Adelaide River catchment water resource assessment

Document title	Adelaide River catchment water resource assessment
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Approved by	Executive Director Water Resources
Date approved	May 2025
Document Review	42-D25-15795

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Report No. 07/2025

ISBN: 978-1-74350-467-3

To cite this report:

Water Assessment Branch, *Water resources of the Adelaide River Catchment. Technical Report* 07/2025. Northern Territory Department of Lands, Planning and Environment. Palmerston, Northern Territory.

Cover image: Adelaide River Floodplain, March 2024. Photo courtesy of Stephen Trudgeon

Acknowledgements:

The Northern Territory Government respectfully and proudly acknowledges the Northern Territory's Aboriginal people and their rich cultures. We pay respect to Elders past and present. We acknowledge Aboriginal peoples as the traditional owners and custodians of the lands and waters that we rely on for our livelihoods. We recognise the intrinsic connection of traditional owners to Country and value their ongoing contribution to managing the lands and waters. We support the need for genuine and lasting partnerships with traditional owners to better understand cultural connections, and we will work to establish lasting partnerships to manage water together, now and into the future.

Acronyms

Acronyms	Full form
AHD	Australian Height Datum
BGL	below ground level
CLA	Cambrian Limestone Aquifer
CSIRO	Commonwealth Science and Industrial Research Organisation
DHI	Danish Hydraulic Institute
DLPE	Department of Lands, Planning and Environment
GL	gigalitre
km	kilometre
km^2	square kilometre
L/s	litres per second
m	metre
mAHD	metres above Australian Height Datum
mBGL	metres below ground level
mg/L	milligrams per litre
ML	megalitre
mm	millimetre
NAM	Nedbor-Afstømnings Model, translating to Precipitation-Runoff Model
NAWRA	Northern Australian water resource assessment
NT	Northern Territory
NTU	nephelometric turbidity units
PET	potential evapotranspiration
plan	water allocation plan
RSF	recharge scaling factor
SILO	Queensland Government gridded and point climate data archive
SW	surface water
TLA	Tindall Limestone Aquifer
µg/L	microgram per litre
WMZ	water management zone
WQ	water quality

Glossary

Term	Definition
aquifer	see *Water Act* 1992
aquifer (confined)	an aquifer bounded above and below by impermeable beds, or by beds of distinctly lower permeability than that of the aquifer itself and the upper water surface is the bottom of the upper confining bed
aquifer (perched)	an aquifer underlain by a confining layer (see aquitard) that occurs above the regional watertable, within the vadose zone
aquifer (unconfined)	an aquifer that isn't confined beneath relatively impermeable rocks; also referred to as a phreatic aquifer
aquitard (confining layer)	a geological formation that may contain groundwater but is not capable of transmitting significant quantities of groundwater
bed and banks	see *Water Act 1992*, section 4(1)
bore	see *Water Act 1992*, section 4(1)
catchment area, surface water	the extent of land where water from precipitation drains into a waterway
climate	generalised weather conditions of a region or place
dry season	the period from 1 May to 30 September
environment	see *Water Act 1992*, section 4(1)
ephemeral	something which only lasts for a short time, typically used to describe rivers, lakes and wetlands that are intermittently dry
evapotranspiration	the evaporative loss of water from a hydrologic system via evaporation or transpiration by plants
evapotranspiration (potential)	the potential evaporative loss of water from a hydrologic system via evaporation or transpiration by plants that would occur if unlimited water was available
flow	see *Water Act 1992*, section 4(1)
flow duration curve	show the distribution of flow exceedance as a proportion of the flow record
fresh water	water with a concentration of total dissolved solids less than 1,000 mg/L
gauge datum	arbitrary local datum established at a river gauging station
groundwater	see *Water Act 1992*, section 4(1)
mean	obtained by adding several quantities together and dividing the sum by the number of quantities. It is the same as average
median	the middle number in a series of numbers. The median is a value where 50% are higher and 50% are lower values
NAM	a precipitation runoff model developed by DHI
overland flow	water that runs across the land after rainfall, either before it enters a watercourse, after it leaves a watercourse as floodwater, or after it rises to the surface naturally from underground
perennial	something that is ongoing, typically used to describe waterway flows that continue throughout the dry season due to discharges from groundwater and other storages
persistent flow	ephemeral waterway flows that continue later into the dry season due to contributions from groundwater and other storages, but do not flow perennially

Term	Definition
recharge	a hydrologic process whereby water moves from the Earth's surface to groundwater. The recharge value represents the amount of water that goes into the groundwater system and may be expressed in units of depth/time e.g. mm/yr or volume/time e.g. ML/yr
river catchment	the extent of land where water from precipitation drains into a waterway
runoff	a hydrologic process whereby rainfall volume or intensity exceeds soil infiltration capacity, leading to flows across the ground surface and into drainage lines and waterways
surface water	see *Water Act 1992*, section 43
tidal forcing	the continuous increase and decrease in water level in the tidal estuary due to the gravitational field of the moon
variance	a statistical measure of dispersion, or the spread of numbers in a data set
water allocation plan	see *Water Act 1992*, section 22B
water control district	see *Water Act 1992*, section 22
watertable	the water surface where water pressure head is equal to the atmospheric pressure. Or more easily conceptualised as the surface where rock or soil becomes fully saturated. Also known as the phreatic surface
waterway	see *Water Act 1992*, section 4(1)
wet season	the period from 1 October to 30 April

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1. Executive summary

A water allocation plan (plan) is currently under development for the Adelaide River catchment and is due to be completed in 2026. The plan area covers an area of 7455 km^2 and includes all catchments and subcatchments of the Adelaide River and its tributaries, from the headwaters in Litchfield National Park to the coastal plains of the Arafura Sea extending up to Cape Hotham and includes all rivers and creeks flowing into the Adelaide River including its major tributary, the Margaret River. The plan will manage surface water resources, however a parallel Darwin Rural strategy coupled with the extension of the Darwin Rural water control district to include the Adelaide River catchment, will aid in collecting groundwater use data.

As a part of development of the plan a water resources assessment was undertaken to bring together historical and contemporary data and knowledge to describe the hydrological (surface water) features and characteristics of the Adelaide River catchment.

The Adelaide River catchment lies within the wet-dry tropics of northern Australia and has a strongly seasonal climate with a hot-wet summer and a warm-dry winter. Summer rainfalls across the catchment average 1,500 mm between November and April, with very little rain from May to October. An increasing trend in annual rainfall is evidenced since the 1960's.

River flows are also highly seasonal, with very low flow rates in winter, many streams cease flowing in most years, and significant flows during summer which can lead to extensive flooding across the coastal plain and upland alluvial floodplains. On average, 1738 GL per year are discharged from the upper catchments into the lower catchment, while mean total catchment flow at end of system is 2354 GL per year (Petheram et al, 2018).

The catchment has generally low relief, with alluvial floodplains developed along the middle reaches and an extensive coastal floodplain along its tidal reaches. The river is macro-tidal, with tidal influence reaching 80 km inland to the Marrakai road crossing. The coastal plain is generally less than 8 m above sea level, with the floodplain extending to a width of 25 km near the coast, and more than 60 km inland. Inundation of the floodplain appears to largely result from direct rainfall and overland flow within the floodplain subcatchments. Lateral connection to the river channel occurs infrequently and not in all years, but for an extended duration when it does occur. Extensive wetlands have developed across the floodplain, some of which persist late into the dry season and are ecologically and culturally significant.

Due to low relief and shallow channels, the hydrology of the non-tidal catchments is complex with multiple flow paths and diversion of discharges from primary channels at relatively low flows. At the upstream limit of tidal influence, the river becomes constricted between low hills punctuating the floodplain which constricts flood flows from the upper catchment to the tidal estuary. A natural storage occurs upstream of the constriction which has supported development of an upland alluvial floodplain.

Groundwater contributions to the Adelaide River and its tributaries are minor, with perennial baseflows occurring in the upper reaches of the Adelaide River which intersects the Tindall Limestone and Jinduckin Formations, and in Coomalie Creek which intersects the Coomalie Dolostone. Other low yielding fractured rock aquifers also appear to contribute to persistent flows along some waterways in the upper Adelaide River catchment, however the upper Adelaide River only flows perennially to Marrakai Crossing in 40% of years. The Margaret River catchment receives no groundwater discharges and typically ceases flowing by July in every year. Groundwater is accessed via bores for agricultural development and stock and domestic use in the area, but is restricted to small precincts such as Acacia, Marrakai and Adelaide River township where the town drinking water supply is sourced from the Burrell Creek Formation.

The measurement and collection of water data is complicated by the complex catchment hydrology, and difficulty of access during the wet season. Flow records are often only available for specific ranges of the hydrograph, and few flow records exist for the Margaret River and lower Adelaide River catchment areas.

The catchment is sparsely populated in general, outside of the Darwin Rural area in the northwest of the catchment around the Lambell's Lagoon area. Development in the catchment is largely pastoral, however intensive agricultural development does occur in some areas including Howard East, Acacia, Marrakai and around Adelaide River township.

Historical development in the catchment was horticulture and water supplies for small communities and townships including Adelaide River township. Surface water gauging started in the catchment at the Adelaide River railway bridge in 1953 and Dirty Lagoon in 1963. Gaugings also began in 1957 on the Margaret River, the largest tributary to the Adelaide River.

Water quality in the river is strongly influenced by rainfall patterns as well as the geology, soils and regolith of the surrounding catchment area, with seasonal runoff a key factor. Surface water quality monitoring dates back to the 1950's, with sampling initially conducted on an ad hoc basis. Data collection has historically been aligned to the flow monitoring gauge stations. More regular monitoring programs have recently been established in response to the proposed development of the water resource.

Salinity, measured by electrical conductivity, exhibits both spatial and temporal variation along the river. During the dry season, salinity levels are higher, while in the wet season salinity decreases due to increased freshwater runoff. Notably, conductivity drops in the lower catchment during the wet season, where salinity temporarily shifts to a freshwater condition. As the dry season progresses, conductivity increases in the lower catchment, signifying a transition from freshwater to brackish conditions. These fluctuations are influenced by tidal cycles and stream discharge, especially during peak flow events in the wet season.

Turbidity shows strong seasonal variability, with significant increases during the wet season. Turbidity can exceed 500 NTU, while during the dry season in the upper Adelaide River catchment, it can drop as low as 0.1 NTU. Generally, turbidity increases downstream, reflecting the accumulation of suspended sediments as water flows through the catchment.

Nutrient concentrations are elevated at times, especially during the wet season. The highest concentrations have been observed at sites in the lower catchment, particularly around Dirty Lagoon and the Arnhem Highway.

Metals have been detected in elevated concentrations, with aluminium, copper and zinc reported well above the default trigger values for aquatic ecosystems. Recent sampling conducted in 2023, by both the Department of Lands, Planning and Environment and the Department of Mining and Energy, Legacy Mines Unit reported metal concentrations with all soluble analytes complying with the default trigger values for 95% protection of aquatic ecosystems, with the exception of aluminium.

Natural sources in the catchment, such as laterite formations and certain soils, contribute metals like aluminium and iron to the Adelaide River. Historically, mining has been significant in the upper Adelaide and Margaret River catchments, with active mines and legacy sites present. While natural sources contribute aluminium, the impact of anthropogenic activities will continue to be monitored.

Much of the catchment has protected area status with:

- conservation reserves on the coastal plain, Black Jungle: Fogg Dam: Harrison Dam and Melacca Swamp
- Djukbinj National Park, in the northeast of the catchment
- Litchfield National Park, in the southwest of the catchment.

In 2013, Power and Water Corporation undertook an options assessment of Darwin's future water supplies. To meet future demand, the options put forward included Manton Dam's return to service and an off-stream storage reservoir known as the Adelaide River Off-stream Water Supply. The Adelaide River Off-stream Water Supply would source water from the Adelaide River to supply the storage. Both Manton Dam and the proposed Adelaide River Off-stream Water Supply location are within the Adelaide River catchment.

This report provides an assessment of the surface water resources in the Adelaide River catchment, as well as an overview of the groundwater resources.

2. Introduction

2.1 Purpose

The purpose of this report is to characterise and quantify the surface water resources within the boundaries of the proposed Adelaide River water allocation plan (plan) to provide an overview of inflow sources, characterise and quantify seasonal and annual flow variations and identify past and emerging climatic and hydrological trends based on the hydrometric data record and other documented reference material.

2.2 Study area

The plan area encompasses the entire surface catchment area of the Adelaide River catchment, covering an area of approximately 7,445 km^2 to the east and southeast of Darwin (Figure 1). The Adelaide River catchment falls within the Tanami – Timor Sea Coast drainage division, with the Adelaide River and its tributaries flowing in a generally northerly direction from the broken foothills in the south of the catchment to the Arafura Sea in the north. Adelaide River township is the largest settlement within the Adelaide River catchment, lying in the south of the catchment. Other settlements within the catchment include Batchelor on the western boundary, and the Acacia Hills and Marrakai rural districts. Three Aboriginal communities, Acacia Larrakia, Amangal Indigenous Village and Gulngarring, also occur within the plan area.

The catchment is a part of the Darwin Rural and Adelaide River water control district. A water allocation plan is being prepared for the Adelaide River catchment, to be finalised by mid 2026. The plan will manage and regulate the use of surface water across the catchment.

Figure 1 shows the location of the proposed Adelaide River water allocation plan area along with other water allocation plans either declared or under development. Land use within the catchment is largely pastoral, however market gardening and orchards are also common particularly around Acacia and Marrakai districts. A significant proportion of the area is protected within reserves and national parks including parts of Litchfield National Park, Manton Dam Recreation Area, Djukbinj National Park, Fogg Dam and Harrison Dam Conservation Reserves, Black Jungle/Lambells Lagoon Conservation Reserve and Melacca Swamp Conservation Area.

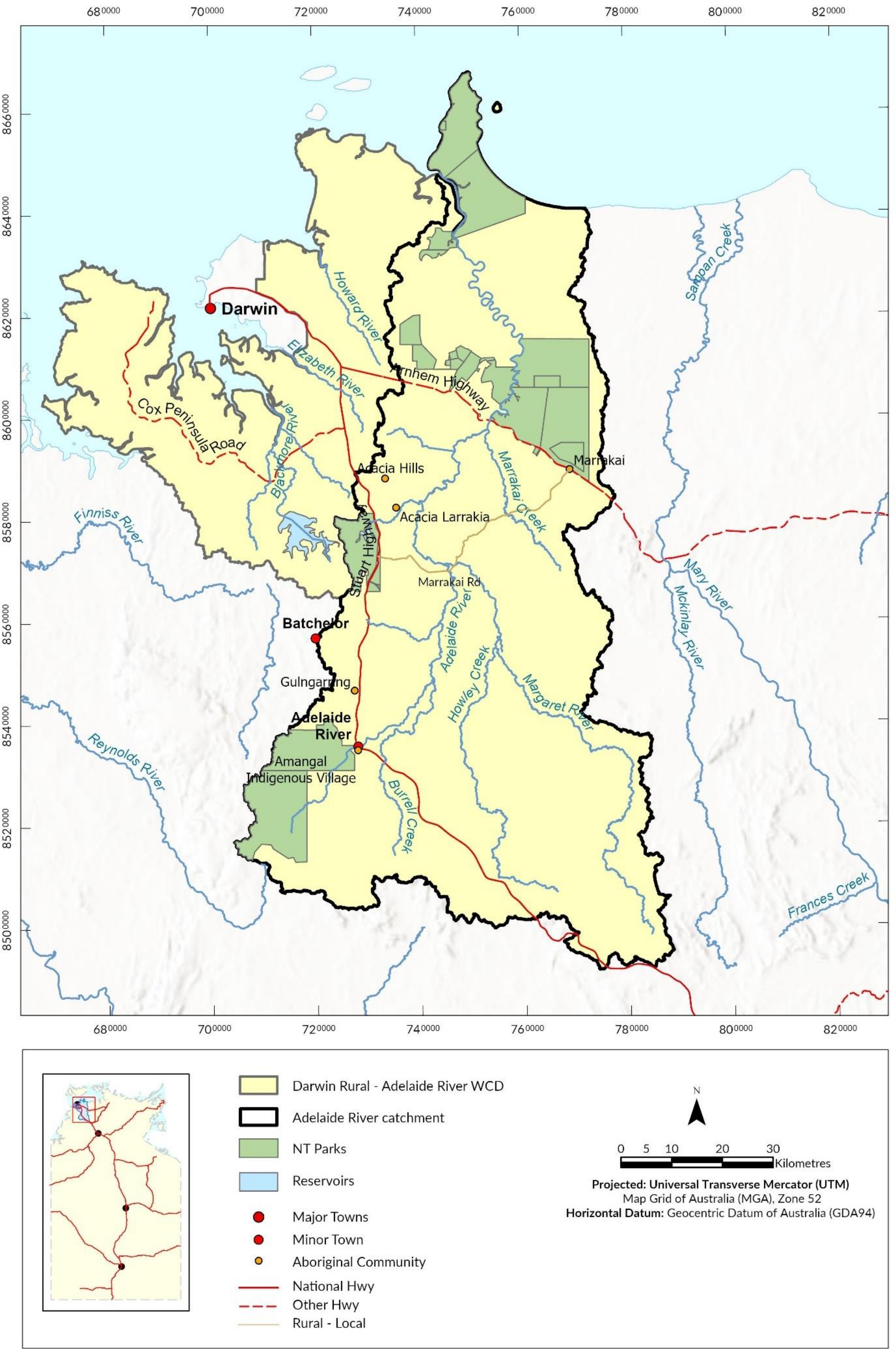


Figure 1. Locality of the Adelaide River catchment

2.3 Previous studies

Several studies have previously been undertaken in the north Australian region, including within the Adelaide River catchment. Figure 2 shows the coverage of other recent studies that have been undertaken in the Adelaide River catchment region, NB. only components of studies undertaken in the Northern Territory (NT) are shown.

2.3.1 Northern Australia sustainable yields project

The Northern Australia sustainable yields project emerged from a Council of Australian Governments initiative to expand sustainable yield assessments of surface and groundwater systems into Northern Australia. Funded by the National Water Commission, the project was delivered by CSIRO with support from state and territory governments, the projects provided estimates on the impacts of development, groundwater extraction, climate variability and anticipated climate change on surface and groundwater resources throughout Northern Australian catchments.

The project was divided into four regions, of which the Van Diemen region of the Timor Sea drainage division included the Finniss, Adelaide, Mary, Wildman, South Alligator, East Alligator River catchments, as well as Tiwi Islands.

2.3.2 Northern Australia water futures assessment

The Northern Australia water futures assessment was a National Water Commission funded multidisciplinary program delivered through the Commonwealth Department of Sustainability, Environment, Water, Populations and Communities between 2007 and 2012. The project was undertaken by Tropical Rivers and Coastal Knowledge Commonwealth Environmental Research Facility, a collaboration of Commonwealth and state government agencies and tertiary institutions.

The Northern Australia water futures assessment was undertaken to provide essential information on the water resources in the northern Australian landscape and the watering needs of key ecosystem, community and cultural assets, and the risks to the values of those assets arising from changes in the hydrological regime through threats including development and climate change.

2.3.3 Northern Australian water resources assessment

In 2015 CSIRO produced the Our North, Our Future: White Paper on Developing Northern Australia prioritising regions in northern Australia where more detailed water and agriculture resource assessments should be undertaken. The Darwin catchments, including Finniss, Adelaide, Mary and Wildman River catchments, were selected as the first of a number of potential catchments within the NT to undergo a water resource assessment due to their proximity to Darwin. The Northern Australian water resource assessment (NAWRA) was a collaboration led by CSIRO and included Bureau of Meteorology, state and territory governments and various universities across Australia.

NAWRA focussed on the availability of water and soils suitable for agriculture, as well as evaluation of surface water storage options, viability of agricultural development, Aboriginal aspirations and water values and freshwater, riparian and inshore marine ecology. The NAWRA reports were published in 2018.

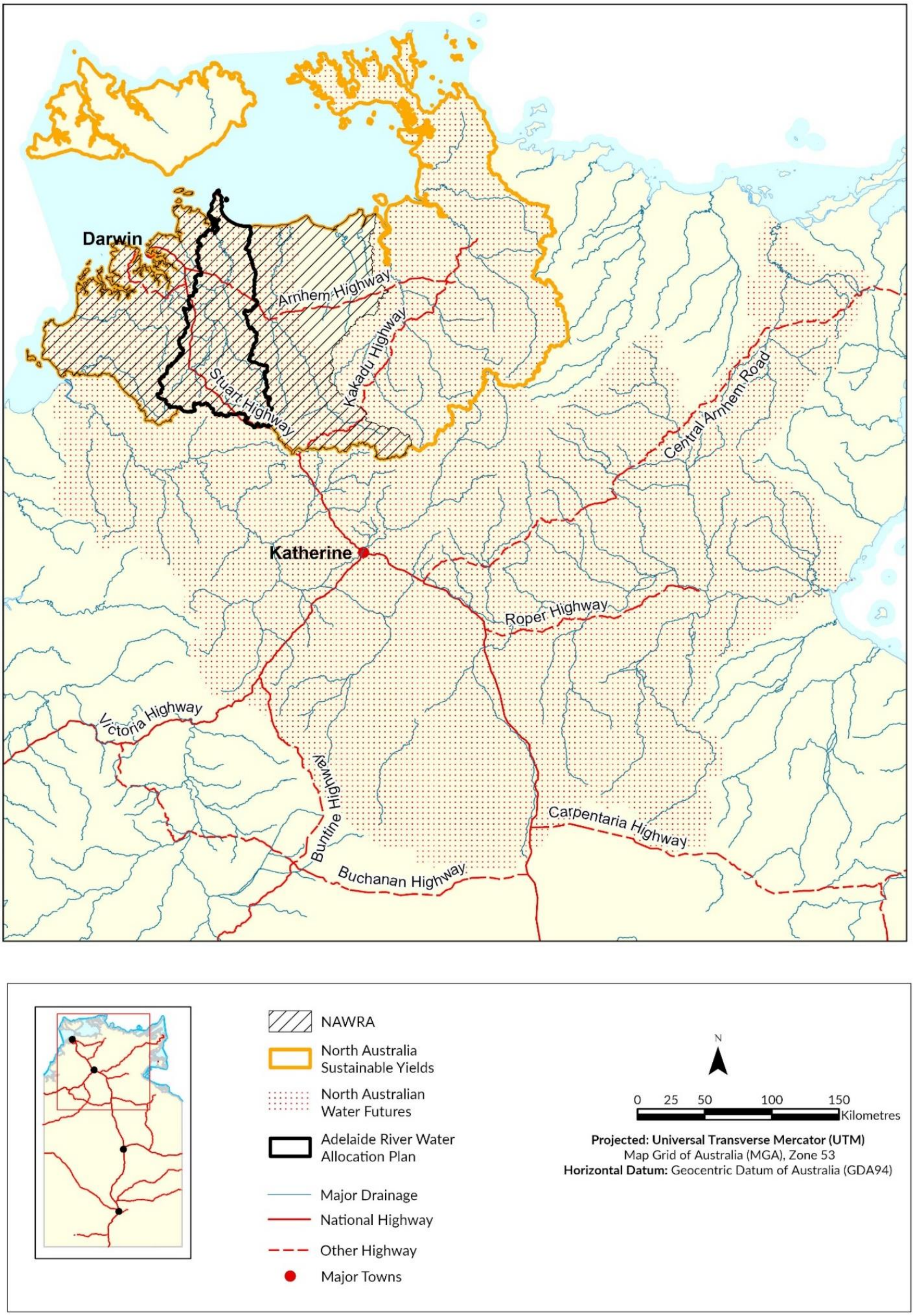


Figure 2. Previous and recent studies within the Adelaide River catchment region

2.4 Physiography

The study area predominately falls into two bioregions: Darwin Coastal and Pine Creek, with the southwestern fringes falling within the Daly Basin bioregion. Topography in the study area ranges from approximately 0 to 300 m Australian Height Datum (AHD).

Figure 3 shows the topography and surface drainage for the study area. Most of the catchment is defined by low elevation and low relief, with most of the northern half of the catchment having a surface elevation below 10 m AHD. Areas of higher elevation in the southwest incorporate the broken foothills at the northern periphery of the Daly (geological) catchment, while higher elevations to the southeast make up the northern periphery of the Pine Creek basement rock, however most of the catchment consists of shallow lowland valleys with extensive alluvial floodplains to the north (DSEWPC, 2011; TRaCK, 2012).

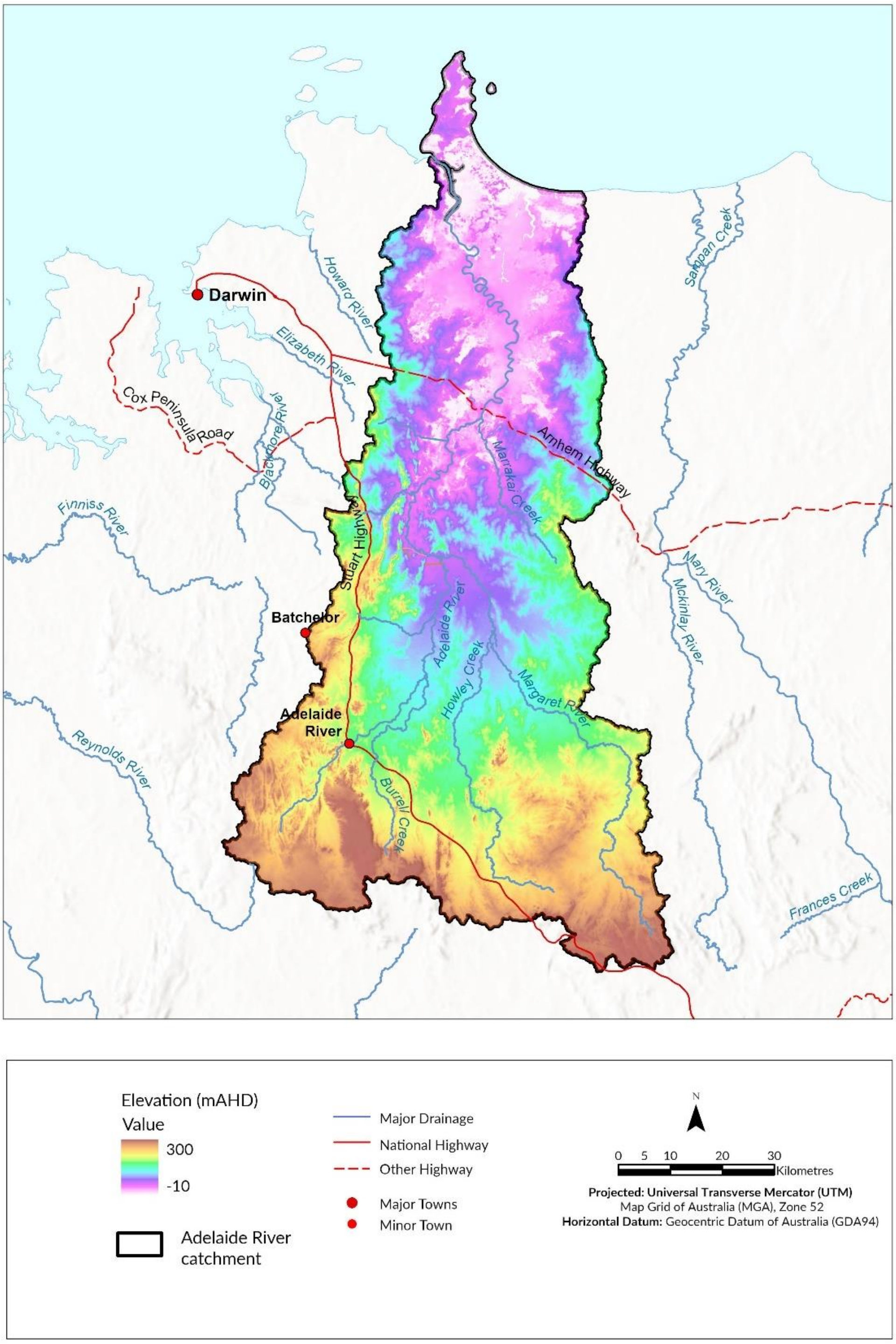


Figure 3. Topography and major surface water drainage

2.5 Climate

The Adelaide River catchment lies within the wet-dry tropics of northern Australia, entirely within the tropical savannah climate zone based on the Köppen climate classifications (Köppen, 1884). Figure 4 shows the location of the Adelaide River catchment relative to the Köppen climate zones. 95% of rainfall in the Adelaide River catchment occurs during the summer wet season between November and April (CSIRO, 2009; Petheram et al, 2018), when the monsoon trough is drawn southward from the equator. Very little rainfall occurs during the dry season from May to October (Figure 5). Early wet season rainfall occurs as high intensity, localised convective storms during the build-up and early wet season, and during monsoon break periods. The bulk of wet season rainfall occurs when monsoonal troughs descend over the Top End and release widespread rainfall of moderate to high intensity over periods extending from days to several weeks. The wettest months typically occur in December, January, February and March.

Rainfall analysis from 1991 to 2024 reveals a notable north-south gradient across the study area, with approximate mean annual rainfall decreasing from 1,700 mm in the north-west, to 1,500 mm in the central region of the catchment, and declining to 1,400 mm in the south, a decrease in median rainfall of around 150 mm per half degree of latitude from north to south. Figure 6 shows mean annual rainfall across the Adelaide River catchment between 1991 and 2020.

