments	6
Jerrabattagulla Creek	7
Kangaroo River	8
Kowmung River	9
Lake Burragorang	10
Little River	11
Lower Cox River	12
Mid Coxs River	13
Mid Shoalhaven River	14
Mongarlowe River	15
Mulwaree River	16
Nattai River	17
Nerrimunga River	18
Prospect Reservoir	19
Reedy Creek	20
Upper Coxs River	21
Upper Nepean River	22
Upper Shoalhaven River	23
Upper Wollandilly River	24
Werri Berri Creek	25
Wingecarribee River	26
Wollondilly River	27
Woronora River	28

Figure 30: Water supply works within the Catchment (WaterNSW)

Table 22: Registered water supply works (bores)

Bore category	2013 Audit		2016 Audit		2019 Audit	
	Number [a]	% of total [b]	Number [c]	% of total	Number	% of total
Contamination/Remediation	68	2	1	0.03	2	0.04
Mining	17	0.5	-	-	12	0.2
Aquaculture	21	0.6	2	0.06	4	0.07
Water Supply	11	0.3	4	0.11	4	0.07
Industrial	108	3.2	43	1.20	56	1
Irrigation	260	7.7	195	5.42	208	3.88
Stock/Domestic	2884	85.6	2907	80.79	4091	76.27
Monitoring	-	-	292	8.12	538	10.03
Recreation	-	-	24	0.67	25	0.47
Fire fighting	N/A	N/A	N/A	N/A	4	0.07
Water conservation	N/A	N/A	N/A	N/A	2	0.04
Other	-	-	28	0.19	3	0.06
No purpose listed	-	-	102	2.83	415	7.74
Total number of Bores	**3369**	N/A	**3598**	N/A	**5364**	N/A

[a] estimated based on percentages and total number of water supply works, [b] GHD (2013) Figure 4.6
[c] ELA (2016) Table 20

The total number of registered water supply works for this audit is about 49% higher than reported during the previous audit period, when 3598 licensed bores were identified.

The review indicates that 538 of the 5364 licences showed an 'ACTIVE' status, indicating that they have not yet been converted to the *Water Management Act 2000* and are still managed under the *Water Act 1912*. Of these, two 'ACTIVE' licenses were identified during the current 2019 audit period. Similar to the previous 2016 audit, the majority of the bores that have not yet been converted are monitoring bores (536 bores) with the other two being BLR bores for domestic, stock and farming purposes.

The 5364 licensed water supply works represent a total of 59 registered purposes. These have been rationalised to 11 purposes using the categories identified from the previous 2016 audit period. A further two categories (firefighting and water conservation) have also been included that were not identified in the 2016 audit. The assignment process therefore includes a degree of interpretation bias. The results are presented in Table 22.

As with the 2016 Audit, the majority of water supply works (76%) have a registered purpose of water use for stock and domestic purposes. Other significant bore use categories are monitoring (10%) and irrigation (approximately 4%). The proportions of different purposes have changed slightly between the 2013 and 2016 audits and the current audit as can be seen in Table 22.

12.5 Groundwater level monitoring

Groundwater level data for the 2019 reporting period has been provided by DPI Water and WaterNSW for a total of 45 bores in the Catchment (Figure 31). A total of 59 bores were initially identified, however the following fourteen bores do not contain new data since the previous audit, hence have not been included in this assessment:

- GW409701
- GW409702
- GW075413
- GW040971
- GW075102
- GW041052
- GW752011
- GW075171
- GW075175
- GW041045
- GW075182
- GW075210
- GW075114
- GW075115

Of the 45 bores assessed for this audit, 17 are monitoring bores that log groundwater level with automated data loggers (Figure 32). These assets are currently operated by WaterNSW (previously the responsibility of DPI Water). Four of these monitoring locations are established in the Thirlmere Lakes area, and another two were installed in the Southern Highlands as part of the same drilling campaign. These monitoring bores started collecting data in late 2012 and continue to collect data during the 2019 reporting period.

WaterNSW also operates the remaining 28 of the 45 monitoring bores in the south of the Upper Nepean River Surface Water Catchment (Figure 33). These bores were installed as a potential source of water during drought.

In terms of available data for the 2019 reporting period, it is noted that 28 of the 45 monitoring bores do not contain water level data records past November 2018. In particular, the monitoring bores in the Upper Nepean Surface Water Catchment (27 of 28 bores) show datasets ending in July to November 2018.

A summary table with water level observations for all monitoring bores is listed in Table 23. Bore hydrographs with daily rainfalls as well as cumulative rainfall departure curves (CRDC) of the nearest climate station are presented in Volume 3 Appendix E. None of the 45 observation bores show any indication of a downward trend that would indicate a decline in groundwater storage in the Catchment. However, as shown in Figure 31, the monitoring bores only cover a very small proportion of the catchment (only 5 of the 27 sub-catchments) and therefore are only able to provide a very localised picture of groundwater level trends in the catchment. Monitoring bores are also not necessarily located near key extractive industries, such as mining areas, or near key groundwater dependent ecosystems (also shown in Figure 31 to Figure 33) within the catchment.

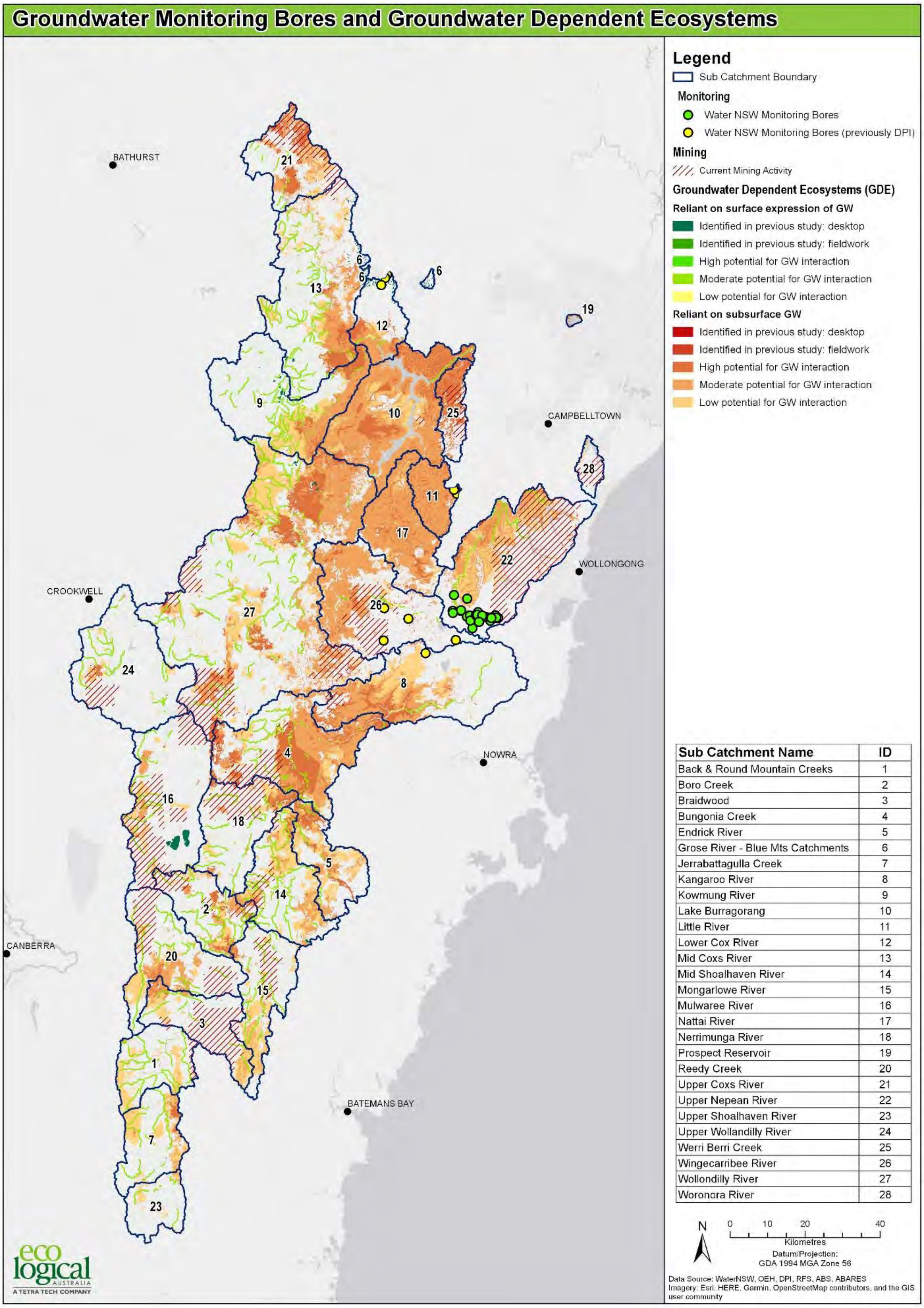


Figure 31: Groundwater monitoring bores in relation to GDEs and active mining areas (45 bores from WaterNSW)

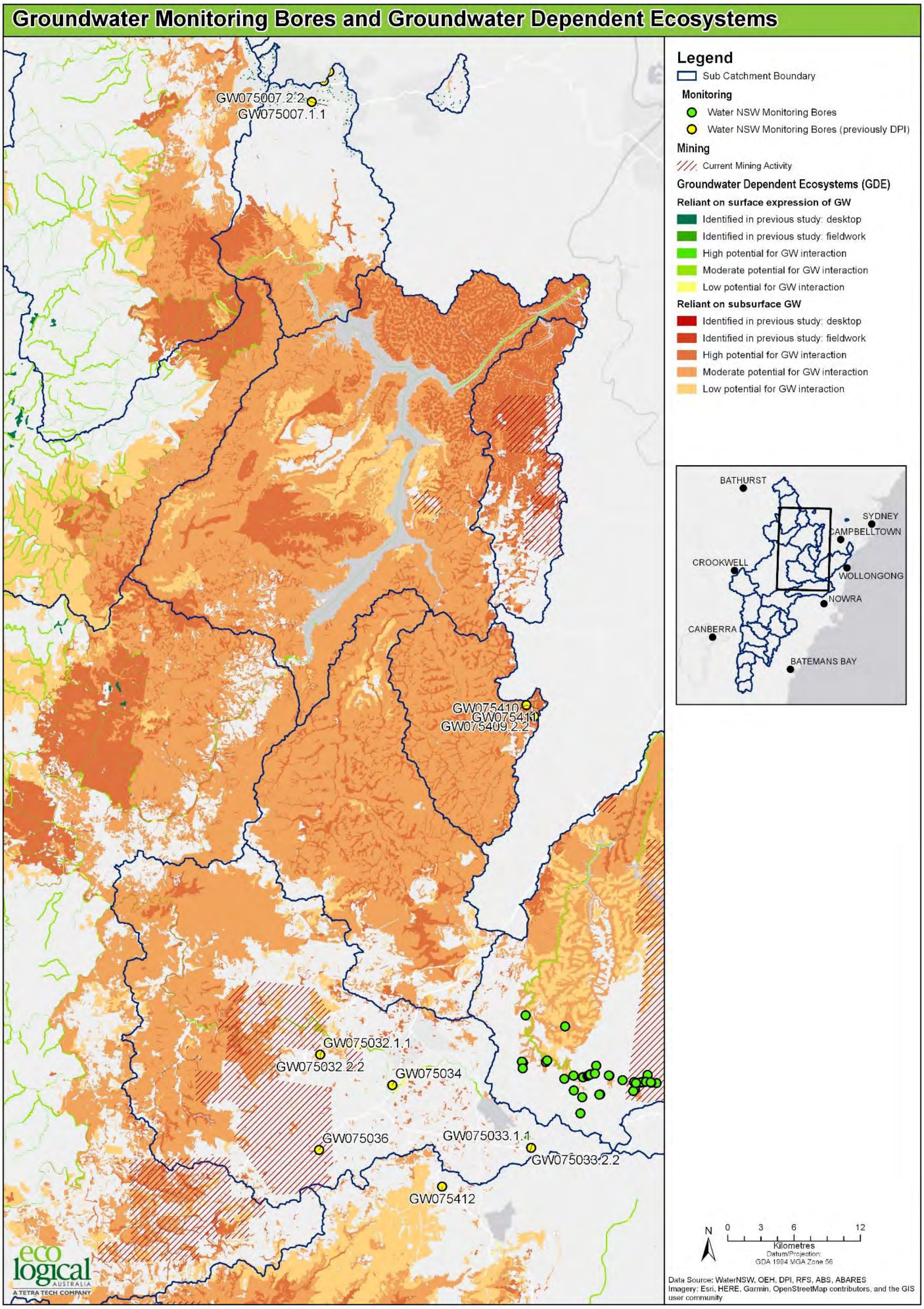


Figure 32: Locations of groundwater monitoring bores (yellow bores that were previously owned by DPI Water) in relation to GDEs and active mining areas (WaterNSW) for the north-east region

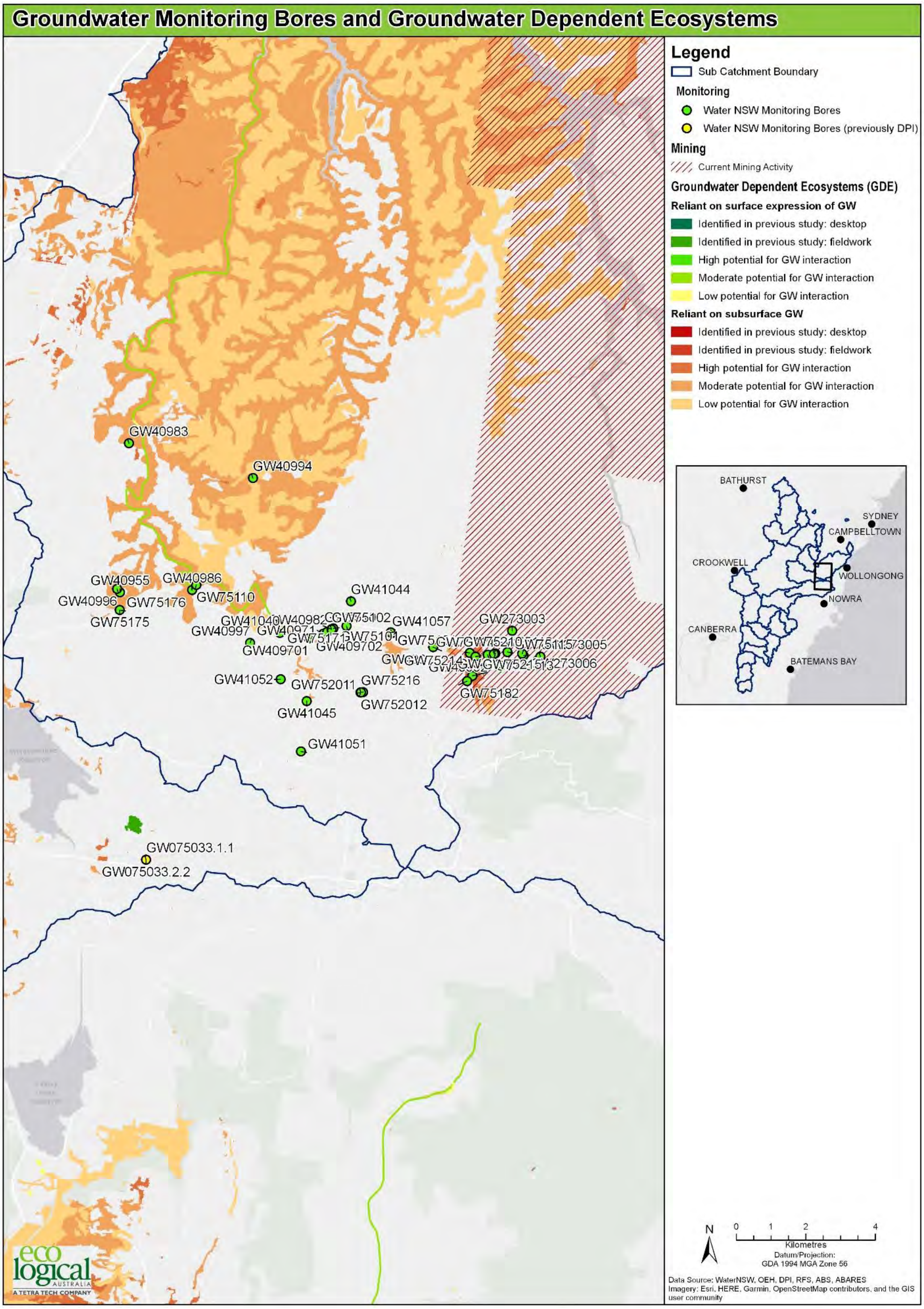


Figure 33: Locations of other WaterNSW groundwater monitoring bores (green bores) in relation to GDEs and active mining areas (WaterNSW) for the eastern region

Table 23: Summary of groundwater level trends

Legend	
Increase in groundwater level observed	
Stable groundwater level observed	
Decline in groundwater level observed	
Short term climate response observed	
No observed climate response recorded	
No or insufficient data available for assessment	

NOTES:

Stable levels are within historical variation.

Decline and increase is observed to be outside of historical variation.

Sub-catchment	Bores	Trend	Climate impact	Rainfall station
Lower Coxs River	GW075005.1.1			63227
	GW075005.2.2			63227
	GW075006.1.1			63227
	GW075006.2.2			63227
	GW075007.1.1			63039
	GW075007.2.2			63039
Kangaroo River	GW075412			68009
Upper Nepean River	GW40955			68202
	GW409701			68202
	GW409702			68202
	GW40971			68202
	GW40972			68202
	GW40982			68202
	GW40983			68202
	GW40986			68202
	GW40994			68202
	GW40996			68202
	GW40997			68202
	GW41040			68202
	GW41044			68202
	GW41045			68202
	GW41051			68202
	GW41052			68202
	GW41057			68202
	GW75100			68202
	GW75101			68202
	GW75102			68202

Sub-catchment	Bores	Trend	Climate impact	Rainfall station
	GW75110			68202
	GW75171			68202
	GW75175			68202
	GW75176			68202
	GW75181			68202
	GW752011			68202
	GW752012			68202
	GW75216			68202
	GW273003			68224
	GW273005			68224
	GW273006			68224
	GW40992			68224
	GW41063			68224
	GW75112			68224
	GW75113			68224
	GW75114			68224
	GW75115			68224
	GW75182			68224
	GW75210			68224
	GW75214			68224
	GW75215			68224
	GW075032.1.1			68186
	GW075032.2.2			68186
Wingecarribee	GW075033.1.1			68045
	GW075033.2.2			68045
	GW075034			68045
	GW075036			68045
	GW075409.1.1			68166
Little River	GW075409.2.2			68166
	GW075410			68166
	GW075411			68166
Endrick River*	GW075413			68033

NOTES:
*GW075413 located outside the Sydney Catchment boundary, closest sub-catchment area is Endrick River (located west of the bore).

This shortcoming in monitoring locations in the Sydney Catchment has been highlighted during previous audits and in a more general sense for NSW during the Independent Review of Coal Seam Gas Activities in NSW by the NSW Chief Scientist and Engineer (2014).

It is anticipated that some of these monitoring shortcomings in the Catchment will be addressed by the NSW Water Monitoring Framework (WMF), which is an ongoing high-profile commitment by the NSW Government to expand its groundwater monitoring network. A key element of the WMF is the Water Monitoring strategy for Coal Basins in NSW, which was guided by recommendations made in the Independent Review of Coal Seam Gas Activities in NSW by the NSW Chief Scientist and Engineer. The WMF identifies eight priority areas to target an expansion of the NSW public groundwater monitoring network, two of which are relevant for the Sydney Catchment: the Western Coalfields (South) and Southern Coalfields.

Capital funds of $22.8 million are anticipated to be used to update the public groundwater monitoring network in the eight priority areas through to 2019/20, with real-time monitoring due to commence shortly thereafter. Each monitoring bore will be equipped with logging instrumentation to measure water level, temperature and electrical conductivity of the groundwater and each bore will be constructed to allow regular water quality sampling. In addition to the expansion of the public monitoring network the WMF aims to harness water data collected by coal and CSG industries and to make this data publicly available through portals such as the DPIE Water website.

12.6 Recommendations

The following recommendations are made in addition to those in Chapter 10:

- Consider, as part of the scheduled review of the Metropolitan Water Plan, the option of managed aquifer recharge within the Catchment.
- Ensure sufficient water entitlements are retained by all mines operating in the Special Areas to cover potential surface water losses resulting from mining induced effects, including predicted climate change impacts.
- Review the obligations and capacity of mines in the Catchment to undertake rehabilitation and restoration works.

This auditor also supports the recommendations of the Independent Expert Panel on Mining in the Catchment (IEPMC 2019), including:

- To establish an inter-agency working group to identify acceptable levels of surface water loss due to mining in the Catchment after considering the significance of different thresholds of surface water loss due to mining in the Catchment.
- To establish performance measures related to changes in groundwater pressure and/or pressure gradients where these have the potential to impact on surface water diversions or losses for all future mine approvals in the Special Areas.
- To investigate and quantify the potential impacts of historic and current mining for long-term cumulative impacts on water quantity and quality in the Special Areas, for the purpose of properly informing mine design, offsets, mine rehabilitation and closure planning, planning assessments and rehabilitation bonds.

The NSW Government has also recognised the need to expand its groundwater monitoring network across NSW, consistent with the NSW Water Monitoring Framework (WMF). Improved groundwater level monitoring in the Catchment means that subsequent audits will be able to carry out a more relevant and thorough water level analysis. This is critical in assessing the long-term sustainability of groundwater resources across the Catchment.

BIODIVERSITY AND HABITATS

Figure 34: Habitat creation and water treatment in a constructed wetland in the Blue Mountains LGA

13. Fire

13.1 Definition and context

Fire is a natural part of the landscape and ecology of the Australian environment, and many plants rely on fire for germination. However, high frequency or intensity fire can harm ecosystems and destabilise the hydrological characteristics of the Catchment. Poor water quality, including higher risk of cyanobacterial blooms, can result from large amounts of sediment, nutrients, ash and other pollutants being washed or leached into waterways and stored waters following significant fire activity. This is particularly a problem where heavy rain occurs in areas that have been severely burnt and there is no protective vegetation cover remaining.

The main factors contributing to the severity and spread of bushfire in the Catchment are:

- weather and climate conditions, including wind speed, temperature, relative humidity and drought index
- dryness of the fuel, the type of fuel (grass, heath, woodland or forest) and the fuel load (surface and overall)
- physical structure (fine fuels or heavy fuels) and arrangement of vegetation (surface, elevated, bark or canopy)
- the terrain in which the fire is burning
- effectiveness of fire management (prevention and preparation) and suppression actions, particularly initial observation and response to an ignition.

There are two main categories of fire:

- Uncontrolled bushfire – which can be caused by natural and human activities. Arson and accidental fires are common where access to bushland areas is relatively easy. Natural fires started by lightning are also common, with dry thunderstorms a regular occurrence in late spring and summer. These fires have the potential to burn large areas of bushland, as they often originate where access is difficult and may burn for some time before suppression commences, by which time they are of considerable size. Under hot, dry weather conditions fire can spread rapidly and threaten life, property, assets and other values of the wider region. Suppression within the Catchment is often difficult due to remoteness, access and rugged terrain and if fires are not controlled while small they typically require a significant and extended commitment of firefighting resources.
- Prescribed burns – also known as hazard reduction burns or planned burns. These are carefully planned and implemented by agencies in consultation with the community. They aim to achieve a mosaic of burning, contributing to the retention of natural landscape and biodiversity values by implementing appropriate fire intervals and thresholds for the vegetation types.. Prescribed burning on public land within the Catchment is undertaken by the Rural Fire Service (RFS), NSW Fire and Rescue, Forestry Corporation, WaterNSW and DPIE. The RFS undertake prescribed burning in areas of native vegetation on private lands within the Catchment, at a smaller scale than burning of public land. An emphasis is placed by these agencies on managing vegetation at the urban/bushland interface to reduce fire risk to life and property.

Bushfire management in NSW is led by the RFS and the 'window' when controlled burns can be undertaken is reducing as the fire season extends under climate change .

There have been no traditional Aboriginal land burning activities recorded in the Catchment during the audit period.

13.2 Data

The most comprehensive NSW fire history databases (BRIMS and ICON) are held by the RFS based on inputs from the RFS, NSW Fire and Rescue, DPIE, local councils and WaterNSW.

- BRIMS provides a consolidated record of hazards, risks and mitigation activities in a bushfire context across NSW (e.g. for the Prevention phase of the Prevention, Preparedness, Response and Recovery model). BRIMS also includes information relevant to fire and development impact assessments, and community engagement activities and complaints.
- ICON is used by the firefighting agencies from an operational perspective to provide a consolidated record of bushfires (and other emergencies) across NSW (e.g. for the Response phase of the Prevention, Preparedness, Response and Recovery model).

However, due to the focus on operational fire-fighting during the period when this audit report was prepared, the RFS were unable to provide the BRIMS or ICON data to the auditors.

An alternative, publicly available dataset was obtained via the portal for Sharing and Enabling Environmental Data (SEED) for the whole of government in NSW. The history of uncontrolled and prescribed burns, primarily in national park estate, was from the DPIE.

13.3 Findings

Higher rainfall prior to and during 2016 promoted vegetation growth across the Catchment. This was followed by extensive vegetation die-off as drought conditions dominated in 2018-19 (refer to Section 1.2 of this Volume for more information on rainfall patterns). The available fire records show that there were relatively low levels of uncontrolled fire during the audit period (Figure 36 and Table 24). However, devastating wildfires occurred in the Spring and Summer of 2019/20 (outside the current audit period) as a result of hot, dry conditions and a substantial fuel load in an extreme level of dryness (Figure 36).

The available data indicates that the total extent of prescribed burning was similar to previous years and the main driver of uncontrolled burns is climate patterns. Interestingly, at a Catchment-scale, there doesn't appear to be any relationship between the locations of prescribed burn activity and locations of uncontrolled burn activity over the audit period. Table 24 provides some anecdotal findings that prescribed burning may have resulted in decreased uncontrolled fire activity in following periods for some sub-catchments, however more detailed spatial analysis over an extended period to assess the effectiveness of prescribed burning and relationship to uncontrolled burn extent and intensity is required. Vegetation and climate monitoring should directly inform bushfire management preparedness.

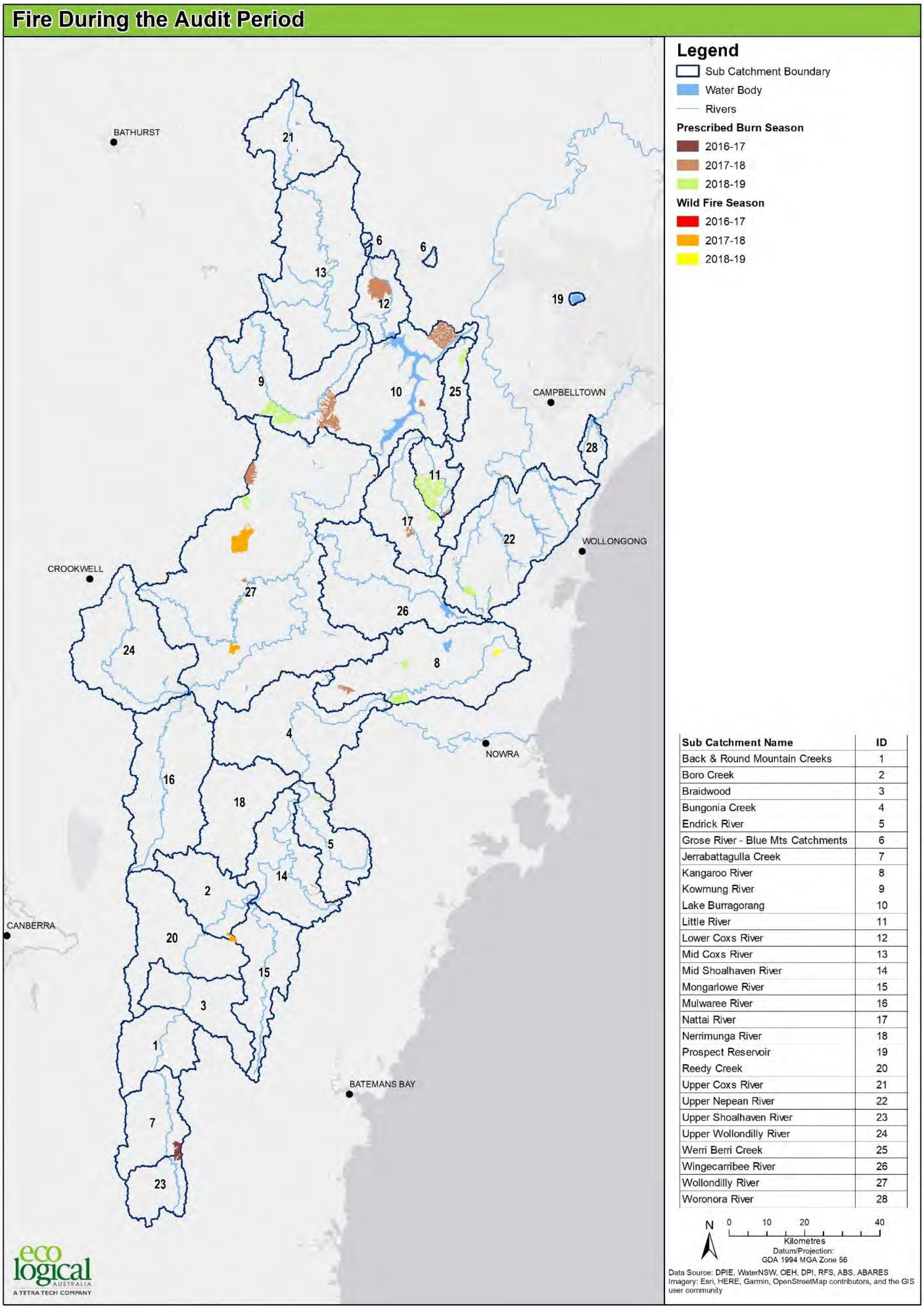


Figure 35: Uncontrolled and prescribed burn areas during the audit period (DPIE)

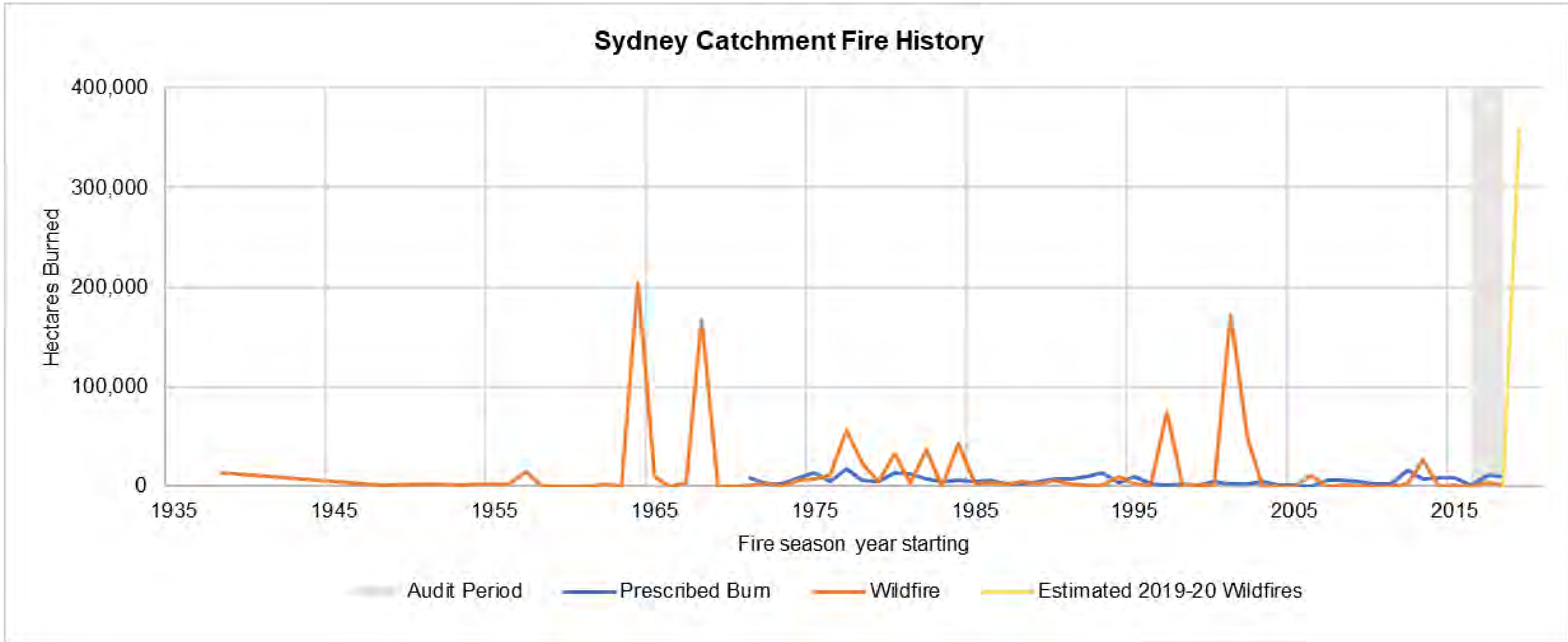


Figure 36: Long term trends in fire extent in the Catchment (DIPE data)

Table 24: Extent (ha) of prescribed and uncontrolled fires in the Catchment during four audit periods (data from DPIE)

Sub-catchments	Prescribed				Uncontrolled				Total			
	2007-10	**2010-13**	**2013-16**	***2016-19***	**2007-10**	**2010-13**	**2013-16**	***2016-19***	**2007-10**	**2010-13**	**2013-16**	***2016-19***
Back & Round Mountain Creeks					12.61				12.61			
Blue Mountains	278.39	61.84	121.07	*5.97*					278.39	61.84	121.07	*5.97*
Boro Creek			244.54		155.33		299.21	*217.34*	155.33		543.74	*217.34*
Braidwood	540.43		646.01				29.10	*0.00*	540.43		675.12	*0.00*
Bungonia Creek		1972.51	628.51	*27.34*	17.66	105.70	0.03		17.66	2078.21	628.53	*27.34*
Endrick River			2022.66	*157.82*							2022.66	*157.82*
Jerrabattagulla Creek				*541.25*								*541.25*
Kangaroo River	1232.86	2521.48	1453.15	*1851.70*	1165.32	14.40	17.93	*223.35*	2398.17	2535.88	1471.08	*2075.05*
Kowmung River	3647.13	4246.61	247.85	*3625.33*			87.24	*0.78*	3647.13	4246.61	335.09	*3626.12*
Lake Burragorang	354.40	6.28	6094.89	*4467.17*	432.30	3.43	5.11	*23.13*	786.69	9.71	6100.00	*4490.30*
Little River	17.47	455.29	1067.73	*3581.02*	7.46	0.13	18.58		24.94	455.43	1086.31	*3581.02*
Lower Coxs River	282.39	853.20	853.99	*2715.22*	115.95	571.30	178.60	*2.27*	398.33	1424.50	1032.58	*2717.49*
Mid Coxs River	3223.99	6339.62			2.23	28.99	4796.87	*7.39*	3226.22	6368.61	4796.87	*7.39*
Mid Shoalhaven River			648.91	*285.04*		2.43	555.30	*9.89*		2.43	1204.21	*294.94*
Mongarlowe River		216.75	1612.06		35.68		1254.14	*72.22*	35.68	216.75	2866.20	*72.22*
Mulwaree River			1.97								1.97	
Nattai River	4551.98	1705.48	2666.65	*802.84*	2.42	4.58			4554.40	1710.06	2666.65	*802.84*
Nerrimunga River		578.43	995.97				0.18			578.43	996.15	
Prospect Reservoir		0.60					0.46			0.60	0.46	
Reedy Creek	5.07		333.32					*50.35*	5.07		333.32	*50.35*
Upper Coxs River					5.89		6711.92	*13.54*	5.89		6711.92	*13.54*

Sub-catchments	Prescribed				Uncontrolled				Total			
Upper Nepean River	177.07	852.00	855.65	*712.20*	2.88	1098.7	13535.0	*47.33*	179.95	1950.75	14390.6	*759.53*
Upper Shoalhaven River			1012.05	*258.08*	78.33	1.25		*0.05*	78.33	1.25	1012.05	*258.13*
Werri Berri Creek	262.98	460.03	224.23	*530.07*		63.12			262.98	523.14	224.23	*530.07*
Wingecarribee River	25.85	783.36	46.07		0.17		0.02	*10.92*	26.02	783.36	46.09	*10.92*
Wollondilly River	2815.37	71.76	1806.99	*1911.84*	28.14	57.39	65.37	*3021.4*	2843.51	129.15	1872.36	*4933.31*
Woronora River				*15.76*		21.32				21.33		*15.76*
Grand Total	17415.3	21125.2	23584.2	*21488.6*	2062.36	1972.8	27555.0	*3700.0*	19477.7	23098.0	51139.3	*25188.6*

13.4 Bushfire management

Section 63 of the *Rural Fires Act 1997* (RF Act) requires all land managers in NSW to prevent the occurrence or spread of bushfires on and from land it directly manages. Landscape scale bushfire risk management in the Catchment is coordinated through eight multi-agency Bush Fire Management Committees (BFMCs). The BFMCs are required to develop Bush Fire Risk Management Plans (BFRMP) in accordance with Section 52 of the RF Act. The BFRMP allows for the identification and mapping of land and infrastructure in the Catchment as an asset at risk of bushfire.

BFRMP need to be reviewed every five years in accordance with Section 52 of the RF Act. Dates when the latest BFRMPs were approved for each zone in the Catchment are as follows (based on information available from the RFS website):

- Blue Mountains – May 2016
- Cumberland – September 2010
- Macarthur – June 2012
- Sutherland – October 2016
- Wollondilly - Wingecarribee– May 2017
- Illawarra – March 2017
- Lake George – November 2018
- Southern Tablelands – March 2019

Annual fire management works for land management agencies are derived from the BFRMPs and focus on the protection of human life and property.

WaterNSW has procedures in place to respond quickly in the event of observed bushfire in the Catchment presenting a risk to drinking water storage and supply. This includes installing booms and curtains in storages to minimise the amount of ash and sediment delivered to the water filtration plants.

In response to the forecast increased bushfire risk and the length of the fire season for the Catchment, particularly for its lands and the Special Areas, WaterNSW has increased its fire management resources including:

- Planning: A permanent Specialist Fire Planner position to identify priority hazard reduction burn program, maintain and modify fire strategies with new information from the RFS and other agencies, and to maintain a collaborative fire management planning approach with RFS and DPIE to protect water quality. This includes funding of prescribed burns and asset protection works on DPIE lands within the Special Areas under the Land Management Program.
- Operations: A permanent Fire Program Manager to manage fire delivery. The Fire Program Manager leads delivery of an agreement with RFS for dedicated fire mitigation resources to undertake hazard reduction activities on WaterNSW lands and escalation in bushfire season to eight crews and a dedicated helicopter for rapid response. The resources allow full-time fire staff to be assigned to key fire management activities including implementation of WaterNSW's annual priority hazard reduction plan. In addition, WaterNSW still maintains internal staff with fire operation management skills who can respond to fires or act as incident liaison or field site controller.

- Research and emerging trends: WaterNSW collaborates with the Bushfire Risk Management Research Hub on topics such as strategies to improve fire management and reduce the risk bushfires pose to people, property and the environment. WaterNSW is also seeking opportunities for collaborative research on fire management and water quality with fire management agencies and land management agencies.

13.5 Conclusion and recommendations

Incomplete data meant that it was not possible to determine fire trends during the audit period. It is therefore recommended that all agencies provide real-time fire data into a single database that is publicly available via SEED. This would be in addition to the Fire Extent and Severity Mapping (FESM) database currently available on SEED based on satellite imagery. This could then be used by multiple agencies and other organisations to inform planning, operations and research.

The majority of the BFMCs have plans that comply with their obligations under Section 52, although the Cumberland and Macarthur BFRMPs have not been updated within the required timeframe. It is recommended that all BFRMPs relevant to the Catchment are updated to better recognise and reduce the risks to natural assets and water quality. The plans should apply Strategic Fire Advantage Zones principles to protect water storages.

It is noted that an Independent Bushfire Inquiry has been instigated following the summer 2019/20 bushfire season. Some findings and recommendations from the Inquiry may have relevance to management of the Catchment.

14. Fish

14.1 Definition and context

The *Fisheries Management Act 1994* defines a ‘fish’ as any marine, estuarine or freshwater fish or other aquatic animal life at any stage of their life history (whether alive or dead). It excludes whales, mammals, reptiles, birds and amphibians which are managed under other legislation. Therefore, a ‘fish’ includes not only fin fish (including sharks), but also crustaceans, molluscs, worms, insects and other invertebrates with an aquatic life stage.

The numbers and proportions of native fish and exotic species present within each sampled water body is the recommended measurement for the Catchment audit (NOW 2009). The total number of native species is often used as a measure of the general health of aquatic ecosystems because it has been shown that the number of native species declines with increasing environmental stress. The presence of introduced species also reflects the general condition of the aquatic ecosystem and may represent both a symptom and a cause of declines in stream health and disturbance (Harris 1995).

14.2 Data and method

In 2016, DPI Fisheries released two state-wide models of the distribution of threatened fish and rated the fish community status of major waterways (Riches et al 2016). Those data have not been revised during the 2016-19 audit period. Survey data for the Catchment was sourced from fish research conducted by DPI Fisheries. Other supplementary fish records were sourced from mine monitoring reports, council fish monitoring programs and public records lodged on the Atlas of Living Australia and BioNet. Additional fish surveys have likely occurred in the study area but were not made available for inclusion in this audit.

14.3 Potential distribution of threatened fish

DPI Fisheries used records of threatened species collected since the late 1990s to map indicative distributions for threatened freshwater species in NSW. A geographic model (maximum entropy) was used to predict the distribution for each listed species. The maps were created for regional and site-based planning and assessments and represent the last remaining known populations of the species in NSW, or in similar environmental areas that are suitable. The state-wide modelling excluded translocated populations, such as stocked Macquarie Perch in the Mongarlowe River, which is considered likely to be the result of a translocation from the Murray-Darling Basin (Lintermans 2008). Several threatened species were data-deficient and could not be modelled to the required accuracy. This includes the Adams Emerald Dragonfly and Sydney Hawk Dragonfly, that have historically been recorded in the Catchment.

Two threatened fish species are currently likely to occur within the Catchment: Fitzroy Falls Spiny Crayfish (49 km in Kangaroo River and Wingecarribee River sub-catchments) and Macquarie Perch (507 km in Lake Burragorang, Little River, Mid/Lower Coxs, Nattai River, Upper Nepean, Werri Berri Creek, Wollondilly River and Woronora River sub-catchments) (Figure 37). The Australian Grayling is also mapped in the Catchment, but only as a result of mapping ‘line work’ crossing over a barrier (i.e. Shoalhaven River downstream of the Tallowa Dam towards Nowra), although there is potential for the species to migrate upstream via the fish lift installed in 2009.

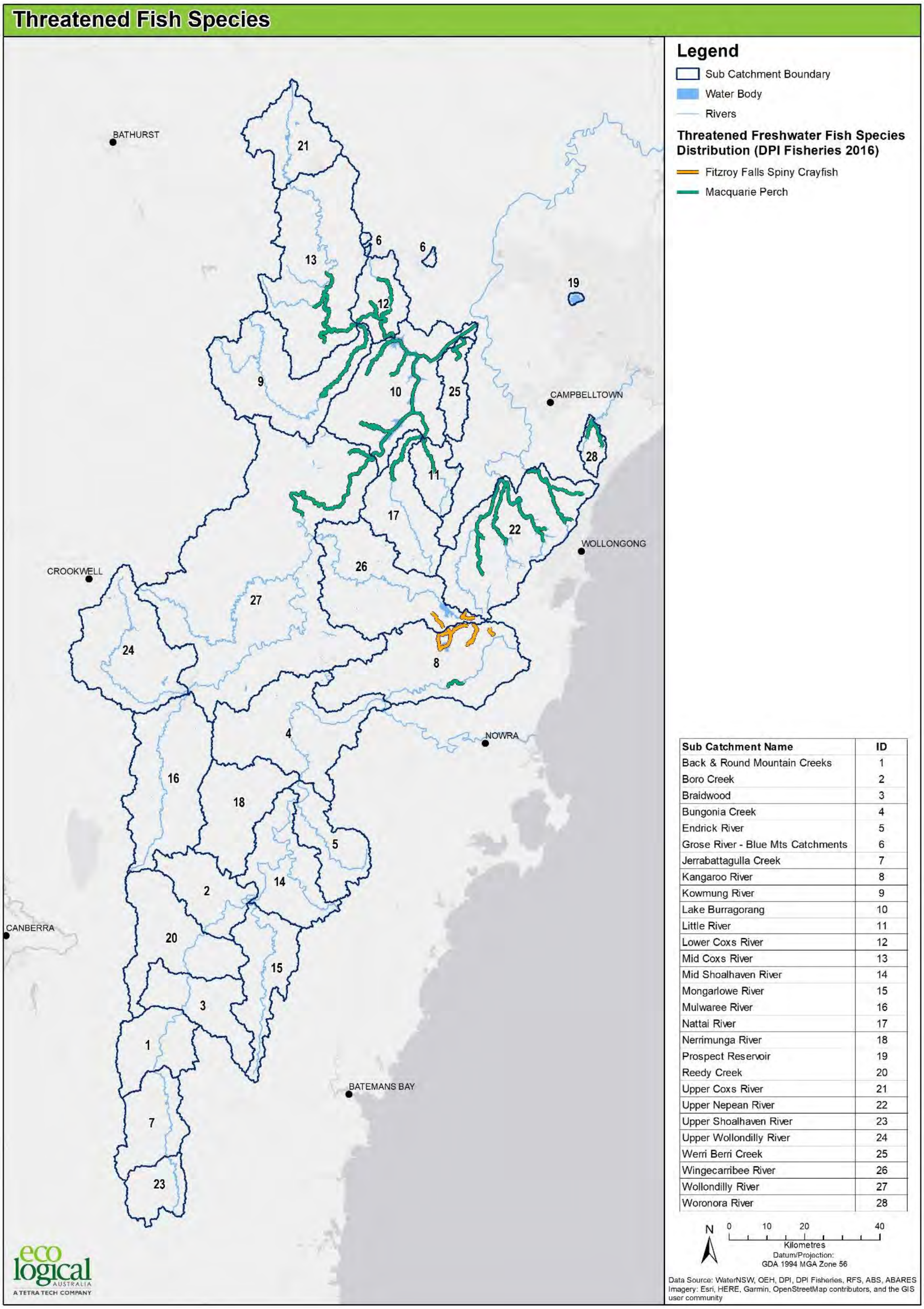


Figure 37: Likely threatened species distribution in the study area (from Riches et al 2016)

14.4 Fish community status

DPI Fisheries created a map using three indicators of condition (expectedness, nativeness and recruitment) to show the status of fish communities in NSW. The indicators were built from DPI Fisheries datasets, field sampling, environmental variables (National Hydrological Geospatial Fabric Version 2) and other modelling. The condition outcomes rate the fish communities as very good, good, fair, poor or very poor.

A total of 3547 km of stream length was assessed in the mapping project. Of this, fish community status is comprised of fair (12%), poor (63%) and very poor (24%) (Figure 39). Sub-catchments that have waterways with a predominantly very poor status are:

- Mulwaree River
- Nerrimunga River
- Upper Wollondilly River
- Wollondilly River.

14.5 Fish surveys

Results of fish surveys are presented in Table 25 and Table 26, formatted to build on previous audit results. DPI Fisheries increased its sampling in the Catchment compared to the previous audit period, although the spatial spread only covered four sub-catchments (Figure 40) as the surveys were designed for specific research goals. In Lake Burragorang and Werri Berri Creek, three sites were sampled using boat electrofishing, gill nets and unbaited traps. A total of 225 fish were recorded from 12 species (seven native and five introduced). In the Kangaroo River and headwaters of Wingecarribee River, 39 sites were sampled using boat and backpack electrofishing, gill nets, fyke nets and unbaited traps. A total of 2079 fish were recorded from 13 species (11 native and two introduced). Other surveys conducted by consultants or public observations provide patchy data for an additional six sub-catchments.

In total, during the audit period, 24 species were identified across 10 sub-catchments. These comprised 19 native species and five introduced species. No species outside of their known distribution were discovered. A list of 24 native fish species that were expected in the Catchment pre-1930s was determined from NSW Fisheries and the Australian Museum records (2003 Sydney Drinking Water Catchment Audit Report: DEC 2003). Occurrence of several expected species pre-1930s was dependent on unobstructed passage between fresh and marine waters, such as Australian Grayling, Estuary Perch, Shortheaded Lamprey and Southern Blue Eye that migrate across both habitat types during their life cycle (diadromous fish). There are no records of these migratory species since DPI Fisheries commenced routine surveys within the Catchment. This factor suggests that either large impoundments are an obstruction to fish passage, even with fish lifts or ladders, or those species are not in an abundance to be recorded at the limited survey sites.

Additional native species compared to the pre-1930s conditions were found in this audit period, but were either not identified to species level (but were of the same genus as expected) or have been recorded several times since 2005 (e.g. Silver Perch and Freshwater Catfish), or are outside of the fish's natural range (e.g. Murray Cod, presumed translocated).