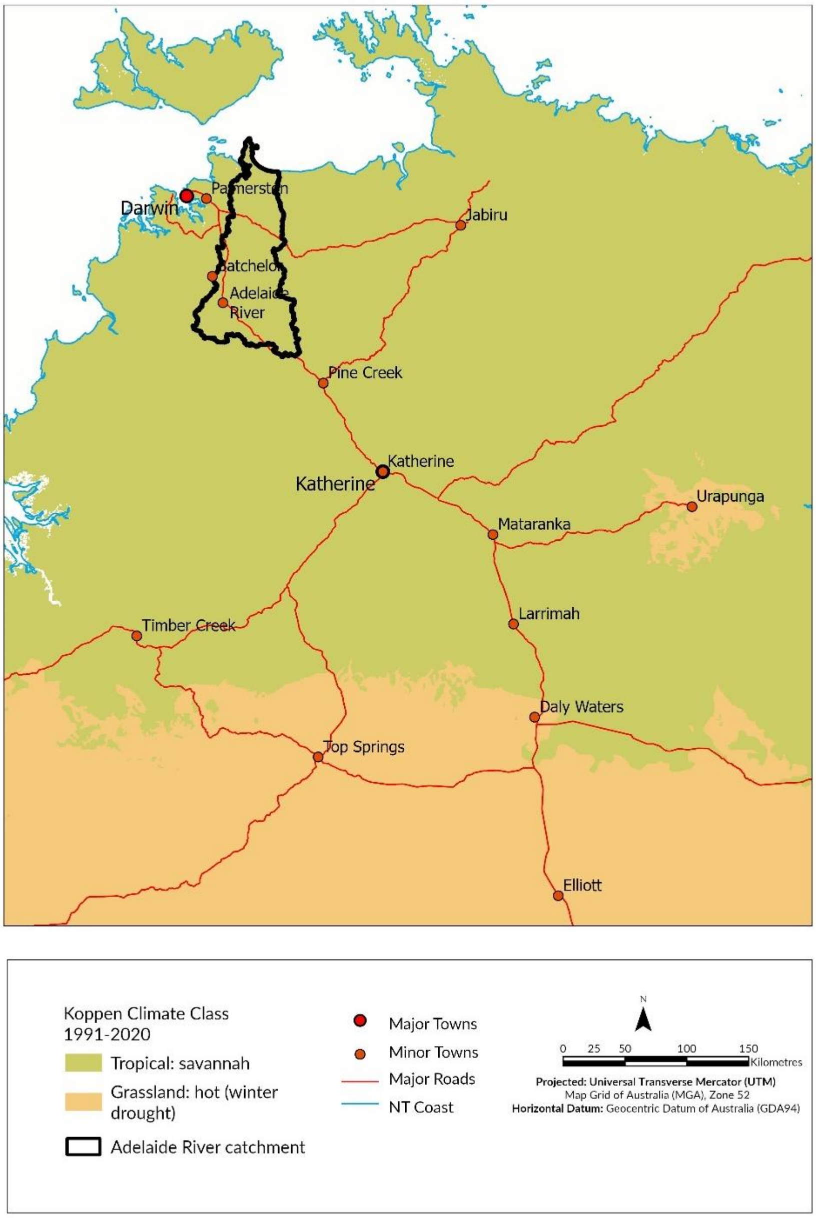


Figure 4. Köppen climate classification

Potential evapotranspiration (PET) is annually greater than rainfall (CSIRO, 2009), significantly exceeding rainfall from April through to November (Figure 5) resulting in water limited conditions over these months (CSIRO, 2009). Conversely, rainfall significantly exceeds PET during the wet season months. PET is relatively consistent across the catchment with only a slight increasing trend from north to south. Mean annual PET in the north of the catchment at Koolpinyah is 2,640 mm, increasing to 2,727 mm in the south at Adelaide River township based on data from 1970 to 2024. Average monthly PET across the catchment peaks in October at around 280 mm and rarely drops below 170 mm during wet season months.

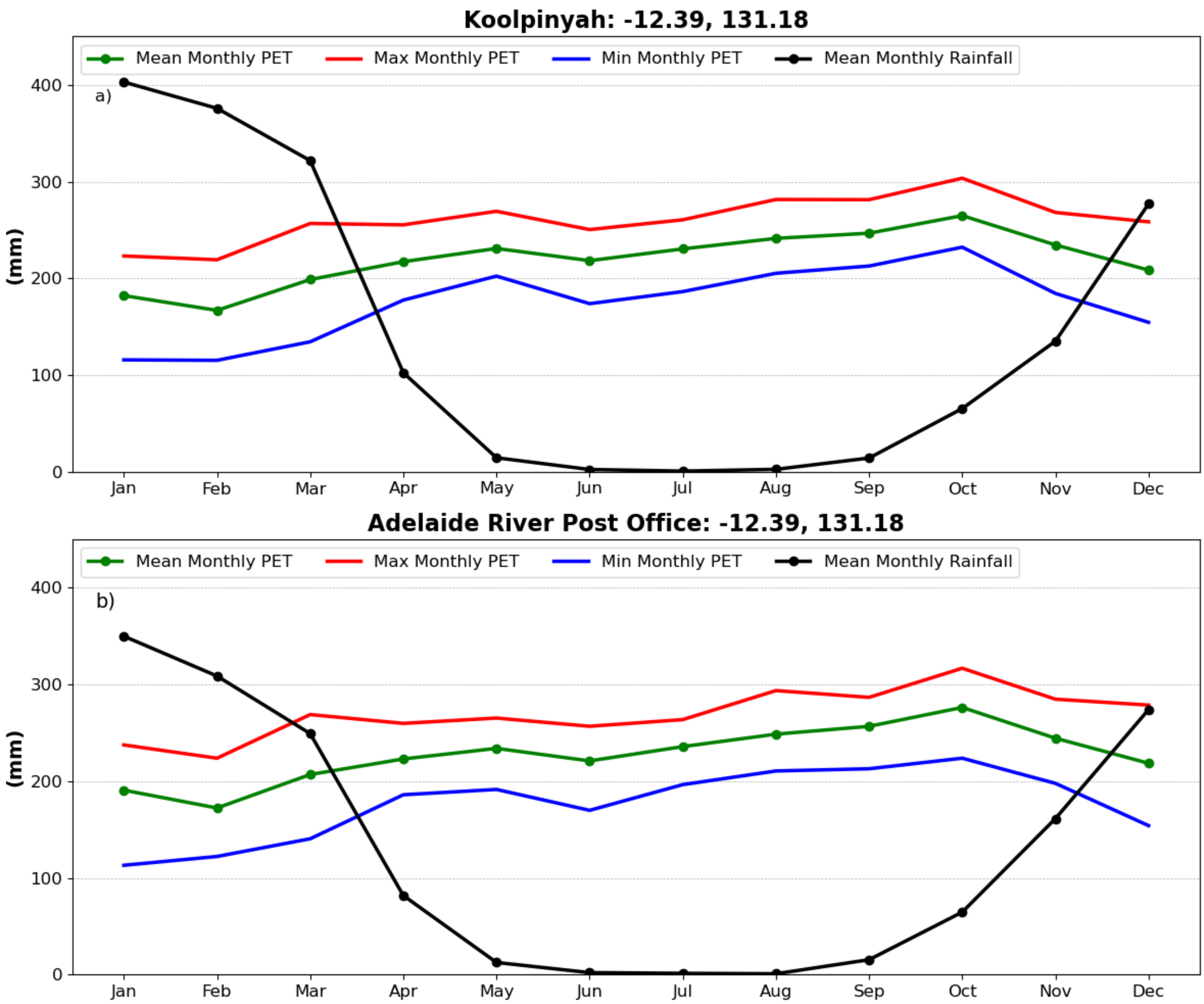


Figure 5. Mean monthly rainfall and potential evapotranspiration (PET) at Koolpinyah and Adelaide River post office for the period 1970 to 2024 (SILO, 2024)

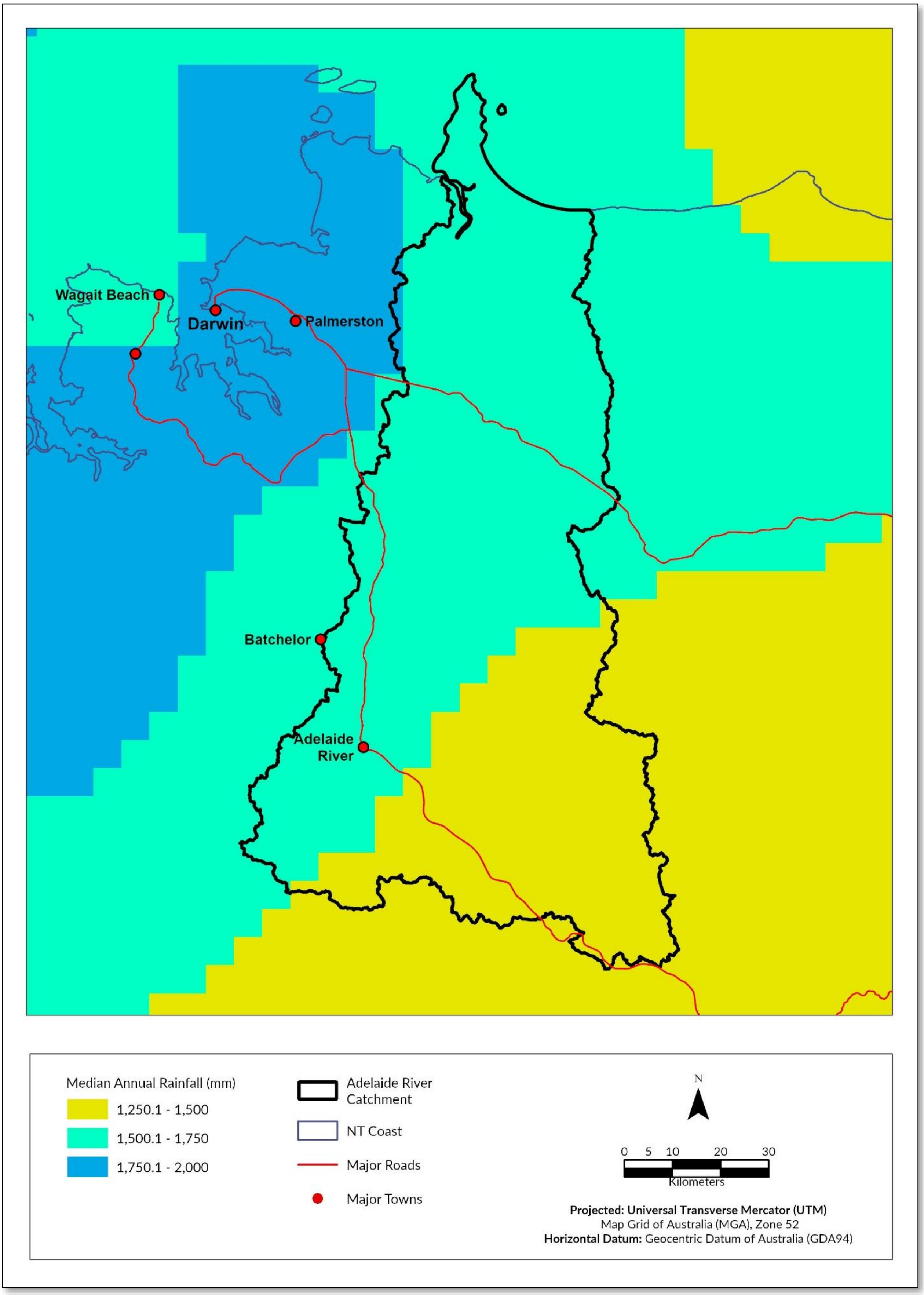


Figure 6. Mean Annual rainfall 1991 to 2020 (Source: Bureau of Meteorology)

The area is hot year round, with the long-term maximum temperatures from 1900 to 2024 being 34.7°C at Koolpinyah and 35.7°C at Adelaide River township. The long-term average minimum temperatures are 19.3°C and 17.8°C respectively. Typical of coastal catchments, temperatures in coastal regions are moderated by proximity to the ocean while temperatures in inland areas have greater daily variability (Barry & Chorley, 2003). Mean daily maximum temperatures exceed 35°C in the wet season and are typically just below 35°C in the dry season. Mean daily minimum temperatures rarely fall below 12°C in the dry season and exceed 20°C in the wet season. October or November are typically the hottest months of the year, depending upon wet season onset, while July is usually the coldest month of the year (Figure 7).

The maximum temperature measured at Koolpinyah and Adelaide River post office were 39.4°C and 42.3°C, respectively (occurred in 2019).

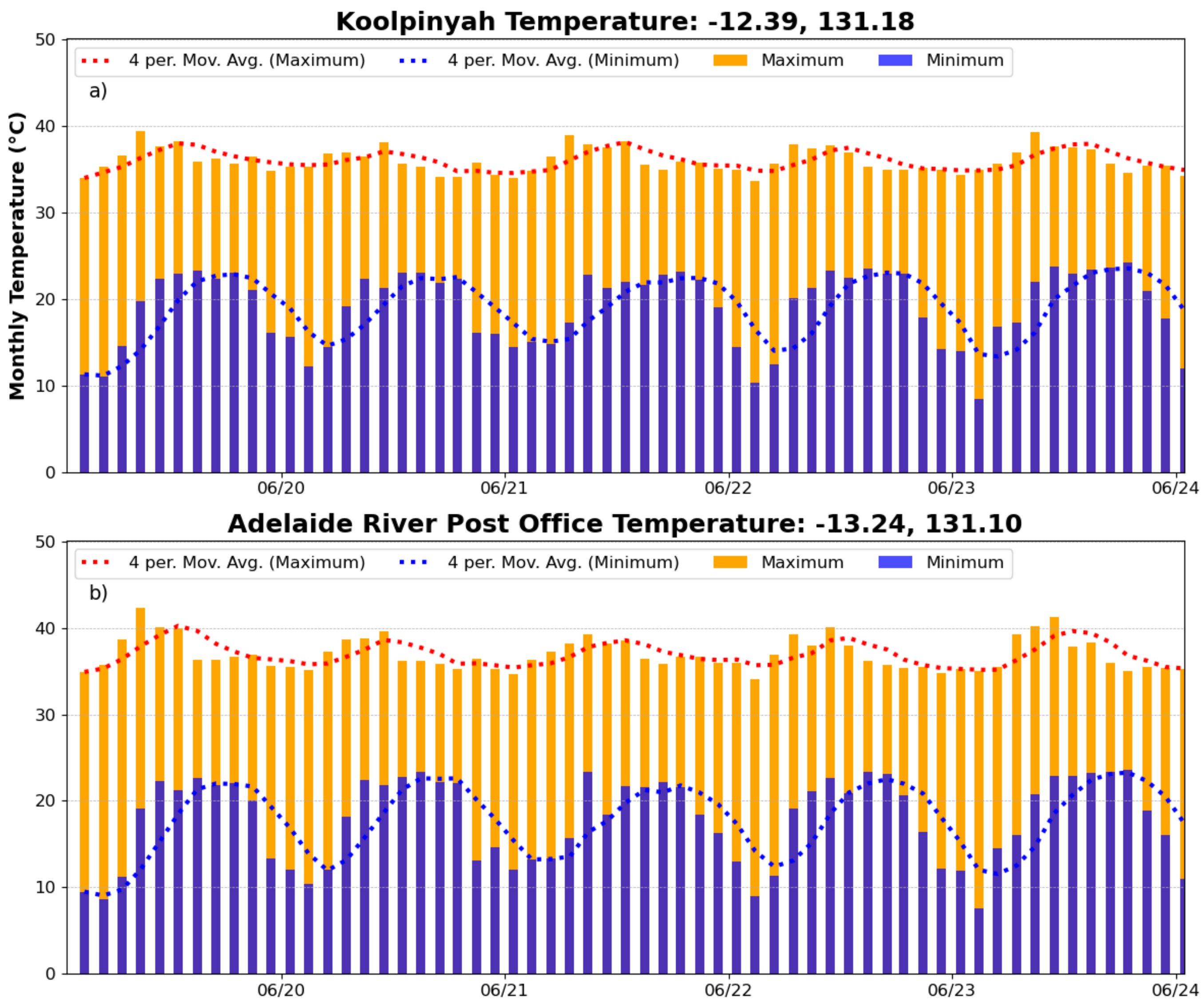


Figure 7. Temperature variations at Koolpinyah and Adelaide River post office (SILO, 2024)

2.6 Climate variation

In the Northern Australia water resource assessment, Petheram et al (2018) noted irregular runs of wet and dry years occur across the 'Darwin catchments' potentially influencing the scale, profitability and risk of water resource investments. Rainfall records demonstrate an overall trend of increasing rainfall across the region including the Adelaide River catchment since 1900 (CSIRO, 2009), however this increase has not been constant. Cycles of wetter and drier periods are evident within the rainfall record relative to the overarching increasing trend. For the purposes of this analysis, rainfall totals have been aggregated for each water year (1 July to 30 June) so that total annual wet season rainfall can be analysed.

Figure 8 and Figure 9 show the annual rainfall record for Adelaide River township in the south, and Koolpinyah in the north of the Adelaide River catchment. They show significant variation in rainfall totals year to year, however a distinct increasing trend is emerging.

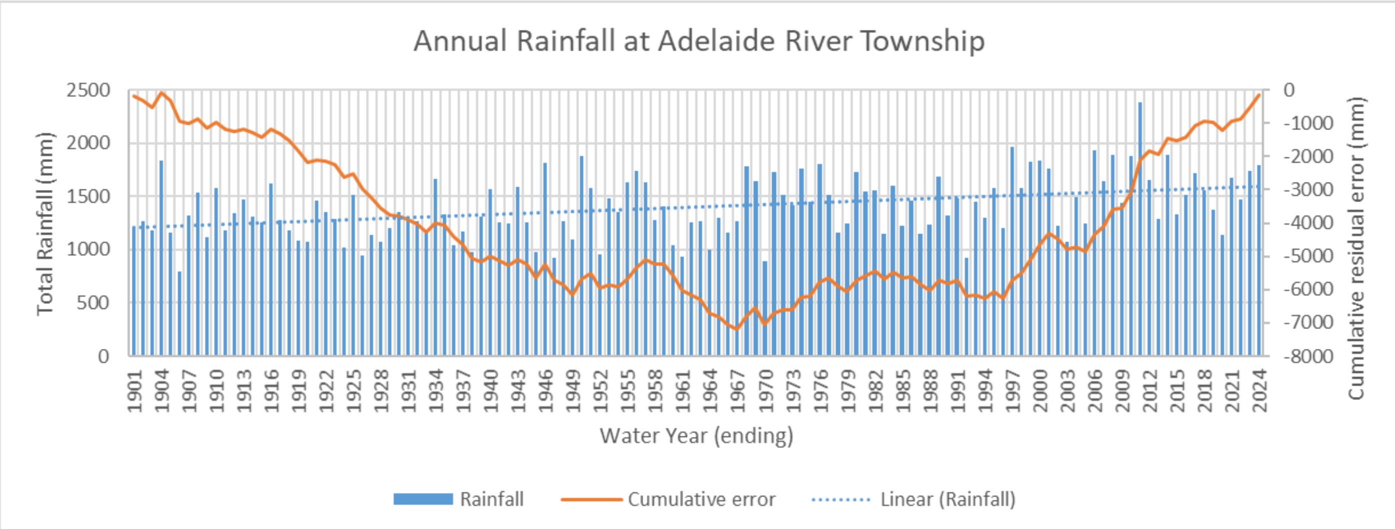


Figure 8. Total annual rainfall (water year) from 1900 to 2024 at Adelaide River Township (data source: SILO)

The cumulative residual error plot of the mean shows two macro-trends, with generally lower than average rainfall for most of the last century to 1967 followed by a period of higher than average rainfall from 1968 to current. Both graphs also show a sharp increase in annual rainfall from the mid 1990's.

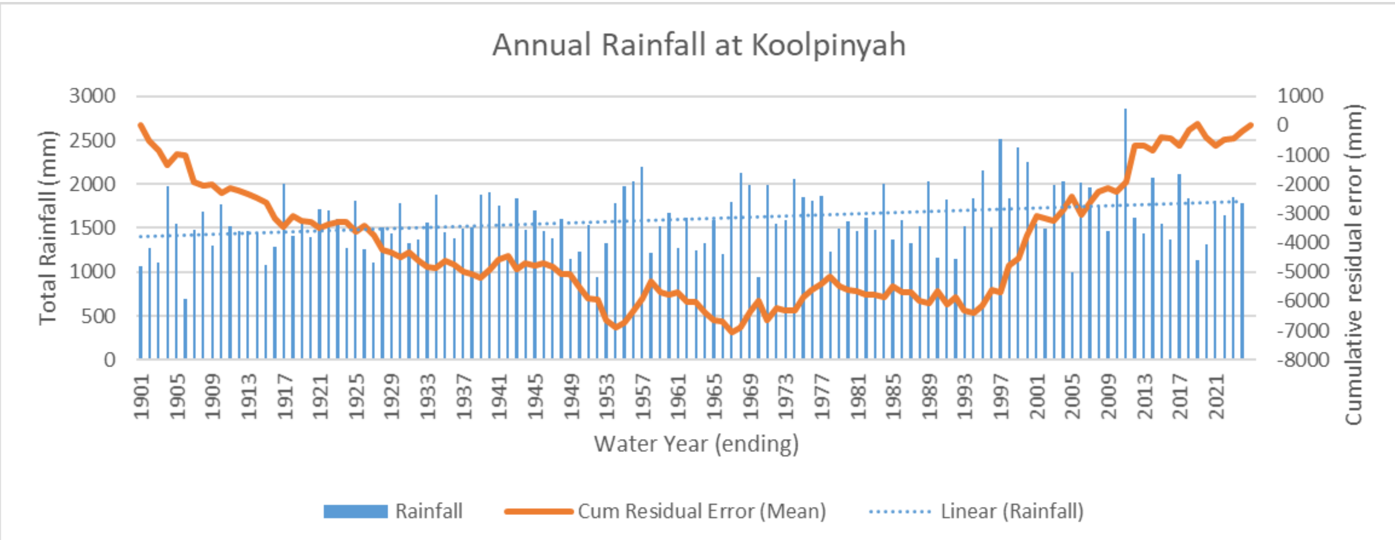


Figure 9. Total annual rainfall (water year) from 1900 to 2024 at Koolpinyah (data source: SILO)

Table 1 and Table 2 shows mean annual rainfall for key trend periods identified in Figure 8 and Figure 9. They demonstrate a gradual increase in rainfall across the Adelaide River catchment from 1968, followed by a sharper increase since the mid 1990's.

Table 1. Period rainfall means - Adelaide River town

Rainfall period	Mean annual rainfall (mm) 1 July to 30 June
1900 to 1967	1292
1968 to 1996	1430
1997 to 2024	1618

Table 2. Period rainfall means - Koolpinyah

Rainfall period	Mean annual rainfall (mm) 1 July to 30 June
1900 to 1967	1493
1968 to 1993	1620
1994 to 2024	1808

Analysis of rainfall trends at finer detail does identify wetter and dryer periods at roughly decadal intervals. Appendix B shows rainfall trends identified through analysis of cumulative error from the rainfall trendline. These analyses further demonstrate the larger trends, with a recent dryer period from 2014 to 2022 having higher mean annual rainfall than wetter periods from the early to mid 1900's.

The occurrence of two distinct climatic periods since 1900 was postulated by Yin Foo et al (2021) when investigating recharge variations in southern regions of the Top End. They found that prior to 1960, distinctly lower groundwater recharge occurred than during the post 1960 period, most likely due to unfavourable climatic conditions including total annual rainfall. Rainfall trends within the Adelaide River catchment show a 20-25% increase in mean annual rainfall from 1900 to 1967 and 1997 to 2024, suggesting a similar climate pattern in the northern Top End.

Investigations into potential future climate scenarios in NT catchments have been undertaken by CSIRO (2009, 2020). The studies predicted future climate conditions from 16 global climate models and compared dry, medium and wet scenarios for each of the high, medium and low warming scenarios relative to a baseline period, 1930 to 2007. They demonstrate that recent rainfall across the Adelaide River catchment, 1996 to 2007, was statistically significantly wetter than the baseline period, with a 14% increase in rainfall leading to a 44% increase in runoff (CSIRO, 2009). In the short term, rainfall and runoff to 2030 is predicted to be similar to the long-term conditions, however longer-term projection from seven climate models showed a decrease in mean annual runoff from the long-term mean, while eight models showed an increase in mean annual runoff. For the high emissions scenarios, four models predicted a decrease in mean annual runoff by more than 10%, while three models predicted an increase in mean annual runoff by greater than 10% from the 1930 to 2007 baseline. More recent projections reported by CSIRO (2020) estimate end of century ranges for dry season rainfall of -45% to +44%, and for wet season of -23% to +19%, with more intense rainfall events which is likely to lead to increased proportion of runoff.

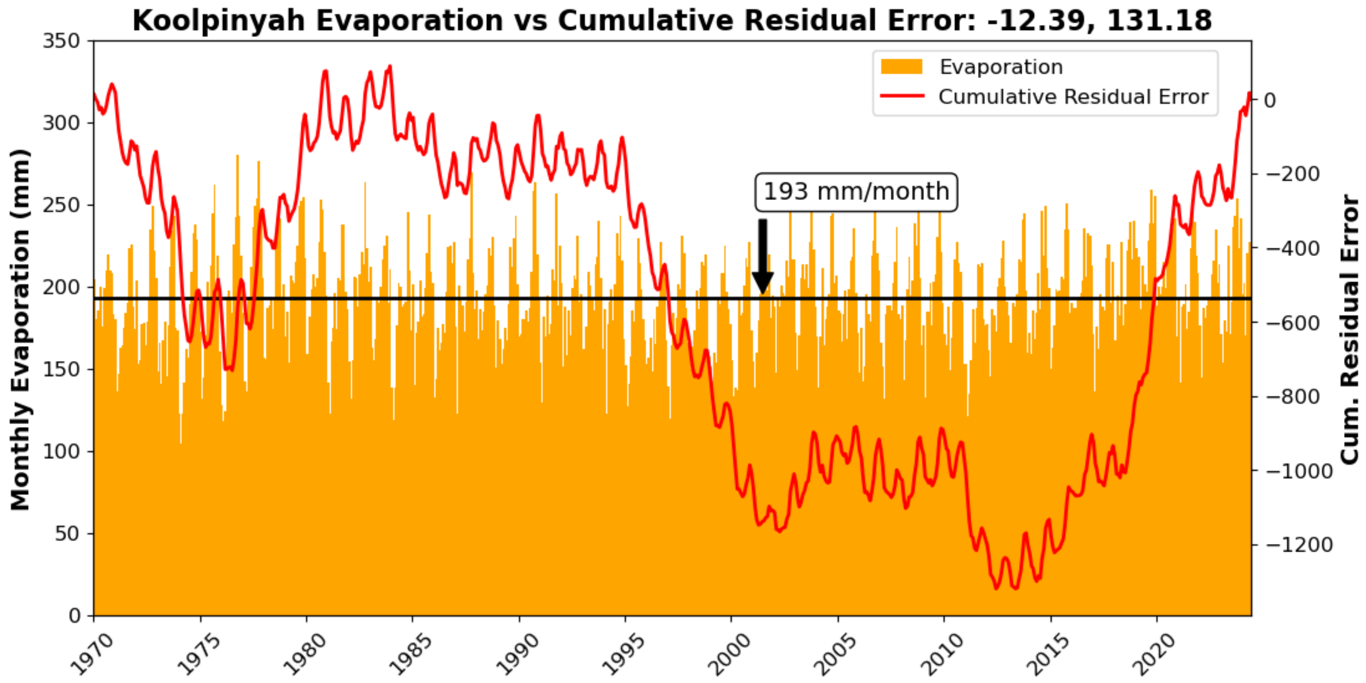
Crosbie et al. (2009, 2013) compared the 2050 climate parameter for low, medium and high CO_2 emission scenarios relative to a baseline period (1970) to develop a recharge scaling factor (RSF) for groundwater. RSF of 1 indicates no change in recharge compared to the baseline; values greater than 1 indicate increased recharge rates, and values less than 1 indicated reduced groundwater recharge due to global warming.

RSF's for water control districts covering part of the plan area, summarised in Table 3, are based on recent hydrological records along with increased intensity in rainfall events.

Table 3. Recharge scaling factor's for water control district and water allocation plan areas covering the proposed plan area

Region	Median projection			Dry projection			Wet projection		
	low	medium	high	low	medium	high	low	medium	high
Darwin Rural area water control district	0.96	1.00	0.94	0.88	0.88	0.73	1.08	1.22	1.08
Howard water allocation plan (draft)	0.94	0.98	0.91	0.86	0.85	0.68	1.07	1.22	1.25

PET is directly correlated with air temperature, wind speed and solar radiation, and inversely correlated with relative humidity. Figure 10 illustrates the monthly evaporation for the period from 1970 to 2024 at Koolpinyah and Adelaide River post office. Consistent daily Class A pan evaporation data are not available in Australia before 1970 (Rayner et. al., 2004). The cumulative residual error from the mean shows periods of generally below average and above average evaporation. From 1970 to middle 1990's, monthly evaporation oscillated around the average of 193 mm, with some significant deviations such as a very big fall in evaporation in 1974, and significant increases in evaporation in 1978 and 1980. A general correlation exists between lower evaporation from early – mid 1990's until 2013 and increased rainfall over this period, likely due to increased cloud cover accompanying increased rainfall. Since 2014, evaporation has significantly increased in both the north and south locations, probably linked to higher temperatures since 2012. Higher evaporation has occurred since 2014 with significant increases during the lower rainfall period between 2015 and 2021. Since 2022 higher evaporation rates have persisted even though rainfall totals across the catchment have also increased.



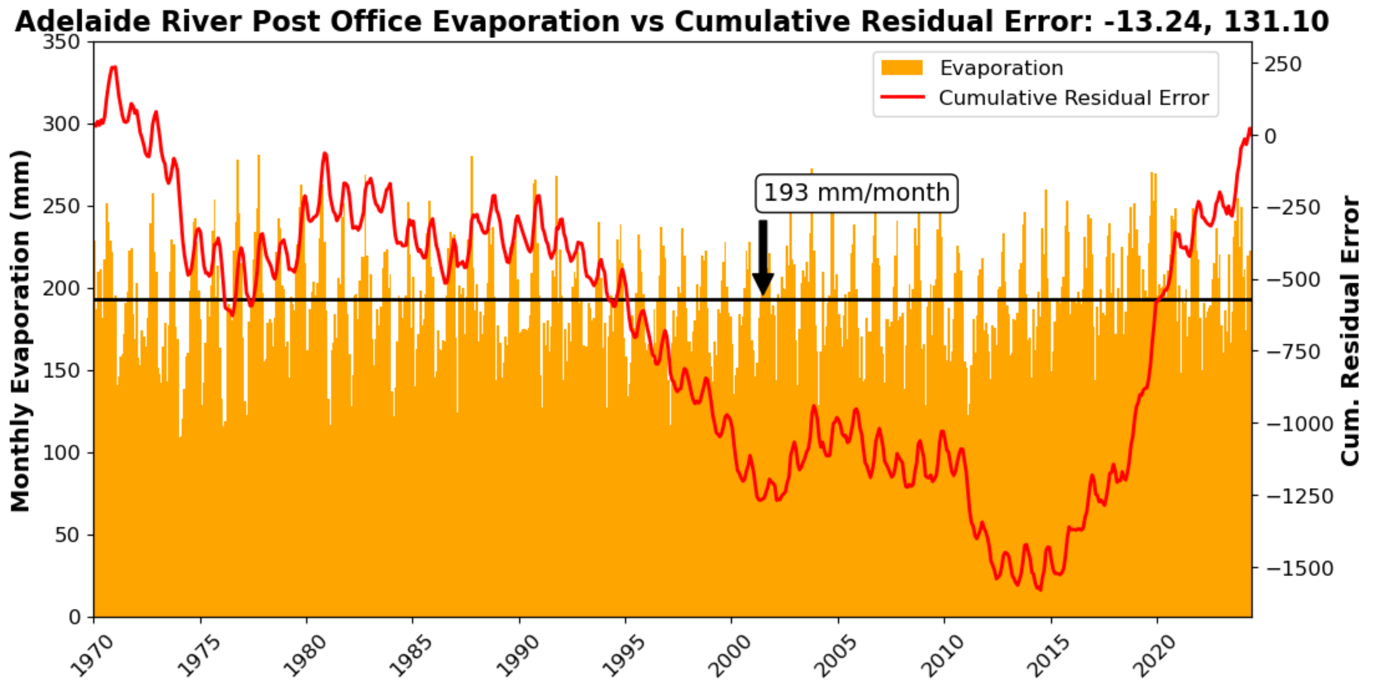


Figure 10. Monthly evaporation and cumulative residual error at Koolpinyah and Adelaide River post office (SILO, 2024)

Recent higher evaporation rates despite higher rainfall and increased cloud cover since 2022 may result from increasing temperatures across the catchment. Figure 11 and Figure 12 shows annual maximum and annual minimum temperature at Koolpinyah and Adelaide River township. They show annual maximum temperatures have been gradually increasing across the catchment since 1900. They also show annual minimum temperatures have been decreasing. As minimum temperatures occur overnight or in the early morning when no, or very little, solar radiation occurs, decreasing minimum temperatures do not have any significant impact on evaporation.