Five of the seven known introduced species were recorded during this audit period, with no new species. The absence of any native or exotic fish species from the surveys isn't necessarily a reflection of a change in catchment condition overall, as species have distributions unique to certain areas of the Catchment and may be outside the sampling area (e.g. the invasive Redfin Perch occurs in the Catchment but is not known from the sub-catchments that DPI surveyed).

Similar to other audits since 2005, there is insufficient information to assess the whole-of-catchment condition or long-term health. This is discussed further below.

Figure 38: Fish habitat in Wingecarribee River adjacent Bong Bong Common

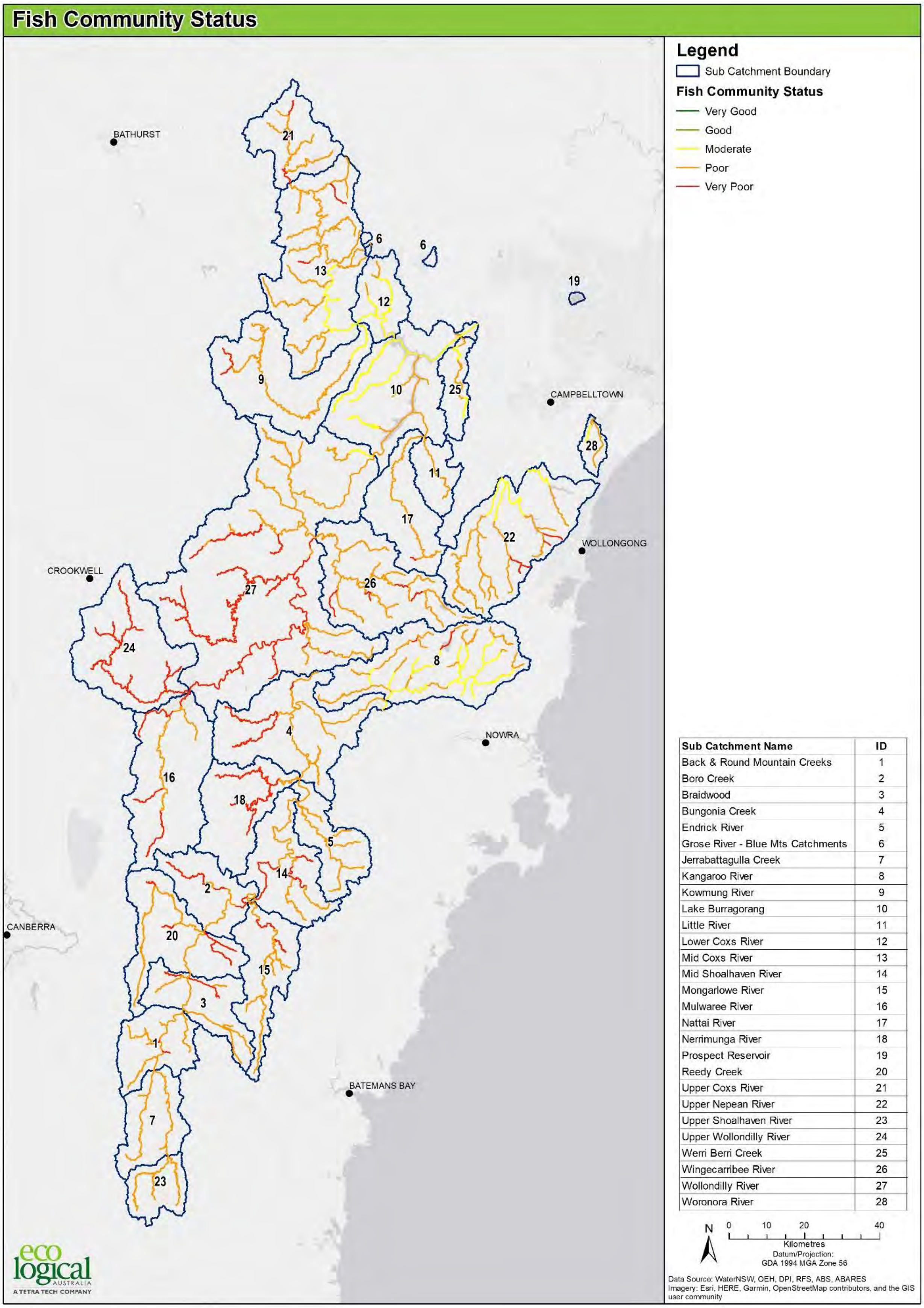


Figure 39: Fish community status in the study area (from Riches et al 2016)

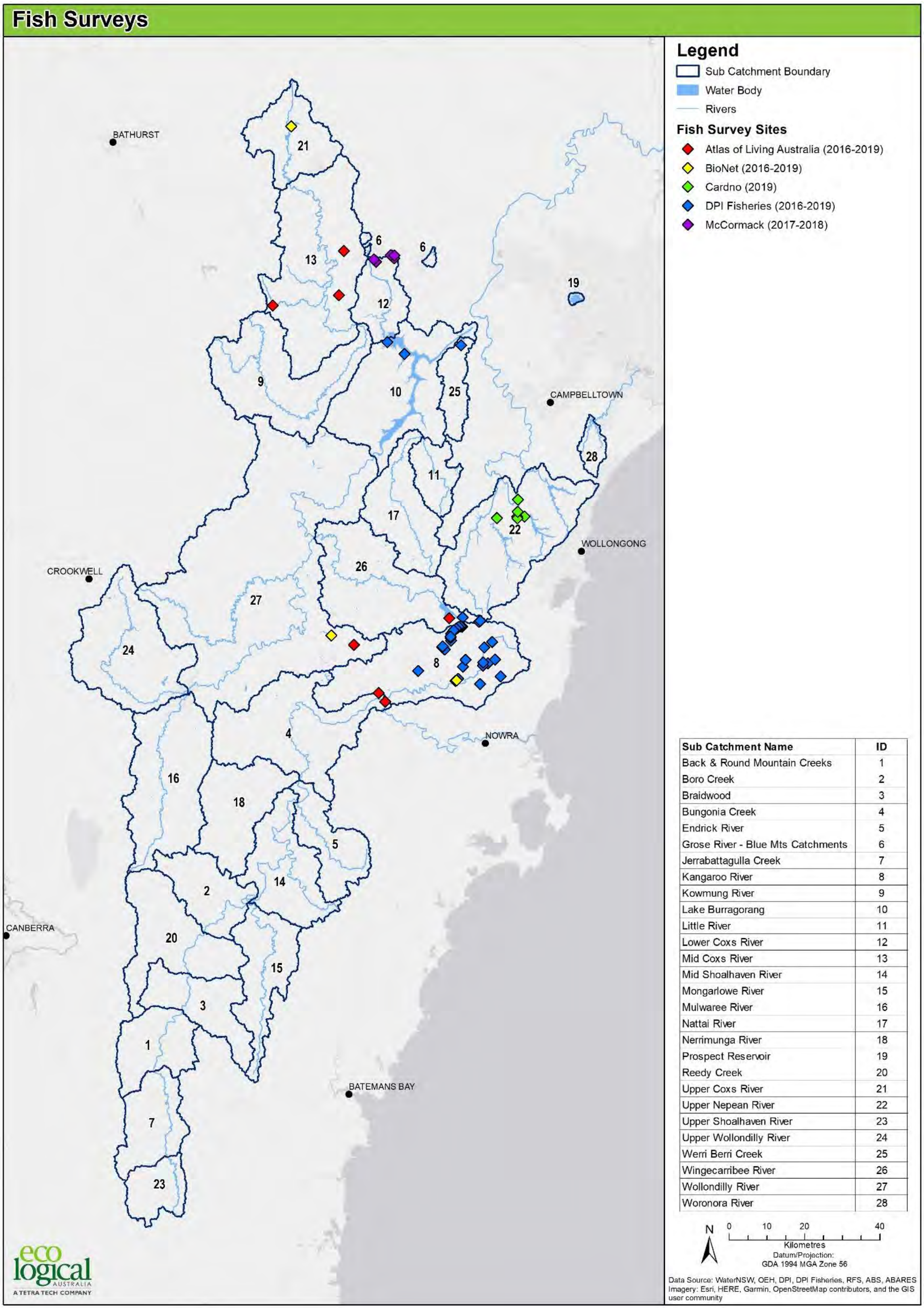


Figure 40: Location of fish surveys conducted between June 2013 to June 2016

Table 25: Fish species expected to occur (pre-1930s) and collected between June 2005 and June 2019 in the Catchment

Species	Common name	Status	Expected to occur (pre-1930s)	June 2005 - June 2007	July 2007 - June 2010	July 2010 - June 2013	July 2013 - June 2016	July 2016 - June 2019
Anguilla australis	Short-finned Eel	Native	x	x	x	x		
Anguilla reinhardtii	Long-finned Eel	Native	x	x	x	x		x
Anguilla sp.	Unidentified Eel	Native						x
Bidyanus bidyanus	Silver Perch	Native		x		x		x
Carassius auratus	Goldfish	Introduced		x	x	x		x
Cherax destructor	Yabby	Native	x				x	x
Cyprinus carpio	Common Carp	Introduced		x	x	x		x
Euastacus australasiensis	Sydney Crayfish	Native						x
Euastacus dharawalus	Fitzroy Falls Spiny Crayfish	Native	x				x	x
Euastacus spinifer	Giant Spiny Crayfish	Native						x
Euastacus yanga	Southern Lobster	Native						x
Euastacus sp.	Unidentified Crayfish	Native						x
Galaxias brevipinnis	Climbing Galaxias	Native	x	x		x		
Galaxias maculatus	Common Jollytail	Native	x			x		x
Galaxias olidus	Mountain Galaxias	Native	x	x	x	x	x	x
Galaxias sp.	Unidentified Galaxid	Native						x
Gambusia holbrooki	Eastern Gambusia	Introduced		x	x	x	x	x
Gobiomorphus australis	Striped Gudgeon	Native	x	x	x	x		
Gobiomorphus coxii	Cox's Gudgeon	Native	x	x	x	x		x
Hypseleotris compressa	Empire Gudgeon	Native	x			x		
Hypseleotris gaii	Firetail Gudgeon	Native	x		x	x		x

Species	Common name	Status	Expected to occur (pre-1930s)	June 2005 - June 2007	July 2007 - June 2010	July 2010 - June 2013	July 2013 - June 2016	July 2016 - June 2019
Hypseleotris klunzingeri	Western Carp-gudgeon	Native		x	x	x		
Hypseleotris sp.	Unidentified Carp-gudgeon	Native		x		x		x
Maccullochella hybrid	Trout Cod-Murray Cod hybrid	Native				x		
Maccullochella macquariensis	Trout Cod	Native				x		
Maccullochella peelii	Murray Cod	Native		x				x
Macquaria australasica	Macquarie Perch	Native	x	x	x	x		
Macquaria colonorum	Estuary Perch	Native	x					
Macquaria novemaculeata	Australian Bass	Native	x	x	x	x		x
Misgurnus anguillicaudatus	Oriental Weatherloach	Introduced		x	x	x	x	
Mordacia mordax	Shortheaded Lamprey	Native	x					
Mordacia praecox	Lamprey	Native			x			
Mugil cephalus	Sea Mullet	Native	x			x		
Notesthes robusta	Bullrout	Native	x			x		
Oncorhynchus mykiss	Rainbow Trout	Introduced		x	x	x		x
Perca fluviatilis	Redfin Perch	Introduced		x	x			
Philypnodon grandiceps	Flat-headed Gudgeon	Native	x	x	x	x	x	x
Philypnodon macrostomus	Dwarf flat-headed Gudgeon	Native	x	x	x	x	x	x
Potamalosa richmondia	Freshwater Herring	Native	x			x		
Prototroctes maraena	Australian Grayling	Native	x					
Pseudomugil signifer	Southern Blue Eye	Native	x					
Retropinna semoni	Australian Smelt	Native	x	x	x	x		x
Salmo trutta	Brown Trout	Introduced		x	x	x		x

Species	Common name	Status	Expected to occur (pre-1930s)	June 2005 - June 2007	July 2007 - June 2010	July 2010 - June 2013	July 2013 - June 2016	July 2016 - June 2019
Tandanus tandanus	Freshwater Catfish	Native		x	x	x		x
Trachystoma petardi	Freshwater Mullet	Native	x			x		

Table 26: Number of native and introduced fish species collected in the Catchment between June 2005 and June 2019

Sub-catchment		Boro Creek	Bungonia Creek	Endrick Creek	Kangaroo River	Kowmung River	Lake Burragorang	Little River	Lower Coxs River	Mid Coxs River	Mid Shoalhaven River	Mongarlowe River	Mulwaree River	Nattai River	Prospect Reservoir	Reedy Creek	Upper Coxs River	Upper Nepean River	Upper Shoalhaven River	Upper Wollondily River	Werri Berri Creek	Wingecarribee River	Wollondily River	Woronora River
June 2005 - June 2007	Sites Sampled		4		5		4	1	2	2	1	3	1	2				12		3	1	2	6	
	Native		7		7		7	1	5	1	2	5	0	3				12		2	2	2	6	
	Introduced		2		2		1	0	2	2	0	0	2	1				1		2	2	0	5	
	Species richness		9		9		8	1	7	3	2	5	2	4				13		4	4	2	11	
July 2007 - June 2010	Sites Sampled	2	5	1	8	3	3	4	1	4		1	1					17	1			3	11	2
	Native	0	8	3	7	0	10	4	4	2		4	2					11	1			2	6	2
	Introduced	3	3	0	3	3	3	2	1	3		3	1					2	1			3	4	1
	Species richness	3	11	3	10	3	13	6	5	5		7	3					13	2			5	10	3

Sub-catchment		Boro Creek	Bungonia Creek	Endrick Creek	Kangaroo River	Kowmung River	Lake Burragorang	Little River	Lower Coxs River	Mid Coxs River	Mid Shoalhaven River	Mongarlowe River	Mulwaree River	Nattai River	Prospect Reservoir	Reedy Creek	Upper Coxs River	Upper Nepean River	Upper Shoalhaven River	Upper Wollondilly River	Werri Berri Creek	Wingecarribee River	Wollondily River	Woronora River
July 2010 - June 2013	Sites Sampled		7	1	24	3	1	4		4	1	2	1			1	7	16	1	2		1	2	1
	Native		17	2	9	1	3	6		2	2	5	0			2	3	13	2	3		2	4	1
	Introduced		4	0	2	1	2	2		3	1	3	2			0	4	2	2	3		1	2	0
	Species richness		21	2	11	2	5	8		5	3	8	2			2	7	15	4	6		3	6	1
July 2013 - June 2016	Sites Sampled				7																			
	Native				5																			
	Introduced				2																			
	Species richness				7																			
July 2016 - June 2019	Sites Sampled		2		28		2		8	3							1	7			1	4	2	
	Native		2		9		4		4	2							1	4			4	5	2	
	Introduced		0		2		3		0	0							0	0			0	0	0	
	Species richness		2		11		7		4	2							1	4			4	5	2	

14.6 Long-term results

Previous audits have described the composition of native species versus introduced species using surveys primarily conducted by DPI Fisheries. Due to the various survey methods, locations and research intent, comparison of sites, waterbodies or sub-catchments does not necessarily reflect actual change in condition. Table 26 lists the number of native and introduced fish species collected during each survey period per sub-catchment. Of note is the variable number of sites sampled over time and between sub-catchments. Using data from 2005 onwards, results from each audit period is plotted in Figure 41 as a logarithmic trendline of number of sites against native species richness. The long-term trend shows that in any given audit period:

- the dominant cluster of sampling events produced less than eight native species
- sub-catchments with more than eight native species are Bungonia Creek, Kangaroo River, Lake Burragorang and Upper Nepean River
- there a few catchments with more than 10 sampling sites
- there is a positive correlation between sampling effort (number of sites) and number of native species (richness).

Missing from this analysis are details on the survey method, such as:

- number of electrofishing 'shots' (e.g. 10 minutes at one site versus 15 x 5 minute shots at a sampling site will collect a different composition)
- diversity of methods (e.g. traps only versus a site with a mix of methods including electrofishing, fyke nets, gill nets and unbaited traps)
- season or flow (specific programs investigating success of fish ladders)
- purpose (targeted threatened species versus overall composition).

An example may be Bungonia Creek in the 2013 audit, where a low site sample number produced the greatest species richness, which is inverse to the overall trend. Sampling effort within each site may have been greater, by covering a range of habitats using different techniques and for greater length of time. Such information is not presented in any audit, so comparing any individual site or sub-catchment over time requires further context to draw a meaningful conclusion.

14.7 Fish passage

Structures such as dams, weirs and road crossings can prevent or inhibit fish passage and the cumulative effect of barriers to fish passage has been identified as a Key Threatening Process to the continuing survival of several species of native fish. In addition to the dams and weirs operated by WaterNSW for water supply purposes, a number of weirs in the Catchment are privately managed for irrigation or amenity. NSW DPI is mapping and assessing barriers to fish passage across NSW with the aim to better understand and improve fish habitat.

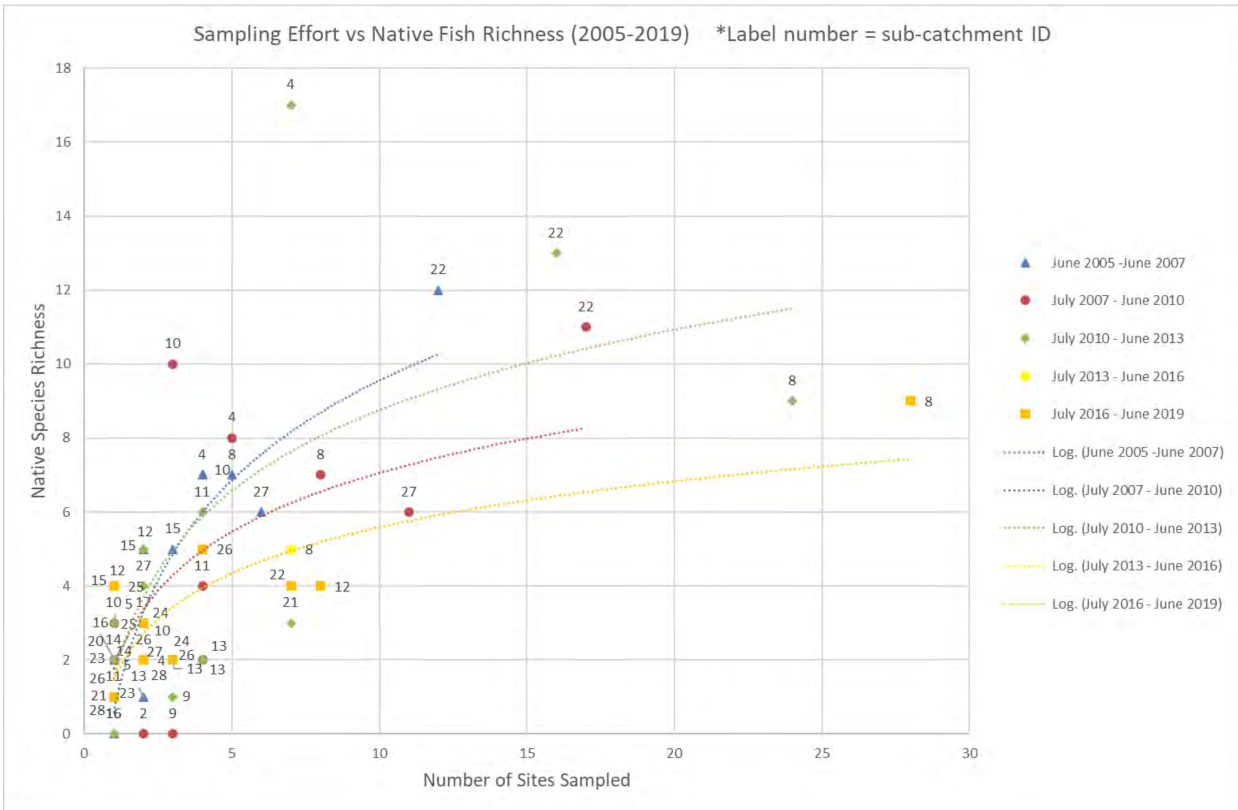


Figure 41: Correlation analysis of number of sampling sites with native species richness (2005-2019)

Sub-catchment ID: 1 Back & Round Mountain Creeks, 2 Boro Creek, 3 Braidwood, 4 Bungonia Creek, 5 Endrick River, 6 Grose River - Blue Mts Catchments, 7 Jerrabattagulla Creek, 8 Kangaroo River, 9 Kowmung River, 10 Lake Burragorang, 11 Little River, 12 Lower Coxs River, 13 Mid Coxs River, 14 Mid Shoalhaven River, 15 Mongarlowe River, 16 Mulwaree River, 17 Nattai River, 18 Nerrimunga River, 19 Prospect Reservoir, 20 Reedy Creek, 21 Upper Coxs River, 22 Upper Nepean River, 23 Upper Shoalhaven River, 24 Upper Wollondilly River, 25 Werri Berri Creek, 26 Wingecarribee River, 27 Wollondilly River, 28 Woronora River.

14.8 Conclusion

Lack of comparable methods and evenly distributed data across the audit periods means that it is not possible to accurately determine the state or trends of populations of threatened fish species, fish communities or diversity of fish species. In its current form, surveys by DPI and others serve a purpose for individual study requirements but cannot be simply scaled-up to inform the health of the whole Catchment. To provide more information about the numbers of species and composition of native/introduced species at each site, a fish monitoring program that is integrated over the entire Catchment, using comparable methods and sampling effort per site would be required. To achieve this, a widespread catchment survey would be designed and implemented by DPI Fisheries specifically for the audit. In lieu of such a resource-intensive program, alternative analysis would be needed for future audits using a subset of available data during and across audit periods, including:

- presence of fish species in waterbodies previously uninhabited by those species (e.g. migration of native species across a catchment; new exotic species entering a waterbody)
- loss of native fish species in waterbodies previously inhabited by those species (e.g. disappearance of a threatened species from a known location)
- age class at representative sites using representative species (e.g. species length and/or weight to document life cycle success).

15. Macroinvertebrates

15.1 Definition and context

Aquatic macroinvertebrates are small aquatic organisms, mostly insects, that live in creeks and rivers, mainly on the stream bed. They perform several ecological functions, such as processing organic matter, and making nutrients and energy available for other organisms in river food webs (such as fish, birds, lizards and platypus). Aquatic ecosystems mostly have abundant macroinvertebrates present that represent complex assemblages of different species and higher groupings (genera, families and orders).

Aquatic macroinvertebrates are widely used for measuring the ecological dimensions of water quality and biological health as they are generally highly responsive to water pollution, impaired water quality and habitat quality (Rosenberg and Resh, 1993; Cairns and Pratt, 1993). Application of macroinvertebrate surveys are commonly used for monitoring human activities such as urban development (Walsh, et al., 2001), sewage (Wright, et al., 1995) and water pollution from mining (Wright and Ryan, 2016).

Macroinvertebrate data is often regarded as being complementary to water chemistry data (ANZECC 2000). Whilst water chemistry represents a series of 'snap-shots' of water quality, macroinvertebrates represent a cumulative measure of water quality and habitat conditions over their life cycles that range from weeks to years (Cairns and Pratt, 1993).

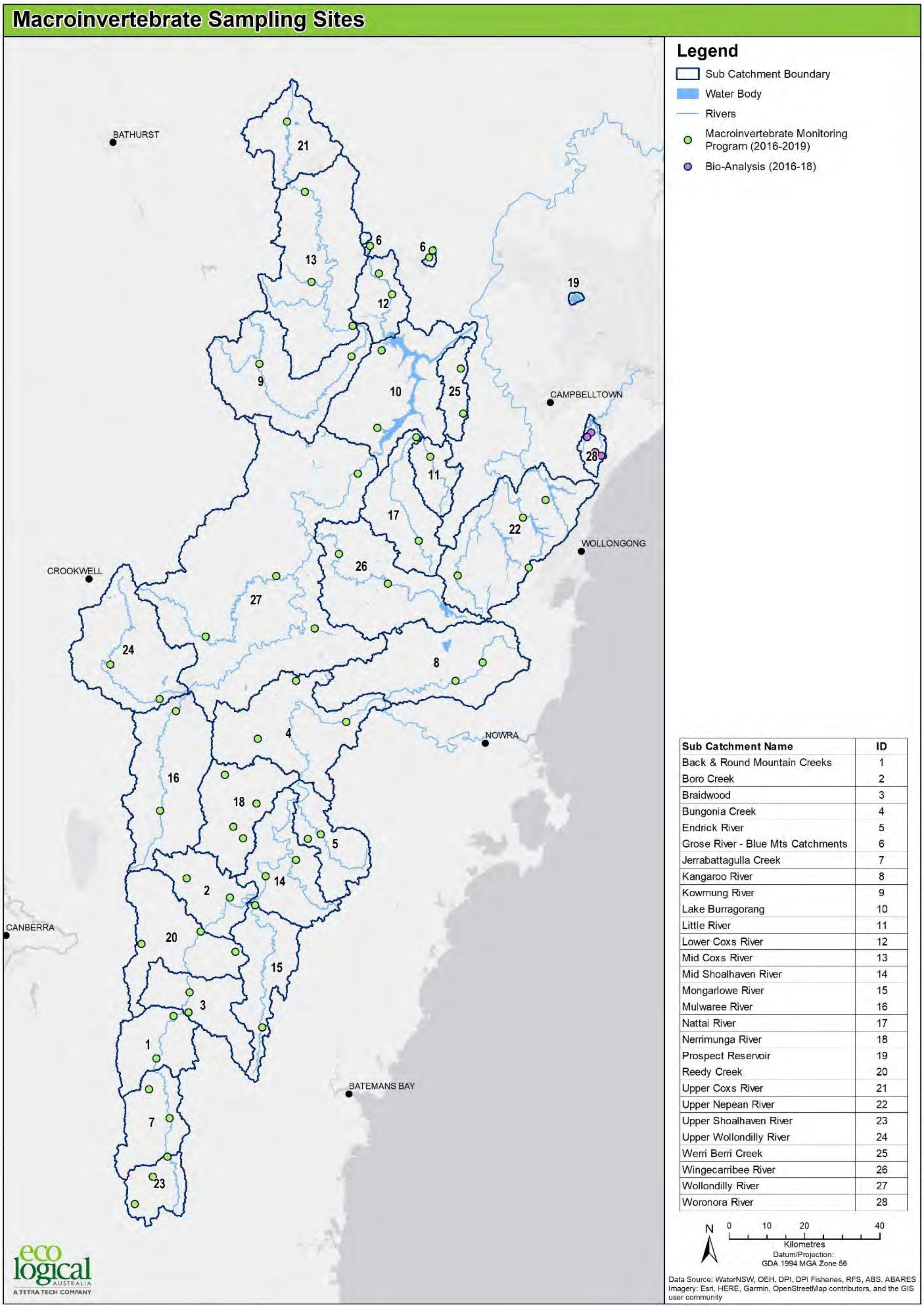
15.2 Data and methods

The AUSRIVAS (Australian River Assessment System) is a widely used Australian methodology for conducting sampling, assessment and reporting of aquatic macroinvertebrates (ANZECC 2000). It compares actual (observed) macroinvertebrate results collected from sampling sites with predicted results (expected) modelled from undisturbed regional reference sites (Turak and Waddel, 2000). The AUSRIVAS ratio of observed to expected macroinvertebrates is used to classify the samples into a number of results bands (Table 27). This varies from Band X and Band A that represent healthy macroinvertebrate assemblages, through Bands B, C and D that represent moderate to severe biological impairment, respectively. The cause of the impairment is not revealed, however, and can be due to water pollution or to disturbance of river habitats.

The Macroinvertebrate Monitoring Program (MMP) for WaterNSW collected 362 samples of macroinvertebrates during the current audit period and applied an AUSRIVAS Band to 306 of those. Sampling was conducted during spring 2016 (n = 68), 2017 (n = 121) and 2018 (n = 117) in 27 of the 28 sub-catchments. Other macroinvertebrate sampling data were sourced from publicly accessible mine monitoring reports, which in this period only included the Woronora River sub-catchment. A total of 439 samples from the data available to the auditor were relevant to the analysis.

Table 27: AUSRIVAS criteria applied in this audit

Band Label	Band Name	Comments
Band X	More biologically diverse than reference sites	More families found than expected. Indicative of a potential biodiversity hot-spot.
Band A	Reference condition	Most or all of the expected families found. Indicative that water quality and/or habitat condition is roughly equivalent to reference sites.
Band B	Significantly impacted	Fewer families than expected. Potential impact on water quality and/or habitat, or both.
Band C	Severely impacted	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantial water quality and/or habitat quality.
Band D	Extremely impacted	Few of the expected families remain. Extremely poor water quality and /or habitat quality.
OEM	Outside experience of model	



Sub Catchment Name	ID
Back & Round Mountain Creeks	1
Boro Creek	2
Braidwood	3
Bungonia Creek	4
Endrick River	5
Grose River - Blue Mts Catchments	6
Jerrabattagulla Creek	7
Kangaroo River	8
Kowmung River	9
Lake Burragorang	10
Little River	11
Lower Coxs River	12
Mid Coxs River	13
Mid Shoalhaven River	14
Mongarlowe River	15
Mulwaree River	16
Nattai River	17
Nerrimunga River	18
Prospect Reservoir	19
Reedy Creek	20
Upper Coxs River	21
Upper Nepean River	22
Upper Shoalhaven River	23
Upper Wollondilly River	24
Werri Berri Creek	25
Wingecarribee River	26
Wollondilly River	27
Woronora River	28

Figure 42: Macroinvertebrate sample sites

15.3 Findings

The Lower Coxs River sub-catchment was again the highest scoring sub-catchment (Bands X and A - best condition), followed by Upper Wollondilly River, Mid Coxs River, Kowmung River, Grose River Blue Mountains Catchments, Braidwood and Back & Round Mountain Creeks (Table 28). Sub-catchments with a notable proportion of lower scores (Bands C and D – poorer condition) and few high scores were Woronora River, Nerrimunga River, Little River and Mid Shoalhaven River. No sites were surveyed in Prospect Reservoir sub-catchment. All sites in the Upper Coxs River fell outside the experience of the model (i.e. the environmental/habitat variables found at these sites can't be confidently matched to an expected reference condition used in the AUSRIVAS model).

Results from the previous audit period (2013-2016) found that 50% of macroinvertebrate samples collected were biologically similar or more diverse than reference condition (Bands X and A). The remaining 50% of samples in the previous audit were indicative of significant impairment (Band B) or severe ecological impact (Band C) or extreme ecological impact (Band D) (Figure 43). Those 2013-2016 results were similar to, but slightly worse than historic records prior to 2013. Results from the current audit period (2016-2019) reveal a marked shift from the long-term trend. From the 439 samples, 38% were biologically similar or more diverse than reference condition (Bands X and A). A total of 59% of samples were indicative of significant impairment (Band B) or severe ecological impact (Band C) or extreme ecological impact (Band D); and 3% fell outside of the model's capabilities (Figure 43).

The concentration of sampling in the Woronora River (n = 145) provides a good representation of those sites, but imbalances the whole-of-Catchment overview. In comparison, within each of the 27 sub-catchments sampled in the MMP, between four and 24 AUSRIVAS Bands were applied during the audit period (average of 11.3 sites per sub-catchment, Table 28). In the previous audit, the MMP collected at least 12 samples per sub-catchment (core and roaming sites), which was an intentional reduction from previous years in order to focus on core monitoring sites, rather than various roaming sites that do not provide a good representation of change (WaterNSW 2018). For the current audit, the heavy weighting of mine-related sampling (n = 136) does not provide a means to review river health across the Catchment as the majority of Woronora River samples fell into impact Bands B and C. The Woronora sub-catchment features river habitat that is predominantly bedrock, which naturally has a lower diversity of macroinvertebrates, and therefore a lower AUSRIVAS score than the model is designed for. Previous audits did not include macroinvertebrate data from mining reports. If those mine monitoring results were excluded from this analysis for the purpose of a whole-of-Catchment overview, the proportion of bands found in the MMP is more in line with previous years (i.e. 50% Bands X and A; 46% Bands B, C and D; and the remainder outside of the model's experience).

In 2018, WaterNSW conducted a review of the MMP to provide a long-term analysis of macroinvertebrate data and associated environmental variables (WaterNSW 2018). Assessed over the 2002-2016 period, the Sydney drinking water sub-catchments all fell within reference and below reference AUSRIVAS band grades. Sub-catchments with ≥50% of sites in the highest quartile for all indices included the Kowmung, Lower Coxs, Mid Coxs and Upper Shoalhaven sub-catchments. The Nerrimunga sub-catchment had ≥50% of sites ranked in the lowest quartile for all measured indices. Trends in macroinvertebrate health were largely site-dependent. From 2002-2016, seven sites showed an improvement and 12 sites showed a decline in at least one macroinvertebrate index. A decline in multiple macroinvertebrate indices was found at five sites: Wollondilly River at Goonagulla (MMP27), Titringo Creek at High Forest (MMP11), Shoalhaven River at Hillview (E861), Mongarlowe River at Monga (R13) and Nerrimunga River at Minshull Trig (E8361).

Macroinvertebrate community structure was more strongly associated with physical habitat variables than with stream water physical and chemical variables. A land use gradient was apparent in Warragamba catchment, with agricultural and urban samples showing a stronger association with higher silt, conductivity and turbidity readings. Tallowa samples did not separate clearly by land use, potentially reflecting the higher heterogeneity of land use in the Tallowa catchment. These findings illustrate the importance of accounting for physical habitat attributes in future sampling designs and suggest that a sufficient environmental gradient exists in the Warragamba catchment to distinguish macroinvertebrate communities in agricultural and vegetated sites. A more sensitive land use classification method may be required to separate agriculturally impacted and reference sites in the Tallowa catchment.

Power analysis showed that the current sampling design provides an adequate level of site replication for the Boro, Braidwood, Lower Coxs, Nerrimunga and Wingecarribee sub-catchments. Additional sites are required in the remaining sub-catchments to confidently detect a change of one AUSRIVAS band grade. To meet this requirement would require increasing the total number of core sites from 69 to 105.

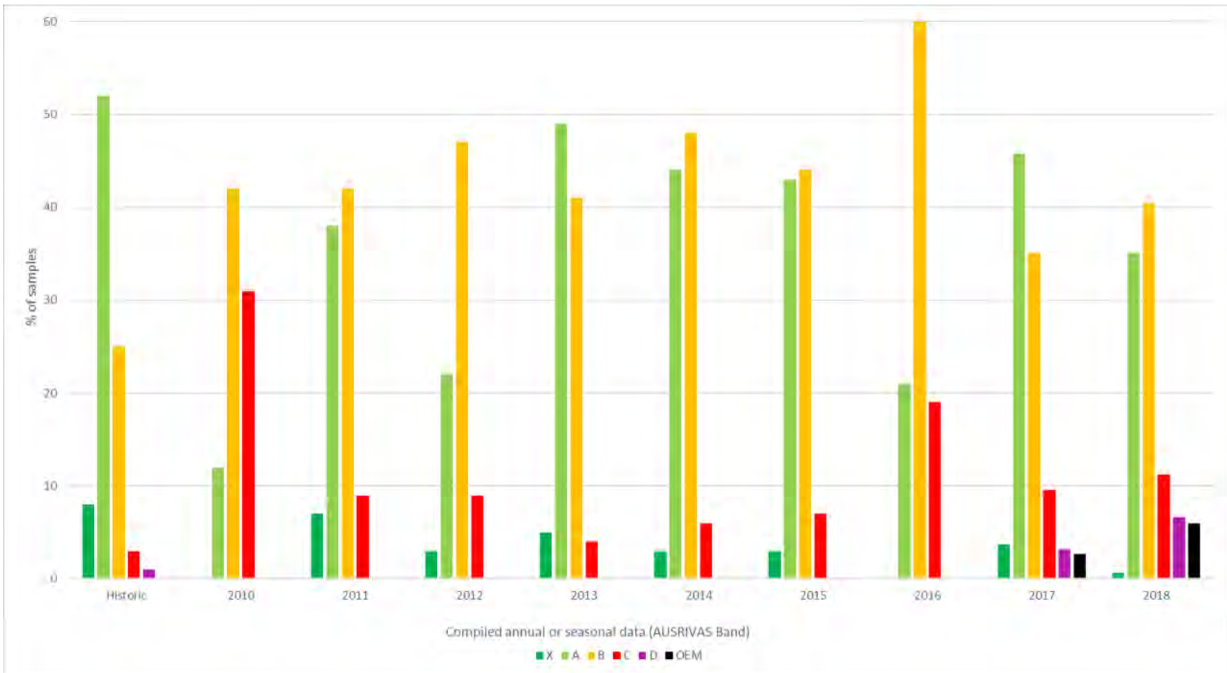


Figure 43: Average annual AUSRIVAS categories for macroinvertebrates across all catchment sites

Table 28: Percentage of macroinvertebrate samples collected in 2016-19

Sub-catchment	Number of samples	% of Band X	% of Band A	% of Band B	% of Band C	% of Band D	% of OEM
Back & Round Mountain Creeks	12	8	67	17	8	0	0
Boro Creek	12	0	33	58	8	0	0
Braidwood	12	8	67	25	0	0	0
Bungonia Creek	16	0	31	56	13	0	0
Endrick River	12	0	42	17	8	0	33
Grose River - Blue Mts Catchments	10	10	30	40	10	10	0
Jerrabattagulla Creek	10	0	60	40	0	0	0
Kangaroo River	12	0	58	42	0	0	0
Kowmung River	8	13	50	38	0	0	0
Lake Burragorang	4	0	50	50	0	0	0
Little River	4	0	25	50	25	0	0
Lower Coxs River	8	13	88	0	0	0	0
Mid Coxs River	12	8	75	8	0	0	8
Mid Shoalhaven River	10	0	30	50	20	0	0
Mongarlowe River	12	0	58	42	0	0	0
Mulwaree River	8	0	50	50	0	0	0
Nattai River	8	0	63	25	13	0	0
Nerrimunga River	24	0	13	54	25	0	8
Prospect Reservoir	0	0	0	0	0	0	0
Reedy Creek	16	0	38	63	0	0	0
Upper Coxs River	4	0	0	0	0	0	100
Upper Nepean River	24	0	50	33	17	0	0
Upper Shoalhaven River	18	6	67	22	6	0	0
Upper Wollondilly River	8	13	63	25	0	0	0
Werri Berri Creek	6	0	33	67	0	0	0
Wingecarribee River	8	0	38	38	0	0	25
Wollondilly River	16	0	63	31	0	0	6
Woronora River	145	0	13	54	23	10	0
% of Total		**2%**	**36%**	**43%**	**12%**	**4%**	**3%**
Total number of sites	**439**	**8**	**160**	**187**	**54**	**16**	**14**

OEM = Outside Experience of Model

15.4 Conclusion

Macroinvertebrate composition showed a decline in river health in 2016 compared to the previous audit and longer-term data but improved during 2017 and 2018. Severe drought during the audit period may have contributed to the lower AUSRIVAS scores relative to previous periods. The trend may also be an artefact of different sampling effort, with a marked difference between 2016 (n = 68), 2017 (n = 121) and 2018 (n = 117). This audit period is the first since pre-2010 where some individual sites received the poorest AUSRIVAS Band D – Extremely Impacted (Woronora River and Grose River - Blue Mountains Catchments). The Lower Coxs River sub-catchment in the Blue Mountains was again the highest scoring (best condition) sub-catchment.

Detailed investigation of each site would be needed to determine the influence of factors such as macroinvertebrate habitat availability and condition. A review of the long-term data used in the MMP concluded that additional core sampling sites are required in most sub-catchments in order to detect change in river condition over time.

16. Native vegetation

16.1 Definition and context

The NSW *Biodiversity Conservation Act 2016* (BC Act) and *Local Land Services Act 2013* (LLS Act) define native vegetation as any trees, shrubs, understorey plants, groundcovers established in New South Wales before European settlement. It includes wetlands but does not extend to marine vegetation (being mangroves, seagrasses or any other species of plant that at any time in its lifecycle must inhabit water other than fresh water).

The extent and condition of native vegetation across the Catchment affects ecosystem services such as water quality and availability by helping to stabilise soils, and filter nutrients and pathogens. Widespread healthy native vegetation within a catchment supports good quality surface water and groundwater, and biodiversity. An increase in the extent of native vegetation is therefore considered to be an improving trend, whereas loss of native vegetation indicates a worsening trend.

In 2013, OEH prepared a *Native Vegetation Information Strategy 2014-2018* that defines the Vision for NSW as 'conservation, planning and regulation are enabled through easy access to consistent, relevant and scientifically robust native vegetation information'. The strategy identifies eight objectives for the production, maintenance and delivery of native vegetation information for NSW. OEH advised that an updated native vegetation spatial database was being developed.

16.2 Data

Previous audits in 2013 and 2016 presented a Statewide Landcover and Trees Survey (SLATS) map, supplied by the NSW Office of Environment and Heritage (OEH). The assessment of 'woody vegetation' in these maps includes both native and non-native vegetation, so it does not directly relate to the gazetted native vegetation indicator required by the audit.

The DPIE (formally OEH) supplied updates of the SLATS map for the current audit, showing the location and extent of woody vegetation clearing for the 2016-2017 and 2017-2018 periods. Mapping for the 2018-2019 period was not yet available. Information about native vegetation within the Catchment was available from the following publicly accessible DPIE databases:

- The Bionet database comprises data collected by ecologists undertaking surveys in accordance with a scientific licence under Part 2 (Division 3) of the BC Act. This data relates to the type and location of species rather than the type, condition or extent of native vegetation communities.
- The Southeast NSW Native Vegetation Classification and Mapping (SCIVI) classifies, describes and maps native vegetation types at 1:100,000 interpretation scale. The vegetation classification is based on a compilation of approximately 8,500 full-floristic field survey sites from previous studies. This dataset was last updated by OEH in 2011.
- Sydney Metro v3.1 contains mapping of the native vegetation communities of the Sydney Metropolitan area. Vegetation communities was derived from the analysis of 2200 floristic sites for the study area, and mapped using a combination of detailed image interpretation, relationships between sample sites and abiotic environmental variables. This dataset was last updated by OEH in 2016.

- State Vegetation Type Map (SVTM): Central Tablelands Region Version 1.0. was developed under the OEH State Vegetation Map project. It contains a map of NSW's native vegetation types classified according to Formation, Classes and Plant Community Types (PCTs). It is derived from spatial models, visual interpretation and existing map products. This dataset was last updated by DPIE in May 2019.
  The map developed under the SVTM program presents a single surface raster that combines the best available information on vegetation extent for NSW. This map is referred to as the NSW Native Vegetation Extent 5m Raster v1.2. The surface is built on the 2011 5m NSW Woody Vegetation Extent (Fisher et al., 2016), with updates up to 2018 (Fisher et al., 2017), with the addition of native grasslands, woodlands and wetlands from the visual interpretation of high-resolution imagery (OEH, 2017). The surface also delineates softwood forest plantations and water bodies.
- South East Local Land Services Biometric vegetation map, 2014 VIS_ID 4211 was developed by Eco Logical Australia on behalf of the South East LLS. The map is compiled from a combination of existing available data. Only the footprint is publicly available.

16.3 Native vegetation extent

The extent of native vegetation across the Catchment is shown in Figure 44. This map is based on data from the NSW Native Vegetation Extent 5m Raster v1.2. The formation of vegetation in the NSW Native Vegetation Extent 5m Raster v1.2 was determined from the following vegetation mapping sources*:

- SVTM: Central Tablelands Region v1.0
- SCIVI v9
- South East Local Land Services Biometric vegetation map, 2014*
- Sydney Metro v3.1
- Wollondilly 2011

*In cases where a vegetation formation description was not available for vegetation mapped in the NSW, Native Vegetation Extent 5m Raster v1.2, the 'Vegcover' type followed by '(unsubscribed)' were used to label this vegetation.

It is important to note that:

- The data does not give an indication of what portion of the 'native vegetation' was exotic species.
- The data presented in this Audit report includes candidate native grassland. This was not included/available for the previous 2013-2016 Audit.

The area of native vegetation in each sub-catchment is in Table 29. This indicates that:

- the Enrick River, Grose River, Lake Burragorang, Little River, Lower Coxs River, Nattai River, Upper Nepean River, Upper Shoalhaven River and Woronora River sub-catchments had greater than 90% of their area with native vegetation
- the Mulwaree River and Upper Wollondilly River sub-catchments had relatively little (<40%) native vegetation cover as a proportion of the sub-catchment area. This is a greater percentage compared with the previous audit in which they were estimated to have <20% native vegetation cover.

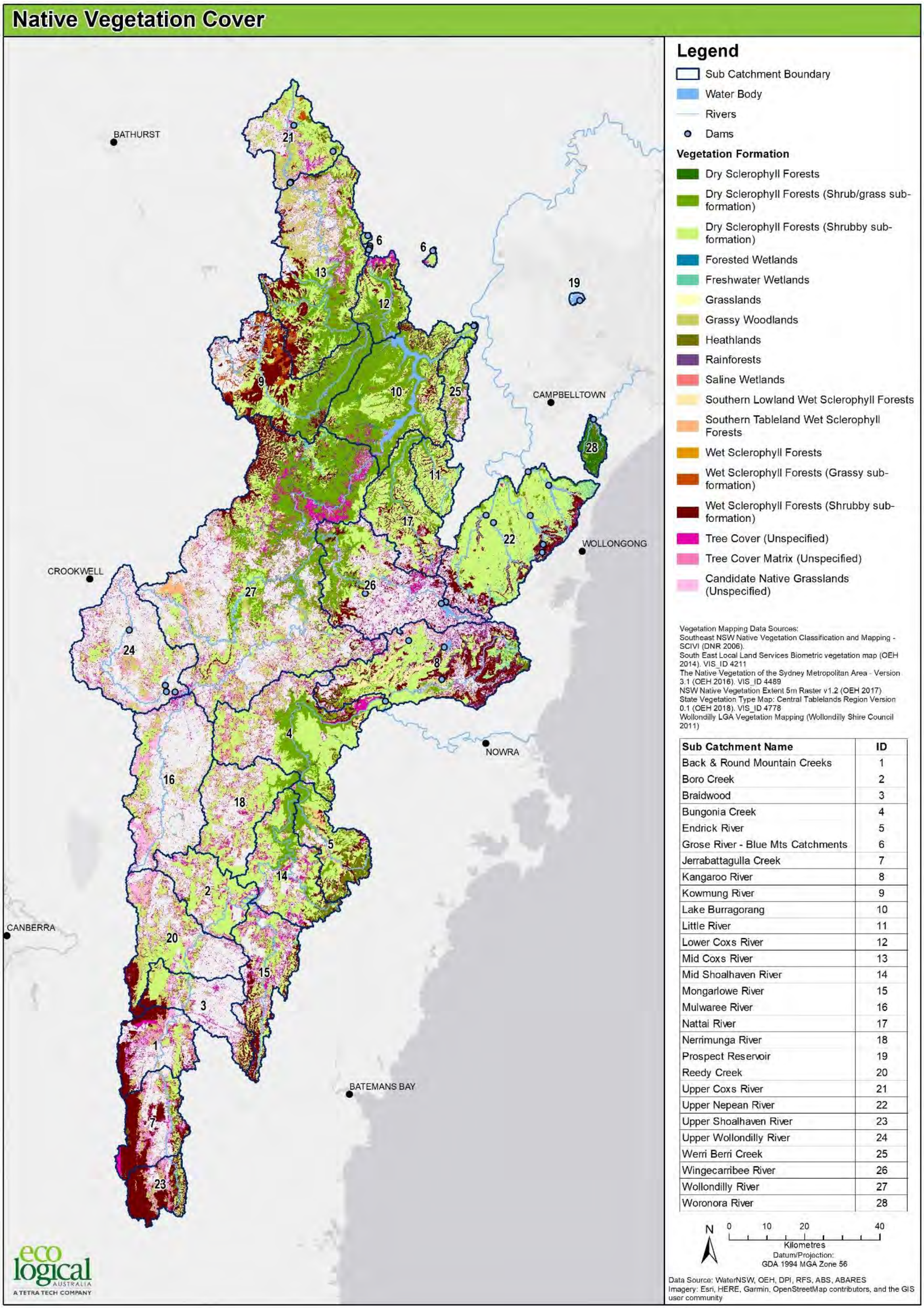


Figure 44: Native vegetation cover (DPIE 2019)

Table 29: Native vegetation extent within each sub-catchment

ID	Sub-catchment	Area of native vegetation (ha)	Native vegetation extent	
			% of sub-catchment	% of whole catchment
1	Back & Round Mountain Creeks	22,577	65	1
2	Boro Creek	25,165	71	2
3	Braidwood	17,992	48	1
4	Bungonia Creek	66,396	83	4
5	Endrick River	31,834	94	2
6	Grose River - Blue Mts Catchments	2,063	97	<1
7	Jerrabattagulla Creek	27,087	75	2
8	Kangaroo River	69,230	80	4
9	Kowmung River	64,231	83	4
10	Lake Burragorang	74,044	92	5
11	Little River	18,130	99	1
12	Lower Coxs River	24,061	98	2
13	Mid Coxs River	88,536	83	6
14	Mid Shoalhaven River	42,232	85	3
15	Mongarlowe River	33,800	79	2
16	Mulwaree River	27,808	35	2
17	Nattai River	39,938	90	3
18	Nerrimunga River	32,102	66	2
19	Reedy Creek	34,190	59	2
20	Upper Coxs River	27,257	71	2
21	Upper Nepean River	81,097	91	5
22	Upper Shoalhaven River	20,317	93	1
23	Upper Wollondilly River	23,582	32	2
24	Werri Berri Creek	12,398	75	1
25	Wingecarribee River	41,113	54	3
26	Wollondilly River	181,540	67	12
27	Woronora River	7,027	95	<1

16.4 Change in native vegetation extent

Temporary or permanent changes to the extent, condition or type of vegetation typically result from one or more of the following:

- Natural cycles of native vegetation death and regeneration
- Bushfire or controlled fire (refer to Chapter 13 for further details)
- Natural disasters such as flood, drought or windstorm
- Managed regeneration, revegetation and rehabilitation in accordance with BioBanking offsets, Property Vegetation Plans (PVPs), Vegetation Management Plans (VMPs) etc.
- Anthropogenic climate change* directly impacting vegetation through changes to temperatures and rainfall, and intensifying threats such as weeds, bushfire and disease
- Clearing native vegetation* by illegal activities or approved land uses (e.g. infrastructure, forestry, mining, urban/rural development, agriculture)
- Dieback / disease* - exotic fungal infections (such as Phytophthora and Myrtle rust), viruses and other pathogens which can weaken and kill native vegetation species at a local or landscape scale
- Weed invasion* and control – weeds out-compete native vegetation, and aquatic weeds in particular can adversely impact water quality

*These are listed as 'key threatening processes' under Schedule 4 of the NSW *Biodiversity Conservation Act 2016* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.*

The NSW *Native Vegetation Act 2003* (*NV Act*) and *Native Regulation 2013* were the main pieces of legislation for regulating the clearing of native vegetation on all land in NSW except for national parks and other conservation areas, state forests and reserves, and urban areas prior to 25 August 2017. The legislation aimed to prevent broadscale clearing unless it improved or maintained environmental outcomes. This legislation and associated regulations were repealed in November 2016.