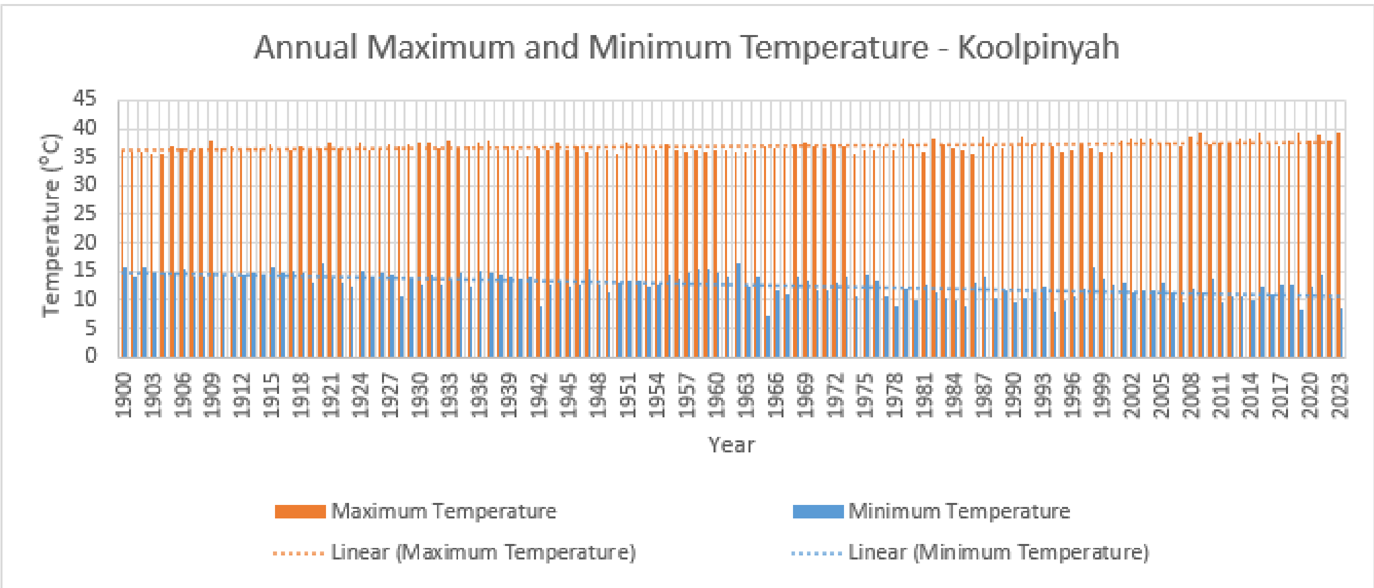


Figure 11. Annual max and min temperatures at Koolpinyah

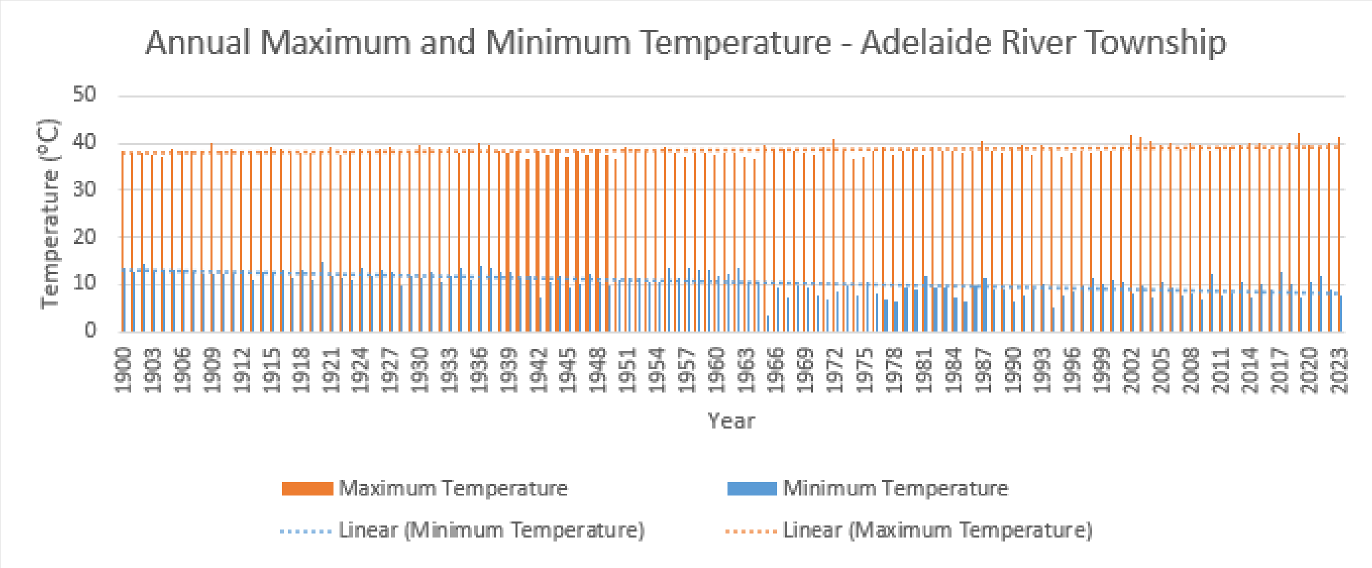


Figure 12. Annual max and min temperatures at Adelaide River township

This general increase in annual temperatures is reflected in a general increase in PET across the catchment since 1970 (Figure 13).

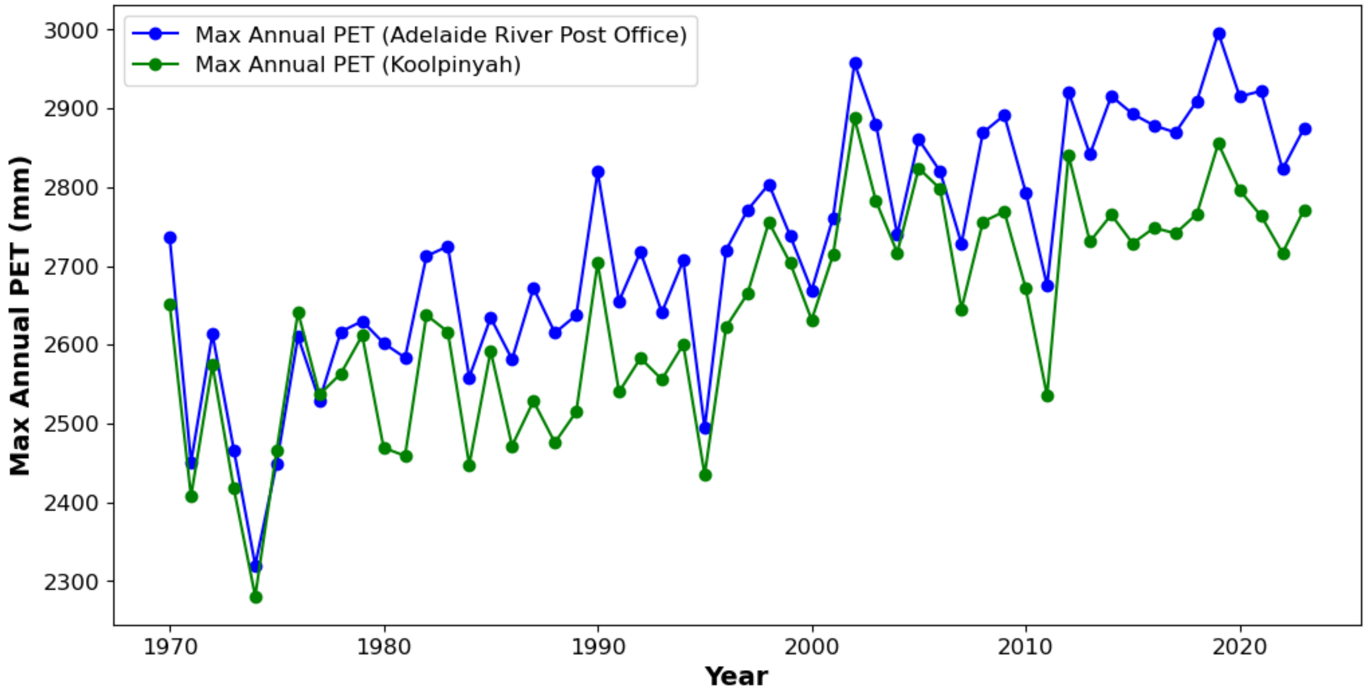


Figure 13. Maximum annual PET for Koolpinyah and Adelaide River post office for the period 1970 to 2024 (maximum instantaneous SILO data, 2024)

3. Groundwater resources

3.1 Geology

The majority of aquifers in the catchment are hosted in steeply dipping folded and faulted sedimentary rocks of Proterozoic age; mostly between 1,800 and 2,500 million years old. In places these have been intruded by granite batholiths of the Cullen Supersuite and dolerite dykes of the Zamu Dolerite. These are locally unconformably overlain by younger gently dipping to flat-lying formations; notably the Tolmer Group, Daly River Group and the Darwin Formation. A summary of selected stratigraphic units in the district is presented in Table 4 and a geological map of the catchment is shown in Figure 14.

Table 4. Stratigraphy of the Darwin district (modified after Ahmad and Hollis, 2013)

CRETACEOUS		Darwin Formation	Kaolinitic claystone, basal conglomerate and sandstone
UNCONFORMITY			
PALAEOZOIC	Daly River Group	Jinduckin Formation	Dolomitic siltstone with minor sandstone and dolostone
PALAEOZOIC	Daly River Group	Tindall Limestone	Limestone, dolostone and minor siltstone
UNCONFORMITY			
MESOPROTEROZOIC	Tolmer Group	Waterbag Creek Formation	Mudstone and minor sandstone
MESOPROTEROZOIC	Tolmer Group	Hinde Dolostone	Dolostone and minor limestone
MESOPROTEROZOIC	Tolmer Group	Stray Creek Sandstone	Laminated sandstone and siltstone
MESOPROTEROZOIC	Tolmer Group	Depot Creek Sandstone	Sandstone. Quartzite and conglomerate
UNCONFORMITY			
PALAEO-PROTEROZOIC		Cullen Supersuite	Granite
PALAEO-PROTEROZOIC		UNCONFORMITY	
PALAEO-PROTEROZOIC		Zamu Dolerite	Dolerite
PALAEO-PROTEROZOIC		Burrell Creek Formation	Siltstone, shale, greywacke and phyllite
PALAEO-PROTEROZOIC		South Alligator Group	Shale, siltstone, haematitic siltstone, minor dolostone and dolomitic siltstone
PALAEO-PROTEROZOIC		Wildman Siltstone	Carbonaceous shale, haematitic siltstone, sandstone and quartzite
PALAEO-PROTEROZOIC		Acacia Gap Quartzite	Quartzite, sandstone and minor shale
PALAEO-PROTEROZOIC		Whites Formation	Calcareous and carbonaceous shale, minor dolomitic siltstone and dolostone
PALAEO-PROTEROZOIC		Koolpinyah Dolostone	Dolomitic marble, dolomitic mica schist, dolomitic limestone, calcareous quartzite
PALAEO-PROTEROZOIC		Coomalie Dolostone	Dolostone, magnesite and minor shale
PALAEO-PROTEROZOIC		Crater Formation	Conglomerate, sandstone, minor siltstone and shale
PALAEO-PROTEROZOIC		Welltree Metamorphics	Quartz-feldspar-mica schist and gneiss, minor quartzite and marble
PALAEO-PROTEROZOIC		UNCONFORMITY	
PALAEO-PROTEROZOIC		Celia Dolostone	Dolostone and magnesite
PALAEO-PROTEROZOIC		Beestons Formation	Conglomerate, sandstone and minor siltstone
UNCONFORMITY			
ARCHAEAN		Dirty Water Metamorphics*	Schist, gneiss, dolostone, banded iron formation
ARCHAEAN		Woolner Granite*	Granite

* Only known in the subsurface beneath a cover of Darwin Formation and Cenozoic estuarine sediments.

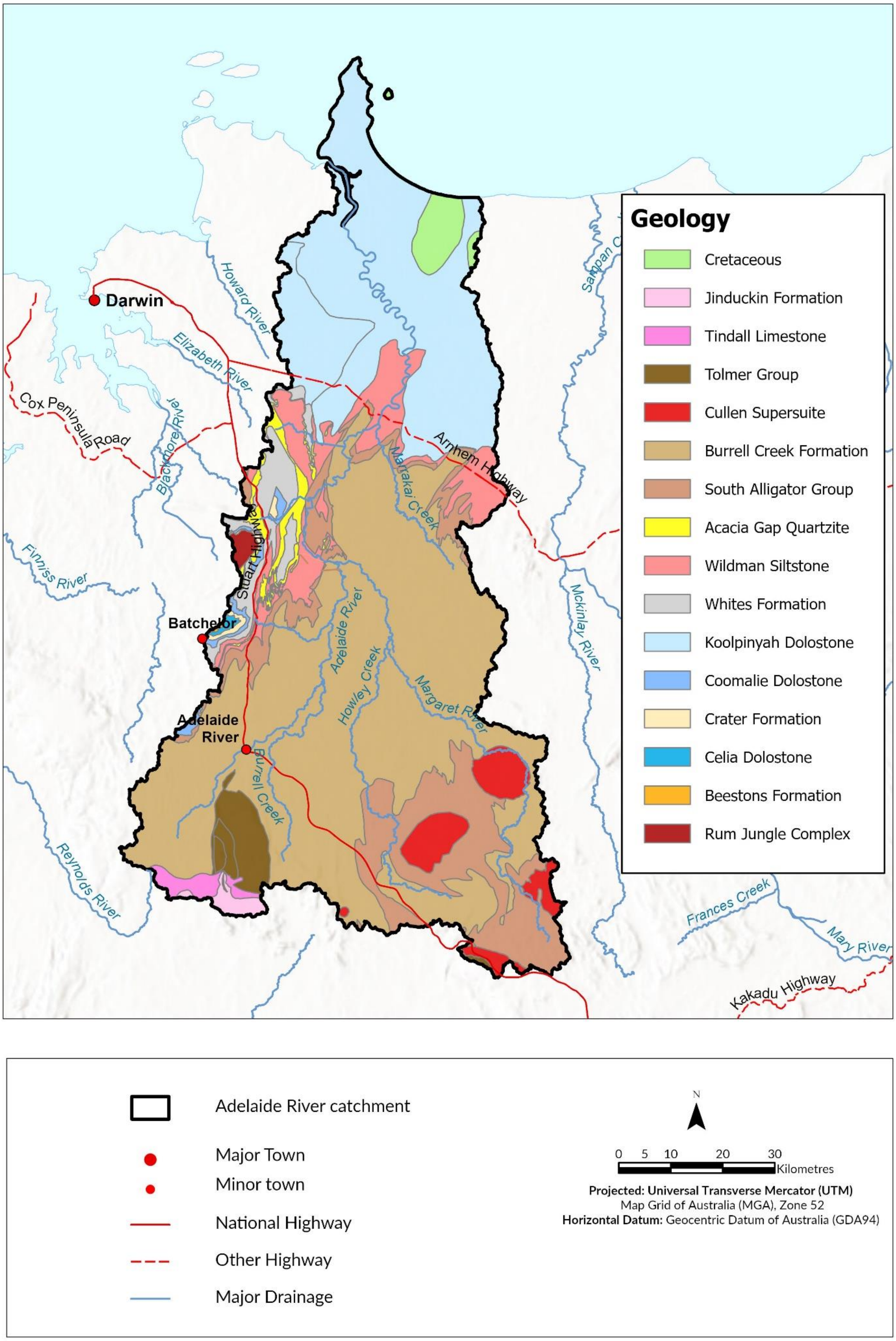


Figure 14. Geological map, note: Cenozoic sediments not shown

3.2 Aquifer types

Four classes of aquifers are recognised based on the nature of the pores that groundwater is stored in and moves through:

- fractured and karstic aquifers developed in dolostone and limestone
- fractured rock aquifers developed in a variety of rocks including shale, siltstone, greywacke, sandstone and quartzite
- fractured rock aquifers with only minor groundwater resources in granite and dolerite
- sedimentary rocks with primary porosity in sandstone.

Most aquifers in the district owe their existence to weathering of the rock which has created or enhanced the permeability and porosity, particularly associated with fracture networks. The main exception is the sandstone at the base of the Darwin Formation which has primary porosity, and its aquifers are classed as sedimentary rocks with intergranular porosity.

3.2.1 Fractured and karstic aquifers

Dolostone and limestone are composed of carbonate minerals and are considerably more soluble than other rocks and are prone to the formation of solution cavities, which enhance permeability and porosity. Cavities are commonly formed by the enlargement of fractures and can vary in scale from submillimetre to metre. In the upper part of the weathered zone, dolomite crystals tend to be replaced by silica and complete replacement is common, forming a sandstone-like rock with a sugary texture. In that situation, the aquifer comprises a framework of silicified dolostone crystals with abundant fine intergranular voids. Boxwork textures are also present where silica or secondary calcite has infiltrated intersecting sets of fractures forming a box-like framework. This material is very porous but tends to be fragile when drilled, which can result in washout of the borehole wall. Cavernous zones in more competent rock beneath that material are often targeted in production bores. This type of aquifer tends to be the most productive. Several formations host significant aquifers including the Koolpinyah and Coomalie Dolostones, the Tindall Limestone and Jinduckin Formation.

The Koolpinyah Dolostone is the most extensive dolostone aquifer, mostly occurring north of the Arnhem Highway. It is often overlain by the basal sandstone of the Darwin Formation. Verma and Qureshi (1979) recognised that they were in hydraulic connection and proposed the name McMinns Hydrostratigraphic Unit. This terminology is not followed here because the sandstone is discontinuous and cannot be mapped with the available information. However, the hydraulic connection is recognised.

The Coomalie Dolostone forms narrow strip-like bodies that vary in width from 200 m to 3 km. In places, they are discontinuous. It occurs as several isolated bodies along the western margin of the catchment between Acacia and west of Adelaide River township. The Celia Dolostone is only present in the district in one small area northeast of Batchelor. For the purpose of this study, it has not been differentiated from the surrounding fractured rock aquifers.

The Tindall Limestone and Jinduckin Formation both host significant fractured and karstic aquifers. They are part of the Daly Basin but only a relatively small section of it extends into the southwestern headwaters of the catchment.

3.2.2 Fractured rock aquifers

Fractures, also known as joints, are cracks formed by brittle deformation of the rock, commonly caused by tectonic processes such as folding and faulting. Both tensile and compressional forces can form fractures. They are also formed by unloading, where rocks that were formerly deeply buried become exposed by erosion. They cool, contract and become relaxed elastically, leading to the formation of fractures.

Fractures tend to occur as sets with one or more common orientations that relate to the orientation of the stress field that the rocks were subjected to. The scale of fractures varies considerably both in their lateral extent and spacing, ranging from centimetres to hundreds of metres. Faults are a type of fracture along which lateral displacement of the rock has occurred. Most fractures show no visible displacement.

The ability of fractures to form aquifers is dependent on their intensity and the degree to which they are interconnected. Fractures are often best developed in the more brittle rocks such as sandstone, quartzite and hard shale. The rocks which are deformed by the Litchfield and Barramundi orogenic events, 1,850 to 1,880 million years ago, were folded, faulted, and deeply buried; all processes favourable for the formation of fractures.

Chemical weathering of the rock can either enhance or reduce the permeability of fractures due to volume changes of the rock mass that accompanies replacement of the original mineral assemblages with new ones. Movement of groundwater along fractures can result in their enlargement by dissolution or their blockage by precipitation of minerals.

Open fractures are more common immediately above the fresh rock. A near continuous horizontal sheet-like aquifer is often present, associated with that part of the weathering profile. The aquifer is often semi-confined by the overlying highly weathered rocks in which fractures are typically closed or absent. Standing water levels generally lie above the main aquifer zone within the highly weathered rock.

Fractured rock aquifers occur in Proterozoic aged formations which comprise shale, siltstone with minor sandstone and quartzite. These include the Wildman Siltstone, Whites Formation, Burrell Creek Formation, South Alligator Group, Acacia Gap Quartzite and Crater Formation.

3.2.3 Fractured rock aquifers with minor groundwater resources

These are a sub-set of the fractured rock aquifer class in which the rock types are not prone to the formation of intense fracture networks. The aquifers are also controlled by weathering of the rocks but tend to be more localised than fractured rock aquifers due to a lower density of fractures. Formations hosting these aquifers include the various granites, and the Dirty Water Metamorphics.

3.2.4 Sedimentary rocks with intergranular porosity

The Darwin Formation occurs mostly north of the Arnhem Highway and hosts a minor aquifer in its basal sandstone. The sandstone has minor intergranular porosity and is up to 10 m thick but is often clayey which reduces its permeability.

3.3 Groundwater management zones

Although there are no plans to actively manage groundwater use in the Adelaide River water allocation plan the aquifers have been grouped into 14 water management zones (WMZ) (Tickell et al, 2023) as shown in Figure 15. The “management zone” terminology used here is for descriptive purposes only. A similar methodology to define zones was used here as was used in the adjoining Darwin water control district to delineate water management zones. Many of the zones are common to both the Darwin water control district and the Adelaide River catchment.

The WMZ consist of aquifers that have distinctive properties and can consist of a single geological formation and those that include two or more formations. Bore airlift yield statistics were the main tool for grouping aquifers (Table 5). In particular, median yield was used as a basis for comparing aquifers. There are considerably less boreholes in the Adelaide River catchment than in the Darwin area, so where there was insufficient data for a particular formation, it was assumed to have similar hydrogeological properties to that in the Darwin area.

Groundwater salinity was also used to define WMZ. Saline to brackish groundwater is associated with coastal and estuarine plains. Such areas overlie the Cretaceous, Howard and Noonamah WMZ and where the groundwater is brackish or saline the word “saline” is added to the WMZ name, for example Noonamah_saline. The location of the fourteen WMZ are shown in Table 5 and their key properties are summarised in Table 6.

The Howard zone is based on the Koolpinyah Dolostone aquifer, an extensive fractured and karstic aquifer. It is subdivided into four WMZ, depending on the thickness and nature of the overlying formations and water quality. In the Howard Saline zone, the dolostone is overlain by thin estuarine deposits associated with the Adelaide River coastal floodplain. Bores in those areas are few in number and intersect brackish to saline water. The Koolpinyah and Coomalie Dolostones have slightly higher median airlift yields and significantly higher maximum yields than the other zones.

Noonamah is the most widespread WMZ. It comprises several geological formations which are dominantly mud rocks (shale, mudstone and siltstone) and include lesser sandstone, quartzite and minor dolostone. Aquifers are extensive but may be localised in places due to stratigraphic variations. They are characterised by low median airlift yields mostly in the range 1.5 to 3 L/s. The South Alligator Group has a slightly higher median yield of 4 L/s. These higher yields occur on gold mining leases. The fracture networks are likely denser there because of localised faulting.

Table 5. Airlift yield statistics

Geological unit	Water management zone	Mean (L/s)	Median (L/s)	Mode (L/s)	Max (L/s)	Count	% bores with no aquifer
Coomalie Dolostone	Coomalie	7.5	5	10	50	76	13
Koolpinyah Dolostone	Howard_ central	4.8	4	3	38	120	<1
Koolpinyah Dolostone	Howard_ south	8.1	5	5	57	679	<1
Crater Formation #	Noonamah	2.9			6	14	
Wildman Siltstone #		4.3	3	3	30	224	2
Whites Formation #		5.7	2.5	1	60	304	3
South Alligator Group#		4	4	4	40	231	6
Acacia Gap Quartzite #		2.7	2	5	20	70	11
Burrell Creek Formation#		2.7	1.5	1	25	393	8
Note: units marked with # above are combined into this category		2.9	1.8	1	40	793	12

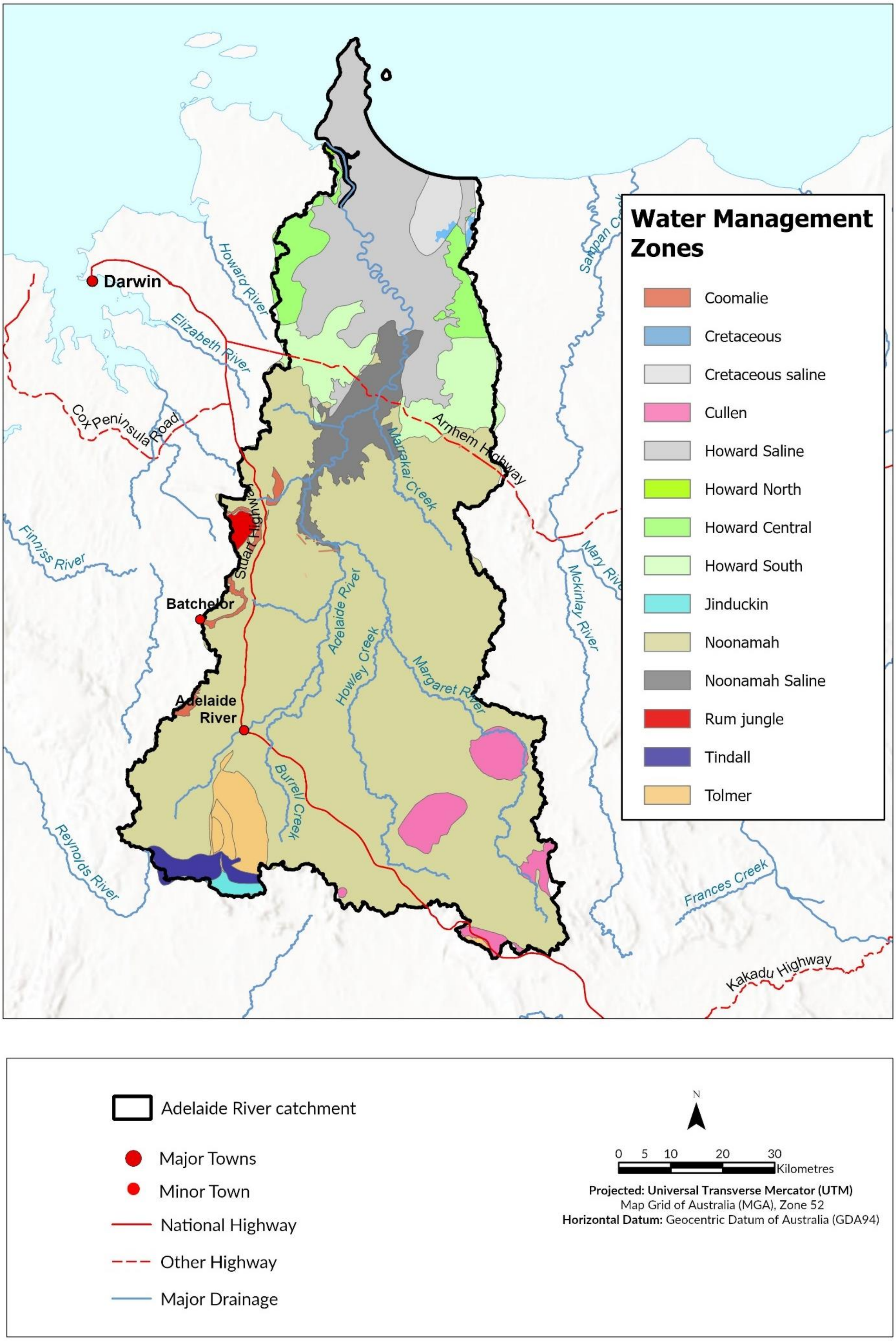


Figure 15. Water management zones

Zones with minor groundwater resources include the Rum Jungle and Cullen WMZ. The aquifers formed in granite or in metamorphic rocks are low yielding and are localised. A high percentage of bores are likely to find insufficient water to warrant their construction.

There were insufficient bores in the Howard_north, Howard_saline, Noonamah_saline, Tindall, and Jinduckin WMZ to characterise airlift yields and percentages of bores striking no aquifer. No bores have been drilled in the Tolmer WMZ. In these cases, data from the same WMZ in the Darwin water control district were used. For the Tindall and Jinduckin WMZ airlift data from Tipperary Station immediately south of the catchment were used.

Table 6. Water management zones

Name	Description
Coomalie	This zone comprises several isolated, narrow strips of Coomalie Dolostone. Water quality is fresh and standing water levels range from 2 to 20 mBGL. An outlier of the aquifer located east of the Stuart Highway in the Acacia area is used to irrigate mangoes. The bores yield up to 10 L/s. The main aquifer is typically at depths from 40 to 60 m and water levels are shallower than 20 m.
Cretaceous	Located on the northeastern side of the Adelaide River floodplain this zone comprises sandstone of the Darwin Formation at depths of 20 to 40 m. Standing water levels are less than 10 mBGL. Airlift yields are low and there is a high percentage of bores striking no aquifer.
Cretaceous_saline	The aquifer is developed in sandstone of the Darwin Formation. In some places the aquifer includes the top part of the underlying Dirty Water Metamorphics or the Woolner Granite. Airlift yields are low and there is a high percentage of bores striking no aquifer. Standing water levels are shallower than 5m and the groundwater is saline.
Cullen	Several granite batholiths are situated in the south-eastern part of the Adelaide River catchment. Sporadic aquifers are hosted in the weathered zone, and they are usually shallower than 20 m. Airlift yields are low, and a high percentage of bores strike no aquifer. Standing water levels are shallow.
Howard_North	This zone is restricted to a small area on the northwestern estuarine plain where the top of the Koolpinyah Dolostone lies at depths greater than 80 m. It is confined by dense marine clays of the Darwin Formation which are likely to limit recharge to low values. No bores have been drilled into this zone. Groundwater is likely to be brackish.
Howard_Central	This zone lies on the eastern and western sides of the Adelaide River floodplain. The thickness of the Darwin Formation overlying the aquifer varies between 40 and 80 m and is a mixture of clay and sandstone with a basal sandstone aquifer often in direct contact with the underlying Koolpinyah Dolostone aquifer. The groundwater in the dolostone is fresh and active recharge takes place, although less than in the Howard_South WMZ. Patches of saline to brackish water may occur adjacent to the floodplains. Standing water levels range from 1 to 30 mBGL. Artesian conditions may occur adjacent to the plains. The Koolpinyah aquifer is utilized for stock and domestic purposes, mainly on the western side of the floodplain.
Howard_South	This zone extends from just south the Howard_Central WMZ. The thinner Cretaceous cover of less than 40 m allows for higher recharge. The basal sandstone in the Darwin Formation is common and is in direct contact with the underlying Koolpinyah Dolostone aquifer. The groundwater is fresh and standing water levels mostly range from less than 1 to 30 mBGL. Artesian conditions may occur adjacent to the floodplains. The Koolpinyah aquifer is utilized for horticulture and stock and domestic purposes, particularly at Lambells Lagoon and Middle Point. Irrigation bore yields are mostly within the range 10 to 30 L/s.
Howard_Saline	The Koolpinyah Dolostone aquifer is overlain by up to 40 m of Darwin Formation which is in turn overlain by several metres of dense, grey, cracking clay soil. The latter were formed on estuarine and alluvial clays deposited by the Adelaide River. The groundwaters in the underlying aquifer are brackish/saline and often saltier than seawater. Fresh water may be present near the landward margins. The clay soils are thought to be almost completely impervious with low or no recharge. Standing water levels probably range from 1 to 10 mBGL. Few bores have been drilled in this zone.