Provisions regulating the clearing of native vegetation are now in the following Acts, Policies and Regulations:

- Part 5A of the *Local Land Services Act 2013* (*LLS Act*) regulates the clearing of native vegetation in rural areas. This is generally administered by LLS, however DPIE has responsibility for native vegetation mapping and compliance under that Part of the Act.
- Part 5C of the *Forestry Act 2012* regulates the clearing of native vegetation in rural areas, in respect of private native forestry. This is generally administered by the EPA and provides an interim regulatory regime until the current forestry reform is completed.
- The *State Environmental Planning Policy (Vegetation in Non-Rural Areas) 2017* deals with the clearing of native vegetation in urban, peri-urban and environmental areas. This is administered by the Department of Planning and Environment.
- The *Biodiversity Conservation Act 2016* (*BC Act*) and the *Biodiversity Conservation (Savings and Transitional) Regulation 2017* regulates impacts to biodiversity and threatened species. This is administered by DPIE.

No data is available to show changes in native vegetation for the Catchment within the audit period 2016-2019. An alternative approach is given here which refers to the woody vegetation mapping (SLATS) compiled by DPIE using data from 2016-2018 (Figure 45).

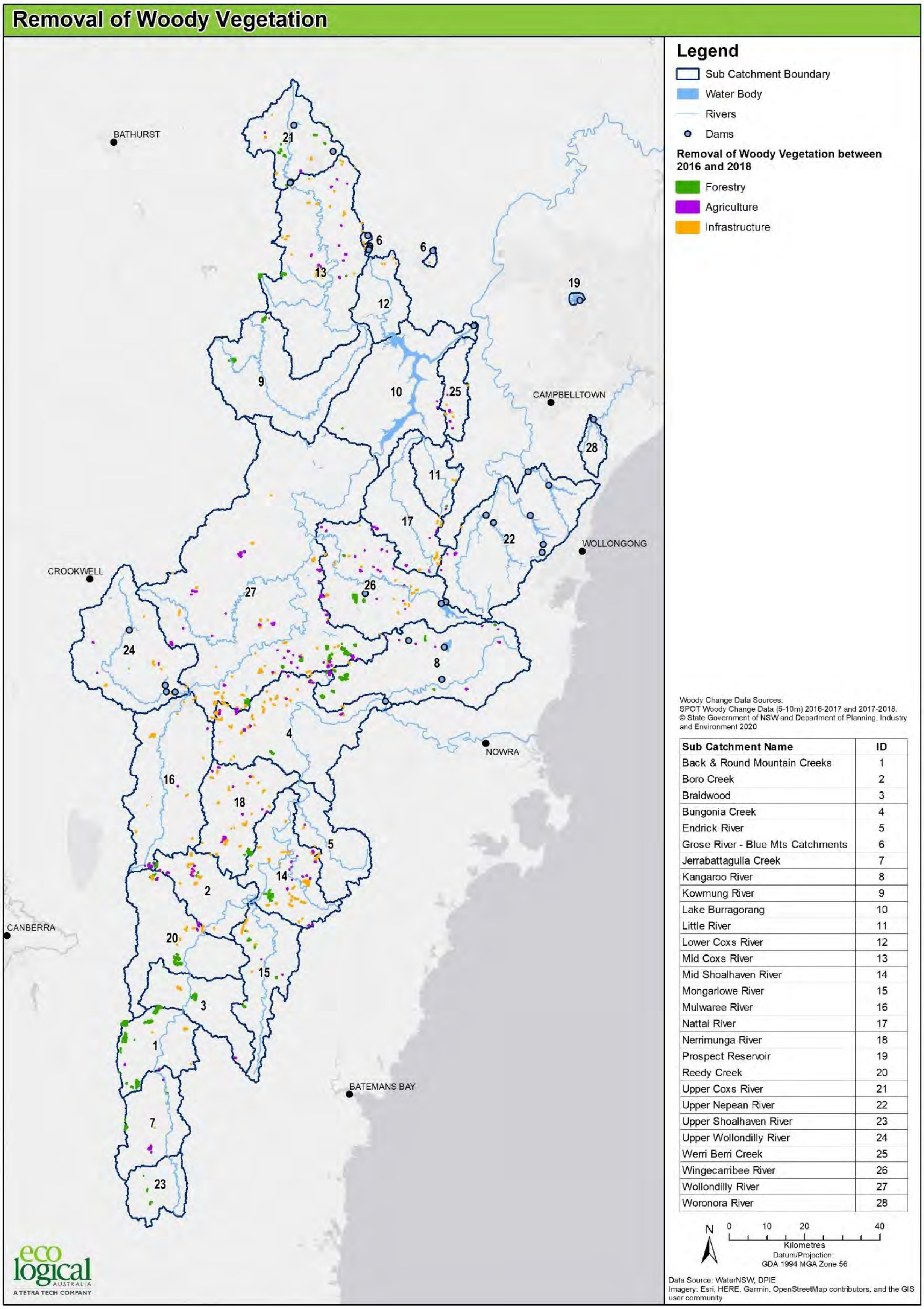


Figure 45: Woody vegetation cover lost to land uses in the Catchment 2016-2018 (DPIE 2018)

It is acknowledged that this may misrepresent changes in native vegetation extent but is presented as the best available sources of information within the audit period. Table 30 shows that forestry had the greatest impact on woody vegetation cover in 2016-2018. Fire has not been included in this section, as it does not usually result in a permanent removal of woody vegetation. However, while vegetation may grow back following fire (so the loss of cover would be temporary), the ecological community may change, especially following frequent and/or intense fires.

Longer term changes in woody vegetation since the previous audit period are identified in Table 30 based on SLATS data. This does not show the impact that fires had on vegetation in the Catchment.

Table 30: Removal of woody vegetation (SLATS) 2014-2018

Cause of removal	2014/15 (ha)	2015/16 (ha)	2016/17 (ha)	2017/18 (ha)
Agriculture	44.46	138.04	0.00	271.89
Forestry	499.41	688.27	451.02	715.49
Infrastructure	61.15	218.93	0.00	279.73
Natural physical process	0.01	0.00	0.00	0.00
Total	**605.03**	**1653.20**	**451.02**	**1559.90**

16.5 Native vegetation condition

The condition of native vegetation was affected by the proportion of weeds present. While data is not available regarding the condition of native vegetation across the Catchment, this would be affected by the presence of weeds and how they were managed. Exotic species data is available from the following sources:

- Bionet Atlas and the Atlas of Living Australia (ALA). This information is for individual species. The surveys from which the data has been sourced have not been sampled across the entire catchment area or for the purpose of determining the extent or distribution of exotic species. The information therefore does not provide a representative picture of weeds in the Catchment.
- NPWS Pest and Weeds Information System (PWIS). Not accessible to the public.
- Data from the LLS/LGAs that is collected via the Sydney Weeds App (https://sydneyweeds.org.au/publications-and-apps/)
- Correspondence with Benjamin Russell (NPWS Pests and Weeds Manager, DPIE) and Hillary Cherry (NPWS Senior Weeds Officer, DPIE). 12/03/2020

The *Commonwealth's Intergovernmental Agreement on Biosecurity (2012)* and NSW weed reforms resulted in changes to the framework for regional weed management during the current audit period. Overarching state legislation includes NSW Biosecurity Strategy 2013 – 2021, NSW Invasive Species Plan 2018 – 2021 and NSW *Biosecurity Act 2015.*

Regional Strategic Weed Management Plans (RSWMP) are developed through the Regional Weeds Committee every five years and provide regional weed management frameworks as part of overarching state legislation. RSWMPs relevant to the Sydney Catchment audit are those for Central Tablelands (2017 – 2022), Greater Sydney (2017 – 2022 (revised September 2019)) and South East (2017 – 2022).

Weed control, bush regeneration and revegetation activities within the Catchment are undertaken by a variety of natural resource management groups. These include Bushcare and Landcare groups, with councils and LLS supporting community volunteers.

Revegetation programs that generally rely on landholders to control weeds include the Rural Landscape Program and Rivers of Carbon – Source Water Linkages. The Rural Landscapes Program is an initiative between South East LLS and WaterNSW which provides financial assistance to land managers aimed at improving water quality within targeted areas. Similarly, Rivers of Carbon – Source Water Linkages is a Rivers of Carbon and WaterNSW partnership working in conjunction with local landholders and Greening Australia, aimed at protecting and restoring riparian areas and rivers within the catchment. There were 204 properties involved in these projects during the audit period, covering 48,507 ha of the Catchment.

16.6 Conclusion and recommendation

It is acknowledged that DPIE is in the process of updating the native vegetation spatial database in accordance with the *Native Vegetation Information Strategy 2014-2018*. However, lack of data about the extent and / or condition of native vegetation in the Catchment meant that it was not possible to determine if trends were improving or worsening during the current audit period. Up-to-date native vegetation data will be needed for the next catchment audit.

The continuation of revegetation / regeneration programs such as Rivers of Carbon, Bushcare, Landcare and the Rural Landscape Program is supported, as more trees across the landscape assist the hydrological cycle and reduce erosion. Future evaluation of the effectiveness of these programs will rely on good quality data.

17. Riparian vegetation

17.1 Definition and context

The riparian zone is the land adjacent to watercourses that is influenced by the stream and has an influence on the stream. The width of a riparian zone varies depending on soil type, hydrology and topography. Riparian zones are widely acknowledged as important elements of the landscape because they influence the flows of energy and nutrients across the terrestrial and aquatic ecosystems, perform functions including assisting in protecting water quality and bed and bank stability that help to maintain aquatic ecosystems, and provide a range of ecosystem services. The importance of riparian vegetation is detailed in the *Fisheries Management Act 1994* (FM Act), which identifies 'the degradation of native riparian vegetation along New South Wales watercourses' as a key threatening process.

Under the *Water Management Act 2000* (WM Act) and the associated *Guidelines for controlled activities on waterfront land – Riparian corridors* (NRAR 2018), the expected width of the riparian zone is more prescriptive, with set riparian widths required for certain developments on waterfront land. Waterfront land includes the bed and bank of any river, lake or estuary and all land within 40 m of the highest bank of the river, lake or estuary. The prescribed riparian corridor widths are based on a hierarchical system, termed Strahler Stream Order, where small headwater streams have a 10 m riparian corridor on each side, up to the largest streams and watercourses requiring a 40 m zone on each side. The following analysis adopts this classification when summarising riparian land.

17.2 Data

The type of data available for the 2019 audit was limited to broad mapping and assumptions, as well as the same datasets used in the 2016 audit, such as the Riparian Vegetation Extent (RVE) dataset and Hybrid Riparian Native Vegetation Extent (HRNVE) dataset that contributed to the NSW River Condition Index (RCI). These datasets have not been updated since 2010. The NSW River Styles online database was published in 2019, allowing access to data relating to type, geomorphic condition and recovery potential of rivers in NSW, but has limited application in assessing riparian condition or protection. As outlined in Chapter 16 of this report, the area of native vegetation in each sub-catchment has been calculated based on data from DPIE updated to 2018, however it is not possible to determine what percentage of this native vegetation cover exists within riparian zones. As such, only three datasets were available for this audit:

- Strahler stream order mapping and associated riparian buffers
- Riparian buffers in grazing
- Collated information from local councils and LLS on riparian management.

Other data that may include the riparian zone is presented elsewhere in this audit, such as wetlands (Chapter 19), physical form (Chapter 18) and soil (gully) erosion (Chapter 6).

17.3 Strahler stream order mapping and associated riparian buffers

Drainage lines identified on 1:25,000 topographic maps are used by the Natural Resources Access Regulator (NRAR) as a trigger for waterfront land, or at least use that as a starting point for ground validation at a finer scale. Each drainage line has a prescribed Strahler stream order classification between 1 and 11 across NSW. The study area contains 52,948 km of watercourses, comprising:

- 30,467 km of 1st order streams
- 11,044 km of 2nd order
- 5,549 km of 3rd order
- 5,889 km of 4th order and above (Figure 46).

There was 64,153 ha of riparian zone (or potential riparian zone) in the study area according to NRAR's riparian guidelines to quantify the spatial extent of the riparian zone (NRAR 2018). The condition of this defined riparian land would vary dramatically from cleared grazing land to near-pristine forest. It is, however, a reference point for understanding the extent of land valued under the WM Act and FM Act.

NRAR have advised that they have developed a draft Waterfront Land e-tool to assist in the identification of waterfront land, however there is still no way for the public to determine which waterways have vegetation management plans for riparian zones enforced under a Controlled Activity Approval or if a creek has previously been approved for removal (pers comm., NRAR 2019) (e.g. the legislative requirement for works on waterfront land can be removed if the waterway does not meet the definition of a 'river' under the WM Act). Therefore, if a creek is removed it will remain on the Water Management (General) Regulation 2018 Hydroline spatial data. Also, some low-value 'rivers' (usually degraded 1st or 2nd order creeks) may be removed on a case-by-case basis if they are offset elsewhere to retain the net riparian area. As such, there is no measurable way to identify a change in waterfront land since the previous audit.

17.4 Riparian buffers in grazing

Grazing land is extensive within the study area, contrasting with the protected forests that share the landscape. Grazing is predominantly from cattle and sheep, but may also include horses, goats and other hoofed livestock. The impacts of grazing in riparian corridors is well documented, and can occur directly through plant consumption and trampling, or indirectly through effects on nutrient cycling and soil structure. The impacts of livestock on vegetation near water depends on animal physiology, population numbers and the time spent near the water source. Native grazers, such as kangaroos, are efficient water users so are able to spend more time further away from water sources, resulting in less impact on the vegetation around the water (Jones and Vesk, 2016).

Protection of riparian vegetation and waterways is achieved through exclusion fencing or managed stock numbers and rest periods. Fencing waterways has its merits if the riparian zone is also managed for biodiversity and bank stability. Poorly managed riparian zones may lead to an increase in weed invasion, shift in plant composition, degradation of water quality and compromised bed and bank stability in the adjacent waterway. Controlled grazing in these instances may reduce weed infestations and fuel for bushfires. As such, classifying a waterway as either 'protected' or 'unprotected' does not necessarily imply the riparian zone is for better or worse. It does, however, give an indication that the riparian corridor has some form of physical protection, rather than undocumented owner-driven controls (rotational, timed, seasonal or crash grazing) (Jones and Vesk, 2016).

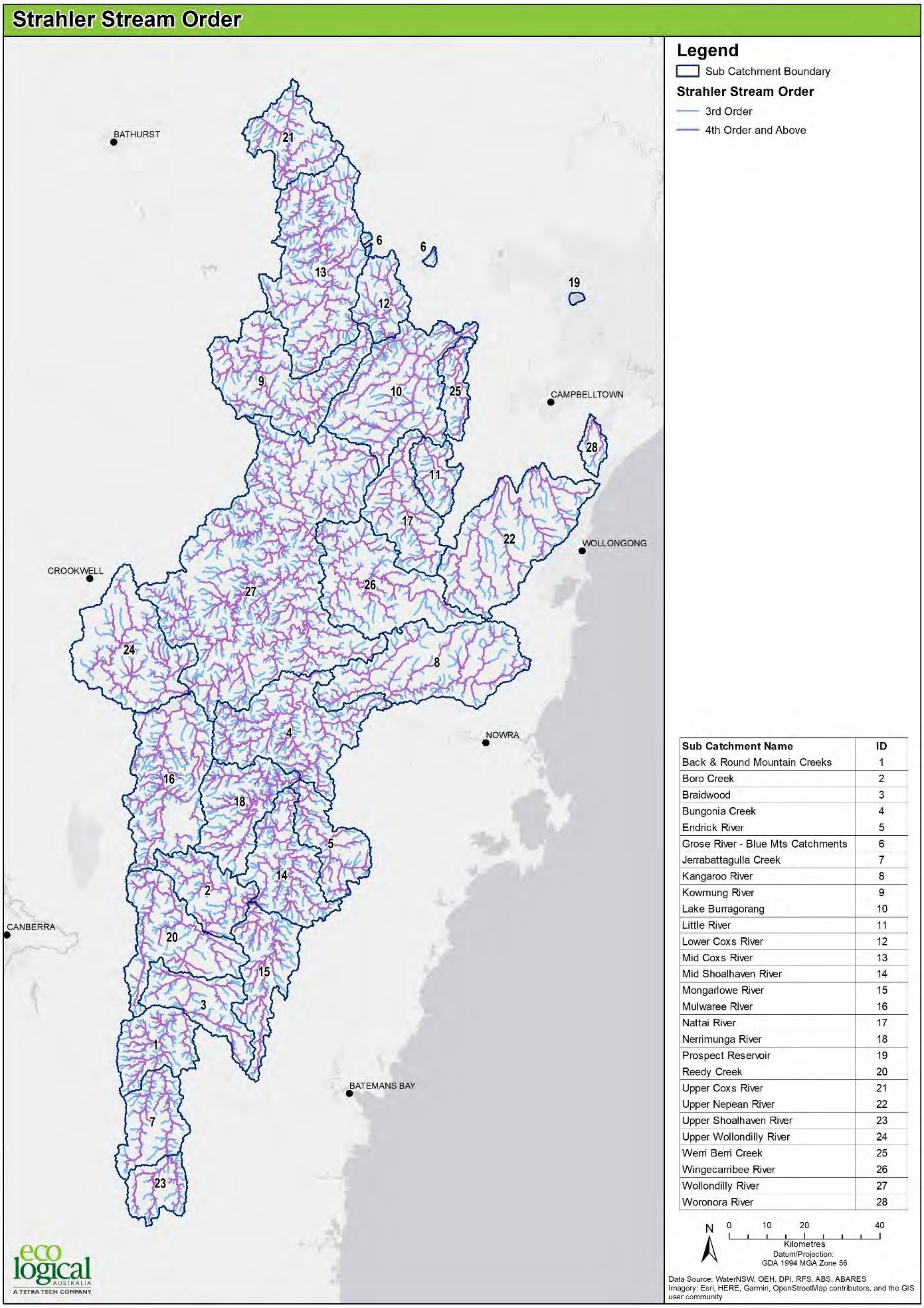


Figure 46: Watercourses in the study area classed by Strahler Stream Order

In 2019, the Australian River Restoration Centre (ARRC), in partnership with WaterNSW, published *Stock & Waterways: A NSW Manager's Guide*, designed to assist farmers in NSW balance the needs of stock and waterway protection while still ensuring their land remains viable for agricultural purposes. The guide outlines the environmental benefits of restricting access for stock to riparian corridors, including improvements to water quality, bank stability and vegetation cover as well as financial benefits such as reducing the amount of stock lost to drowning and the amount of fertile land lost to erosion, salinity and waterlogging (Staton and O'Sullivan, 2019). The guide has been applied as part of projects managed by ARRC's on-ground not for profit organisation, Rivers of Carbon. The Rivers of Carbon: Goulburn District River Linkages project started in 2016 and is working with landowners to protect riparian vegetation by fencing off remnant vegetated riparian corridors and revegetating degraded areas. Funded by the NSW Environmental Trust Bush Connect Program, this project has to date fenced 54 km of riparian corridors and rehabilitated 307 ha of riparian areas, as well as engaged more than 1000 people in community activities (RoC, n.d.).

Riparian improvements have been similarly targeted in the Rural Landscape Program, which is a joint initiative between SE LLS and WaterNSW. Participating landholders are assisted with controlling stock access to waterways using fences, alternative stock watering and stock crossings. Channel and gully erosion controls and revegetation with native species further support improvements to riparian corridors on these properties. Refer to section 2.5.1 for further detail.

Available data on grazing and riparian protection is presented in Figure 47. Of the 19,118 km of waterways identified in grazing country, 15% are 'protected', 47% are 'unprotected' and 38% have 'protection unknown'. Most sub-catchments have some degree of grazing land, except the large areas of native forest. The highest proportion of 'protected' riparian zones across grazing land occurs in sub-catchments Upper Nepean River (54% protected), Kangaroo River (53% protected), Bungonia Creek (36% protected) and Werri Berri Creek (29% protected). Sub-catchments with the highest proportion of 'unprotected' riparian land are Braidwood (87% unprotected), Reedy Creek (63% unprotected), Upper Wollondilly River (60% unprotected) and Kangaroo River (46% unprotected).

No updated data on protection of riparian areas in grazing country was available for this audit, so it has been assumed that the areas under protection within the current audit period remain the same as for the 2016 audit. The 2016 audit identified a significant change in riparian area with potential to be accessed by stock (half as much area as had been identified in 2013), however this was attributed to the difference in length of watercourses calculated across the two audit periods.

The above discussion demonstrates there is no detailed assessment of grazing impacts on riparian corridors, beyond broad 'protection' labels. Therefore, there is still insufficient data and lack of clarity (across all audits) to identify a meaningful trend.

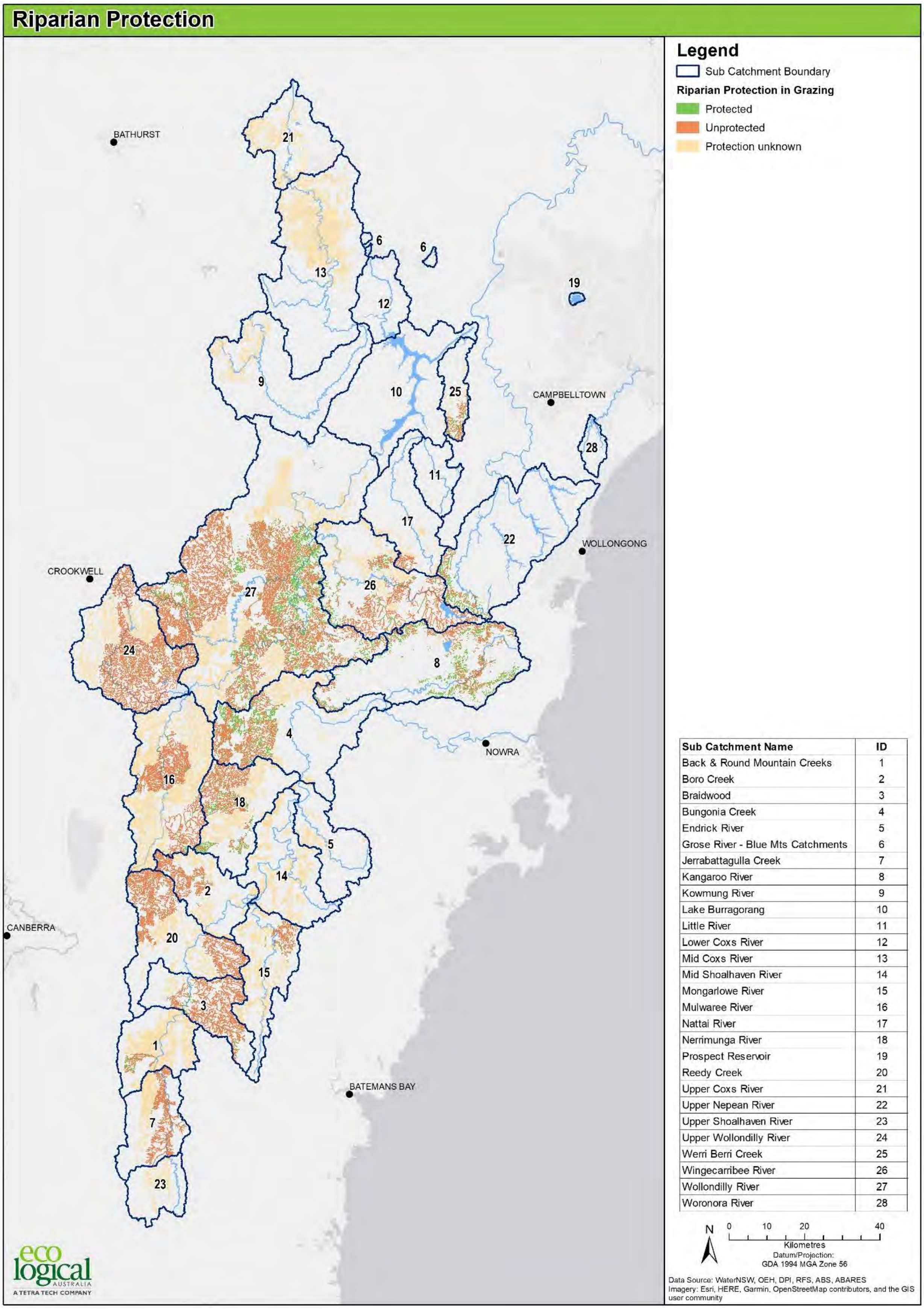


Figure 47: Riparian protection from grazing in the study area

17.5 Local council riparian management

Several local councils contributed to riparian protection or management in the Catchment during the audit period. Examples are given below of projects delivered by councils.

Case Study 1 – Bong Bong Common, Wingecarribee River

Wingecarribee Shire Council

Weed control

Revegetation

Bush regeneration

Installation of habitat features for microbats (see photo)

Comment – ongoing Council initiative with strong community support and engagement, includes recreational path

Case Study 2 – Farmers Creek

Lithgow City Council

Partly funded by Federal Government

Works done under the 2017 Farmers Creek Precinct Masterplan include weed control, revegetation and bank stabilisation. Community are notified via weekly updates and involved in planting days. There will be a pathway from the visitors' centre to Farmers Creek Dam, including two bridges.

Comment – high staff turnover in Council and related partners has affected project delivery

Case Study 3 – Drainage into Wentworth Falls Lake (Jamison Creek catchment)

Blue Mountains City Council

Partly funded by WaterNSW

Bioretention systems for stormwater treatment and flood mitigation. Works included weed control, revegetation, bank stabilisation and habitat creation. Monitoring and adaptive management approach.

Comment – program is considered best practice; it has strong support from Council leadership with multi-discipline collaboration (environmental scientists with engineers) which has contributed to its success; knowledge sharing with other councils and practitioners

17.6 Conclusion and recommendations

Corridors of native riparian vegetation contribute to healthy waterways and improved water quality outcomes. Protection of riparian corridors is paramount to ensuring water quality and channel bed and bank stability within the Catchment are not compromised. Local councils and LLS are continuing to protect the integrity and connectivity of riparian zones, however key performance criteria need to be developed to ensure that these reporting on these actions and programs include measurable targets that can be captured in future audits and therefore allow for trends in riparian vegetation extent to be identified. This should include records of the length of streams protected from stock either through conservation land use or fencing of agricultural lands.

The continuation of constructive partnerships under the Rural Landscapes Program and Rivers of Carbon is supported.

18. Watercourse physical form

18.1 Definition and context

Physical form describes the geomorphic complexity of a river. An understanding of the physical form and underlying physical processes occurring within a river system can be used to predict the likely trajectory of a waterway (with and/or without management interventions) and target areas for investment. Furthermore, an understanding of geomorphic processes is fundamental to understanding the likely water quality conditions that will arise within the Catchment, due to the strong interdependency of fine sediment loads and nutrient loads.

One system for assessing physical form is provided by the River Styles Framework (Brierley and Fryirs 2005). The River Styles Framework has been applied extensively throughout NSW to capture data at a river reach-scale on the geomorphic character, behaviour, condition and expected recovery potential. The River Styles assessments undertaken across NSW provide the only widespread, systematic and reach-scale evaluation of the geomorphic character and condition of waterways, so are therefore the primary dataset of interest for the physical form indicator. DPIE Water has recently uploaded their state-wide River Styles dataset to an online web map service (2019):

https://trade.maps.arcgis.com/apps/webappviewer/index.html?id=425c7364e9dc4a71a90c4ba353b8949f

18.2 Data

Previous audits in 2013 and 2016 have presented the River Styles dataset and acknowledged that the assessment has not been repeated or refined over this time within the Catchment. Each audit presented the data as follows:

- 2013 – presented River Styles statistics on stream Condition and Recovery Potential
- 2016 – re-analysed the River Styles data to add a new Risk metric to provide an improved understanding of the risk for sediment and nutrient delivery to downstream reaches.

In the absence of updates to the River Styles mapping since 2012, the systematic understanding of geomorphic river condition across the Catchment has not substantially advanced since the previous audit. However, the DPIE Water has re-analysed the River Styles data and applied a new Fragility index across the state for inclusion in the 2019 data release. This analysis is presented below.

18.3 Method

Raw River Styles data were first clipped to the Catchment boundary. Unlike previous audits, this boundary included the Prospect Reservoir sub-catchment. Data were then checked for errors and, in a small number of cases, manually corrected. Errors were related to reaches incorrectly labelled as 'tidal'. In those instances, all attributes associated with a line feature were manually edited in ArcGIS to match the upstream or downstream reach, with analysis of aerial imagery used to determine the best physical match.

The Fragility index developed by DPIE Water (Hancock, in prep.) is an extension of the River Styles - Stage 2 assessment of the *sensitivity* of a River Style to change (i.e. capacity to adjust, Brierley and Fryirs, 2005). Fragility scores reflect the tendency for a river channel to adjust in any of three degrees of freedom:

1. channel attributes (channel size, geometry and relationship to any adjacent floodplain)
2. channel planform (number of channels, lateral stability and sinuosity)
3. bed character (bedform and bed materials).

Each degree of freedom is further divided into three levels of adjustment (high/medium/low), giving nine sets of potential alteration. If any two of the three degrees of freedom are high and the other high or moderate, the inherent Fragility is high (i.e. higher risk of change). If any two degrees of freedom have moderate capacity for adjustment and the other is moderate or high, the Fragility is moderate. If any two degrees of freedom have low capacity to adjust, then the Fragility is low (i.e. more stable). The Fragility index is now applied consistently across the state dataset derived from multiple regional reports. This process is described in further detail in the NSW River Styles Summary Report (Hancock, in prep).

For this audit, reach data for Fragility was scaled up to produce a whole score for each sub-catchment, firstly by replacing high/moderate/low with 1/2/3 scores, respectively, and then standardising the total score relative to total stream length in each sub-catchment. Reaches with an 'unknown' Fragility rating were first excluded from the total reach measurement. This results in a possible score for the whole sub-catchment from 1 to 3, meaning high to low Fragility (sensitivity to change), respectively.

18.4 Results

CONDITION

There are 8,900 km of River Styles reaches in the Catchment. Overall, 41% of the reach length was in good condition, 31% moderate condition, 8% poor condition and the remaining classed as 'none' or 'unknown' (Figure 48). Across each of the 28 sub-catchments, 16 followed this pattern of good to poor. Sub-catchments that didn't follow this pattern may indicate disproportionate pressures, which may be amplified in larger catchments compared to smaller catchments. Of note, the Upper Wollondilly River sub-catchment only had 15 km of good condition reaches, but 276 km of moderate condition reaches. The Wollondilly River sub-catchment had the greatest length of good condition reaches in the Catchment (549 km) but had a greater length of moderate condition reaches (556 km). When compared to the next three largest catchments, the Mid Coxs River, Kowmung River and Bungonia Creek sub-catchments had a notable majority of good condition over moderate and poor condition. Smaller sub-catchments with a lower proportion of good condition reaches were Upper Coxs River, Reedy Creek, Prospect Reservoir, Nerrimunga River, Mulwaree River, Jerrabattagulla Creek, Grose River - Blue Mts Catchments, Braidwood, Boro Creek, and Back & Round Mountain Creeks.

RECOVERY POTENTIAL

Overall, 41% of the combined reach length in the Catchment was in or adjacent to conservation zones and has not been assigned a recovery potential rating. A total of 9% of reach length was classed as having high recovery potential, 24% moderate recovery potential and 4% low recovery potential (Figure 49). The remainder of stream length was classed as 'rapid recovery, 'strategic recovery', 'none' or 'unknown'. The Mid Coxs River sub-catchment had the greatest length of reaches with high recovery potential. Of the sub-catchments with a large proportion of reaches outside of conservation zones, there was a high proportion of stream length with moderate recovery potential, such as Mulwarree River, Upper Wollondilly River and Reedy Creek. Other large sub-catchments also had a high proportion of moderate recovery stream length, especially Wollondilly River and Wingecarribee River.

FRAGILITY

Overall, 17% of the combined reach length in the Catchment had a high Fragility score (i.e. sensitive to geomorphic change), 35% had moderate Fragility, and 30% had low Fragility (i.e. more stable) (Figure 50 and Figure 51). The remainder was 'unknown'. Across each of the sub-catchments, 21 showed a similar or better trend (excluding the 'unknowns'), with a lower proportion of high Fragility reach length. For example, the Upper Nepean River, Woronora River, Werri Berri Creek, Little River, Lake Burragorang, Kangaroo River, Endrick River, Bungonia Creek and Grose River - Blue Mts sub-catchments had a higher proportion of low Fragility reach lengths compared to their combined moderate and high Fragility reach lengths (noting Upper Nepean River and Lake Burragorang also had a large 'unknown' proportion). Overall sub-catchment scores are shown in (Figure 52).

The remaining eight sub-catchments had an inverse pattern of Fragility, where there was a greater proportion of high Fragility reach lengths compared to low Fragility. Mulwaree River was by far the sub-catchment with the greatest proportion of high Fragility reach lengths (Figure 52). To exacerbate this, few reaches in this sub-catchment had high Recovery Potential. Prospect Reservoir also had an overall high Fragility score, however, the lengths of reaches are small and the sub-catchment is protected from development and grazing. Other sub-catchments with overall higher Fragility were Nerrimunga River, Boro Creek and Reedy Creek.

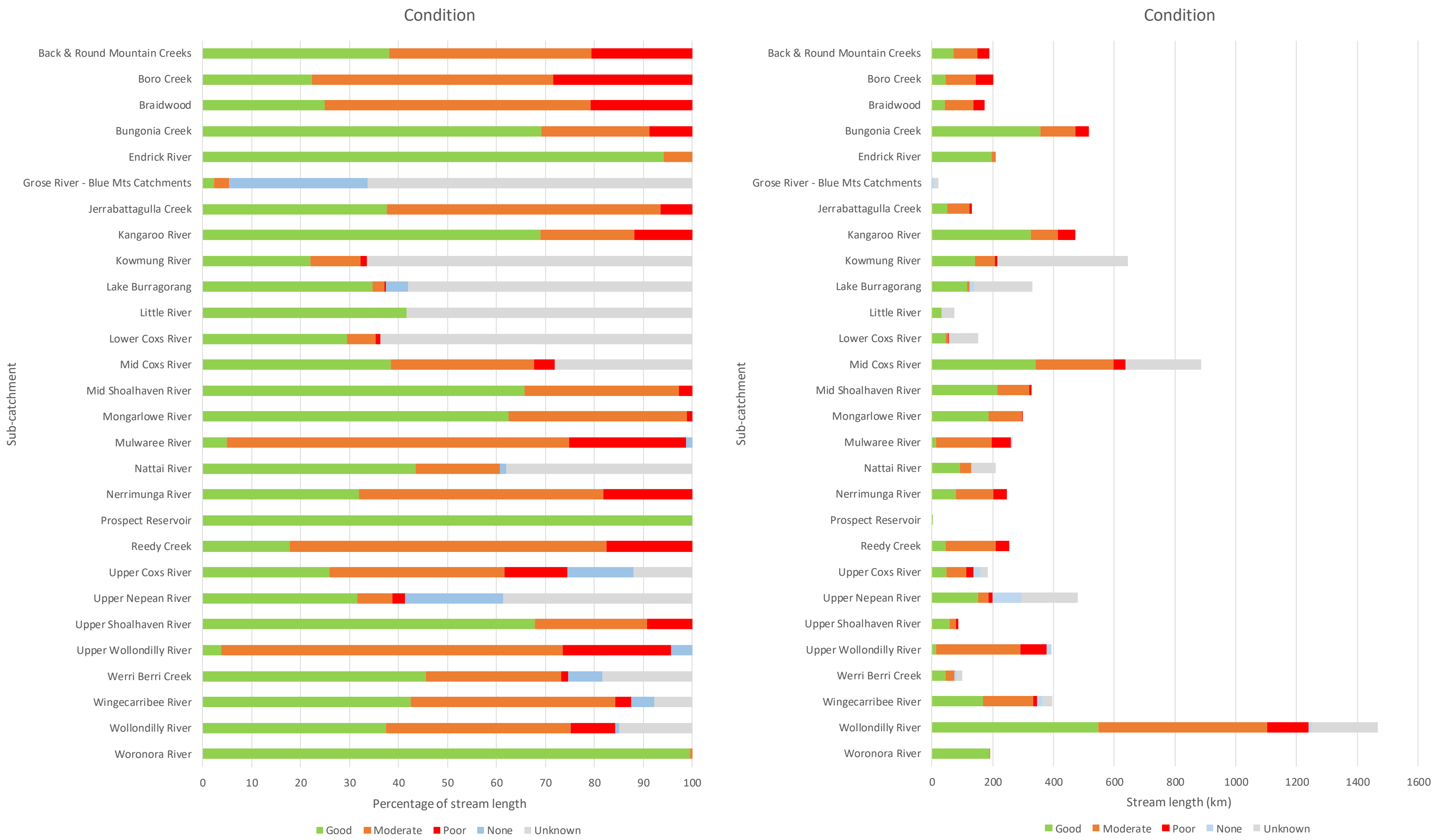


Figure 48: River Styles Condition for each reach per sub-catchment as percent of combined stream length (left) and actual stream length (right)

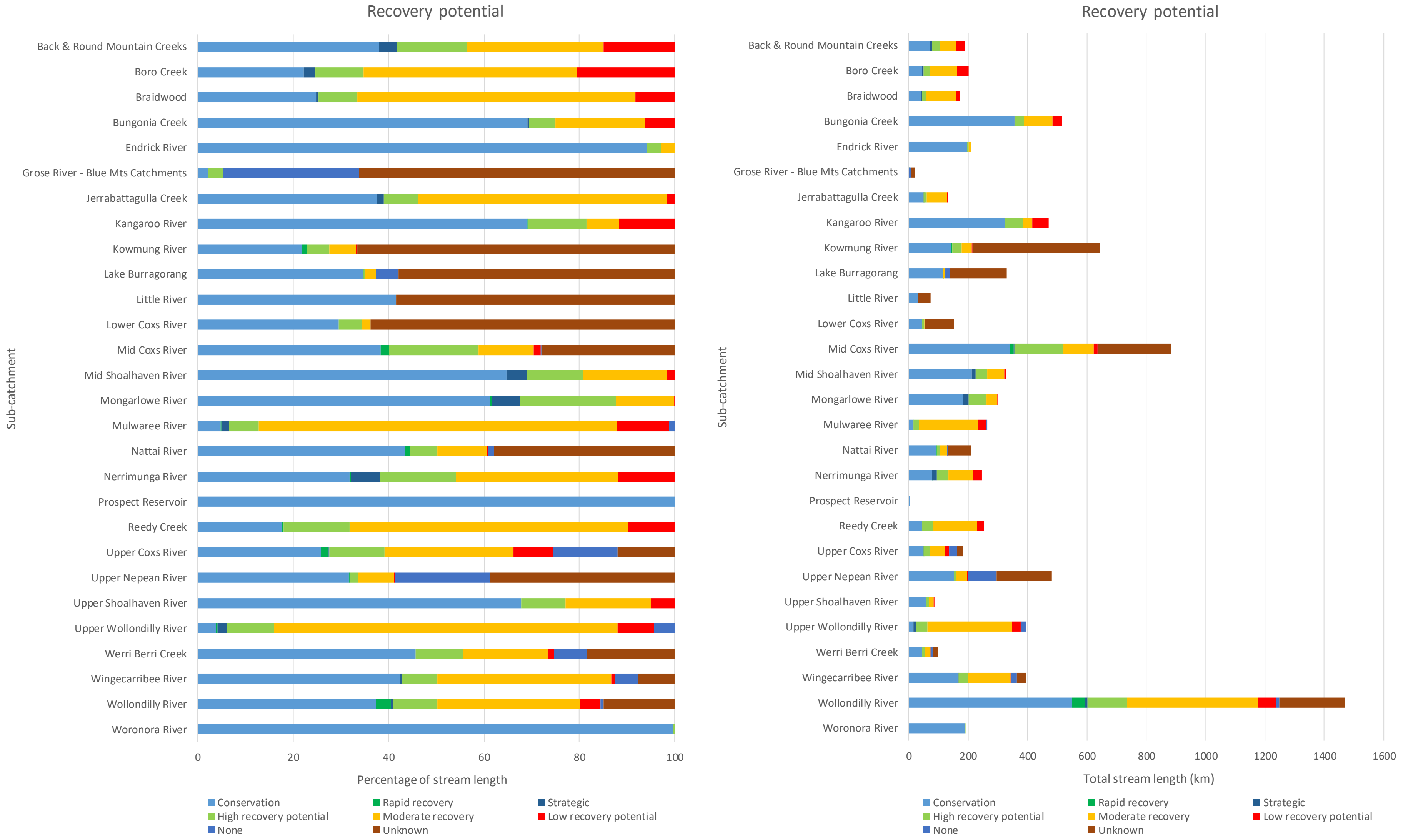


Figure 49: River Styles Recovery Potential for each reach per sub-catchment as percent of combined stream length (left) and actual stream length (right)

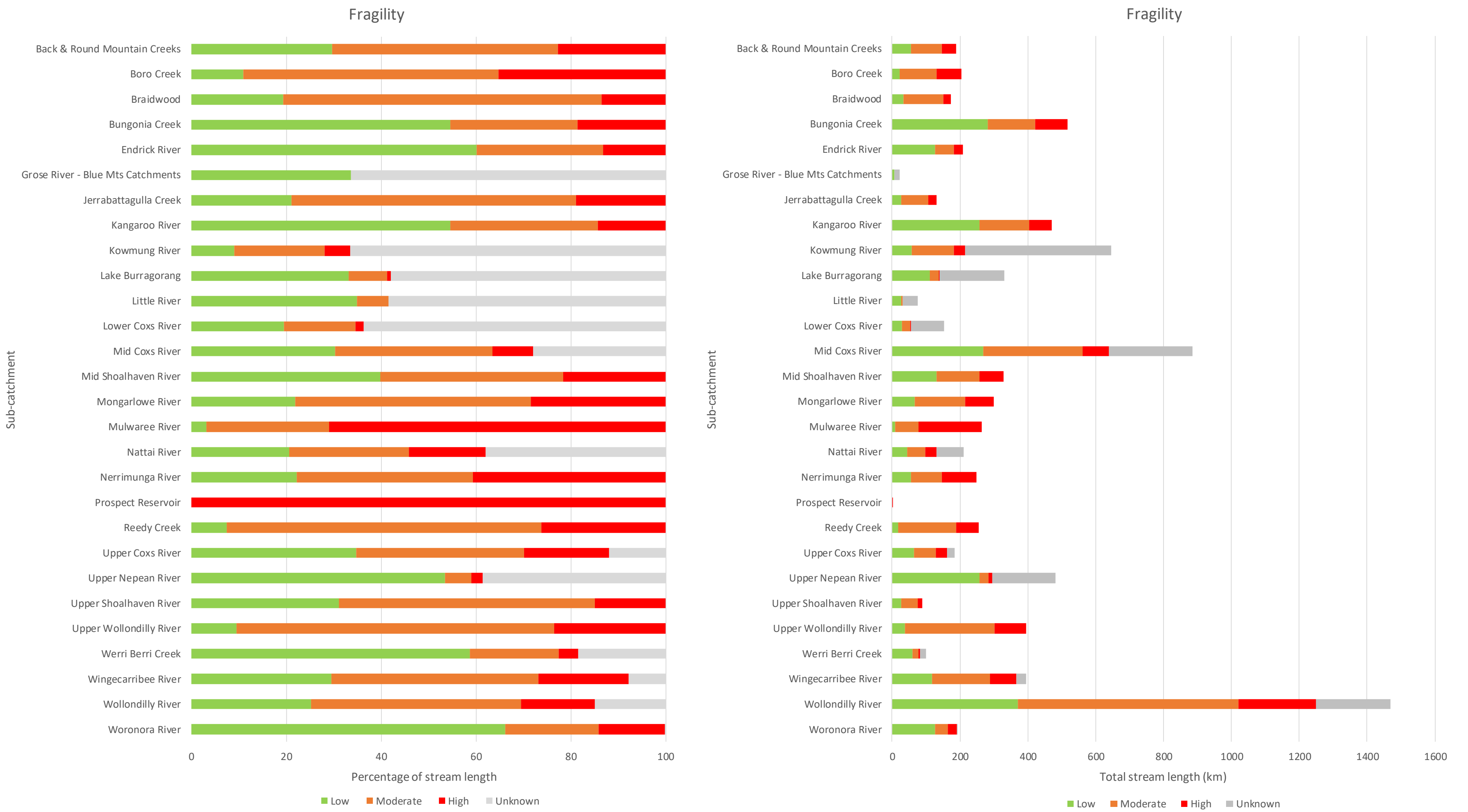


Figure 50: River Styles Fragility Index for each reach per sub-catchment as percent of combined stream length (left) and actual stream length (right)

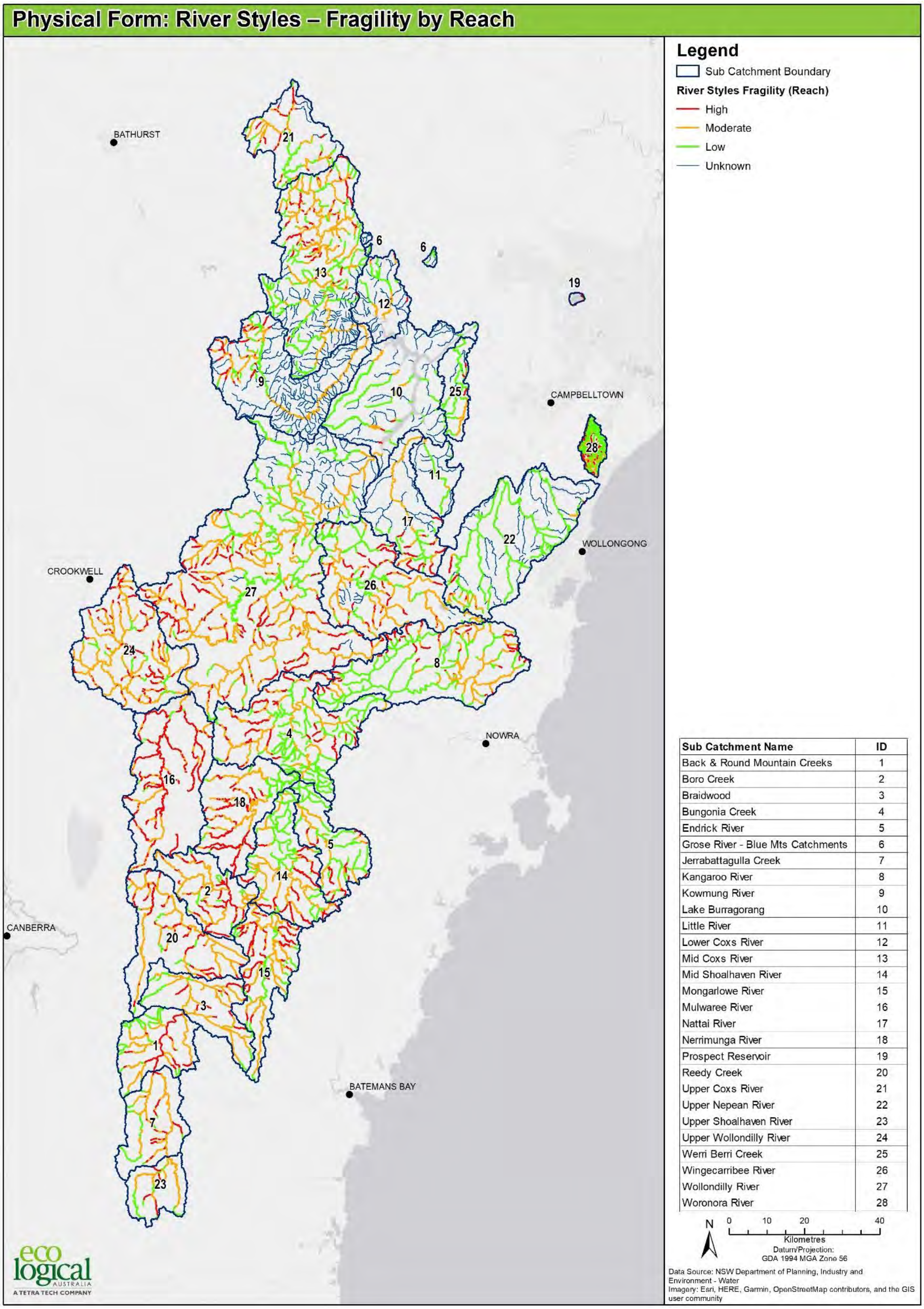


Figure 51: River Styles Fragility index at the reach scale (high = sensitive to change; low = more stable)