Name	Description
Jinduckin	The Jinduckin Formation contains aquifers within near horizontal beds of dolostone, sandstone and dolomitic siltstone. It is part of the Daly Basin and overlies the Tindall Limestone. Airlift yields up to 5 L/s would be expected. Groundwater is hard and in places may have elevated sulphate concentrations. Few bores have been drilled in this zone.
Noonamah	This zone includes aquifers developed in the Wildman Siltstone, Whites Formation, South Alligator Group, Burrell Creek Formation, Acacia Gap Quartzite, Crater Formation, Beestons Formation and Celia Dolostone. Aquifers are related to weathering and appear to be regionally continuous. Lateral hydraulic connectivity may be locally restricted. Standing water levels range from less than 1 to 40 mBGL. Groundwater is mostly fresh but may be brackish to saline adjacent to the floodplains. Water hardness varies from high to low and is dependent on the host geological formation. Usage is mainly for stock and domestic purposes but small-scale irrigation for horticulture takes place in the Marrakai area where bore yields up to 5 L/s and less often 10 L/s can be obtained. Elsewhere bore yields are typically less than 2 L/s.
Noonamah_saline	Where aquifers of the Noonamah WMZ are present beneath the estuarine plain of the Adelaide River the groundwater is saline. The southern-most extent of the saline groundwater corresponds to the present day tidal limit of the river at the Marrakai Crossing. Patches of fresher water may be present south of the Arnhem Highway.
Rum Jungle	This zone occurs as two dome-like granitic features in the south of the water control district. The rocks are largely granite but also minor schist, gneiss and banded ironstone. There are insufficient bores drilled into this zone to characterise yields, success rates and water quality. Comparisons with similar rock types in the Top End suggest very low yields, poor success rates and fresh water. Aquifers may be localised within this WMZ. No information is available on standing water levels.
Tindall	The Tindall Limestone is one of the major aquifers of the Daly Basin which is found in the southwestern margin of the Adelaide River catchment. It is a fractured and karstic aquifer that is potentially capable of producing yields of over 10 L/s. Standing water levels are known to vary between 30 and 70 mBGL. The groundwater is hard but fresh. Few bores have been drilled in this zone.
Tolmer	The Adelaide River flows over this WMZ in its headwaters, immediately downstream of the Daly River Road. It comprises four geological formations (see Table 4). No bores have been drilled into this WMZ but comparison to other areas such as Litchfield Park and Berry Springs suggests that the Depot Creek and Stray Creek Sandstones will contain minor fractured rock aquifers capable of producing stock and domestic supplies. Higher bore yields could be expected from the Hinde Dolostone as it is potentially a fractured and karstic aquifer. The groundwater would be fresh. The uppermost formation the Waterbag Creek Formation is mainly siltstone and has poor prospects for groundwater supplies.

3.4 Recharge

Groundwater recharge is the process by which water from precipitation infiltrates the ground and replenishes aquifers. Factors that affect recharge include the amount and timing of rainfall, evapotranspiration, the nature and thickness of the material overlying the aquifer and topography. In the Top End of the NT, annual rainfall is relatively high, and diffuse recharge is considered to be the dominant recharge mechanism.

In the Darwin area a range of methodologies were applied to determine recharge rates within each of the WMZ (Tickell et al., 2023). The value considered to be the most accurate was selected as the preferred recharge rate. Where the same WMZ are present in the Adelaide River catchment the same preferred recharge rates were adopted. For those WMZ only present in the catchment, recharge values were either taken from available scientific studies or were estimated from interpretation of the hydrogeology when there was no other information.

The recharge for each WMZ represents the total depth of rainfall that infiltrates deeply through the soil and rock profile. The volume of recharge entering the zone per annum is calculated from:

$$\text{Annual recharge } (m^3) = \text{recharge depth } (m) \times \text{area } (m^2)$$

Table 7 presents the average annual recharge for each WMZ and a calculation of the water for consumptive use, using the policy (NTG, 2020) which is 20% of the average annual recharge, rounded to the nearest square kilometre.

The recharge values are simplified for each WMZ, recognising that hydrogeological parameters and processes vary in space and time. The values selected are regarded to be representative within reasonable variation within the WMZ. Using this approach, the volume of recharge is considered to be equally distributed across the WMZ. Under average conditions, the aquifer within each WMZ will fill by the amount (in ML per year) shown in Table 7 each wet season.

Table 7. Recharge and water available for consumptive use

Water management zone	Recharge mm per year	Area km^2	Water for consumptive use ML per year	Source
Coomalie	155	42	1302	1
Cretaceous	163	13	424	1
Cretaceous_saline	50	101	1010	2
Cullen	25	229	1145	2
Howard_saline	65	1004	13052	1
Howard_ north	69	4	55	1
Howard_ central	146	228	6658	1
Howard_ south	155	419	12989	1
Jinduckin	11	26	57	3
Noonamah	117	4790	112086	1
Noonamah_saline	50	324	3240	2
Rum Jungle	42	27	227	1
Tindall	150	80	2400	4
Tolmer	50	174	1740	2

1 Tickell et al. 2023, 2 estimated, 3 Cobban & Tickell 2024, 4 Jolly 1984

3.5 Monitoring network

Groundwater monitoring commenced in the 1970’s. Current monitoring sites are shown in Appendix A and are focussed in areas of significant groundwater extraction. Figure 16 shows the location of the current groundwater monitoring network. Data from these locations is used to determine aquifer parameters so that aquifer properties can be defined to assess yields, recharge and impacts of extraction. Data is also used for the development of groundwater models to estimate impacts of development. The main areas of extraction in the Adelaide River catchment are Howard East, Acacia and Marrakai. Monitoring data has also been collected at other locations on an ad hoc basis for various scientific investigations undertaken in the region.

Besides groundwater levels, baseline water quality sampling has been conducted at monitoring sites sporadically within the plan area between 1978 to 2023.

Prior to the 1990’s groundwater monitoring was undertaken sporadically in the Howard East area. Discrete groundwater monitoring commenced in 1978, while time-series data collection commenced in 1995.

Groundwater monitoring at Acacia has occurred sporadically between 1999 and 2019. Nine monitoring bores were drilled in Marrakai in 2023 with no historic information available.

The network is summarised below:

- Howard East: 41 monitoring bores are located within this groundwater resource. 31 bores have groundwater level time-series recorded data, with 24 loggers currently operational in 2024. One of these bores (RN024716) has an electrical conductivity logger.
- Acacia: 2 bores were constructed in 2024. An additional 11 historic monitoring bores have recorded water level measurements sporadically between the years 1999 to 2000.
- Marrakai: 9 monitoring bores were constructed in June 2023, with loggers deployed in September 2023 to monitor water level. The purpose of these loggers is to gain further information about the groundwater resources in this area.
- Upper Adelaide River: 2 bores were equipped with loggers in January 2024.

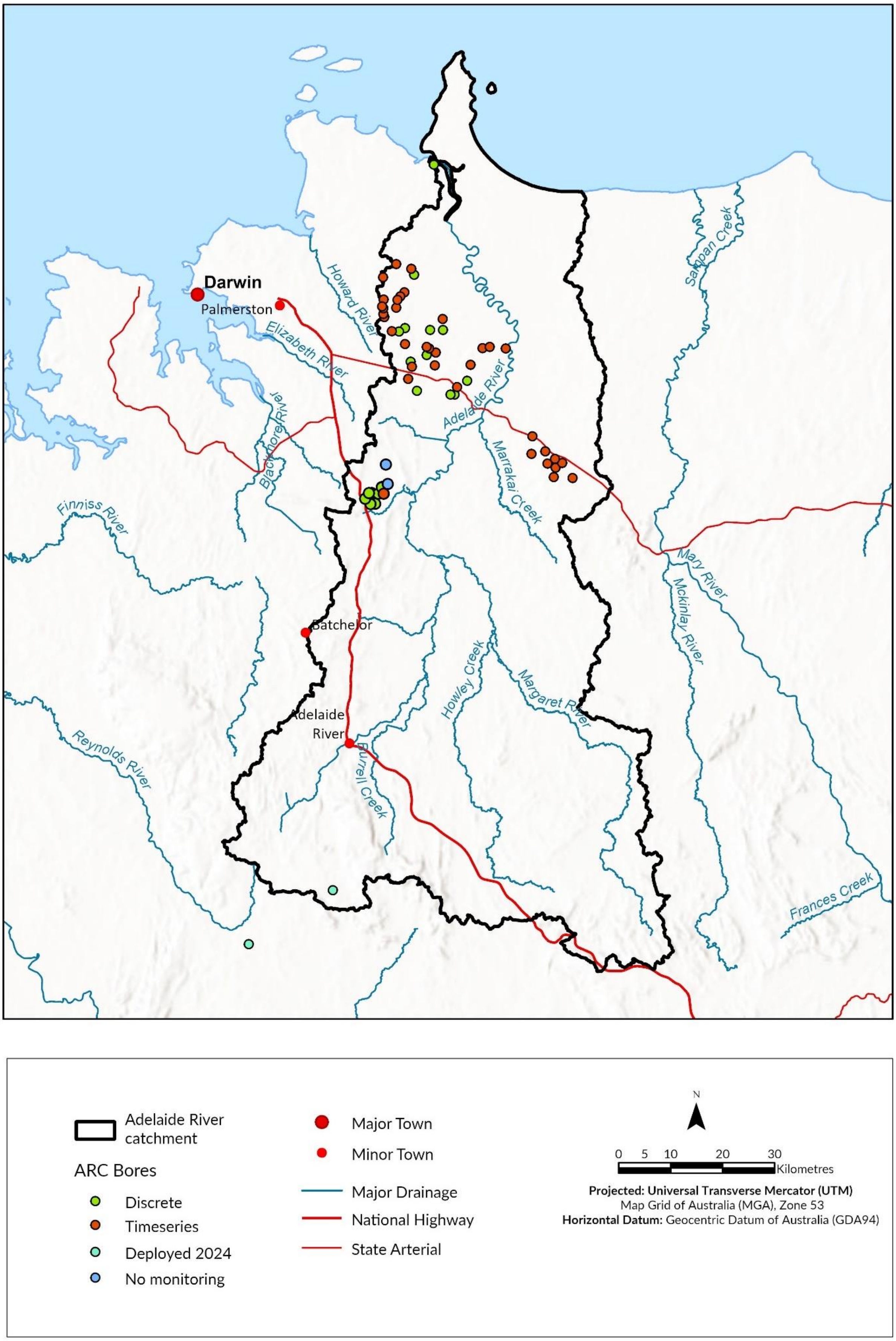


Figure 16. Groundwater monitoring network across the Adelaide River catchment and surrounding areas

3.5.1 Howard East

Major aquifers in the Howard East area typically have yields of 5 L/s and occasionally in excess of 50 L/s (Fell-Smith and Sumner, 2011). This aquifer plays an important role as the main water source for agricultural and horticultural development, stock and domestic use, and public water supply. According to Fell-Smith and Sumner (2011), there is discharge from the Howard East aquifer to Howard Springs, Howard River, Melacca Creek, Baker's Creek, and a myriad of lagoons and several patches of spring fed remnant vegetation including Black Jungle Swamp. Mean groundwater levels below ground level (BGL) in the Howard East area typically varies from 0.67 m to 21.88 m (NR Maps, March 2024). Maximum water level BGL has been recorded at 31.66 m in the Humpty Doo area.

3.5.2 Acacia

The major aquifers underlying this area include the Whites Formation, Coomalie Dolomite and Crater Formation. The yields for the Whites Formation range between 1–5 L/s (Tickell, 2000). Based on ten year observations from 1999 to 2008 for bores RN03454 and RN03455, located in the southern region, mean seasonal water levels vary from 5.35 m to 8.27 mBGL (Yin Foo, 2011). This indicates the area is poorly connected or there are separate aquifer systems. However, two production bores, RN029719 and RN036087 located and monitored by Acacia Hills Farm in the northern-west region showed that the static water level BGL drops to 16 m at the end of the dry season indicating this is an impacted system. The Coomalie Dolomite Formation underlying the Darwin River and Manton Dams has a high yield capacity up to 40 L/s (Yin Foo, 2004). Generally, aquifer yields in the Acacia area vary from low to moderate potential, providing 1.2 ML/ha/year (Tickell, 2000). The mean water level BGL varies between 0.61 m and 13.52 m for all bores in this area. In the Tortilla Flats and Adelaide River town areas, mean water level BGL is estimated at approximately 11.6 m to 13.2 m (NR Maps, March 2024) with low yield capacities (<1 L/s).

3.5.3 Marrakai

Major aquifers underlying the Marrakai area include fractured and weathered rocks with minor groundwater resources, fractured and weathered rocks, and fractured and karstic rocks with water yields varying from less than 1 L/s at local scale up to 20 L/s at local and intermediate scale (Figure 16). Eight new monitoring bores were drilled in 2023 with loggers installed in September 2023 to monitor water levels. The groundwater bores provide water yields ranging from 0.85 L/s at RN043556 to 7.4 L/s at RN043554. BGL was measured during the field work and varied between 19.38 m and 4.70 m (NTG Aquarius, March 2024).

3.6 Modelling

Groundwater modelling for the area is centred on the Koolpinyah groundwater system which underlies the majority of the Howard River catchment and only the western portion of the Adelaide River catchment. Therefore, existing models only cover part of the Adelaide River catchment.

The first groundwater flow model was developed for the area in 2004 using MODFLOW (Yin Foo 2004). The study area overlying the model was then redeveloped to use a FEFLOW platform (EHA 2007) in 2007, with the final update in 2017 (Knapton, 2017). These models were used to support analysis of impacts of groundwater development, as a result of changes in land use on water resources within the Darwin Rural area, and to provide the basis for the determination of annual allocations by forecasting dry season groundwater levels and flow regime at priority discharge areas such as Howard River and Howard Springs.

A major update to the 2017 model, from the previous modelling studies, is the extension of the model domain to incorporate the Middle Point area. The updated model domain includes the majority of the Howard River catchment and has been extended to the north to incorporate the mapped extent of the Koolpinyah dolomite based on Geoscience Australia's interpretation of airborne magnetics and electromagnetics data (Tan et al., 2012).

For completeness of reporting there are local scale models that were developed for specific areas that predate 2004, such as a model for Middle Point (Middlemis, 1999).

4. Surface water resources

Incorporating a catchment area of approximately 7445 km^2, the Adelaide River has a length of 335 km commencing in the foothills to the south of the Adelaide River township and discharging to the Arafura Sea in the north. Typical for the northern coastal catchments of the Northern Territory, the Adelaide River catchment has an extensive coastal floodplain and is characterised by low relief throughout most of its catchment area. Of the 175 km north-south catchment extent, the northern 80 km coincident to the tidal reaches of the Adelaide River has an elevation largely below 10 mAHD. Elevations remain below 50 mAHD for most of the catchment area north of Adelaide River township, with only a few areas of higher elevation mostly around the catchment edges. Figure 3 (section 2.4) shows the relative elevations throughout the catchment and demonstrates the extensive low-lying alluvial plain that covers much of the catchment. This is further demonstrated in the waterway classification map (Figure 17) with large areas of the lower and middle catchment having no defined waterways over large areas due to poor drainage gradients. Shallow and poorly defined channels occur widely throughout the catchment, leading to frequent spilling from existing channels and overland flows along secondary flow paths and onto vast alluvial floodplains. The catchment is fringed by areas of higher elevation yet generally low relief with the exception of the southwest and southeast of the catchment, where extensive broken foothills provide higher relief and well defined, incised channel networks to headwater tributaries.

Along its lower catchment, the Adelaide River is classified as a Stream Order 6 waterway based on the Strahler Stream Order system (Geofabric 2.1). The main tributary to the Adelaide River is the Margaret River which converges with the Adelaide River at the upstream extent of tidal influence. Both the Adelaide and Margaret Rivers are Stream Order 5 waterways at their confluence. Figure 17 shows all the waterways within the Adelaide River classified according to the Strahler stream order system. Lines representing channel and floodplain cross sections are also shown Figure 17.

The Adelaide River drains the western side of its catchment, while the Margaret River drains the southern and eastern parts of the catchment. Upstream of their confluence, the Adelaide River is fed by numerous tributaries including the East and West Branches of the Adelaide River in its headwaters, Burrell Creek, Coomalie Creek, Otto Creek, Snake Creek and Stapleton Creek, while the Margaret River receives contributions from Bridge Creek, Howley Creek, McCallum Creek and Saunders Creek. Downstream of the Margaret River confluence, the Adelaide River receives further inflows from Acacia Creek and Manton River from the west, and Marrakai Creek, Scotch Creek, and Whitestone Creek from the east of the catchment along with numerous other minor tributaries that traverse the floodplain.

4.1 Catchment characteristics

For the purposes of this assessment, the Adelaide River catchment has been divided into three distinct sections:

- The lower Adelaide River catchments, which occur downstream of the confluence of Adelaide River and Margaret River and coincide with the upstream extent of tidal influence, covering an area of 3117 km^2.
- The upper Adelaide River which includes the entirety of the Adelaide River and its tributary catchments upstream of its confluence with Margaret River, covering an area of 1728 km^2.
- The Margaret River which includes the entirety of the Margaret River and its tributary catchments upstream of its confluence with the Adelaide River, covering an area of 2600 km^2.

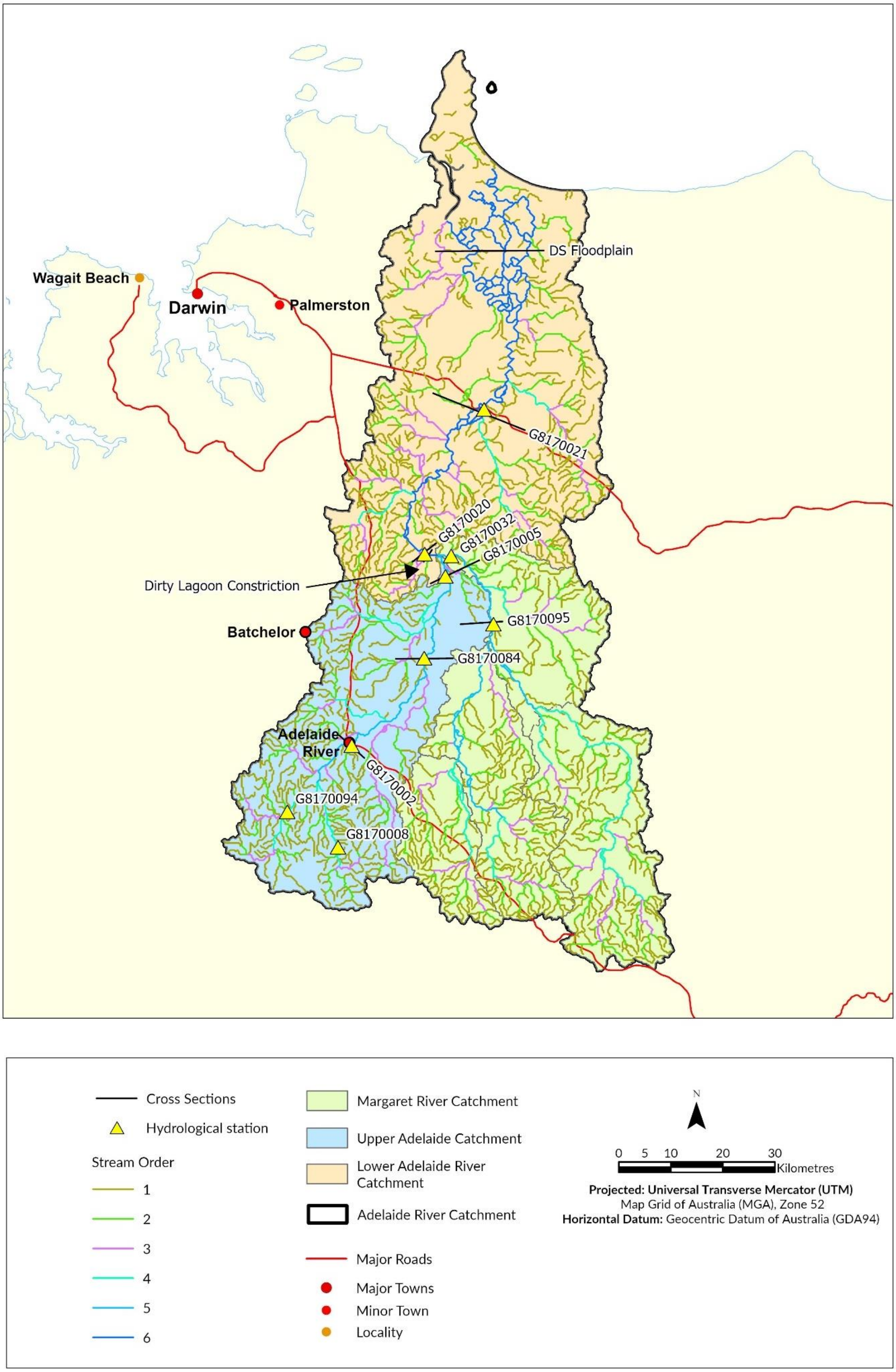


Figure 17. Waterways classified according to Strahler stream order, cross sections and main gauging station locations of the Adelaide River catchment

4.1.1 Lower Adelaide River

The lower Adelaide River catchment includes all the tidally influenced reaches of the Adelaide River to Marrakai Crossing, including all tributaries draining into the tidal reaches. Being macrotidal, the Adelaide River experiences daily tidal variations exceeding 4.0 m, and 6.0 m on spring tides. Low elevation across the coastal plain and large tidal range has allowed the lower Adelaide River catchment to extend 80 km inland from the coast, encompassing almost 42% of the total Adelaide River catchment. The confluence of the Adelaide River and Margaret River occurs just 2.0 km downstream of the Marrakai road crossing, coinciding with the extent of the lower Adelaide River catchment area.

Elevations below 3.0 mAHD and low relief across the coastal plain has allowed extensive floodplains to develop across the lower catchment, extending approximately 60 km inland from the coast (Petherem et al, 2018) and up to 30 km wide at their maximum extent. Towards the river mouth, the floodplain becomes contiguous with the adjacent Mary River floodplain immediately to the east during the wet season.

The Adelaide River estuary and coastal floodplain formed within the last 8,000 years as a result of enhanced sedimentation of drowned river valleys by marine sediments due to sea level increases after the retreat of the last ice age (Vertessy, 1990; Woodroffe et al, 1993). These marine sediments were then overlain by freshwater clays deposited during wet season floods after sea level stabilisation around 6,000 years ago (Vertessy, 1990; Woodroffe et al, 1993, CSIRO, 2009).

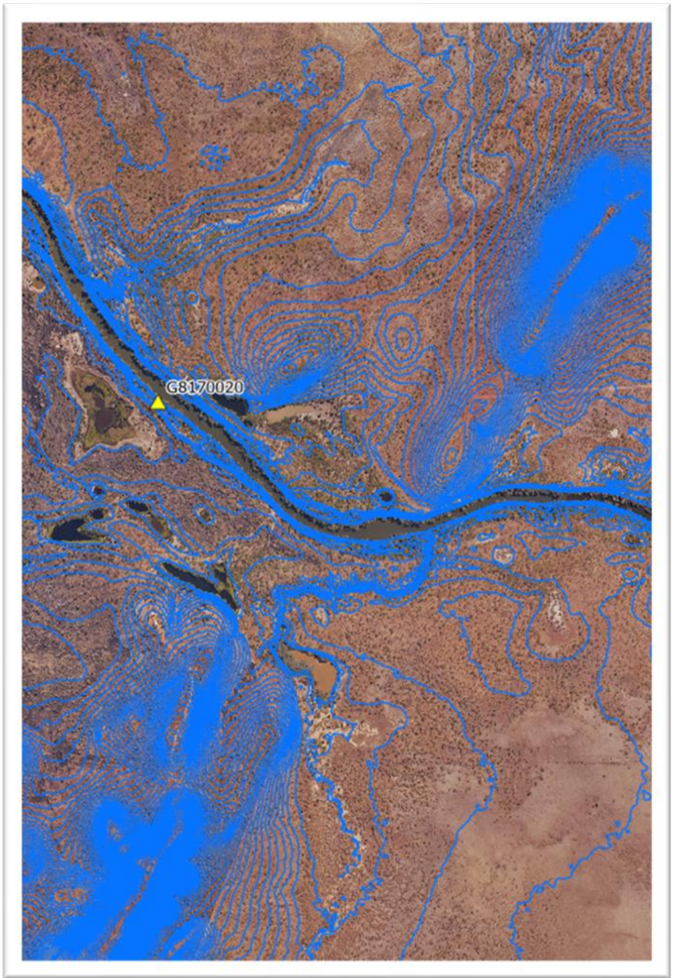


Plate 1. Constriction at Dirty Lagoon (source: NTG)

The Adelaide River meanders through the coastal plain, so that total river length in the tidal reaches measures approximately 145 km. The coastal and alluvial floodplains of the lower catchment form vast seasonally and permanently inundated wetland systems hosting a mosaic of diverse wetland habitats including tidal flats, swamps and mangroves forests (NRETAS, 2007a; Petheram et al, 2018) and are considered to be of outstanding cultural and ecological significance (Close et al, 2012).

Downstream of the Margaret River confluence, the Adelaide River flows briefly northwest for 3 km before coming up against a natural constriction formed by low foothills on the southern boundary of Koolpinyah Station, at a location known as Dirty Lagoon. This range of hills rise 30 m to 50 m above the floodplain, with a narrow gap just 650 m wide through which the Adelaide River flows. Plate 1 superimposes 1.0 m contours over an aerial image of the constriction. The hills create a natural control, with flows above bank level, 39,000 ML per day being regulated by the constriction before discharging to the lower catchment. After passing through this constriction, the river flows north, northeast then north again for 140 km (river length) through a series of increasingly large meanders as it traverses the coastal plain.

Figure 18 shows a cross section of the constriction at Dirty Lagoon, and Figure 19 shows a cross section immediately downstream of the Dirty Lagoon constriction at monitoring site G8170020. Noting the different scales on the horizontal axis, it can be seen that the constriction opens onto a broad, low lying floodplain.

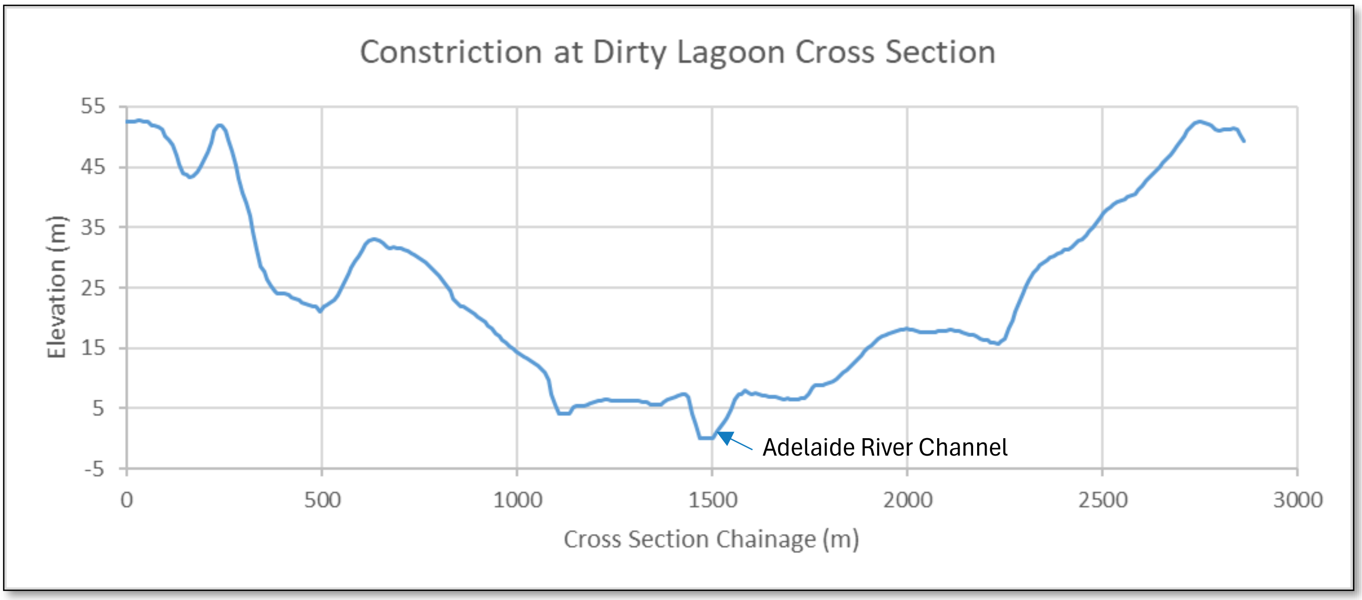


Figure 18. Cross section of constriction at Dirty Lagoon

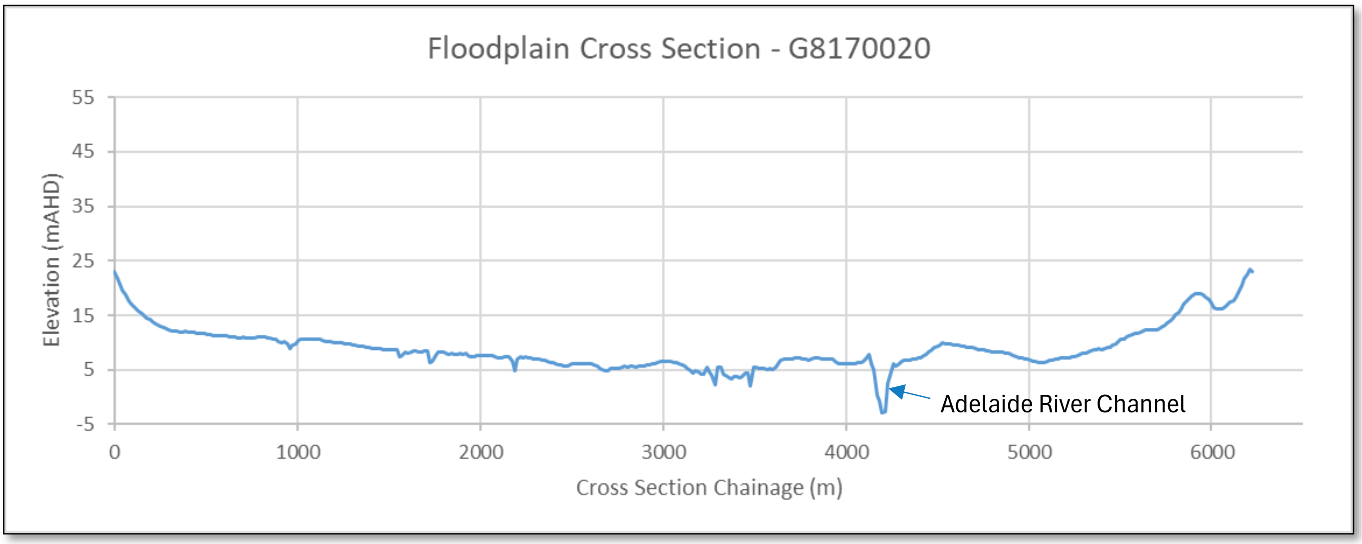


Figure 19. Cross section downstream of Dirty Lagoon constriction

Heading downstream from Dirty Lagoon, the river progressively widens from 50 m at Dirty Lagoon to 140 m at the Arnhem Highway bridge as the river transitions from upstream planiform through increasingly sinuous meanders to its estuarine funnel, which spans over 1 km wide upstream of its mouth. The Adelaide River estuary is deeper than other north draining macrotidal rivers (Vertessy, 1990), with river depth ranging between 7.0 m and 17.0 m in the lower reaches. Additionally, the Adelaide River channel appears to be highly stable, running along its current channel for several millennia having cut into the sub-floodplain laterite surface, explaining its deeper profile (Chappell et al., 1992; Vertessy, 1990). Uniquely, the Adelaide River channel is constricted just prior to its point of contact with the Arafura Sea (Plate 2), narrowing to just 265 m wide as the river passes through a hard rocky headland, most likely claystone or sandstone of the Darwin Formation (Tickell, pers. Comm.). The river channel deepens considerably through this constriction, reaching depths below -27 mAHD from just -7.1 mAHD, 2 km upstream.