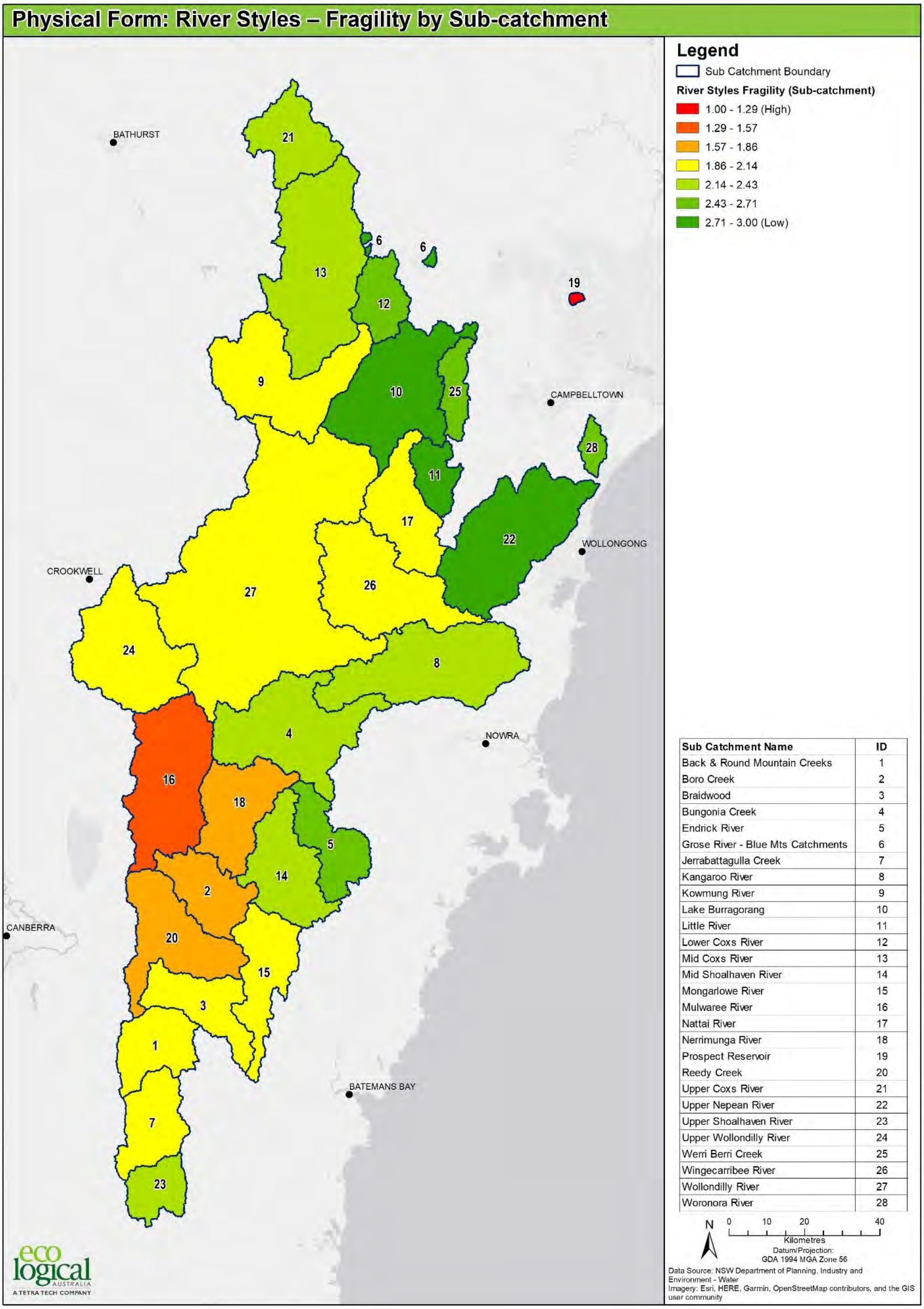


Figure 52: River Styles Fragility index scaled up to sub-catchment scores (high = sensitive to change; low = more stable)

18.5 Conclusion and recommendation

The 2016 audit presented reach and sub-catchment scores reflecting the risk of sediment/nutrient generation through fluvial geomorphic processes. These scores were derived from a matrix of River Style and Condition. The current audit presents a new analysis that DPIE Water has applied state-wide, using three degrees of freedom and three levels of potential adjustment. The latter analysis provides more context to the surrounding floodplain and channel stability, resulting in an improved overview of how sensitive a reach is to change. Should change occur where a River Style requires an erosion event to adjust (as opposed to sediment infill from upstream), then there is the potential for downstream impacts to water quality and habitat through sediment deposition and increased nutrient loads.

Protection of downstream reaches is important from a water quality and habitat perspective. Further analysis of the River Styles metrics (Condition, Recovery Potential and Fragility) would assist in prioritising riparian protection and restoration efforts. For example, priority may be given to creeks that are sensitive to change and have increasing land use pressures (e.g. grazing and urbanisation) and have high recovery potential. The audit presents results at a sub-catchment scale, which does not reflect management or land use zones. Analysis at a smaller scale may be beneficial for prioritising intervention, such as dividing sub-catchments into units relative to impoundments, clearing, grazing, urban and size. This should be done as part of the evaluation of riparian protection programs.

19. Wetlands

19.1 Definition and context

Wetlands provide essential ecosystem services such as water storage and flood mitigation, and a sink for sediments, nutrients and other pollutants mobilised from the Catchment. Under the RAMSAR International Wetlands Treaty, wetlands are defined as:

"areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres" and *"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands."*

Within the Catchment, the term 'wetland' applies to numerous types identified in the Directory of Important Wetlands in Australia (DIWA):

- Inland wetlands
  - B1 - Permanent rivers and streams and waterfalls
  - B2 - Seasonal and irregular rivers and streams
  - B4 - Riverine floodplains including river flats, flooded river basins and seasonally flooded grassland
  - B6 - Seasonal/intermittent freshwater lakes (>8 ha) and floodplain lakes
  - B8 - Seasonal/intermittent saline lakes
  - B9 - Permanent freshwater ponds (<8 ha) marshes and swamps on inorganic sols, with emergent vegetation waterlogged for at least most of the growing season
  - B10 - Seasonal/intermittent freshwater ponds and marshes on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes
  - B13 - Shrub swamps, shrub dominated freshwater marsh, shrub carr, alder thicket on inorganic soil
  - B15 - Peatlands, forest, shrubs or open bogs
  - B17 - Freshwater springs, oasis and rock pools
- Human-made wetlands
  - C1 - Water storage areas; reservoirs, barrages, hydro-electric dams, impoundment's (generally >8 ha)
  - C2 - Ponds, including farm ponds, stock ponds, small tanks
  - C6 - Wastewater treatment; sewage farms, settling ponds, oxidation basins

Several wetlands in the Catchment are listed as threatened under the NSW *Biodiversity Conservation Act 2016* (BC Act), mostly with comparative listings under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (BioNet database accessed 26/03/2020):

- Blue Mountains Swamps in the Sydney Basin Bioregion – Vulnerable (BC Act) Endangered (EPBC Act)
- Coastal Upland Swamp in the Sydney Basin Bioregion – Endangered (BC Act) Endangered (EPBC Act)

- Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions – Endangered (BC Act) Endangered (EPBC Act)
- Newnes Plateau Shrub Swamp in the Sydney Basin Bioregion – Endangered (BC Act) Endangered (EPBC Act)
- Sydney Freshwater Wetlands in the Sydney Basin Bioregion – Endangered (BC Act).

In addition, wetlands are protected under various policies and legislation, such as the NSW Wetlands Policy, NSW *Water Management Act 2000*, NSW *Environmental Planning and Assessment Act 1*979 (EPA Act) and NSW *Fisheries Management Act 1994*. These instruments promote the sustainable conservation, management and use of wetlands in NSW and the need for all stakeholders to work together to protect wetland ecosystems and their catchments.

Threats to wetlands are similar to those for rivers and riparian zones but have additional vulnerabilities, even in remote forested areas. For example, longwall mining has the potential to impact wetlands that are above or hydrologically-connected to a mine's sub-surface operations. The gravity of this impact is recognised in the NSW BC Act, which identifies 'Alteration of habitat following subsidence due to longwall mining' as a Key Threatening Process.

For the purposes of this Audit, a worsening trend is defined as increasing threats to wetlands, or loss or damage of wetlands in the Catchment.

19.2 Data and method

Three main themes are addressed below: wetland extent (2012 dataset and definition of wetlands); long wall mining impacts (based on publicly released reports) and risks to threatened wetlands (recent research on swamp condition).

For this audit, WaterNSW provided a spatial layer of wetlands and supporting report (SCA 2012). Other project-specific mapping is also available (Fryis et al 2018), which is currently being analysed for an upcoming risk assessment of upland swamps in the Sydney Basin, targeting Temperate Highland Peat Swamps on Sandstone and Coastal Upland Swamps in the Sydney Basin (both listed as endangered under the EPBC Act).

19.3 Wetland extent

Approximately 3.1% (49,207 ha) of the Catchment is permanently or periodically inundated by water and therefore considered wetlands (SCA, 2012) (Figure 53 – note that individual wetland extent is not to scale in the map). Of these, 15% of the wetland surface area is in the Lake Burragorang sub-catchment, 15% in Upper Nepean River, 10% in Wollondilly River, 8% in Kangaroo River and 7% in Mulwaree River. The remaining sub-catchments have less than 7% of the total extent each. The wetland types with the greatest combined extent across the Catchment are permanent/lakes/pools (28% of total), permanent rivers/streams/creeks (20%) and shrub-dominated wetlands (16%).

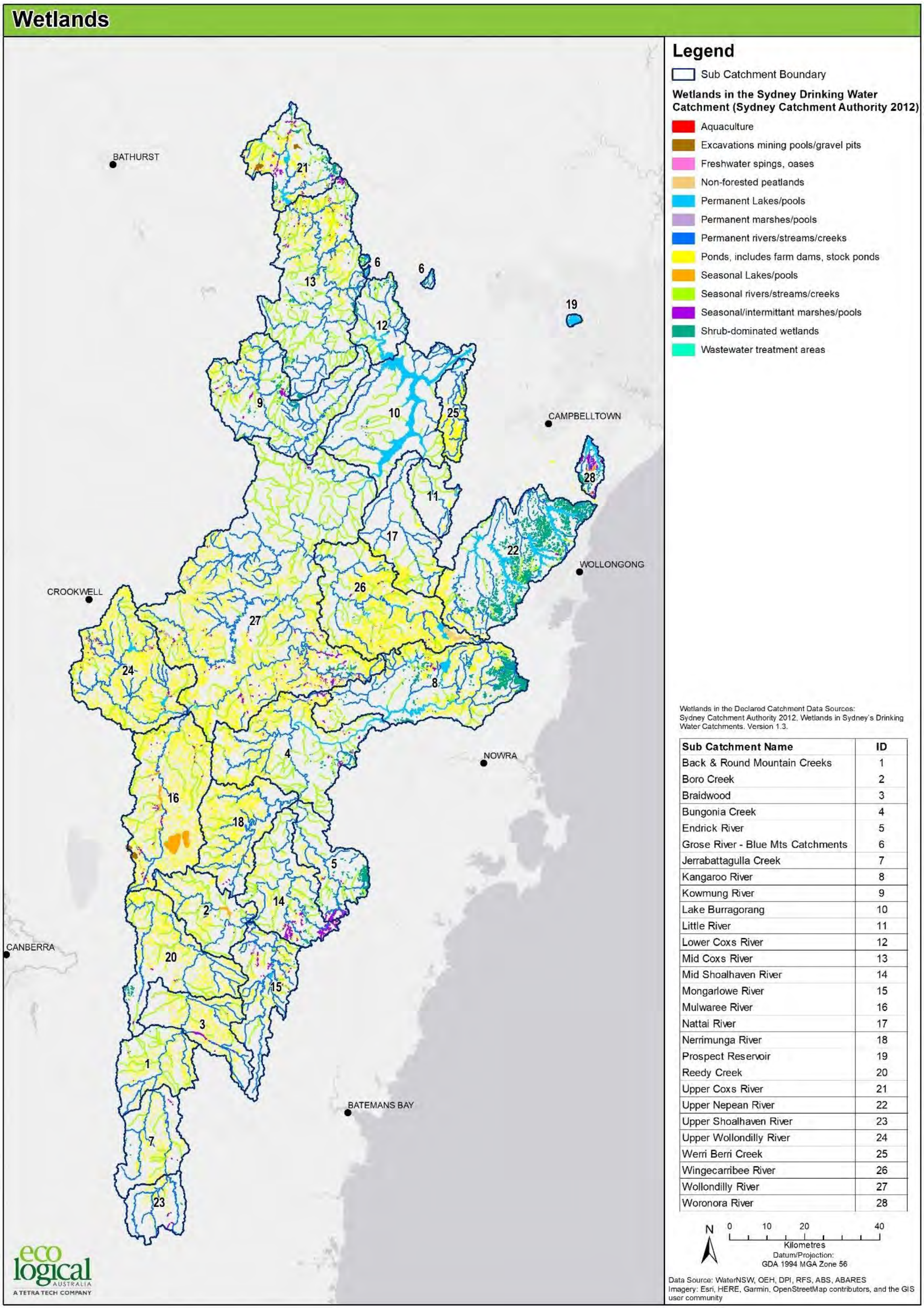


Figure 53: Wetlands in the Catchment

The 2013 Audit (GHD, 2013) provides a description of a selection of important wetlands in the study area, including information from the DIWA and conceptual models of each ecosystem. Specifically, important wetlands include: Wingecarribee Swamp; Long, Hanging Rock, Mundego and Stingray Swamps (Paddys River Swamps); Boyd Plateau Bogs; Budderoo National Park Heath Swamp; Lake Bathurst and the Morass Wetlands; Thirlmere Lakes; and Blue Mountains Swamps.

There is no documented change in total Catchment wetland extent (from the SRC spatial dataset), hence there is no basis for updating the description of each wetland provided in previous audits. There are, however, continued records of longwall mining impacts to wetlands that potentially reduce wetland extent or quality in the long term and thus represent a worsening trend. Wetland restoration has likely occurred in small areas, but not with a documented improvement that outweighs the known or expected impacts from mining and urbanisation.

19.4 Wetland impacts from mining

Longwall mining occurs in several parts of the study area, often intersecting with wetland hydrology (upland swamps and creeks). A number of factors influence the vulnerability of upland swamps to impacts from longwall mining, such as geomorphology and hydrology that determines the retention of water within the swamp itself, but also the direction of flow. DoP (2008) identifies specific threats to upland swamps as a direct result of longwall mining:

- cracking of base-rock
- increased drainage
- change in the water table level
- creation of nick points
- change in surface topography (and subsequent hydrology)
- flushing and erosion of sediment (leading to changes in water quality and impacts to flora and fauna).

The irreversibility of impacts to these wetlands, including Endangered Ecological Communities, are an important consideration for DPIE. For example, if the relatively impermeable base of the Newnes Plateau Shrub Swamps or Hanging Swamps is fractured, then any perched aquifer is likely to drain downwards into the fracture network, thereby altering natural groundwater levels within the swamp and leading to increased desiccation. Desiccation of swamps can lead to increased oxidation and subsidence of peat deposits; increased drying potential and a consequent increase in fire risk; changes in hydraulic conductivity and a loss of recharge potential (the swamp peat loses some of its absorption capacity); 'flashier' flooding during storm events and an increased tendency for the catchment valley to dry up faster in post rainfall periods, that is an increase in the number of cease to flow days (see references in OEH, 2014).

Site-specific impacts are detailed in the 2013 Audit, which stated: 'swamps in the Special Areas have already been impacted, and it is possible that further swamps may be impacted by current (or future) mining operations' (GHD 2013). The 2016 Audit (Alluvium & ELA 2017) reviewed annual reports and other investigations related to seven mines (Angus Place, Berrima, Dendrobium, Metropolitan, Russell Vale, Springvale and Wongawilli).

The following points describe monitoring outcomes that have been published since the previous audit:

- **Angus Place** – Annual reviews of Angus Place Colliery summarise longwall activities, monitoring results and compliance (Centennial Coal 2018a, Centennial Coal 2019a):
  - The mine was placed in 'care and maintenance' on 28 March 2015.
  - On 11 July 2017, Centennial Coal (Centennial) entered into a voluntary undertaking with the Department of Planning and Environment (DPE). The Voluntary Undertaking enforces commitments made by Centennial in a letter to DPE dated 26 May 2017, to secure the biodiversity offsets by 1 April 2018 for the development consents at four mines.
  - Swamp flora monitoring has occurred annually and seasonally between 2013 and 2016 at one 'impact' swamp and one 'control' swamp. Since 2016, a new monitoring program commenced (Angus Place Temperate Highland Peat and Shrub Swamps Monitoring and Management Plan). In Autumn, Spring and Summer 2018, mean native species richness was generally similar between impact plots and control plots.
  - Swamp fauna monitoring occurred in two longwall zones (900W/910N Area and SMP Area) and a future longwall zone (East Area). At 900W/910N Area, there was no significant differences between the habitat characteristics and fauna assemblages found within the control and treatment sites, indicating no discernible impact from underground mining. Sites in the SMP Area include Newnes Plateau Shrub Swamp and Hanging Swamp environments, and at present, there appears to be no evidence of potential impacts from subsidence upon the fauna diversity. The results from the survey of the East Area show that the assemblages found are typical of that found throughout Newnes Plateau and are similar to that obtained in the remainder of Angus Place Colliery.
  - Subsidence monitoring is no longer required to be monitored due to the time since longwall extraction occurred. Photo monitoring continues annually to monitor cracking, flows and vegetation condition at Kangaroo Creek, Narrow Swamp, and Wolgan Swamps. No anomalies were detected by comparing the pre-mining and post-mining results for 900W (Centennial Coal 2017).
- **Dendrobium** – Annual reviews of the Dendrobium longwalls summarise activities, monitoring results and compliance:
  - 2017 Financial Year (Illawarra Coal 2017)
    - During the reporting period Longwall 12 extraction was completed on 31 January 2017, and Longwall 13 extraction commenced on 4 March 2017. As of 10 July 2017, Longwall 13 had extracted approximately 155.7 m.
    - The subsidence parameters measured during the extraction and at the completion of Longwall 12 were generally similar to or less than what was predicted within the Area 3B Subsidence Management Plan.
    - Swamps 05 and 08 were mined under by Longwall 12, and two of the three Swamp 11 sites were within 400 m of Longwall 12. Sites from Swamp 8 are not within mapped swamp boundaries and therefore not subject to the Trigger Action Response Plan (TARP). Hydrographs show that average soil moisture fell below baseline levels in all sites that have been mined under or are within 400 m of the longwall. However, Illawarra Coal note that baseline data for those sites is less than two years and may not be representative of normal variability over the long term. In addition, the latter part

of Longwall 12 was characterised by unusually dry summer conditions during which soil moisture at reference sites and sites yet to be mined under also fell below the limited baseline range (e.g. Swamps 11 and 13).

- Following the 2016 terrestrial monitoring it was found that an ecological response had been detected at several impact sites within Dendrobium Areas 2, 3A and 3B where physical impacts have been observed. The impacts remain within predicted impact levels identified within relevant Environmental Impact Statements for Dendrobium Areas 2, 3A and 3B. However, observed ecological responses of upland swamps and threatened frogs at some monitoring locations result in TARP trigger levels for relevant Dendrobium mining areas.
- A proposal has been put forward by South32 to provide an offset for mining impacts from the Dendrobium Coal Mine and Bulli Seam Operations Project through the conservation of a 598 ha site at Maddens Plains near Helensburgh. The area of land meets the offset requirements for any impacts on the upland swamps at the Dendrobium Coal Mine and vegetation communities at the Bulli Seam Operations Project.

o 2018 Financial Year (Illawarra Coal 2018)

- During the reporting period Longwall 13 extraction was completed on 19 April 2018. Longwall 14 extraction commenced on 22 May 2018, and, as of 30 June 2018, had extracted approximately 294.8 m.
- Subsidence parameters measured during the extraction and at the completion of Longwall 13 were generally similar to or less than what was predicted within the Area 3B SMP.
- Longwall 13 passed within 400 m of shallow groundwater and soil moisture sites within Swamps 11 and 13.
- Analysis of shallow groundwater levels indicated that a Level 1 TARP was triggered within Swamp 11, which exhibited a decline in shallow groundwater level to below baseline, and an increase in the water level recession rate.
- At all soil moisture monitoring sites within Swamps 11 and 13, soil moisture decreased to below baseline levels during the extraction of Longwall 13, which contributed to Level 3 TARP triggers at both sites. Further monitoring during and after heavy rainfall events is required to determine whether, and to what extent, soil moisture levels at Swamps 11 and 13 have been affected by mining.
- Following the 2017 terrestrial ecology monitoring, it was found that an ecological response had been detected at several impact sites within Dendrobium Areas 2, 3A and 3B where physical impacts were observed. The impacts remained within predicted impact levels identified within relevant Environmental Impact Statements for Dendrobium Areas 2, 3A and 3B. However, observed ecological responses of upland swamps and threatened frogs at some monitoring locations resulted in TARP trigger levels for relevant Dendrobium mining areas.
- The Department and the Office of Environment and Heritage supported South32's intention to secure the Maddens Plains biodiversity offset site in perpetuity by transferring this land to the National Park estate. Maddens Plains was transferred to the Minister administering the *National Parks and Wildlife Act 1974* on May 2018.

- 2019 Financial Year (Illawarra Coal 2019)
  - During the reporting period Longwall 14 extraction was completed on 26 February 2019. Longwall 15 extraction commenced on 9 April 2019, and, as of 30 June 2019, had extracted approximately 600 metres.
  - Subsidence parameters measured during the extraction and at the completion of Longwall 14 were generally similar to or less than what was predicted within the Area 3B SMP.
  - Longwall 14 passed within 400 m of shallow groundwater and soil moisture sites within four swamps: Swamps 11, 13, 14 and 23.
  - Analysis of shallow groundwater levels indicated that a Level 3 TARP was triggered in Swamp 11. The swamp has previously exhibited low groundwater levels similar to the baseline period, however the extent of prolonged drying indicates recent levels are likely the result of mine subsidence.
  - Swamp 13 was reported as a Level 3 trigger for groundwater and soil moisture which is likely mining related however it is noted that similar groundwater levels were observed in reference swamps away from mining influence.
  - Field teams reported a decline in groundwater levels in Swamp 14 however further specialist analysis revealed that reference sites exhibited the same decline in groundwater levels, indicating it was due to climatic conditions.
  - Field teams also reported a decline in soil moisture levels in Swamp 23 prior to Longwall 14. Specialist assessment concluded that this was not mining related.
  - The results of the total species richness analysis showed the response to mining at individual swamps is complex, with Swamp 15A(2) and Swamp 15B showing a decline and subsequent increase in total species richness following mining and changes in shallow groundwater. Meanwhile Swamp 1A, Swamp 1B and Swamp 5 displayed no significant decline in total species richness despite observed changes in shallow groundwater availability.
  - When accounting for yearly effects, a statistically significant change in species composition post-mining was detected at Swamp 15B and Swamp 15A(2). As with total species richness, these changes were observed immediately following mining and have continued at Swamp 15B and Swamp 15A(2) for at least four years post-mining.
  - The analysis of LiDAR data was used to assess the extent of upland swamps and their composite vegetation communities. It has detected that the extent of all upland swamps (impact and control swamps) within the study area has decreased substantially during 2018, from the 2014 baseline.