Plate 2. Constriction at mouth of Adelaide River (source: NTG)

The coastal floodplain covers an area of approximately 1300 km2 (Vertessy, 1990; CSIRO, 2009). Figure 20 and Figure 21 show two cross sections of the coastal floodplain, with Figure 20 showing the upper coastal floodplain near Arnhem Highway bridge, and Figure 21 showing a cross section along the lower floodplain 27 km upstream from the river mouth.

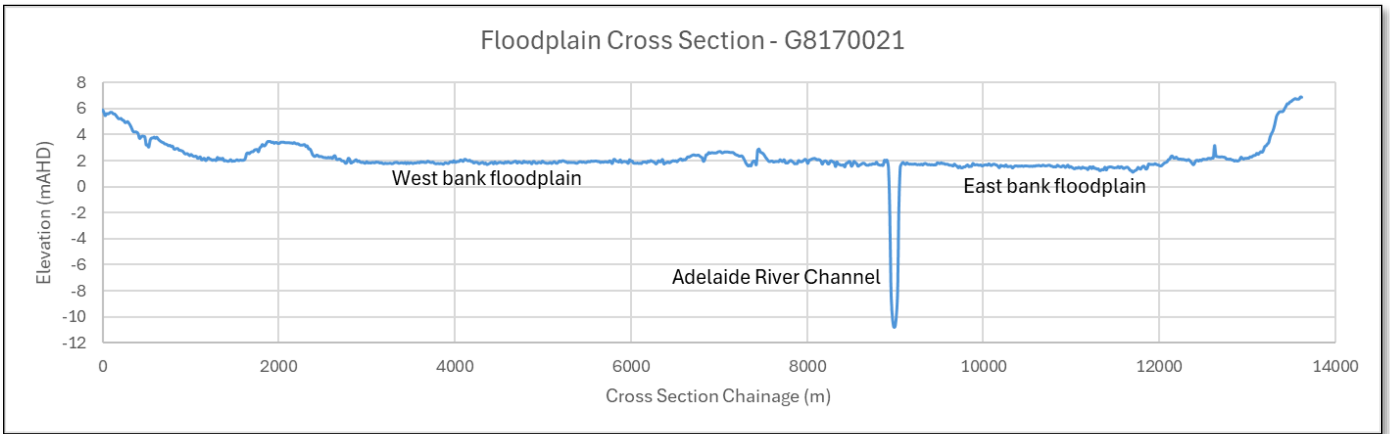


Figure 20. Cross section of floodplain at Arnhem Highway bridge

On the upper floodplain, the top of bank for both sides of the river channel lies at 2.0 mAHD, as does the left bank, stretching over 5 km to the west with little undulation before gradually increasing in elevation towards the edge of the floodplain. The right bank is perched above the eastern floodplain, which gradually drops away for 3 km reaching a low point of 1.2 mAHD at the edge of the floodplain. Downstream at river chainage (RC) 27 km, floodplain elevation is lower with the left bank lying at 1.6 mAHD, from which the floodplain stretches west almost 8 km mostly at elevations between 1.5 m and 1.8 mAHD.

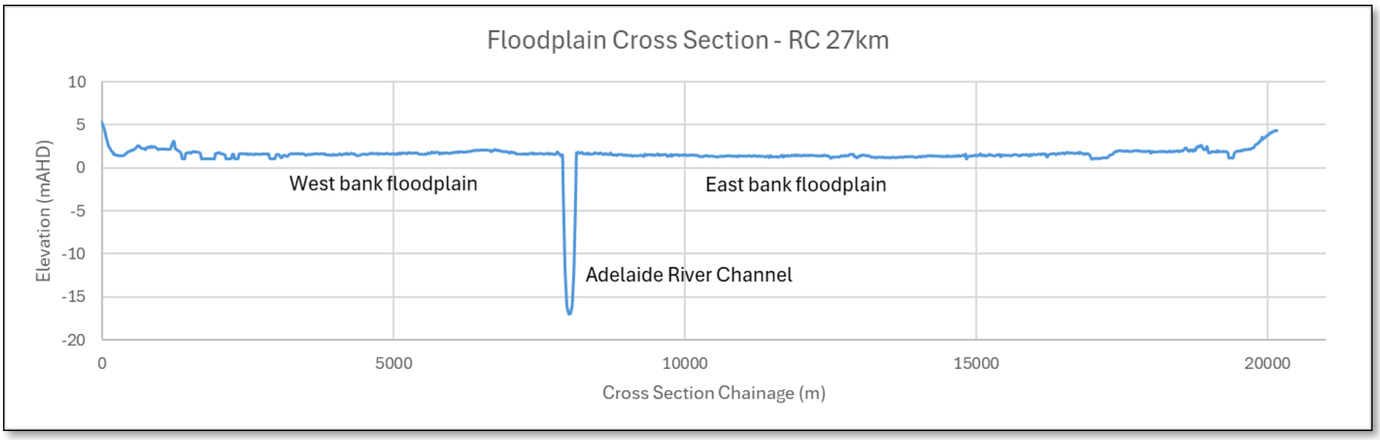


Figure 21. Cross section of floodplain at DS floodplain, 27 km upstream from river mouth

The right bank tops out at an elevation 1.8 mAHD, with the floodplain gradually reducing to 1.2 mAHD over the first 5 km stretching to the east, then gradually increasing to over 2.0 mAHD over the next 5 km. A depression at the eastern edge of the floodplain is evidence of paleochannel from 3,000 year ago, when the Adelaide River discharged to the Arafura Sea to the east of Cape Hotham (Woodroffe et al, 1993).

Classification of the coastal floodplain developed by Woodroffe et al (1986) suggests three provinces: the coastal plain, estuarine-deltaic plain and the alluvial plain. The coastal plain lies at the seaward fringe and is composed of sandy muds, the deltaic-estuarine plain extends along the estuary from the coastal plain to the limit of tidal extent and is covered by black, cracking freshwater clays, and the alluvial plain occurs upstream of the tidal extent and consists of black, cracking clays, gleied muds, silty alluvium and fine sandy materials. Ecological classification within the Adelaide River catchment identified nine ecological subcategories relevant to the coastal floodplain (de Mello et al, 2024) which broadly align with these floodplain classifications. Samphire salt flats align occur within the extent of the coastal plain, while mangroves extend along the lower river reaches that experience significant inter-annual changes to electrical conductivity representing the estuarine-deltaic plain. In the case of the Adelaide River, the mangrove classifications only extend to about 8 km upstream of the Arnhem Highway., with the riparian vegetation classification found along riverbanks extending further upstream in the tidal estuary indicating limited variation in electrical conductivity past this point, despite the river still being tidally influenced for another 70 km. Marsh grass, green marsh and swamp fill out the estuarine-deltaic plain away from the river channel, while the alluvial plain upstream of the tidal extent also appears appropriately represented by the ‘Marsh grass’, ‘green marsh’ and ‘swamp’ classifications.

Ecological classification within the catchment is discussed in section 5.

4.1.2 Upper Adelaide River

The upper Adelaide River (Figure 17) includes all the non-tidally influenced river reaches of the Adelaide River and its tributaries upstream of the Marrakai road crossing.

Headwaters of the Adelaide River occur to the southwest of the catchment, in the upper tributaries of Adelaide River and Burrell Creek which drain the foothills at the northern periphery of the Daly Basin sequence (CSIRO, 2009; Tickell, 2013).

To the west, the east and west branches of the upper Adelaide River rise in Tipperary Station and Litchfield National Park respectively, with the southerly extent of the east branch incising the northern extent of the Tindall Limestone Aquifer for a distance of approximately 8 km. The east and west branches flow north and northeast respectively through dissected foothills before converging approximately 12 km upstream of Adelaide River township to form the Adelaide River. Continuing downstream from Adelaide River township, the Adelaide River flows 25 km northeast where it is joined by Burrell Creek (section 3.4.2) flowing from the south, after which the Adelaide River heads in a northerly direction. 15 km downstream, Coomalie Creek (section 3.4.3) joins Adelaide River from the east after which the Adelaide River flows generally north for another 15 km to Marrakai Crossing.

In the upland areas, river channels are well defined consisting mostly of shallow, narrow cascade and step-pool runs between the dissected hills, transitioning to longer run reaches over sandy bed as valley beds even out and hydraulic gradients ease. Immediately upstream of Adelaide River township, the foothills give way to undulating plains then alluvial plains through which the river flows all the way to its estuary. Downstream of Adelaide River township, stream form is mostly pool-run sequences, with large deep perennial pools (Plate 3) developing along the channel interspersed with narrow, shallow run reaches (Plate 4). Few significant riffles appear to occur downstream of Adelaide River township, most likely due to the bedrock being overlain by alluvial sediments, consistent with low relief and lowland floodplain environments. Some riffles do occur where occasional outcropping of bedrock is exposed at the surface, such as occurs downstream of site G8170005 (Plate 5). Most riffles are created by deposition of sediments and debris after wet season flows, and are dynamic, regularly changing form and location after each wet season or after large events.

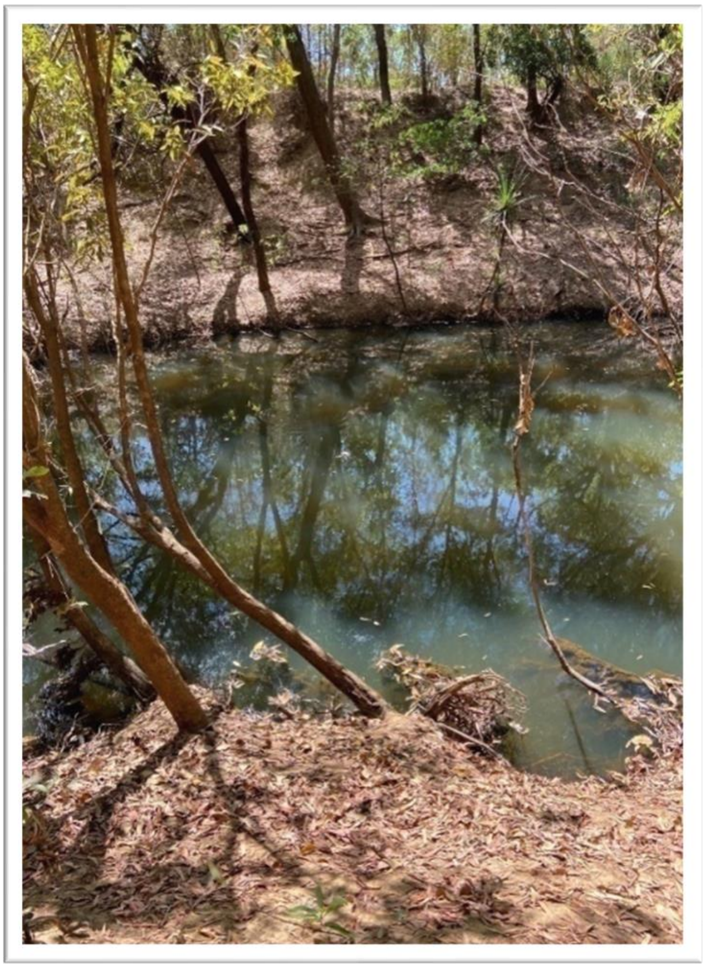


Plate 3. Permanent pool in the Adelaide River

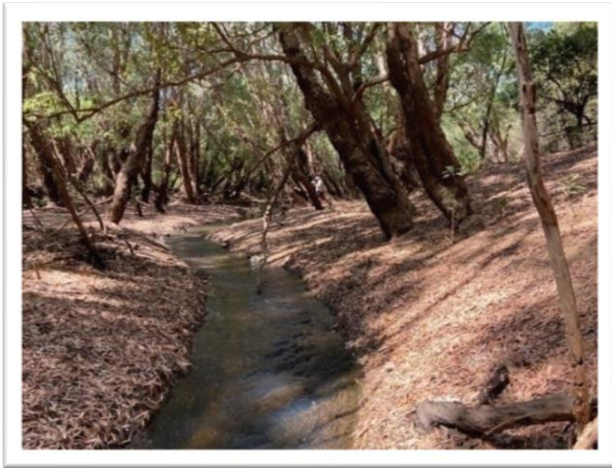


Plate 4. Run reach in Adelaide River channel

Plate 5. Cease to flow in Adelaide River at G8170005

Downstream of its headwaters, the channel of the Adelaide River is initially well defined with primary bank heights typically exceeding 5 m and secondary bank heights exceeding 12 m from the bottom of channel. Figure 22 shows a cross section for Adelaide River at Adelaide River township. It demonstrates a deep channel, albeit perched several metres above its floodplain on the right bank to the south of the river.

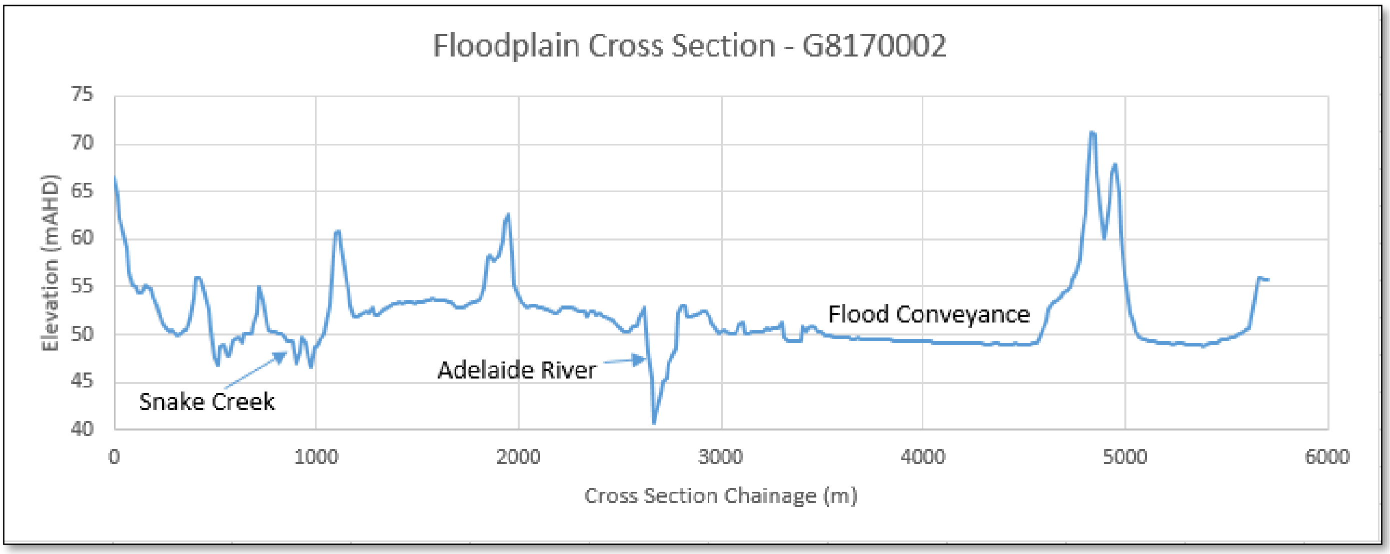


Figure 22. Floodplain cross section of Adelaide River at Adelaide River township

Moving downstream, the channel becomes shallower with bank levels to 6 m however extending out to broader floodplain on either side of the channel. Figure 23 shows the cross section of the Adelaide River downstream at G8170084 (Tortilla Flats). It shows a relatively shallow river channel approximately 6.0 m deep perched well above its floodplain, a feature common throughout the middle reaches of the river. At higher flows, water spills from the primary channel into flood channels and along flood conveyance and wetland areas, complicating river level monitoring, river access and the ability to undertake discharge measurements.

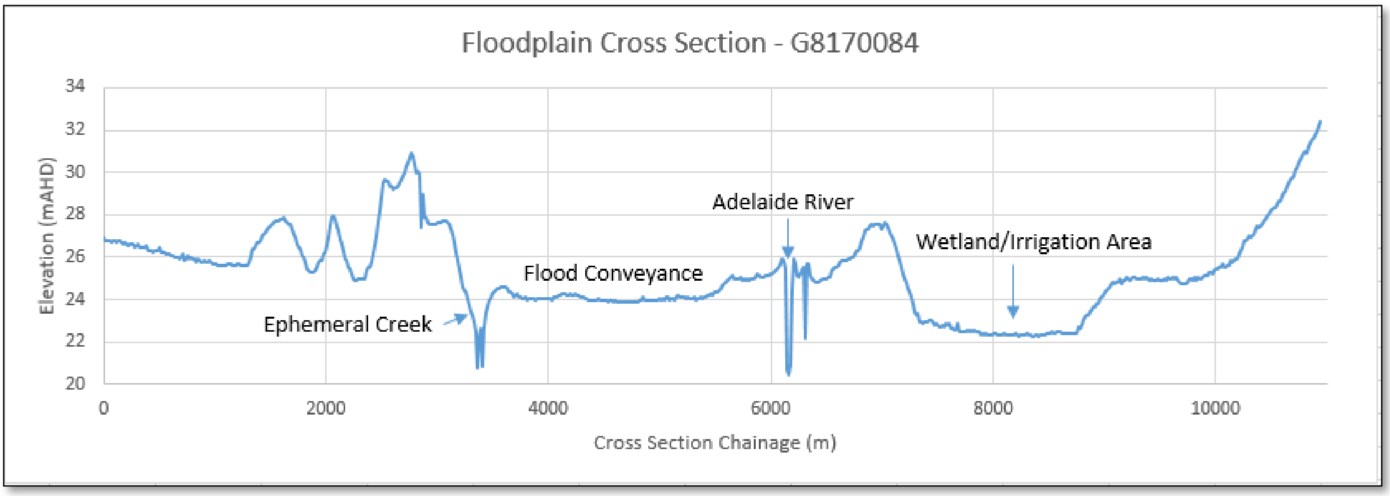


Figure 23. Floodplain cross section of Adelaide River at Tortilla Flat

Figure 24 shows both the Adelaide River and Margaret River upstream of their confluence. At this location, the rivers are separated by relative heights however both appear perched above their floodplains. A large alluvial floodplain has developed upstream of the tidal extent on both the Adelaide and Margaret Rivers due to the backwater impacts of the constriction at Dirty Lagoon. Extending approximately 20 km along both waterways, the temporary impoundment of flood waters spill across the plain. Reduced water velocity allows sediments to drop out of suspension and accumulate across low lying areas, creating the alluvial floodplain.

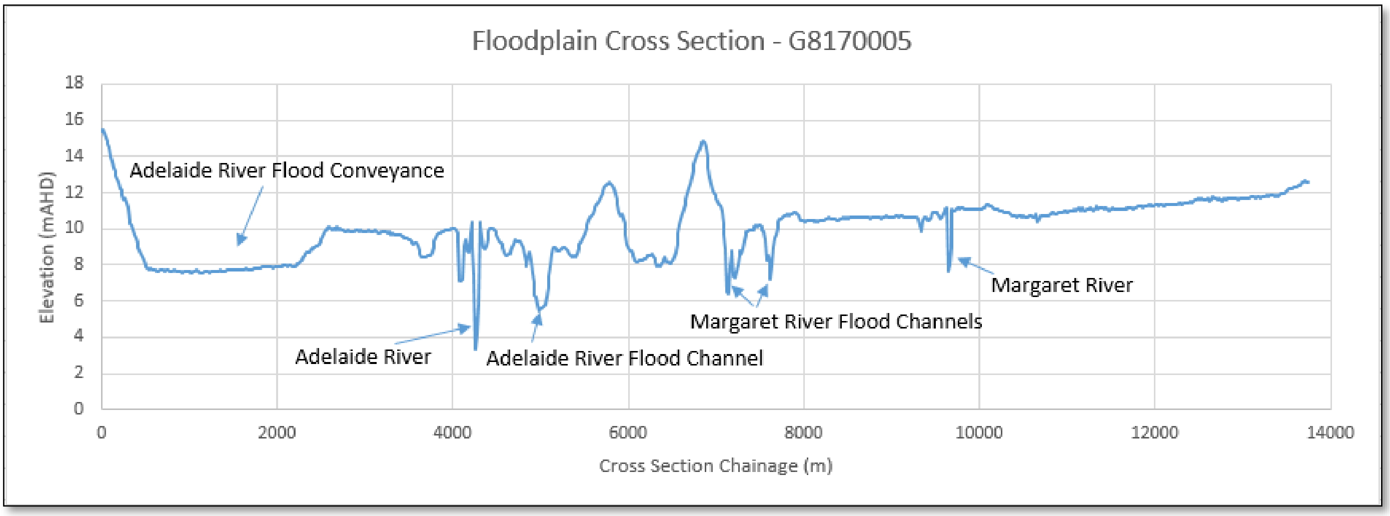


Figure 24. Floodplain cross section of Adelaide River and Margaret River, 4km upstream of Marrakai Crossing

4.1.3 Margaret River

The Margaret River (Figure 17) is the largest tributary to the Adelaide River, with its catchment area of 2,600 km^2 being 50% larger than the upper Adelaide River catchment. The Margaret River drains the southeast of the Adelaide River catchment, which consists largely of broken foothills in the upper ranges transitioning to gently undulating plains through most of the catchment. The headwaters to the Margaret River and its tributaries rise on the Douglas, Ban Ban Springs and Mary River West Stations, draining the relative heights formed by the foothills at the southern periphery of the Pine Creek Orogen geological region (CSIRO, 2009; Tickell, 2013). The upper Margaret River and its tributary Saunders Creek drain the eastern extent of the catchment, flowing in a northerly direction close to the eastern catchment boundary for approximately 50 km before turning northwest towards the centre of the catchment. After another 35 km, Howley Creek converges with Margaret River from the south. Howley Creek and its tributary Bridge Creek drain the central southern section of the Adelaide River catchment, flowing roughly north for 70 km to its confluence with Margaret River. From the Howley Creek confluence, Margaret River travels north and northwest for another 25 km to Marrakai Crossing and the extent of tidal influence. The Margaret River joins the Adelaide River 2.0 km downstream of Marrakai Crossing.

Waterways of the Margaret River catchment are typically shallow, ephemeral channels through unconsolidated sediments and interspersed with occasional deeper in-channel depressions. Figure 25 (upper Adelaide River) includes the Margaret River cross section 9 km upstream of Marrakai Crossing. It shows the Margaret River as a smaller channel than the Adelaide River channel, perched above its floodplain which stretches out on its left bank. Two large flood channels occur on the floodplain through which water is diverted during moderate and high flows from the lower Howley Creek and Margaret River downstream of the Howley Creek confluence. Flow in these channels transect the alluvial floodplain and discharge to the Adelaide River approximately 2.0 km upstream of Marrakai Crossing.

Similar to the upper Adelaide River catchment, a large alluvial floodplain has developed along the lower reaches of the Margaret River created by sediment deposition resulting from the backwater impacts of the Dirty Lagoon constriction. The primary river channel through the lower reaches is characterised by low bank levels typically less than 4.0 m and is anastomosed with numerous minor braided channels through the alluvial deposits. Low flows are retained within the primary channel with moderate and high flows propagating through the braided channel network. The river form in the upper reaches consists of long plane-bed runs interspersed with occasional pool sections through a relatively uniform plain landscape and with few prominent landmark features. The presence of multiple flow paths occurs throughout the catchment, with significant spilling from the primary channel as far upstream as Howley Creek. Figure 25 shows the cross section just below the confluence of Howley Creek and Margaret River. It shows the shallow primary channel with bank levels less than 5.0 m perched above its floodplain on the left bank, with a shallow flood channel also to the right of the primary channel.

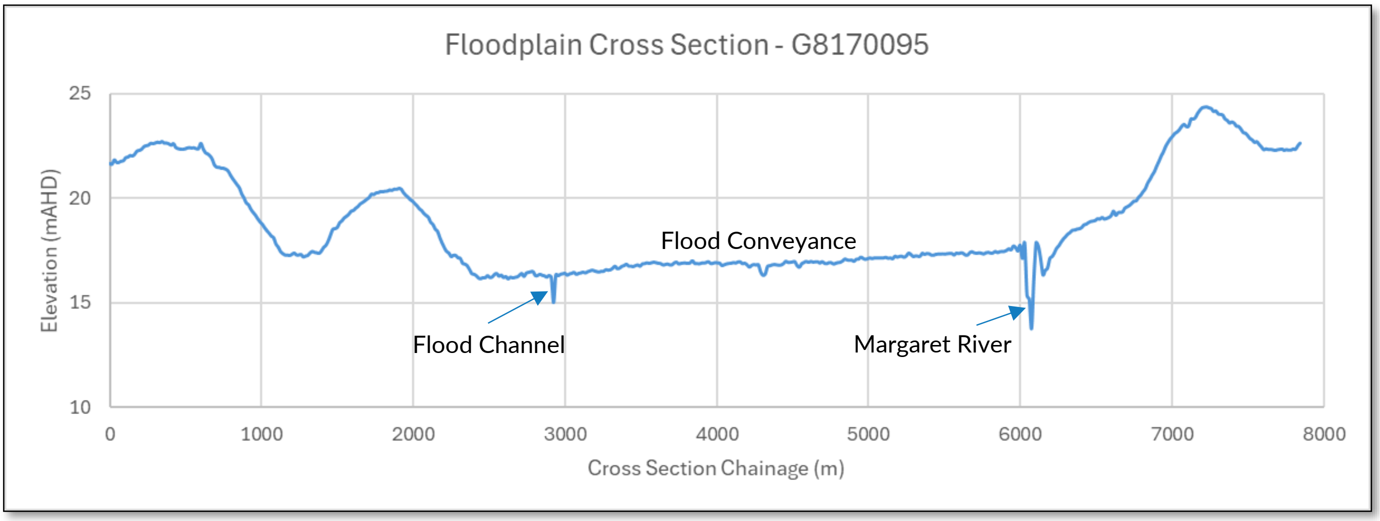


Figure 25. Floodplain cross section at Margaret River, DS Howley Creek confluence

Plate 6 and 8 show water spilling from the primary channel of Howley Creek and Margaret River at 17.5 mAHD and 17.7 mAHD, which equates to a flow of 7,800 ML per day and 10,500 ML per day respectively. As a result of the low banks, diversion of water onto the left bank floodplain and into the flood channel is well established at relatively low flow for a catchment area of over 2,000 km^2.

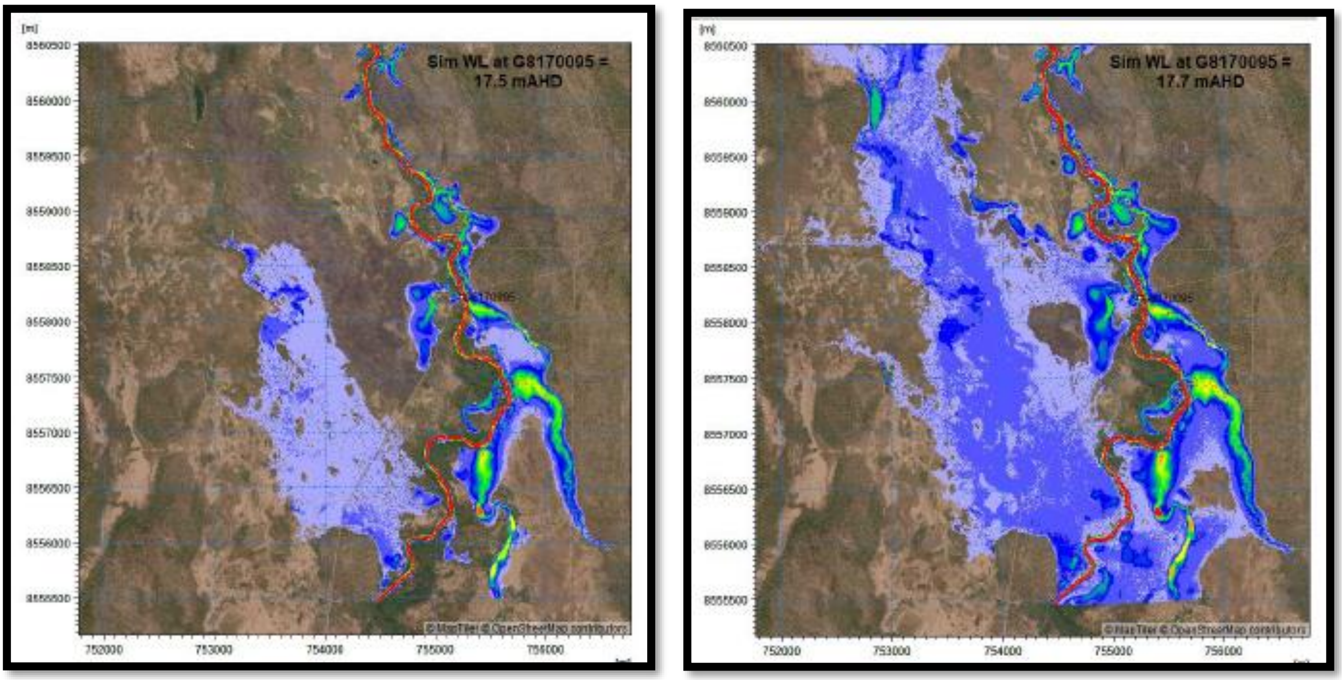


Plate 6 and Plate 7. Overland flows at Howley Creek channel and Margaret River channel at 17.5 m and 17.7 mAHD (DHI, 2024)

Waterways in the Margaret River catchment are lined by a thin riparian zone, with occasional thickets of paperbark or palm forest around persistent waterholes that may also indicate shallow, localised groundwater.

4.2 Surface water monitoring network

The Adelaide River water monitoring network is described in detail in the technical note *'Adelaide River Catchment Water Resource Monitoring Programs 1950–2024'*. The following is a summary of information from that report, however is limited to sites used in this surface water assessment.

Surface water monitoring commenced in the Adelaide River catchment in the 1950's, with flow and water quality data being collected at 60 locations with varying levels of continuity of data collection. Collection of time-series data commenced at G8170002: Adelaide River at Adelaide River Railway in 1953. Table 8 shows all monitoring sites where time-series flow data has been collected in the Adelaide River catchment, while Figure 26 shows the location of these sites within the Adelaide River catchment, including tidally influenced and non-tidal reaches.

Table 8. Current and key historic time-series monitoring sites in the Adelaide River catchment

#	Gauge station	Site name	Parameter	Period of record
1	G8170002	Adelaide River at Adelaide River Railway	Water Level Discharge Rainfall	1953 to current 1953 to current 1989 to current
2	G8170005	Adelaide River upstream Marrakai Crossing	Water Level Discharge Rainfall	1956 to current 1956 to current 2010 to current
3	G8170006	Bridge Creek upstream Railway	Water Level Discharge	1966 to current 1966 to current
4	G8170008	Adelaide River downstream Daly Road	Water Level Discharge Rainfall	1981 to current 1981 to current 1985 to current
5	G8170011	Manton Dam at Intake Tower 2	Water Level Discharge Water Temperature	1956 to 2023 1956 to 2023 1956 to 2023
6	G8170020	Adelaide River at Dirty Lagoon	Water Level Discharge Rainfall	1962 to current 1963 to current 2013 to current
7	G8170021	Adelaide River at Arnhem Highway	Water Level Rainfall	1969 to current 2018 to current
8	G8170026	Litchfield Creek at Track Crossing	Water Level Water Temperature	2015 to current 2015 to current
9	G8170032	Margaret River at Marrakai Road	Water Level Discharge Water Temperature	1957 to current* 1957 to current* 2017 to current
10	G8170033	Manton River at Acacia Gap	Water Level Discharge	1959 to 1986 1959 to 1986
11	G8170065	Howley Creek downstream Brocks Creek Mine	Water Level Discharge	1997 to 2002 1997 to 2002
12	G8170066	Coomalie Creek at Stuart Highway	Water Level Discharge	1958 to current 1958 to current
13	G8170067	Howley Creek at Ringwood Road	Water Level Discharge	2023 to current 2023 to current
14	G8170075	Manton River upstream Manton Dam	Water Level Discharge Rainfall	1965 to current 1965 to current 2019 to current
15	G8170076	Stapleton Creek – Stuart Highway	Water Level Discharge	1963 to 1981 1963 to 1981
16	G8170083	Bakers Creek at Black Jungle	Water Level Electrical Conductivity Water Temperature	1958 to current* 2007 to 2009 2015 to 2022

#	Gauge station	Site name	Parameter	Period of record
17	G8170084	Adelaide River at Tortilla Flats	Water Level Discharge Rainfall	1958 to current 1958 to current 2010 to current
18	G8170085	Acacia Creek at Stuart Highway	Water Level Discharge	1963 to current 1963 to current
19	G8170089	Snake Creek at Stuart Highway 3	Water Level Discharge	1963 to 1969 1963 to 1969
20	G8170094	Adelaide River downstream Red Bank Creek	Water Level Rainfall	2003 to current 2005 to current
21	G8170095	Margaret River downstream Howley Creek	Water Level Discharge Water Temperature	2017 to current 2017 to current 2017 to current
22	G8170240	Margaret River at Bobs Hill	Water Level Discharge Water Temperature	1965 to current* 1965 to 1986 2017 to current
23	G8175079	Melacca Creek Spring Koolpinyah	Water Level	2015 to current
24	G8175088	Banka Spring Creek	Water Level Water Temperature	2015 to 2023 2015 to 2023
25	G8175094	Mclennens Creek at Old Road Black Jungle	Water Level Water Temperature	2015 to current 2015 to 2023

*Denotes non-continuous dataset.

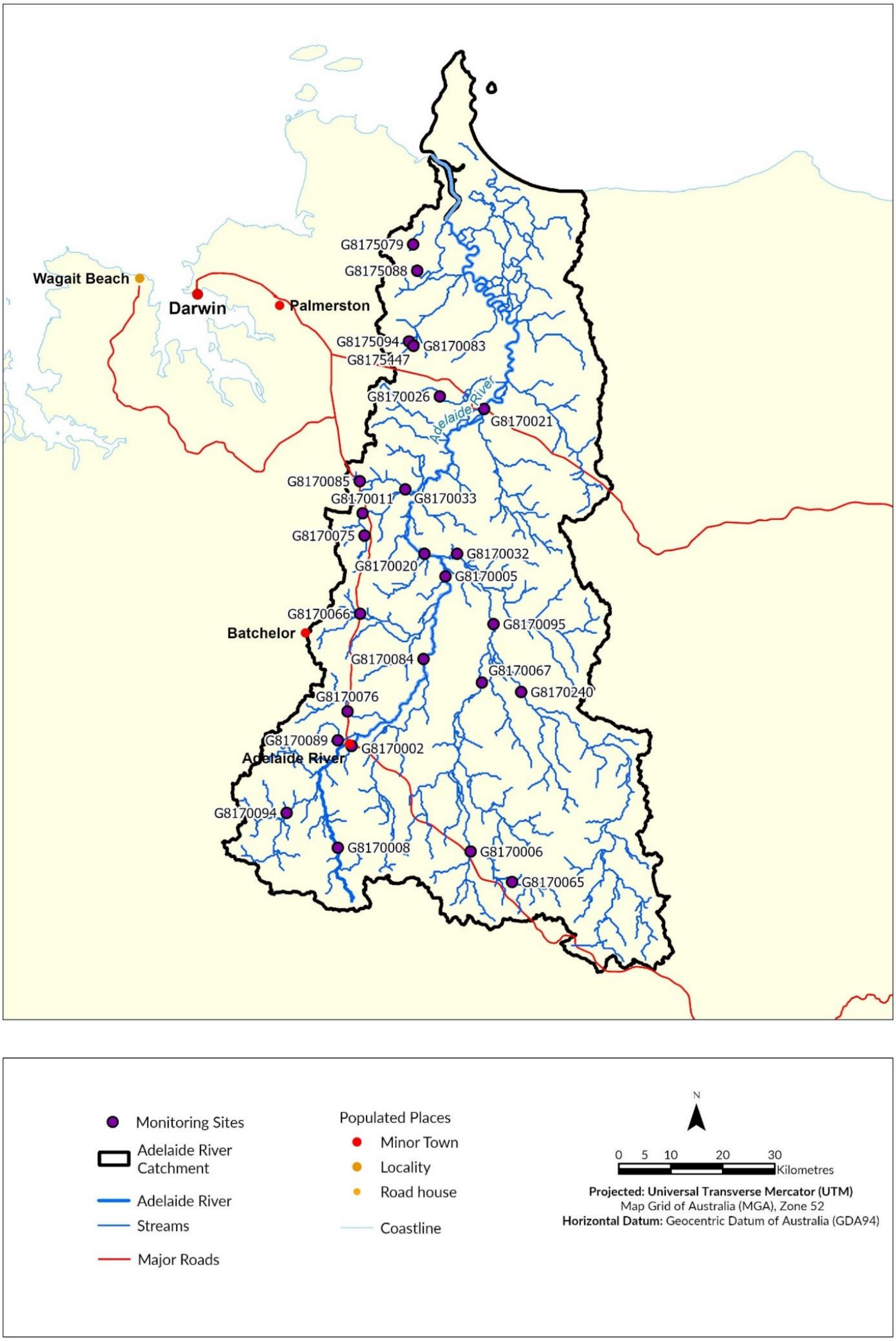


Figure 26. Surface water monitoring network for Adelaide River catchment

4.2.1 Total catchment flow

Total catchment flow is typically collected at monitoring sites in the lower catchment to quantify total discharge from the river catchment. Understanding total catchment flow is a critical component of water planning. Constantly varying water levels within the lower Adelaide River due to macro-tidal impacts complicates the development of discharge rating curves throughout the lower catchment. As such, whole of catchment discharges from the upper catchment are measured at G8170020, immediately downstream of the constriction at Dirty Lagoon and 140 km from the river mouth.

Approximately 40% of the total Adelaide River catchment occurs on the coastal floodplain downstream of the Dirty Lagoon monitoring site, contributing considerable additional flow through direct rainfall runoff over these areas. In the absence of suitable monitoring locations through the lower Adelaide River catchment, development of hydrological models provides the best estimate of discharge from these 'ungauged' parts of the catchment. Models are well calibrated according to the physical characteristics of the catchment, using monitoring data within the gauged sections of the catchment to provide estimates of runoff parameters, allowing catchment flows to be estimated to a good level of certainty using the rainfall record. Modelled runoff based on rainfall over the lower catchment below Dirty Lagoon was undertaken by CSIRO as part of their NAWRA study (2018), allowing them to estimate the median total annual discharge from the Adelaide River catchment to the Arafura Sea at 2,354 GL.

4.2.2 Constructed discharge dataset

Gauging station G8170020 at Dirty Lagoon is located within the tidally influenced upper reaches of the Adelaide River estuary and as such is impacted by tidal influences as seen in Figure 27. Higher flows push the tidal reversal downstream (Vertessy, 1990) so that once water levels exceed 6.5 m, the tidal signature is insufficient to measurably impact on the stage/discharge relationship (Petheram et al, 2018). 6.5 m represents a discharge of approximately 13,000 ML per day.

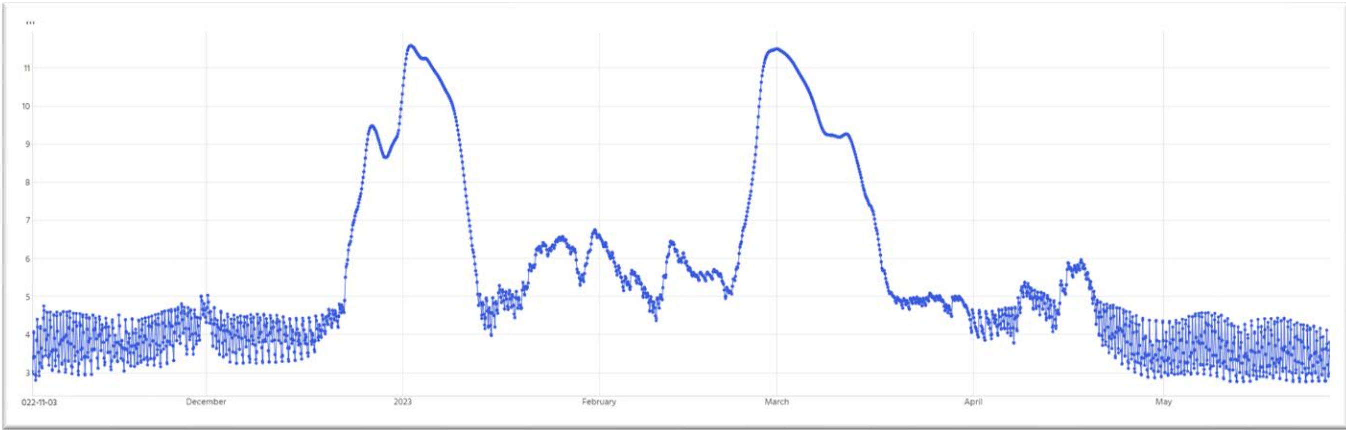


Figure 27. Tidal effects on the hydrograph at G8170020: Adelaide River DS Dirty Lagoon

To overcome limitations from tidal impacts, flows below 13,000 ML per day are calculated from sites G8170005: Adelaide River US Marrakai Crossing, and G8170032: Margaret River US Marrakai Crossing. These two sites are located upstream of the zone of tidal influence at Marrakai Crossing on their relative waterways and provide a whole of catchment discharge for the upper Adelaide River and the Margaret River catchment. Flows up to 13,000 ML per day are measured at each of these sites and calculated to provide whole of catchment flows below the 13,000 ML per day threshold. If the combined flow of these two sites exceeds 13,000 ML per day, the flow data at site G8170020 is given preference.

Monitoring at site G8170032 initially commenced in 1957 and ceased in 1977, only recommencing in 2017. To infill the missing period of record, a hydrological model was developed (WRM, 2024), calibrated to flow data collected between 2017 to 2023 and used to generate a timeseries flow dataset from 1970 to 2023. This data was used to infill the missing record for site G8170032, allowing a complete flow dataset for G8170020 from 1970 to current utilising the SILO rainfall data as the input dataset.

Utilising the recorded and modelled flow data from G8170020, G8170005 and G8170032, a constructed discharge dataset was developed using the following prioritisation logic:

1. Flow record for G8170020 was used for ALL flows above 13,000 ML per day.
2. Flow record below 13,000 ML per day calculated as combined flow record from G8170005 and G8170032.
3. Flow record calculated as combined flow from record at G8170005 and modelled output for G8170032.
4. Modelled flow record only at G8170020 where no recorded data exists.

This allowed the development of a complete flow dataset for total catchment discharges from the Adelaide River and Margaret River upstream of the tidal extent.

Limitations of the modelled flow dataset are outlined in the model report ‘Hydrologic model for the Adelaide River catchment, water availability assessment’ (WRM, 2024) and include:

- Poor coverage of rain gauges between 1970 and 2000.
- Diversion of flood flows from the Margaret River catchment at G8170095 to a channel that joins the Adelaide River downstream of the monitoring site at G8170005. These flows are not able to be accounted for in model calibrations.
- Floodwater is attenuated on the floodplain behind the Dirty Lagoon constriction creating variable backwater conditions which complicate model calibrations.
- Moderate flows between bank full 13,000 ML per day and 26,000 ML per day are not well represented by the model.

4.3 Hydrological characteristics

The wet-dry tropics are noted for their distinct seasonality, with almost all rainfall occurring during the hot, wet summer months followed by an extended dry period during the warm, dry winter. Over 95% of catchment rainfall across the Adelaide River catchment occurs during the wet season months (Vertessy, 1990; Petheram et al, 2018). While the northern wet season occurs reliably every year between October and April, the timing and magnitude of the wet season does vary considerably (Petheram et al, 2018), leading to a high level of variability in total annual flow from year to year, as well as the high seasonal flow variability. Statistically, December, January, February and March are the wettest months in the year for the Adelaide River catchment (Figure 28), however significant rainfall can occur early with a dry tail-end to the wet, or the rains may not arrive until late in the wet season. Highly variable rainfall duration and intensity, as well as variable PET over the wet season months, have significant impacts on catchment runoff and stream flows (Petheram et al, 2018). Figure 28 shows an annual hydrograph for G8170084: Adelaide River at Tortilla Flats for 2022. It is extended to show two wet seasons, one with significantly greater discharges than the other demonstrating annual wet season flow variation, while the contrast of the low flow period during the dry season months shows the large seasonal flow variation between wet and dry seasons.

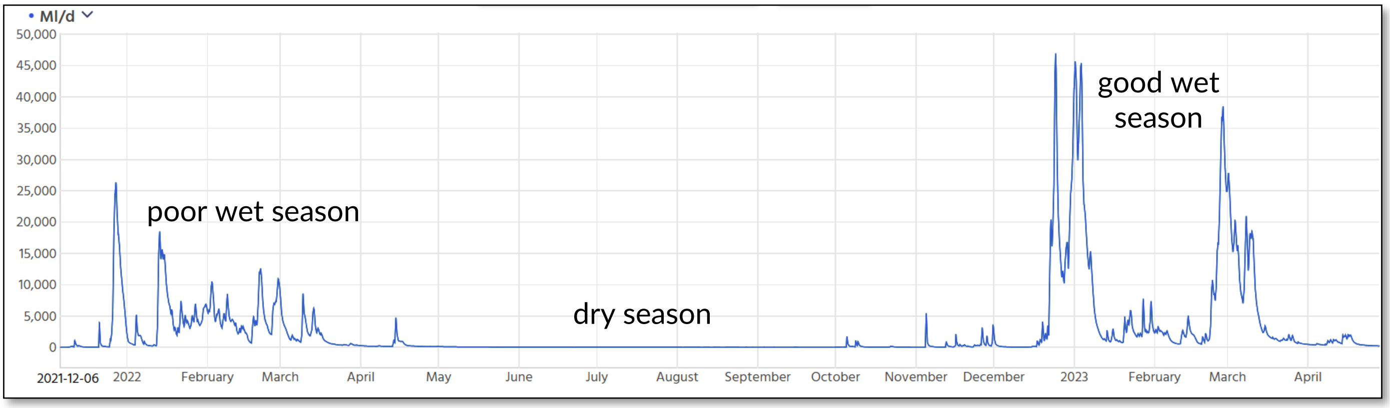


Figure 28. Annual hydrograph at G8170084 for Year 2022

4.3.1 Seasonal flow variability

During the wet season, thunderstorms and monsoonal troughs bring substantial rainfall, on average 1,500 mm per year, across the Adelaide River catchment, leading to high flows throughout the catchments, and instantaneous flows exceeding 300,000 ML per day in the lower catchment on some occasions. Wet season rains and flooding causes widespread inundation of the coastal floodplain, and regularly causes inundation of the upstream alluvial floodplain due to water retained behind the constriction at Dirty Lagoon. By contrast, drought conditions prevail during the dry season months. Flows recede after the cessation of wet season rains and throughout the dry winter months, reaching very low levels by the end of dry season and often ceasing to flow altogether at some locations (Appendix D -Flow duration curves). This seasonal flow disparity occurs across all the catchments to varying degrees, with some waterways ceasing to flow early in the dry season, while others persist until late in the dry season, or may flow perennially where delayed discharges from catchment storage features have sufficient capacity to allow perennial baseflow. Across the Adelaide River catchment, wet season flows exceed any dry season flows by several orders of magnitude, and wet season rainfall is the major hydrological driver within the catchment.

Annual flow cycles of waterways in the wet/dry tropics can be categorised into four distinct components that demonstrate their distinct seasonal characteristics:

- dry season flows
- dry–wet season transitional flows
- wet season flows
- wet season recessional flows.

Figure 28 shows these four flow categories superimposed over a typical annual hydrograph at representative gauging station G8170084.

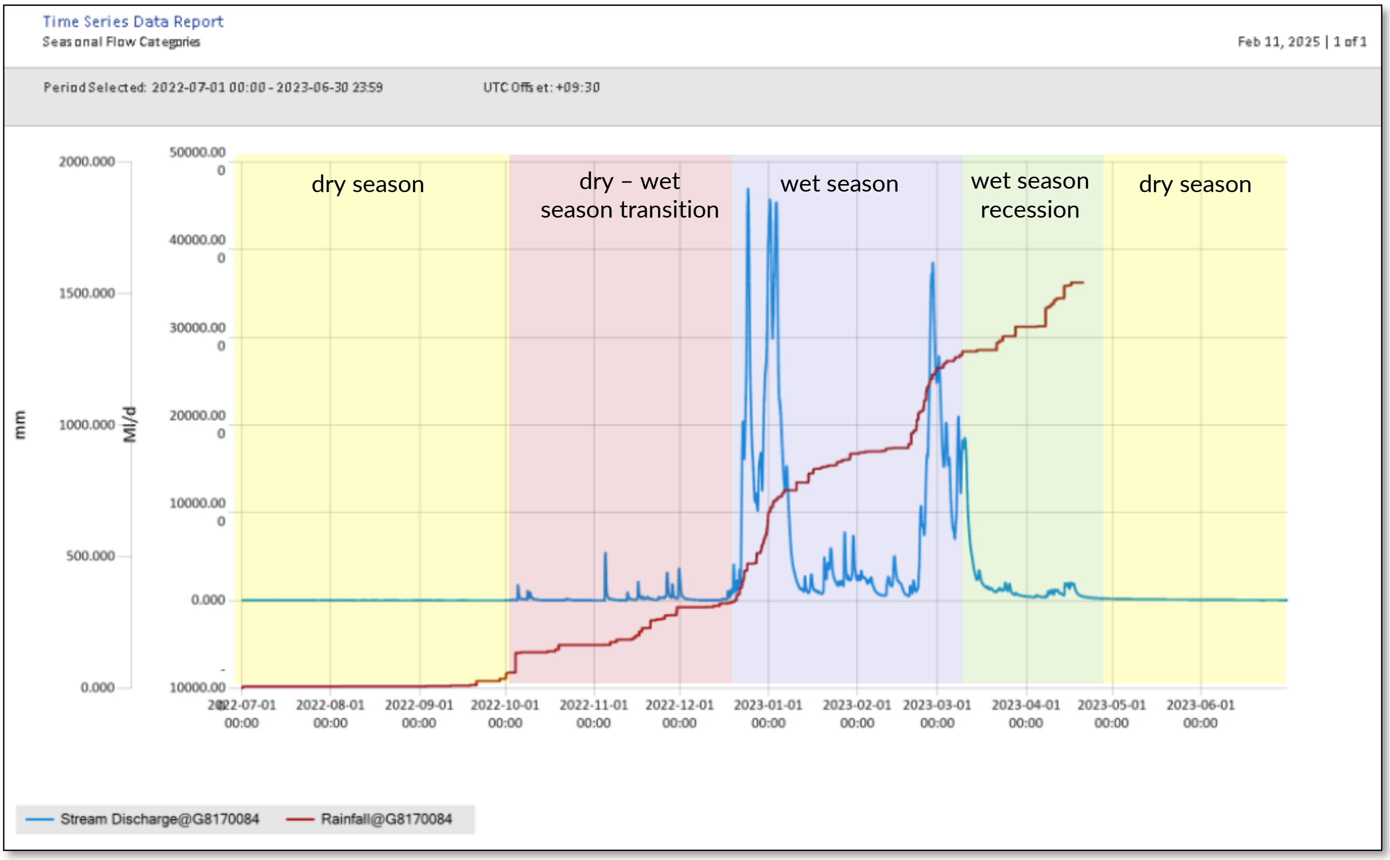


Figure 29. Seasonal flow classifications for the wet dry tropics (source: NTG Aquarius database)

4.3.1.1 Dry season flows

Dry season flows occur after the wet season recession, however, are often a continuation of recessional flows unless a baseflow occurs due to discharges from groundwater or other storage. The onset of dry season flows occurs when direct runoff from rainfall has ceased, with ongoing flow typically sourced from short to long term storages including delayed interflow and bank soil storage, discharges from localised storage such as wetlands and local scale aquifers, and perennial discharges from large storages such as regional scale aquifers.

Commencement of dry season flows varies with magnitude and timing of the previous wet season rains. In the Adelaide River catchment, dry season flows typically commence between early May and early July, usually by early June. Dry season flows continue until the first runoff from storms marking the transition to the following wet season.

Although few key lifecycle functions occur during the dry season, dry season flows are critical for the maintenance of refuge pools and habitats that support aquatic and semi-aquatic species, rich riparian zones and critical watering locations and refuge for terrestrial species.

4.3.1.2 Dry–wet season transitional flows

Commencing in September, increasing humidity and isolated shower and thunderstorm activity from convective storms occur over the Top End. Storm frequency and intensity increases during October and November, although spatial extent typically remains limited. Most rainfall from early wet season storms will be lost to soil infiltration or evapotranspiration. Where higher rainfall intensity events occur, infiltration excess may occur whereby rainfall intensity (mm per hour) exceeds the surface infiltration capacity (mm per hour). This leads to runoff into waterways, transporting accumulated sediments and nutrients, dispersing seeds and initiating biogeochemical processes. These events are unlikely to lead to significant flows and are typically confined within the channel, causing channel depressions to be filled, creating early pools along dry waterways and allowing longitudinal connectivity between refuge pools.

The dry–wet season transition is an important period in the ecological cycle as the pulses of flow along waterways trigger biological queues within various biota to prepare for wet season conditions (Douglas et al, 2019). An important component of the dry–wet transition is the first flush event, which is typically considered the first priming event for the season. The first flush is normally defined as the first event where rainfall induced runoff increases river flows and is typically associated with a high pollutant load as detritus, ash and other contaminants that have accumulated on land over the dry season months are washed into drainage lines and waterways. Depending upon the contaminant load, the first flush may constitute a boon for biological species as potential food items and nutrients are washed from land into waterways, however too high a contaminant load can lead to significantly increased nutrients and an associated boom in microbial growth, leading to lower dissolved oxygen levels and occasionally resulting in blackwater events and significant fish kills.

4.3.1.3 Wet season flows

Wet season flows are usually associated with the arrival of the first monsoon and typically occur between December and March, although initial onset of the northern monsoon is highly variable and may commence as early as November or as late as February. Wet season duration is also highly variable with cessation of the monsoonal activity sometimes occurring as early as January. December, January, February and March are the wettest months in the Adelaide River catchment indicating the northern monsoon is often present across these months. On average, over 99% of total catchment discharges from the upper catchments to the lower catchment occur during the wet season months, highlighting wet season rainfall as the most significant hydrological driver within the catchment.

Wet season flows provide essential environmental services throughout the Adelaide River catchment. Longitudinal connectivity along the entire length of the Adelaide River and its tributaries is achieved, connecting upstream regions to the estuary and allowing flushing of permanent pools, mobilising and distributing sediments and nutrients throughout the catchments, scouring and deposition of sediments and refuse such as woody debris to maintain habitat features and create new habitat features, and to allow migration for recruitment and other lifecycle requirements for many aquatic species. Overbank flows allow lateral connectivity to riparian zones and the extensive alluvial and coastal floodplains that make up such a significant proportion of the Adelaide River catchment, providing access to key nursery locations for juvenile aquatic species, recharge floodplain billabongs and refuge pools and triggering recovery and growth in wetland vegetation communities (Douglas et al, 2019).

4.3.1.4 Wet season recessional flows

Recessional flows occur at the end of persistent rainfall and monsoonal activity. The hydrograph in Figure 29 shows a marked reduction in rainfall from early March (green) with an associated drop in river flow between March and May. This is known as the wet season recession.

Wet season recessional flows occur as large rainfall events and flooding recede, however are still impacted by smaller rainfall events and surface water runoff. Inflows from short term surface water storages such as wetlands, floodplains and soil storage are also a significant contributor to recessional flow, while groundwater discharges also usually peak during this period.

Recessional flows are an important time for migratory species. Longitudinal connectivity is retained however with lower water velocities allowing passage upstream for smaller species such as freshwater prawns and juvenile fish, while larger species migrate to dry season refuge pools or to the sea. Draining of floodplains back into the river redistributes nutrients into the main channel and dry season pools. This period is also a boon for predatory species such as Barramundi, as nursery fish are swept out of the relative safety of the floodplain and into the open water channel.

4.3.2 Annual flow variability

In the NAWRA study, Petheram et al (2018) used modelled discharges to estimate a mean total annual discharge from the Adelaide River catchment to the Arafura Sea of 2,693 GL, with 40% of that discharge derived as runoff from the coastal floodplain. Recorded and modelled data for G8170020, Adelaide River at Dirty Lagoon, includes all flows from upstream catchments discharging into the tidal estuary and is the lowest point in the catchment for which flow records exist. The record shows the mean annual discharge from the upper catchments to the lower Adelaide River is 1,738 GL, or 65% of the NAWRA modelled mean annual discharge; while the median annual discharge of 1,637 GL from the upper catchments equates to 70% of the NAWRA modelled median total annual discharge of 2,354 GL.

Figure 30 shows total annual discharge at G8170020 for each water year from 1970 to present. Visual assessment demonstrates the high variability in total annual discharge that exists from year to year. The minimum annual discharge on record was 319 GL in 1990 and a maximum annual discharge of 5,069 GL occurred in 2011 after an extremely high rainfall year.

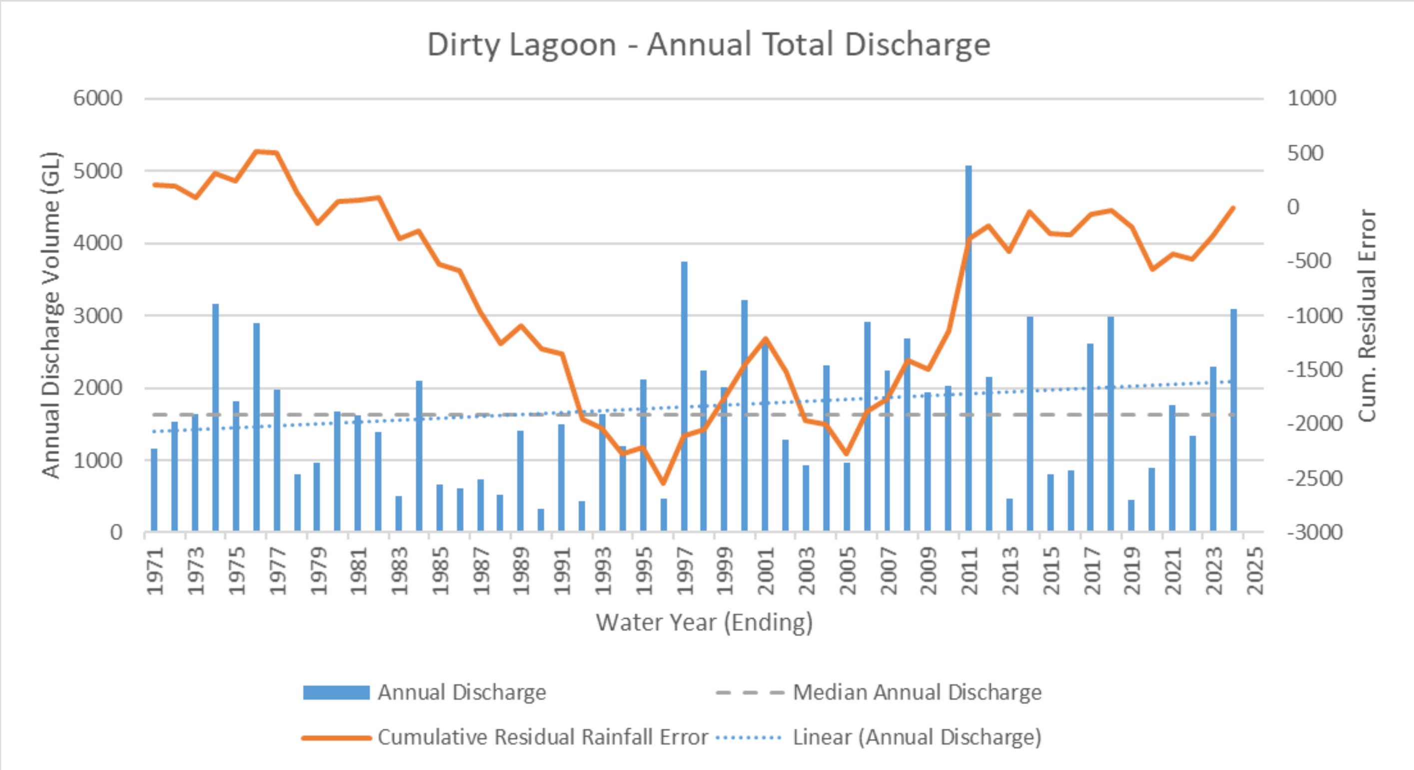


Figure 30. Total annual (water year) discharge at G8170020 – Adelaide River at Dirty Lagoon since 1970

Figure 30 also shows the cumulative residual error for rainfall from mean annual rainfall since 1970 in the upper catchment at Adelaide River post office. It shows periods of lower rainfall correlating with generally lower annual discharges between 1978 and 1996, and again from 2002 to 2005. Wetter rainfall periods correlate to generally higher annual discharge from 1997 to 2001, and 2006 to 2012. A similar trend is evident using rainfall trends at Koolpinyah in the lower catchment. Appendix C contains further graphs comparing total annual discharge to rainfall trends.