- **Metropolitan**
  - Metropolitan Coal submitted the Longwalls 301-303 Extraction Plan in November 2016, with extraction of Longwall 301 commencing in June 2017.
  - During the 2019 monitoring period, environmental consequences (that is, diversion of flows, change in the natural drainage behaviour of pools, iron staining and gas releases) on the Waratah Rivulet, or at least 70% the Eastern Tributary, were variable. Specifically, gas releases were observed at Pools P, U and W along the Waratah Rivulet during the audit period (Peabody 2016, 2017, 2018). Significant changes to the extent of iron staining

occurred in October 2016, while changes to the natural drainage behaviour were observed in January 2017 at the Eastern Tributary (Peabody 2017).

  - The subsidence impact performance indicator related to upland swamp groundwater monitoring has continually been exceeded at longwall Swamps 20 and 28, since 2012 and 2016 respectively. The drying of Swamp 20 coincided with the nearby passing of Longwall 21 (Peabody 2018). The substrate piezometer became saturated at the end of 2018 following rainfall, however levels did not reach the two-standard deviation limit. A reduction in substrate water levels in Swamp 28 is attributed to Longwall 25. Substrate piezometers at this site and associated control sites were dry at the end of 2018 (Peabody 2018).
  - The upland swamp performance indicator 'The vegetation in upland swamps is not expected to experience changes significantly different to changes in control swamps' was exceeded in 2018 at Swamp 28 due to a continual decline in vegetation condition. An assessment against performance measures was undertaken and determined to be exceeded at this site (Peabody 2018).
  - The riparian vegetation performance indicator 'Impacts to riparian vegetation are expected to be localised and limited in extent, similar to the impacts previously experienced at Metropolitan Coal' was exceeded MRIP02 on the Waratah Rivulet in 2016 and 2017, during the audit period. Additionally, between sites MRIP05 and MRIP09 on the Eastern Tributary was observed to exceed the performance indicator in 2016. In 2018, the performance indicator was exceeded at MRIP05 due to an increase in the extent of vegetation dieback along the Eastern Tributary. In accordance with the Metropolitan Coal Biodiversity Management Plan, further assessment was commissioned and the performance measure found not to be exceeded (Peabody 2016, 2017, 2018).
- **Russell Vale**
  - In 2016 a decrease in swamp groundwater levels and soil moisture content occurred at CRUS1, shortly after mining of Longwall 6. No impacts to adjacent vegetation were observed (Biosis 2016).
  - A change in species composition, compared to baseline monitoring, was recorded at post-mining site CCUS3 in 2019 (Biosis 2019). Subsidence monitoring during the entire audit period indicates that effects for upland swamp vegetation did not exceed performance thresholds.
- **Springvale** – Annual reviews of Springvale Colliery summarise longwall activities, monitoring results and compliance (Centennial Coal 2018b, Centennial Coal 2019b):
  - On 11 July 2017, Centennial Coal (Centennial) entered into a voluntary undertaking with the DPE. The Voluntary Undertaking enforces commitments made by Centennial in a letter to DPE dated 26 May 2017, to secure the biodiversity offsets by 1 April 2018 for the development consents at four mines.
  - Several flora performance trigger indicators were found to have exceeded performance indicator triggers during 2016 – 2018 monitoring. These were related to change in species assemblage and change in condition.
  - During the 2017 reporting period, coal was extracted from longwalls 419, 420 and 421. Extraction of longwall 419 was completed on 18 March 2017 with a total chainage of 2340 m. Extraction of longwall 420 commenced on 29 April 2017 and was completed on 9

November 2017 with a total chainage of 2086 m. Extraction of longwall 421 started on 19 December 2017 and chainage at 31 December 2017 was 1628 m. No anomalous surface movements were detected during the reporting period that warranted investigation. Subsidence monitoring results were within predictions detailed in the EIS.

  - During the 2018 reporting period, coal was extracted from longwalls 421 and 425. Extraction of longwall 421 was completed on 19 of June 2018 with a total chainage of 1698 m. Extraction of longwall 425 commenced on 4 of August 2018 chainage at 31 December 2018 was 1060 m. No anomalous surface movements were detected during the reporting period that warranted investigation. Results for the seven subsidence lines surveyed during the reporting period show no triggers were detected.
  - Rainfall deficits observed during the 2017 reporting period are shown to influence water levels observed at all swamp piezometers indicating that, despite the potential for groundwater base flows at some swamps, the water level declines were experienced regionally. Although more recent rates of water level decline appear to be accentuated at two monitoring sites which are in closer proximity to active mining. For the 2018 reporting period, swamps that have been undermined were predominately dry. Some swamp piezometers that have not been undermined displayed permanently water-logged behaviour, suggesting groundwater from perched aquifers as constant seepage. During the 2018 reporting period, an additional seven shallow aquifer piezometers were installed.
  - During the 2017 and 2018 reporting periods, eleven monitoring sites were triggered under relevant TARPs regarding surface water and groundwater triggers, with a mix of suspected causes. For example, the reduction in surface flows observed at one site coincides with a period of decreasing rainfall. However, from comparison with historical rainfall responses and rainfall response at a reference site, it is not considered that rainfall alone was responsible for the observed flow reduction. The hypothesis suggests that mining in the vicinity of significant fault zones can cause changes to standing water levels in swamps. However, the effects of drought and/or prolonged rainfall deficit on monitored swamps are not fully understood, as the duration of monitoring at most impact and reference piezometers is relatively short and began on the back of a prolonged wetting period from 2010 to 2013. For another site, no obvious indication of mining impacts were observed in the gradual decline in groundwater levels, which is considered to be climatically driven.
  - East Wolgan Swamp was impacted over a period of years by a combination of regulator approved mine water discharge and potential subsidence effects. Rehabilitation was conducted in 2014 and 2015. Monitoring and maintenance works indicate the rehabilitation effort is having some success.
- **Wongawilli** (Wollongong Coal 2017, 2018, 2019) – There are no upland swamps within a 35° angle of draw (0.7 Depth) of N1 and N5 Longwall Panels. Monitoring near N1 concluded that there were no observable changes to frog populations and vegetation composition in Wattle Tree Creek or Little Wattle Tree Creek.

19.5 Risks to threatened wetlands

Temperate Highland Peat Swamps on Sandstone (THPSS) and Coastal Upland Swamps in the Sydney Basin are listed as endangered ecological communities under the BC Act and EPBC Act. These 'upland swamps' play a vital functional role within river catchments by providing base flows, element cycling (breaking down organic matter for reuse in the ecosystem), carbon sequestration (long-term storage of carbon dioxide), and they provide the habitat for an array of flora and fauna species (Cowley, et al., 2016; Hensen and Mahony, 2010; Kohlhagen, et al., 2013). A significant proportion of these swamps occur within the World Heritage Blue Mountains and Southern Highlands. Here, longwall mining and urbanisation are impacting on the conservation and protection status of these systems (Fryirs, et al., 2016).

Upland swamps are groundwater dependent ecosystems that occur in the headwaters of streams on gentle sloping plateaus. Their water source is controlled by catchment morphology (valley shape) (Cowley, et al., 2019). Prior to development in the Catchment, these systems were characterised by preferential drainage lines (i.e. no defined channel), dense hydrophilic vegetation (generally shrubs and grasses growing on damp soil), organic rich sediments and no surface disturbance (Fryirs, et al., 2016). The valleys that contain these swamps terminate downstream at a valley constriction or bedrock step, behind which alluvial materials have accumulated, and peat has formed to produce relatively steep swamps (median slope 6.2 per cent, Fryirs, et al., 2019). Understanding water sources of these systems is critical for the determination of likely impacts on THPSS from aquifer interference activities (mining and groundwater extraction), urbanisation and a changing climate (Cowley, et al., 2019). For example, Cowley found in a small study of 12 swamps that four out of five swamps sampled in the Blue Mountains had greater than 30% of water derived from the surrounding bedrock aquifer, whereas swamps in the Southern Highlands received less than 15% of water from the surrounding aquifer (ibid.).

Brierley and Fryirs (2005) have characterised areas which have un-incised drainage lines as 'intact swamps', and areas where channel incision has occurred as 'channelised fills' (Kohlhagen, et al., 2013). Where intact swamps have changed to channelised fills, the sediment structure and functional role can also be impacted. Cowley, et al. (2016) examined the sedimentology of six intact and six channelised fill swamps in the Blue Mountains. There were significant differences in texture, unit thickness, Carbon: Nitrogen (C:N) ratios and moisture content between intact swamps and channelised fills. The two functional swamp layers, in terms of water and carbon storage were almost double the mean thickness in intact swamps than in channelised fills. Moisture content was 30% higher in intact swamps than in channelised fills. Mean C:N ratios for channelised fills were 25% lower than that of intact swamps. Peat forming potential, as defined by C:N ratios N27, started at a greater depth in the sediment profile (0.9 m lower) in channelised fills than in intact swamps.

Fryirs, et al. (2016) undertook a geomorphic condition assessment of swamps in the Blue Mountains and analysed the range of intrinsic and extrinsic controls operating upon them. Of the 458 sites assessed, 120 (26%) were channelised fills and 338 (74%) were intact swamps (Figure 54). All of the intact swamps contained an un-incised valley floor where water flow on the surface was visible. Almost half (165 of the 338; 49%) were in good condition (Table 31). Of the 338 intact swamps, 146 (43%) were in moderate condition. These swamps have sand sheets on their surface and preferential drainage lines that were entrenched into the valley fill. Some have nickpoints present in their downstream sections. Minor urban influences occurred but weed plumes were common. Only 27 of the 338 intact swamps (8%) were in a poor condition. These swamps had often been cleared for grazing, development or were dominated by exotic vegetation. They showed signs of dewatering and desiccation. They were highly modified, highly disturbed and vulnerable to becoming a channelised system.

All of the channelised fill sites contained a continuous channel with water flow within. Of the 120 channelised fill sites, 32 (28%) were rated as being in good geomorphic condition (Table 32). These systems were incised and have experienced channel expansion. They were in a phase of recovery and were characterised by bed aggradation and organic matter accumulation in places. This suggests that inset swamp formation is possible in these systems (see Freidman and Fryirs, 2015). The channels were lined with native vegetation. Of the 120 channelised fill sites, 61 (50%) were in a moderate condition. All of these sites contained active knickpoints within a relatively narrow and deep channel. At many of these sites, large-scale disturbance around stormwater outlets had concentrated high energy flow from hillslopes and surrounding urban areas, changing the hydrology of these systems. The swamp/floodplain surfaces were desiccated and sand sheets were common. Woody, exotic vegetation was prevalent. Of the 120 channelised fill sites, 27 (23%) were in poor condition, displaying active head-cut retreat, channel expansion, and large-scale bank slumping. The channel bed contained sand sheets. Floodplain dewatering and desiccation had occurred resulting in incursion of woody and exotic vegetation. Many of these systems were located in urban areas and contain significant stormwater and other disturbances.

In relation to the discussion above, it is noted that some of the Blue Mountains wetlands assessed by Fryirs are outside the declared Catchment. However, they are in a similar landscape and experience similar pressures, so provide a regional example of how the wetlands are coping. Further detailed analysis of wetlands is supported within the Catchment.

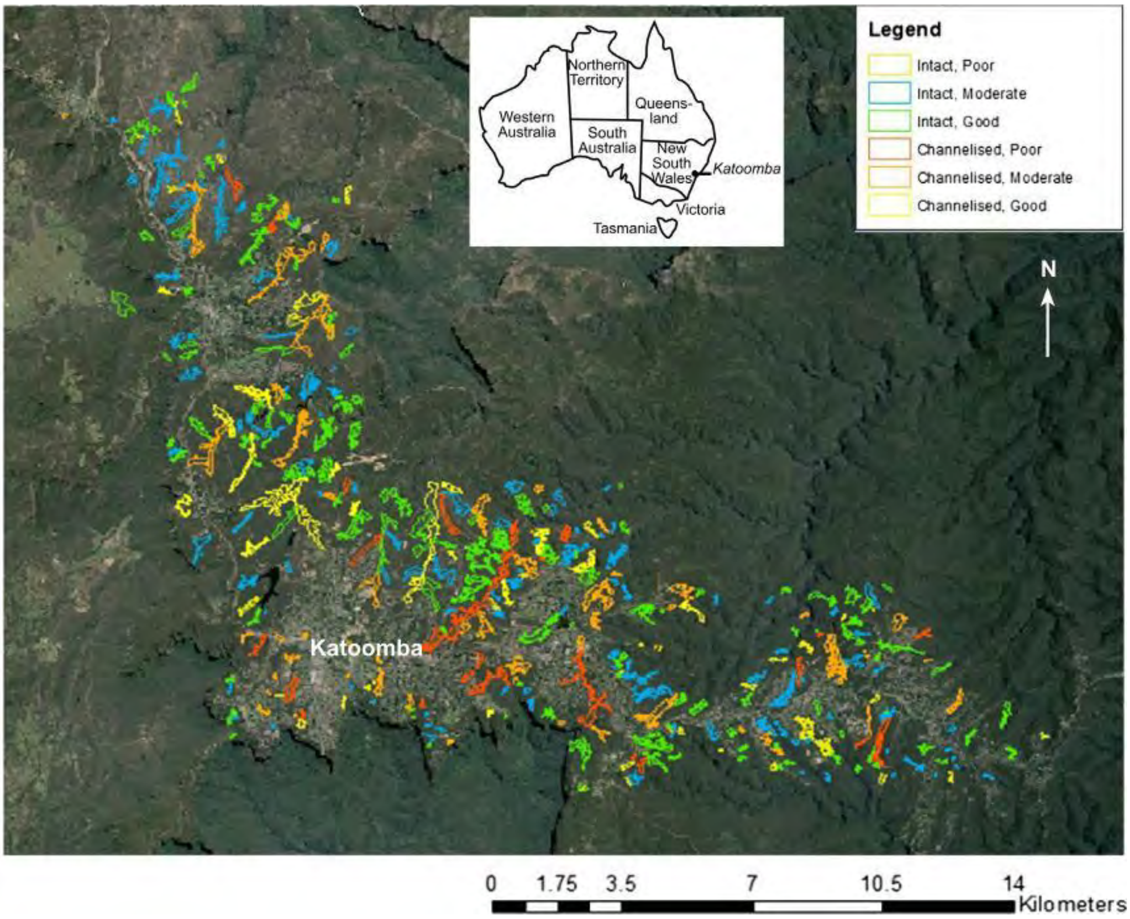


Figure 54: Location of the Blue Mountains upland swamps and their geomorphic condition (from Fryirs, et al., 2016)

Table 31: Summary of the geomorphic condition of intact swamps in the Blue Mountains (from Fryirs et al 2016)

Condition rating	Good condition	Moderate condition	Poor condition
Number of swamps assessed (338 total)	165 (49%)	146 (43%)	27 (8%)
Channel attributes	Water evident on surface of the swamp. Multiple, discontinuous surface drainage lines. Little surface vegetation disturbance. There are no knickpoints in these systems.	Surface water only evident close to drainage lines on the swamp surface. Single, continuous drainage line developing. Significant surface vegetation disturbance around channel. Knickpoints exist in system.	Little surface water and first obvious signs of desiccation of swamp. Small, single channel evident throughout swamp valley fill. Vegetation on the surface of swamp is moderately to highly disturbed and/or cleared.
Channel planform	95–100% of the swamp contains an intact, continuous swamp surface. No channel entrenchment is occurring. The riparian vegetation is native, extremely dense and consists of hydrophilic species that dictate where surficial drainage lines occur. No desiccation is visible.	Less than 70% of the swamp contains an intact, continuous swamp surface. Drainage lines having developed into small, single channel in downstream sections of swamp. Hydrophilic vegetation is confined to lowest relief area of swamp and is severely disturbed in places. Signs of weed plumes. Highest relief margins of swamp becoming desiccated.	50–60% of the swamp contains an intact, continuous swamp surface. Single, well defined channel is evident and is expanding. Hydrophilic vegetation is rare. Riparian zones are generally exotic and scattered. Up to 40% of the swamp contains channelised fill system. These areas are desiccated.
Valley fill character	No incision of drainage lines is occurring. The material accumulating on the swamp surface is comprised largely of organic matter. Only minor sand sheets adjacent to hillslopes may occur. Peat formation is occurring. No sand sheets are visible.	Incision of drainage lines occurring, producing a single, dominant surficial drainage line. Sand sheets and flood outs visible in downstream sections. Little organic matter accumulating.	Major incision into sands. Little to no organic matter accumulating. Sand sheets and flood outs dominate swamp surface.
Types of anthropogenic disturbances observed	No stormwater outlets or sealed roads immediate to the swamp. Gravel roads approximate to swamps.	Stormwater outlets entering swamp. Sealed roads approximate to swamp.	Stormwater outlets entering upstream area of swamp. Sealed roads approximate to swamp.

Table 32: Summary of the geomorphic condition of channelised fills in the Blue Mountains (from Fryirs et al 2016)

Condition rating	Good condition	Moderate condition	Poor condition
Number of swamps assessed (120 total)	32 (26.7%)	61 (50.8%)	27 (22.5%)
Channel attributes	Compound cross section within an incised trench or moderately incised channel. Vegetated benches may be evident. Stable banks with no undercutting or slumping visible. No active knickpoints evident. Occasional tussock vegetation on sand bars throughout channel. Appropriate width:depth ratio.	Symmetrical, incising channel. Banks are exposed and near vertical. Some undercutting may be evident. May contain active knickpoints within system. No aquatic vegetation within channel. Channel has a high width:depth ratio.	Symmetrical, incising channel. Banks and bed are exposed and eroding along entire reach. Active undercutting and slumping occurring. No aquatic vegetation and multiple knickpoints throughout system. Channel has a high width:depth ratio.
Channel planform	The channel is laterally stable with limited adjustment potential. Well defined low flow channels exist within incised macro-channel. Scattered to good condition riparian zone which may contain exotics and/or native flora.	Floodplain is disconnected from channel. Disturbed riparian zone, variable exotic and native vegetation. Signs of desiccation of swamp surface. Minor undercutting of banks may be occurring suggesting active channel expansion in places. Sand sheets may be evident on the channel bed.	Active lateral and vertical expansion of channel. Floodplain disconnected from channel. Little or no riparian zone. Swamp is desiccated, ground table is lowering and no hydrophilic vegetation is evident. Sand sheets may cover channel bed.
Bed character	Bed generally stable due to incision to bedrock. Channel is aggrading in places. Low flow channel redistributes sediment. Sands stored in geomorphic units such as benches, point bars and islands, producing hydraulic diversity on the channel bed. Aquatic vegetation stabilising instream geomorphic units and some organic matter may be accumulating on these surfaces. Reach is acting as sediment transfer or accumulation zone.	Channel bedload dominated by sand. Reach is still releasing some sediment through active knickpoint retreat into the swamp. Moderate bed stability. No organic matter accumulating. Acting as a sediment source zone.	Bedload dominated by sand. Reach has limited capacity to retain sediment. Reach is still releasing sediment from channel banks. Bed may be still incising or has reached bedrock. No organic matter accumulating. No aquatic vegetation.
Types of anthropogenic disturbances observed	Stormwater outlets entering site. Gravel roads approximate to site.	Multiple stormwater outlets entering site. Some sealed and some gravel roads may exist approximate to these sites.	Multiple stormwater outlets entering sites. Sealed roads approximate to all sites.

Table 33: Photographs of intact swamps and channelised fill in good, moderate and poor condition (from Fryirs et al 2016)

	Good condition	Moderate condition	Poor condition
Intact swamps			
Channelised fill			

19.6 Conclusion and recommendations

The available data indicates that there has been a decline in the extent and condition of wetlands in some areas of the Catchment due to longwall mining and urbanisation. This is attributed to rock fracturing, groundwater drawdown and stormwater runoff. Although some restoration efforts have occurred, the scale and success have been disproportionately low compared to the long-term impacts documented in the Catchment.

It is recommended that a detailed risk assessment be undertaken for all swamp types in the Catchment to prioritise protection or restoration and identify swamps that may be vulnerable to future development.

It is also recommended that the ecological values of Wingecarribee Swamp are protected through continued weed control, targeting willows and blackberry, and implementation of the Wingecarribee Swamp Operations Plan. Fences adjacent to stocked land need to be repaired or replaced, especially on the higher risk areas on the northern side of the swamp.

SUMMARY OF DATA ADEQUACY

Good monitoring and evaluation data support good decision-making, as indicated by this sample of comments from the 1999 audit (p.107 CSIRO 1999):

> *"…to be effective, management strategies and planning need to be based on sound information. Therefore, it will be essential to continue to invest in gathering, collating and analysing natural resource information at a range of scales appropriate for management. This information will provide the necessary context and focus to continue monitoring of catchment and water quality indicators.* (p.10 CSIRO 1999)
>
> *A…framework for building and incrementally developing procedures and mechanisms for working with people, their communities and institutions to achieve improved catchment management is the PRIME model as described by Syme et al (1993). Their analysis followed an examination of Integrated Catchment Management in Australia. In this simple strategy, there are five stages through which communities move. These are as follows:*
>
> 1. *Planning*
> 2. *Research*
> 3. *Implementation*
> 4. *Monitoring*
> 5. *Evaluation"*

The following table summarises the adequacy of data available for this audit.

Table 34: Summary of data adequacy for audit

Indicator	Audit comment
Ecosystem and raw water quality	Adequate data
Nutrient load	Adequate data
Cyanobacterial blooms	Adequate data
Surface water flow	Adequate data
Environmental flows	Adequate data
Groundwater availability	Inadequate data – additional monitoring bores needed
Macroinvertebrates	Inadequate data Recommendations from previous review by Jacobs about monitoring program have not been implemented (not statistically valid to detect change within each sub-catchment, but does meet the requirements for whole Catchment)
Fish	Inadequate data DPI Fisheries increased its sampling in the Catchment compared to the previous audit period, although the spatial spread only covered four sub-catchments (Figure 40) as the surveys were designed for specific research goals i.e. crayfish
Riparian vegetation	Inadequate data The type of data available for the 2019 audit was limited to broad mapping and assumptions, as well as the same datasets used in the 2016 audit, such as the Riparian Vegetation Extent (RVE) dataset and Hybrid Riparian Native Vegetation Extent

Indicator	Audit comment
	(HRNVE) dataset that contributed to the NSW River Condition Index (RCI). These datasets have not been updated since 2010
Native vegetation	Inadequate data Lack of data about the extent and / or condition of native vegetation in the Catchment means that it is not possible to determine if trends are improving or worsening during the current audit period.
Fire	Inadequate data BRIMS dataset not available to auditors Inadequate data has meant that it is not possible to determine fire trends during the audit period. It is recommended that all agencies provide fire data into a single database that is publicly available via SEED.
Wetlands	Inadequate data Mining companies have good data for certain sites, however they don't provide a holistic view of all wetlands in the Catchment. As there is no documented change in total Catchment wetland extent (from the SRC spatial dataset), there is no basis for repeating the description of each wetland provided in previous audits.
Physical form	Inadequate data In the absence of updates to the River Styles mapping since 2012, the systematic understanding of geomorphic river condition across the Catchment has not substantially advanced since the previous audit.
Land use	Adequate data Datasets have changed since the previous audit which meant it wasn't possible to determine change, but the datasets are considered adequate
Sites of pollution and potential contamination	Adequate data
Soil erosion	Inadequate data Dataset has not been updated since the previous audit
Population settlements and patterns	Adequate data
Community attitudes, aspirations and engagement	Adequate data

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D2017/94408 (copy of D2017/83198) – update to Board Committee on Water Quality, Health and Catchment Protection 19 July 2017 – Agenda Item 6.3 - ICAM Investigation mining company transformer oil spills Cataract, Avon and Cordeaux Catchments – summarizes improvement actions identified by WaterNSW with End State and Completion Dates

D2017/94407 (copy of D2017/82347 – presentation to Board Committee on 19 July 2017 – summarizes What Happened, Immediate Action/Response, Current Satu's, Issues Identified and Incident Actions

D2017/74881 – Letter from NSW Health on Catchment oil spill incidents 23 May 2017

D2017/74526 – WaterNSW Operational Debrief Catchment Oil Spill Incidents, 1st June 2017

D2017/66664 – Summary points for the inter-agency Joint Operations Group (JOG) meeting 29 May 2017 – chemicals in catchment - summarizes WaterNSW's response and actions with timeline, what we know about sites of interest and Forward Plan for reducing risks from Chemicals in the Catchment from existing activities

D2017/113692 – Inter-agency meeting notes on managing chemicals stored in Special Areas

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Situation Reports at D2017/43849 and D2017/59419.

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