In 20% of years, total annual discharge at Dirty Lagoon was less than 800 GL while in 20% of years, total annual discharge exceeded 2,654 GL. Table 9 shows standard statistical measures used to assess annual flow variation for Dirty Lagoon G8170020, and at Adelaide River township G8170002.

Table 9. Annual flow statistics for Adelaide River at Dirty Lagoon (G8170020) and Adelaide River township (G8170002)

Location	Mean annual flow (GL)	Median annual flow (GL)	Standard deviation (GL)	95% CI (GL)	Coefficient of variance
G8170002	277	248	169	0-560	0.61
G8170020	1738	1637	999	0-3411	0.57

The standard deviation for both locations is almost two thirds of mean annual flow which indicates a very high level of variation in total annual flow from year to year throughout the catchment. This gives a 95% confidence interval that total annual flow at G8170020 will be between 0 GL and 3,411 GL in any given year, and between 0 GL and 560 GL at G8170002, a large range of likely flows. The coefficient of variance is another measure of variation between 0 (no variation) and 1 (no relationship). The coefficient of variance for total annual discharge at both sites is also very high at around 0.60.

4.3.3 Surface water – groundwater connectivity

While waterways within the Adelaide River catchment are overwhelmingly driven by rainfall and surface runoff, persistent and perennial flows do occur in some tributaries to the Adelaide River and contribute to perennial flow in the upper Adelaide River itself in some years. Groundwater discharges are the main contributor to persistent and perennial flows in waterways in the Adelaide River catchment (Water Resources Division, 2024). Groundwater discharges allow surface flows to persist later into the dry season in some waterways, and in some cases perennially as baseflow. For the purposes of this report, groundwater discharges supporting perennial flows in waterways are referred to as 'baseflow', while groundwater discharges supporting flows later into the dry season, but typically ceasing to flow before the end of the dry season, are referred to as 'persistent flow'.

An investigation into groundwater contributions to surface flows within the Adelaide River catchment was undertaken by Water Resource Division in 2024. It found evidence that several underlying geological formations at the local and regional scale contributed groundwater discharges into waterways of the Upper and Lower Adelaide River catchments, however many of these groundwater discharges were not perennial, with flows in most waterways typically ceasing during the dry season (Water Resources Division, 2024). The period of persistent flow varied across waterways and was highly correlated to the volume of wet season rainfall, with wet seasons recording large rainfall volumes supporting persistent flow later into the dry season, while wet seasons with less rainfall were associated with waterways ceasing to flow early in the dry season (Water Resources Division, 2024).

Subcatchments overlying fractured rock aquifers with limited yield such as the Burrell Creek Formation, Whites Formation and the South Alligator Group were more likely to cease flowing during the dry season, while subcatchments overlying higher yield karstic and fractured aquifers such as the Tindall Limestone, Jinduckin Formation and Coomalie Dolostone were likely to maintain flows perennially (Water Resources Division, 2024). Groundwater discharges were found to support perennial flows in two waterways of the upper Adelaide River catchment, the east branch of upper Adelaide River and Coomalie Creek. The Adelaide River East Branch is underlain, in part, by the 'regional scale' Tindall Limestone Aquifer, Jinduckin Formation and Burrell Creek Formation, while Coomalie Creek is underlain by the 'intermediate scale' Coomalie Dolostone and Whites Formation (Water Resource Division, 2024). While recorded data show these aquifers provide reliable, perennial discharges to their receiving waterways, actual flow rates do vary from year to year depending upon wet season recharge. End of dry season flows in the Adelaide River East Branch are typically less than 100 L/s but may be up to 200 L/s after a large wet season, while end of dry season flow in Coomalie Creek is typically less than 20 L/s. Flow records along the upper Adelaide River, underlain by the Burrell Creek Formation, indicate groundwater discharges are sufficient to support perennial flows along the entire Adelaide River during wetter periods.

Monitoring in the Manton River subcatchment and Burrell Creek subcatchment also showed evidence of groundwater discharges, with flows persisting later into the dry season but typically ceasing before the end of the dry season (Water Resources Division, 2024). Upstream of Manton Dam, the Manton River does appear to have a small perennial flow in most years. The Manton River is underlain by the Coomalie Dolostone and Whites Formation while Burrell Creek is underlain by the Burrell Creek Formation.

By contrast, no evidence of groundwater discharges to tributaries within the Margaret River catchment were found (Water Resources Division 2024), with waterways throughout the Margaret River catchment ceasing to flow early in the wet season once surface runoff, interflow and short-term storages are depleted.

With the exception of Manton River, the 2024 Water Resources Division study did not extend to the lower Adelaide River catchment due to paucity of long-term data within the tidal reaches, however the Koolpinyah Dolostone is known to underlie a significant portion of the lower catchment to the north of the Arnhem Highway as well as some areas to the south. The Koolpinyah dolostone is an extensive fractured and karstic dolostone aquifer known to be high yielding (section 2.2), however it is largely confined within the lower Adelaide River catchment by the Cretaceous-age Darwin Formation which limit discharges to the surface to 'nick points and creeks on the edge of the Adelaide River floodplain' (Fells-smith et al, 2011). Seepages occur within tributary waterways to the northwest of the Adelaide River catchment around Black Jungle and at Banka Spring and Melacca Spring (Fell-Smith et al., 2011), all which flow perennially in high rainfall years, however Banka Spring is known to cease flowing during drier periods. Anecdotal evidence suggests isolated seepages and minor discharge points emanating from the Koolpinyah Dolostone immediately to the south of the Arnhem Highway., while a spring along the Marrakai track in the vicinity of Acacia appears to discharge from the Whites Formation, although no investigation has been undertaken. Many of these isolated springs and seepages are not connected to the stream network and do not contribute to flows in the Adelaide River or its tributaries.

4.3.4 Lower Adelaide River

On average, 99.2% of total annual flow, 1,720 GL discharging from the upper catchments to the lower catchment occurs during the wet season months, while just 0.8%, 14 GL occurs during the dry season months. Macro-tidal influences dominate dry season hydrology along the lower Adelaide River to the extent of tidal influence at Marrakai Crossing. The lunar-solar tide cycle generates a constantly varying hydraulic flux within the estuary, with water being drawn downstream during the tidal ebb before being pushed back upstream on the flood tide, a process known as tidal forcing. The increased pressure head from high flow events dampens the impact of tidal forcing in the estuary and pushes the tidal reversal downstream, although the dampening impact reduces towards the coast where tidal forcing is more pronounced.

High flows displace saline water in the river channel, so that water within the Adelaide River estuary is fresh almost to its mouth (electrical conductivity <200 uS/cm) however, as high flow periods recede and the transition to dry season flows progresses, tidal forcing propagates saltwater upstream through the estuary. Initially, differences in water density between freshwater and salt water leads to the development of a salt water wedge in the lower reaches that extends upstream beneath the fresh water as high flows recede, resulting in stratification of the water column and increasing the contact area for mixing, however Vertessy (1990) found that for the most part of the year, estuarine waters were well mixed due to turbulent diffusion (Chappell and Ward, 1985) resulting from the tidal forcing with no evidence of stratification during most of the dry season.

Freshwater inflows to the estuary during the dry season are insufficient to replenish losses to evapotranspiration and abstractions. As the constantly varying tidal flux enhances mixing with seawater at the tidal interface, an extensive salinity profile develops along the river channel (Vertessy, 1990), from fresh water in the upper reaches of the estuary, becoming increasingly saline towards the coast. The saline profile continues to develop over time, becoming more pronounced and extending further upstream so that by the end of the dry season, increased salinity and water quality impacts may extend all the way to Marrakai Crossing after lower rainfall years.

Figure 31 shows time-series electrical conductivity at Dirty Lagoon during the 2020 dry season, following a poor wet season. It shows increasing salinity commencing from early August to mid November. A small reduction in late October was likely due to an early wet season storm.

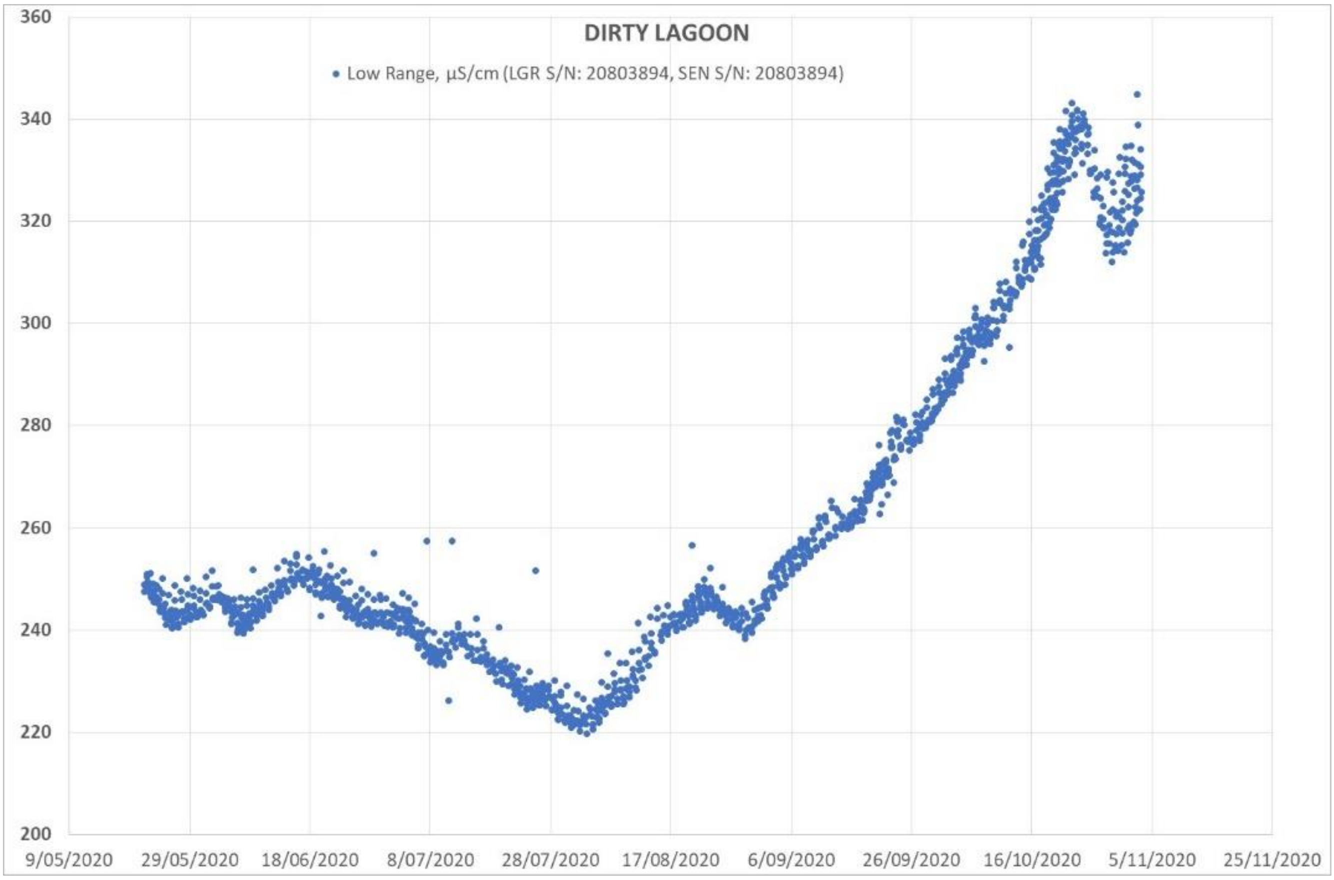


Figure 31. Dry season changes in electrical conductivity at G8170020 in 2020

This increase in electrical conductivity correlates with the cessation of flows from the upper catchment, with flow ceasing at Marrakai Crossing on 28 July in 2020. While overall electrical conductivity level is still low, within Australian Drinking Water Guidelines, it does demonstrate the potential for tidal forcing to impact water quality throughout the estuary.

Climate variability and timing of wet season onset has a significant impact on the water quality in the estuary, with late onset of the wet season potentially resulting in increased salinity and ingress of saline water to the upper reaches of the estuary than would occur with earlier rains. Ecological communities within these reaches are likely to be tolerant to a wide range of water quality conditions within the estuary, however the duration of 'extreme' conditions may be critical in overall ecosystem health with prolonged exposure to such conditions potentially leading to declines in ecosystem health and changes to ecological composition.

During the wet season, the hydrology of the lower Adelaide River catchment becomes dominated by wet season flooding and inundation of the coastal plain. The increased volume of water discharging from the upper catchment along with discharges from the floodplain itself displace the saline waters from the river channel with fresh water. During larger wet seasons, this displacement occurs throughout the entire lower Adelaide River channel to the river mouth, however insufficient data exists to understand the magnitude of discharges required to achieve complete displacement.

Section 4.1 established that the coastal floodplain exhibited very low relief and elevation. Widespread flooding of the coastal floodplain occurs every year on the Adelaide River, reducing in extent with distance inland (Karim et al, 2018) as elevations gradually increase. On the upper floodplain in the vicinity of Arnhem Highway, water elevation in the Adelaide River channel is required to exceed 2.0 mAHD before lateral connectivity between the river channel and floodplain occurs. Figure 32 shows an 11 year portion of the hydrograph at the Arnhem Highway. bridge.

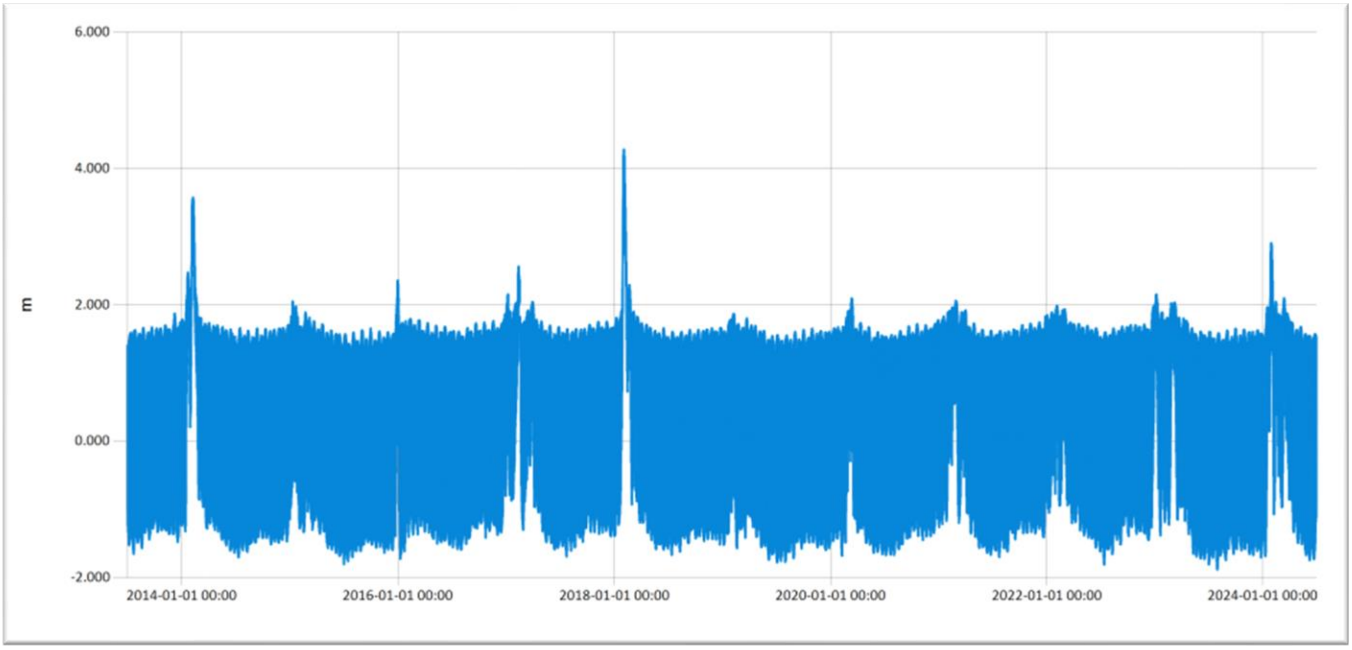


Figure 32. Water elevation (mAHD) at G8170021 Adelaide River at Arnhem Highway bridge

The hydrograph demonstrates that water levels exceed an elevation of 2.0 m only on larger flood events, with lateral connectivity in the upper floodplain achieved for just a few days in most years, often only on high tide for up to 3 hours. Sustained lateral connectivity was achieved in only 3 of the 11 years shown, while no lateral connectivity occurred at all for 20% of years of record. Comparison of the flow record upstream at G8170020 indicates discharge of 69,100 ML per day to 103,700 ML per day is required for lateral connectivity of the river and upper floodplain to occur, depending upon tidal stage.

The extent and duration of inundation of the coastal and alluvial floodplain of the lower catchment is highly dependent upon the timing and duration of wet season rains. Inundation occurs mainly through direct rainfall and runoff from the subcatchments that make up the lower Adelaide River catchment and occurs independently of riverine flooding. Lateral connectivity to the floodplain depends upon high flows discharging from the upper catchments to increase riverine water levels sufficient to exceed riverbank and floodplain elevations, which vary with proximity to the coast and due to channel width and depth. Much of the riverbank and floodplain in the vicinity of the Arnhem Highway lies at 2.0 mAHD, reducing to 1.0 mAHD further north towards the coast. Water levels at the monitoring site at Arnhem Highway bridge, G8170021, show that the river only exceeds 2.0 mAHD during large flood events, with true lateral connectivity in the vicinity of Arnhem Highway bridge only occurring for a limited number of days in each wet season, and often not at all. No water level data exists for the Adelaide River downstream of the Arnhem Highway, however, it is likely that lateral connectivity between the river and the floodplain occurs more frequently towards the coast due to lower bank levels and increased tidal variation.

Due to the low relief and tidal influences, flood propagation velocity is slow along the lower Adelaide River (Karim et al, 2018), leading to longer periods of lateral floodplain connectivity on larger flood events, particularly on the lower coastal floodplain – greater than 20 days in some instances. Further data collection is required to better characterise lateral connectivity dynamics of the lower and upper coastal floodplain.

The constriction at Dirty Lagoon (section 3.1.1) regulates high flows from the upper catchments discharging into the lower Adelaide River, reducing the magnitude of event peaks and extending the period of higher flow conditions as water stored behind the constriction gradually drains. Figure 33 water levels upstream of the Dirty Lagoon constriction in blue: G8170005, and downstream in magenta: G8170020, during the 2023/24 wet season. Figure 33 clearly shows the rounded flood peaks and delayed recession typical of storage features. The storage effect is repeated on the downstream hydrograph, albeit to a lesser degree, with flows remaining higher for longer as water stored behind the constriction slowly drains.

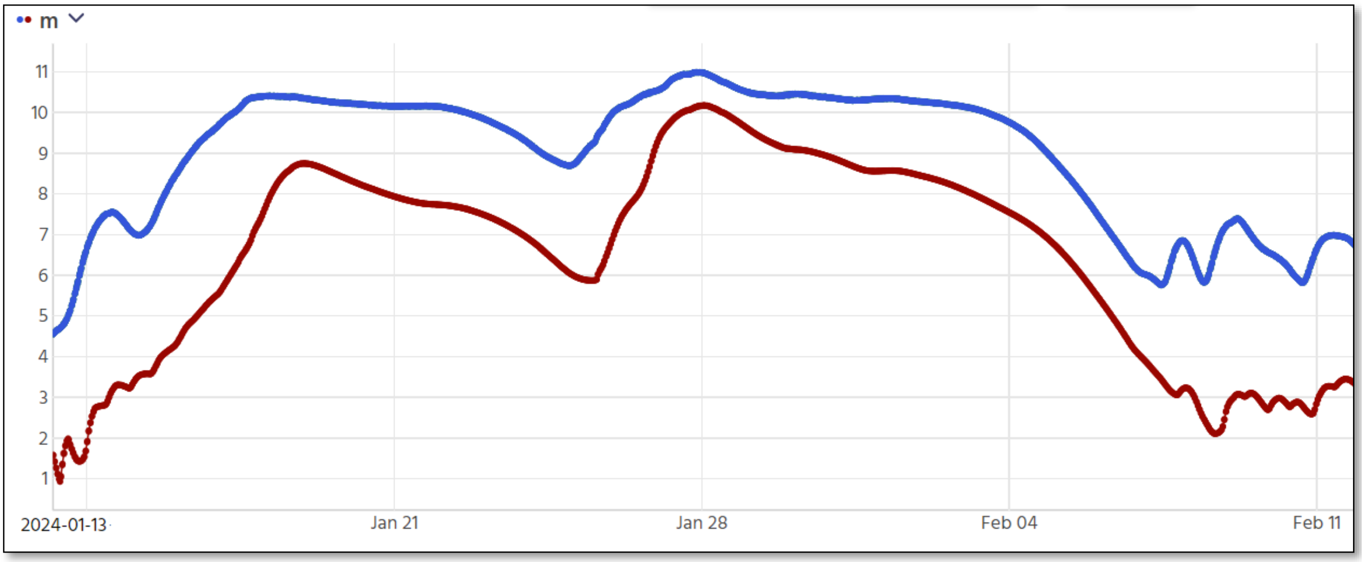


Figure 33. Difference in hydrograph shape upstream and downstream of Dirty Lagoon constriction

A significant volume of water is stored behind the constriction, exacerbating inundation of the alluvial floodplain that has developed upstream of the constriction. As a result, an expansive seasonal wetland has developed upstream of Dirty Lagoon on both the Adelaide and Margaret Rivers. During large events this can appear contiguous with flooding of the upper estuary area and the coastal floodplain leading to the impression of a single, large floodplain extending 100 km inland.

Flow duration curves show the distribution of flow exceedance as a proportion of the flow record and allow us to determine the flow characteristics of a river at a location. Figure 34 shows the flow duration curve for the constructed dataset at G8170020 from 1970 to 2023, which accounts for combined total discharges from the upper catchments into the lower Adelaide River (see section 4.2.2 Constructed discharge dataset).

The period of record since 1970 is known to have been a higher rainfall period than the 80 year period prior to 1970. Table 10 shows that for 50% of the recorded period, combined flow from the upper catchments was less than 80,000 ML per day, while flow was greater than 16,000ML per day for less than 10% of the period of record. At the lower end of the curve, flow ceased altogether for 4% of the record.

Dirty Lagoon lies upstream of the coastal floodplain and has a relatively narrow channel compared to the downstream estuary. The channel cross section at G8170020 (Figure 18) shows the primary channel to be 10 m deep, equating to a bank full discharge of 38,000 ML per day which is exceeded for just 3.5% of the period of record. Overbank flows are relatively confined within a 6 km wide cross section.

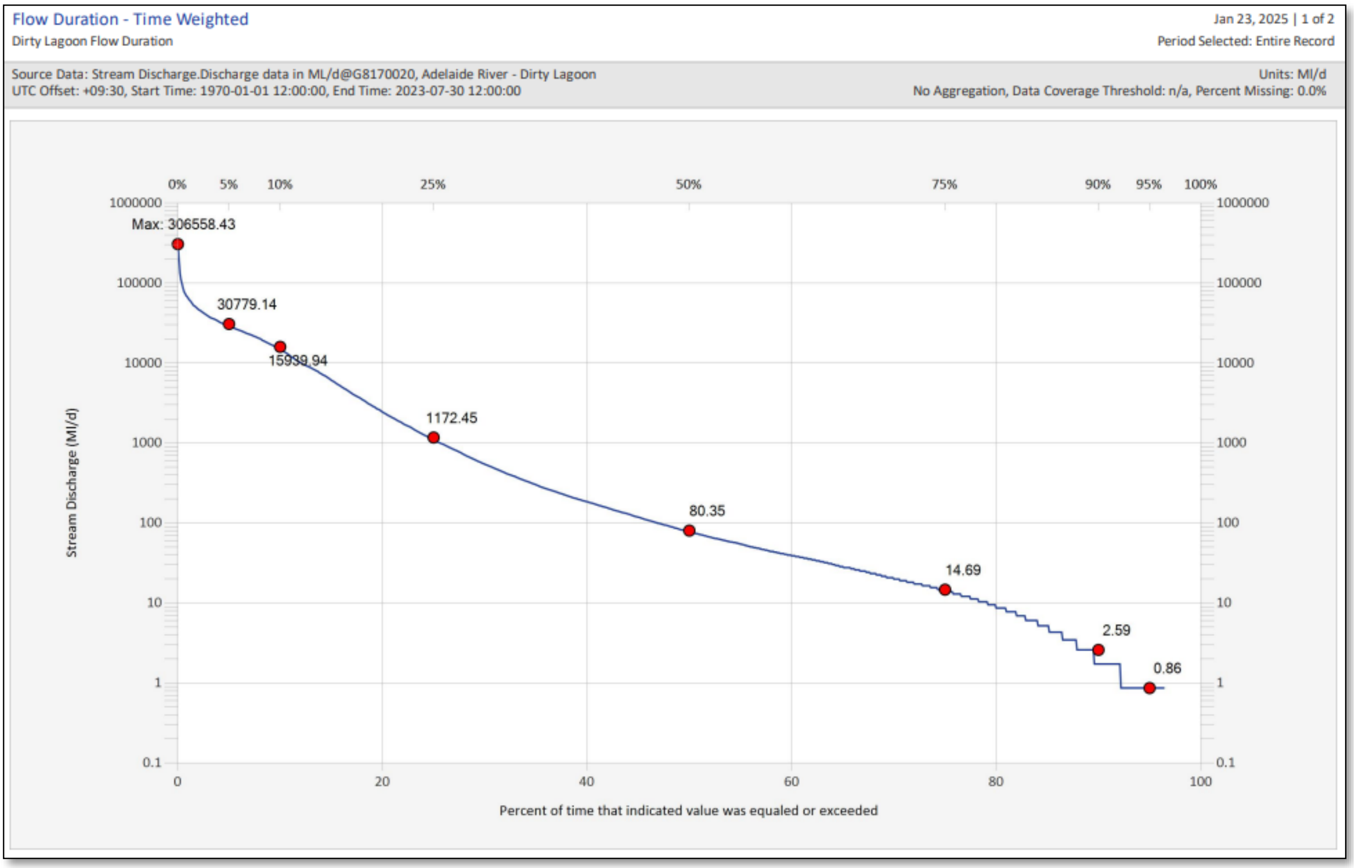


Figure 34. Flow duration curve for G8170020 Adelaide River at Dirty Lagoon

To better understand the magnitude and frequency of wet season flows and flood events, a flood frequency analysis was undertaken to determine the annual exceedance probability of high flows at Dirty Lagoon based on recorded events since 1970. Estimated discharges and exceedance probabilities are shown in Table 10.

Table 10. Annual exceedance probabilities for flows at Dirty Lagoon (WRM, 2024)

Annual exceedance probability %	Return interval (years)	Peak flow (ML per day)
63.3	1	61,171^
50	2	77,155
20	5	161,900
10	10	229,700
5	20	300,700
2	50	399,200
1	100	476,600

^ estimated from ARR design rainfall event (DHI, 2024)

Based on the bank full capacity of 38,000 ML per day, statistically it is anticipated that the bank level will be exceeded at the Dirty Lagoon location every year. However, in 10 years of the 50 year record the peak annual flow at G8170020 was insufficient to generate overbank flows during the course of the wet season.

4.3.5 Upper Adelaide River

Groundwater contributions occurring from several local and regional scale aquifers into key tributaries (section 3.2.3), along with other forms of delayed discharge from soil and wetland storage, are often sufficient to support perennial flows after larger wet seasons. However, in lower rainfall years, delayed discharges are insufficient to allow a perennial flow in the middle and lower reaches of the Adelaide River late into the dry season.

Flow duration curves for upper Adelaide River monitoring sites G1870005: Adelaide River US Marrakai Crossing, G8170084: Adelaide River at Tortilla Flat, G8170002: Adelaide River at Adelaide River township and G8170008: Adelaide River East Branch, can be found in Appendix D. They show that no flows occur at upper Adelaide River outlet at Marrakai Crossing for 6% of the period of record, while no flows occur upstream at Tortilla Flats for 2% of the period of record. Flow at Adelaide River township is perennial due to discharges from the Tindall Limestone Aquifer and Jinduckin Formation into the Adelaide River East Branch, shown at G8170008 in Figure 17, and possible contributions from other groundwater sources downstream from the Tindall Limestone and along Adelaide River West Branch shown at G8170094 in Figure 17 (Water Resources Division, 2024).

The headwaters of the Adelaide River East Branch transect the Tindall Limestone Aquifer and Jinduckin Formation for a distance of approximately 8 km, receiving groundwater inflows from diffuse discharges through the channel bed and banks, and through discrete discharges from springs and soaks, including Sybil Spring and Secret Spring. Flows on the Adelaide River East Branch, G8170008, are perennial throughout the entire period of record. Downstream of the Tindall Limestone, additional minor discharges are likely early in the dry season from localised aquifers, however persistence of these discharges are unlikely to be perennial (Water Resources Division, 2024). The Burrell Creek Formation underlies the Adelaide River West Branch and Adelaide River downstream of the East Branch confluence. Site G8170094 on the Adelaide River West Branch only collects water levels due to difficulty of access during the wet season. Site records show that it ceases to flow every year, however flow duration is difficult to determine due to unstable control conditions. Cease to flow conditions typically occur by September, indicating some delayed discharges are occurring within its catchment, however further investigation is required to confirm this. Sources could include discharges from a seasonal wetland located upstream on a minor tributary, persistent interflow from wet season runoff through soil and banks, or minor discharges from the Burrell Creek Formation or other localised aquifer.

Figure 35 shows flow hydrographs for G8170002, G8170008 and the level hydrograph for G8170094.

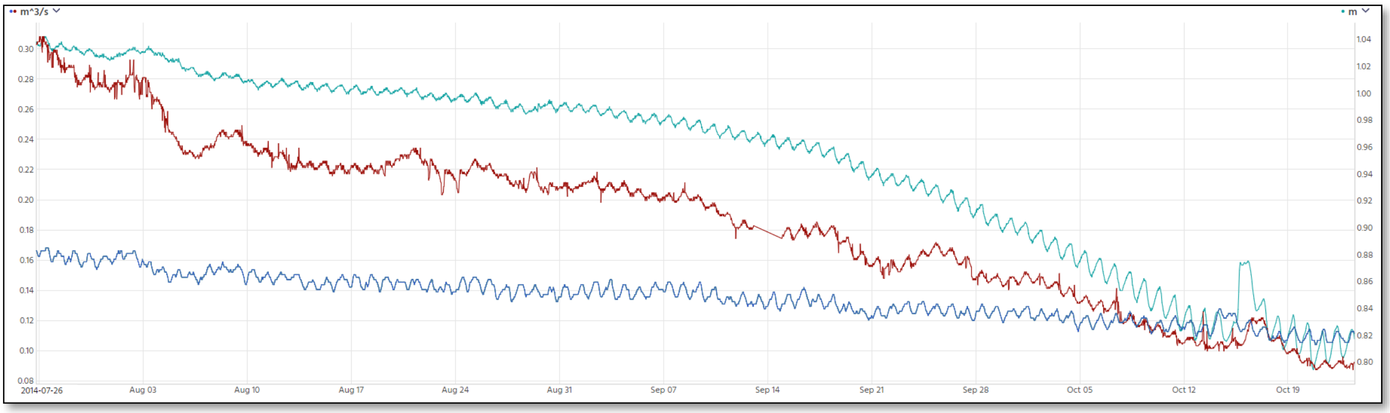


Figure 35. End of dry season flow at G8170002 (magenta), G8170008 (blue) and level at G8170094 (cyan)

Inspection of Figure 35 shows that flows at G8170002 drop within 3 to 4 weeks of cease to flow at G8170094, 1.08 mGH. A comparison of the flow record for G8170008 and G8170002 shows higher flows occur during most dry season months at the downstream site G8170002, indicating an additional source of persistent flow. In most years, flow at G8170002 dips below flow at G8170008 towards the end of the dry season. This indicates other persistent flow contributions to G8170002 typically cease during the dry season, with end of dry season flow sourced from groundwater discharges into Adelaide River East Branch. Losses to evapotranspiration and possible stock and domestic use explain the lower flow at G8170002 compared to G8170008 by end of dry season. The flow duration curves for G8170008 and G8170002 show that both sites recorded flow for their entire periods of record, while for 50% of the period of record, flow at G8170008 exceeded 17 ML per day, and at G8170002 flow exceeded 62 ML per day.

On average, just 0.8% of total catchment discharge from the upper Adelaide River occurs during the dry season months from May to September. Dry season flow as a proportion of total annual flow varies across the upper catchments and subcatchments depending upon climate conditions each year, and their unique characteristics, particularly where delayed discharges occur from storage features such as aquifers or wetlands. Dry season flows account for 2% of total annual flow in the upper catchment at Adelaide River township due to groundwater discharges and also its smaller catchment area for wet season runoff. Little dry season inflow is evidenced downstream of Adelaide River township, with losses to evapotranspiration and other uses typically exceeding any inflows that may occur. Proportional discharges are not able to be calculated at the sites G8170008, G8170084 and G8170005 as their rating tables do not extend to the full gauge range.

Figure 36 shows total annual (water year) discharge for Adelaide River at G8170002 from 1965. Once again annual discharge is highly variable, ranging from just 31.8 GL in 1969-70, to 851 GL in 2010-11 (1970-71 water year was excluded due to missing data). Total annual discharge statistics for G8170002 were provided in Table 9.

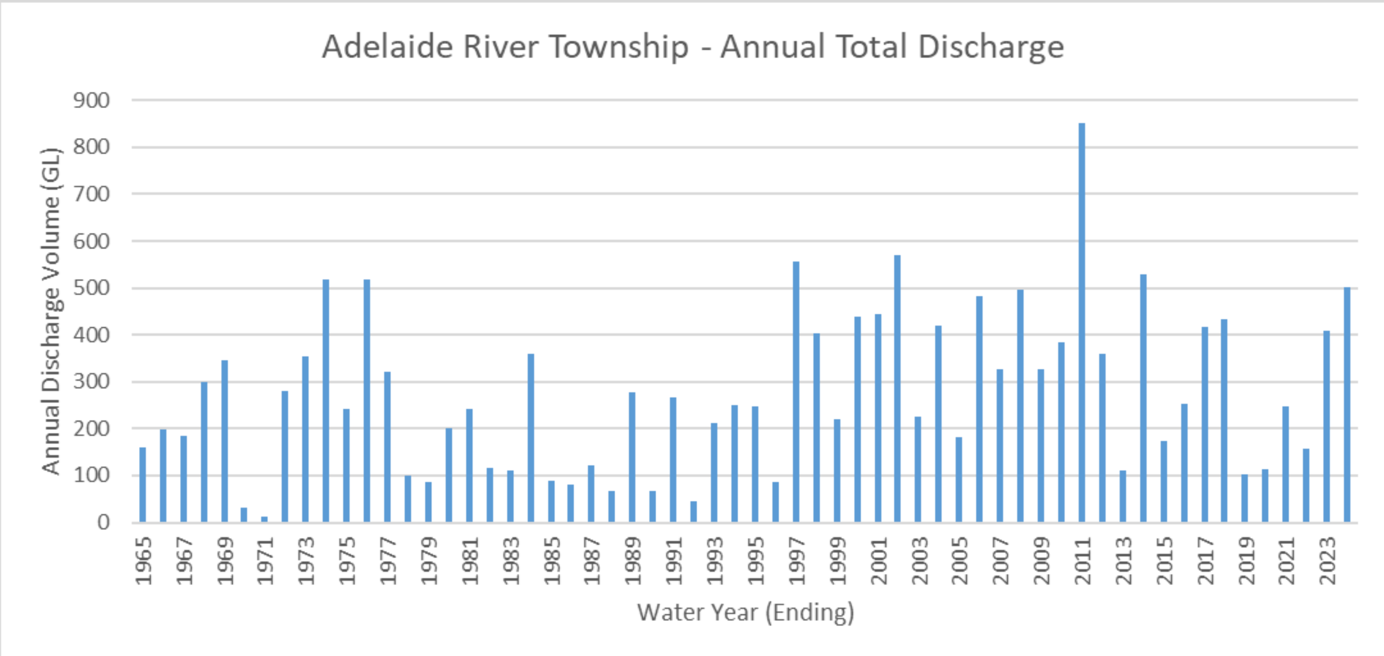


Figure 36. Total annual discharge (water year) at G8170002

Regular cease to flow conditions in the middle reaches mean that longitudinal connectivity does not occur perennially in all years. End of dry season flows from Adelaide River township to the estuary range from approximately 16 ML per day after a large wet season to zero flow after a poor wet season. The Adelaide River only flows perennially to its estuary in about 40% of years, with flows ceasing at G8170005 as early as July during dry periods, or as late as November after moderate wet seasons. The upper Adelaide River typically flows perennially after a large wet season.

Under high flow conditions, the upper Adelaide River becomes laterally connected to the Margaret River in its downstream reaches, with floodwaters from both waterways spilling across the floodplain up to 5 km upstream of their confluence. The floodplain may extend over 20 km upstream of the constriction in both the Adelaide and Margaret Rivers, with variable backwater impacts observed as far upstream as Tortilla Flats on the Adelaide River, and Howley Creek on the Margaret River. A network of preferential drainage paths have been carved through the alluvial plain which direct flows away from the primary channels, often rejoining their primary channels far downstream, or in some cases diverting flow from one primary channel to the other primary channel, for example Margaret River to Adelaide River.

4.3.6 Margaret River

The Margaret River has a length of approximately 145 km and drains a catchment area of 2,600 km^2. Limited monitoring data exists for the Margaret River, while catchment hydrology is complex because of the relatively shallow channel morphology and multitude of secondary and braided flow paths complicating the measurement of higher flows. Limited data that does occur at the downstream location, G8170032 is impacted by backwater from Dirty Lagoon and flow can only be measured up to 13,000 ML per day, while data at the upstream location G8170095 is unreliable above 18,000 ML per day due to flows diverting from the primary channel onto the floodway and into flood channels. Modelled flow data will be required to undertake assessment of high flows and total catchment discharge from the Margaret River catchment.

The Margaret River and its tributaries are ephemeral waterways and cease flowing in every year, usually by the end of June and sometimes earlier. Flows occur in response to rainfall events and monsoonal activity. There is no evidence of persistent flows occurring from delayed discharges within the catchment, from either groundwater or surface water storages. Numerous waterholes occur within the catchment, mostly along the Margaret River channel and also along the lower reaches of the flood diversion channel to the west, some of which persist throughout the dry season. Many billabongs also occur along the length of the river and its tributaries due to regular wet season inundation from overland flows spilling from shallow channels. Most of these dry out by early to mid-dry season, however, some persist until late into the dry season and in some cases are perennial. Flow duration curves for G8170032 Margaret River US Marrakai Crossing, and G8170095 Margaret River DS Howley Creek are found in Appendix D. They show both locations do not flow for over 40% of their periods of record. Higher flow frequencies above 13,000 ML per day and 18,000 ML per day are unreliable due to limitations in high flow monitoring.

Recent hydrodynamic modelling has demonstrated that moderate and high flows spill from the Howley Creek channel upstream of the Margaret River confluence, with a significant volume diverting to the west of the primary Margaret River channel along an area of flood conveyance that culminates in two channels which ultimately discharge into the upper Adelaide River upstream of Marrakai Crossing. Further water spills from the Margaret River channel downstream of the Howley Creek confluence and flows to the west, joining diverted flows from upstream (see section 4.1.3, Plate 6 and 8.

These flows bypass the gauging stations at G8170095 and G8170032 and as such are not accounted for in the current monitoring network, although these flows are accounted for as total discharges into the lower Adelaide River at G8170020. The low levels at which overbank flow occurs, and the large number of locations within the catchment where overbank flows occur, mean that lateral connectivity between the channel and floodplain areas is high during the wet season. Seasonal waterholes and billabongs within the catchments are replenished early and frequently due to the relatively low flow requirement to achieve overbank flows. With no enduring dry season flow, longitudinal connectivity during the dry season is non-existent throughout the Margaret River catchment, with any endemic aquatic species required to adapt to annual subsistence in refuge pools. Little work has been undertaken to survey or describe aquatic species within the Margaret River catchment.

4.4 Waterways of the Adelaide River catchment

Hydrological conditions vary significantly among the subcatchments within the Adelaide River catchment. Limited data exists for most tributaries to the Adelaide River, however well calibrated hydrological modelling allows us the understand flow variability within these subcatchments. This section provides a characterisation of the main subcatchments within the Adelaide River catchment using available data. Figure 37 shows the spatial distribution of the subcatchments within the Adelaide River catchment.

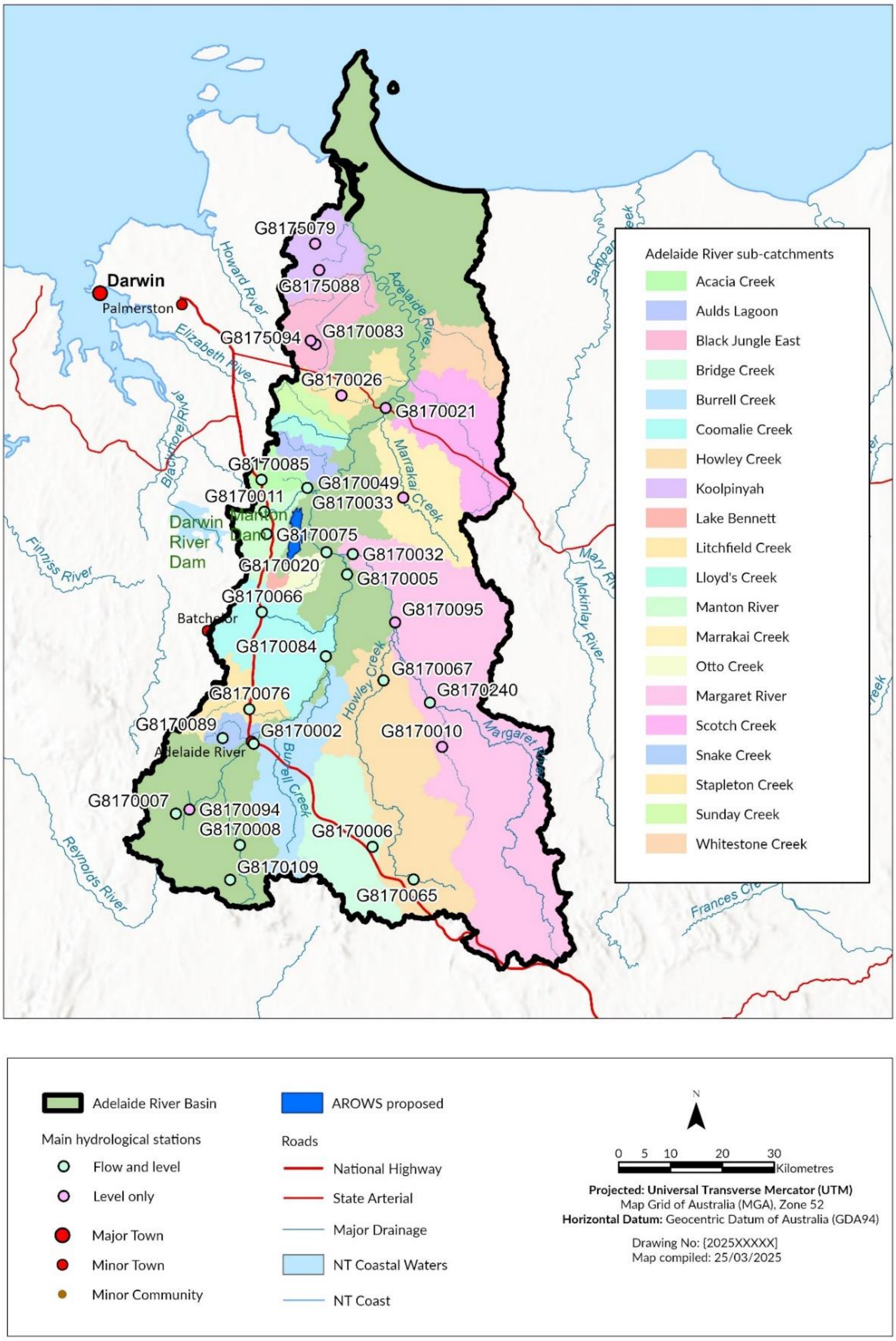


Figure 37. Adelaide River catchment and major subcatchments

4.4.1 Bridge Creek

The Bridge Creek catchment lies in the mid-south of the Adelaide River catchment and covers an area of 378 km². The creek stretches approximately 42.6 km before merging with Howley Creek. Figure 39 shows the waterways and the location of the single hydrological gauging station, G8170006, within the catchment.

Site G8170006: Bridge Creek – U/S Railway, lies approximately 2 km east of the Stuart Highway and 2.2 km downstream of the Bridge Creek Alluvial Gold mine, and measures flows for 126 km², just one third of the Bridge Creek catchment (refer to Figure 39). As such, modelled flows from the NAM rainfall runoff model have been used to calculate whole of catchment flow statistics for the Bridge Creek catchment. Site G8170006 was used to calibrate the NAM model, and useful flow characteristics can be drawn from the 45 year dataset. Table 11 shows the parameters and period of record for site G8170006.

Table 11. Historic hydrological monitoring stations in the Bridge Creek catchment (source: NTG Aquarius database)

Name	Site ID	Parameter	Period of record	Label
Bridge Creek – U/S Railway	G8170006	Water Level	1966 to 2011	Publish
		Discharge	1966 to 2011	Publish

Discharge data at G8170006 shows that Bridge Creek is an ephemeral waterway, flowing in response to storms and wet season rains then ceasing to flow by July in most years, although flow may continue into September or October after a large wet season. Figure 38 shows the flow duration curve for site G8170006. It shows no flows were recorded for 45% of the record, while flow exceeded 20 ML per day for 25% of the record and 100 ML per day for just 12% of the period of record.

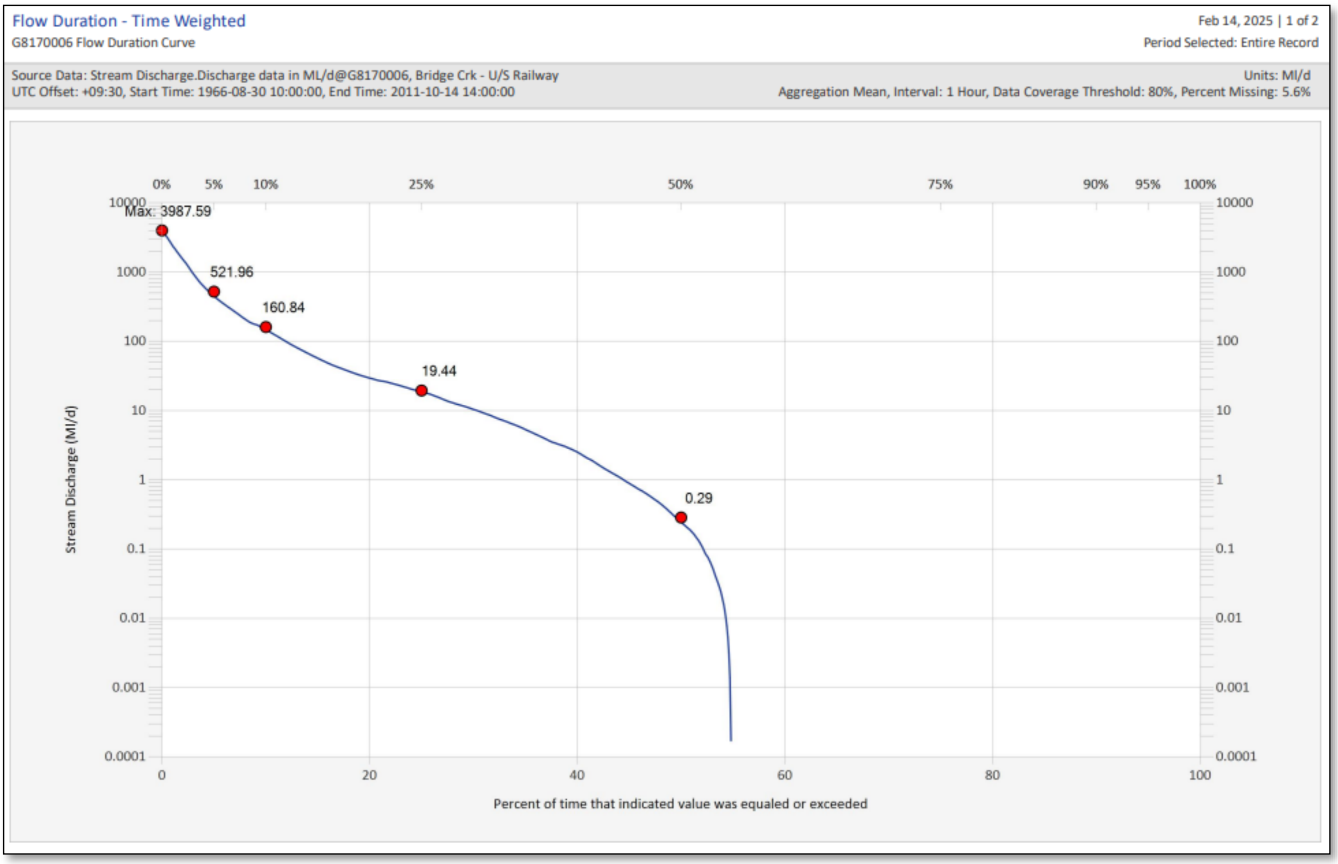


Figure 38. Flow duration curve for Bridge Creek

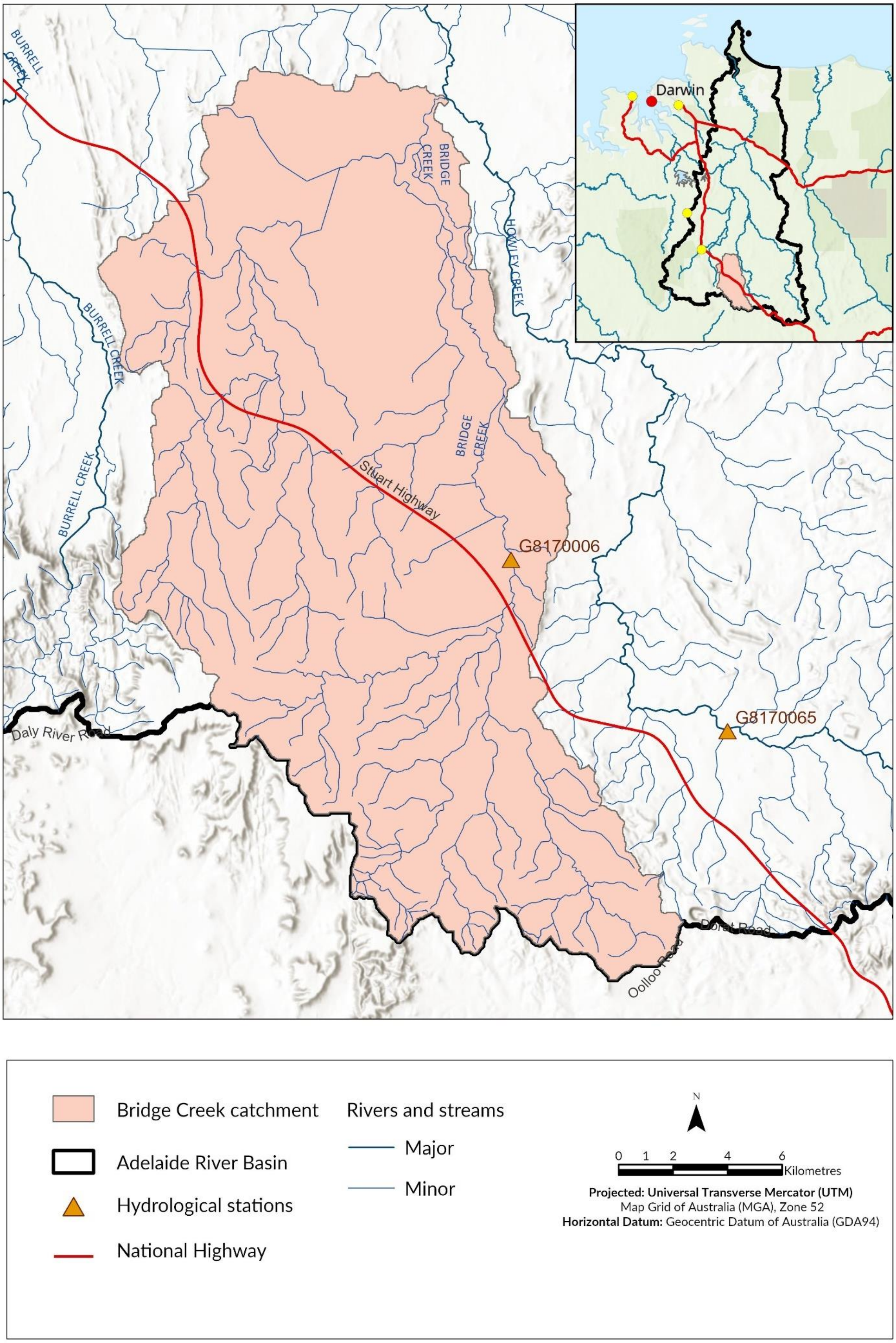


Figure 39. Bridge Creek catchment and the locations of hydrological stations within the catchment

In 2011, Bridge Creek flowed perennially at site G8170006 for the only year on record after a historically big wet season, although flow was less than 100L/s from early July. These persistent flows demonstrate a limited storage capacity exists within the catchment, most likely from fractures within the underlying Burrell Creek Formation, that provide small discharges through the dry season after larger wet seasons.

Substantial variation in annual flow occurs within the Bridge Creek catchment, with total annual discharge at G8170006 ranging from 2.96 GL in 1972/73 to 130.37 GL in 2011/12, and a median annual discharge of 31.0 GL shows the variation in total annual flows (Figure 40). Visual inspection shows a marked increase in total annual discharge from 1998. The largest discharge in Bridge Creek occur in February, March and April. Figure 41 shows mean monthly discharge volume for each month throughout the year. The wet season months of October to April constitute 98% of total annual flow.

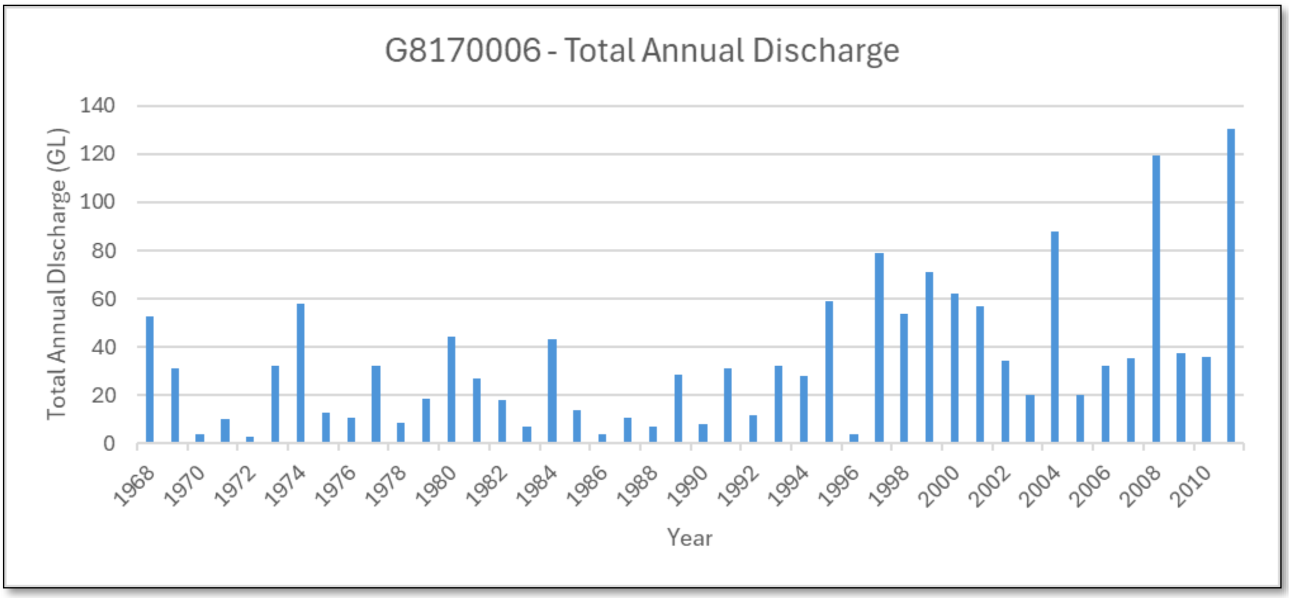


Figure 40. Total annual discharge (water year) at G8170006

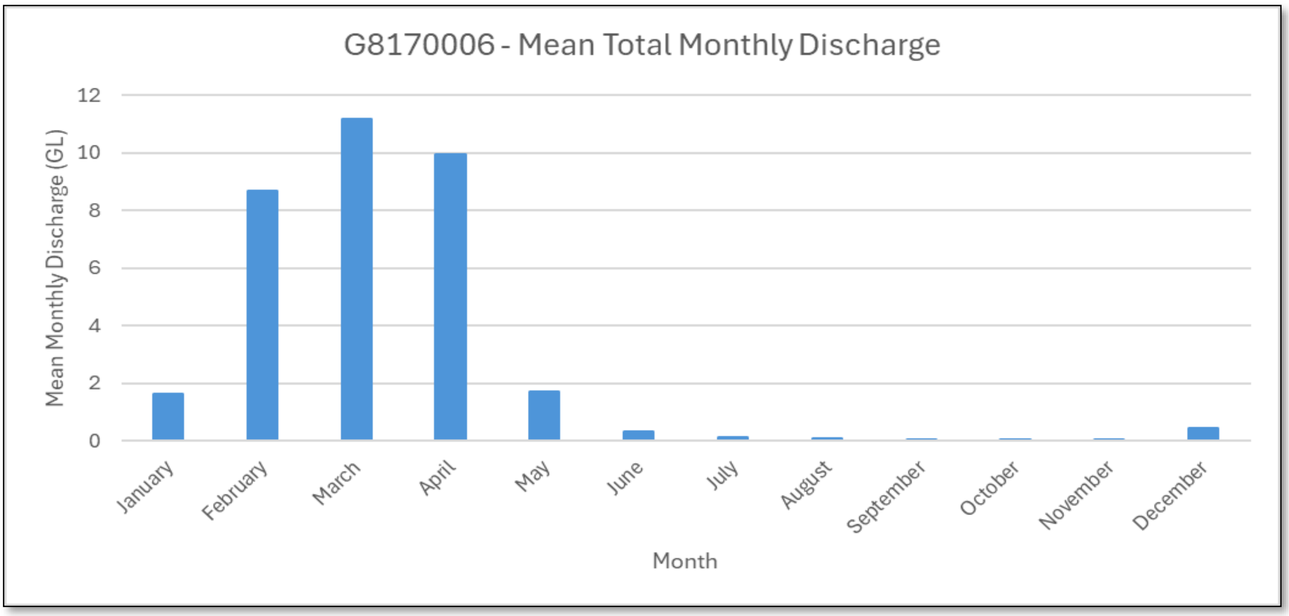


Figure 41. Mean total monthly discharge at G8170006

4.4.2 Burrell Creek

The Burrell Creek catchment is located to the south-east of the upper Adelaide River catchment and covers 319 km^2. The creek extends approximately 60.8 km before joining the Adelaide River approximately 5 km upstream of gauging station G8170084 (Adelaide River at Tortilla Flats). Figure 44 provides an overview of the Burrell Creek catchment, including the location of hydrological gauging stations.

Table 12 lists the parameters and periods of record for data collected at each of the gauging stations.

Table 12. Historic hydrological monitoring stations in the Burrell Creek catchment (source: NTG Aquarius database)

Name	Site ID	Parameter	Period of record	Label
Burrell Creek – Eighty-Seven Mile Jump Up	G8170062	Water Level	1957 to 1986	Publish
		Discharge	1957 to 1986	Publish
Adelaide River – Mount Burrell	R8170090	Rainfall	1996 to 2001	Publish

Site G8170062 is located in the upper Burrell Creek catchment and collects data for a catchment area of 36.2 km^2, just 11% of the Burrell Creek catchment area. As such, this site is not suitable for calculating total catchment discharges. Figure 42 shows the flow duration curve for G8170062. It shows that no flow occurs in the upper reaches of the catchment for 47% of the record.

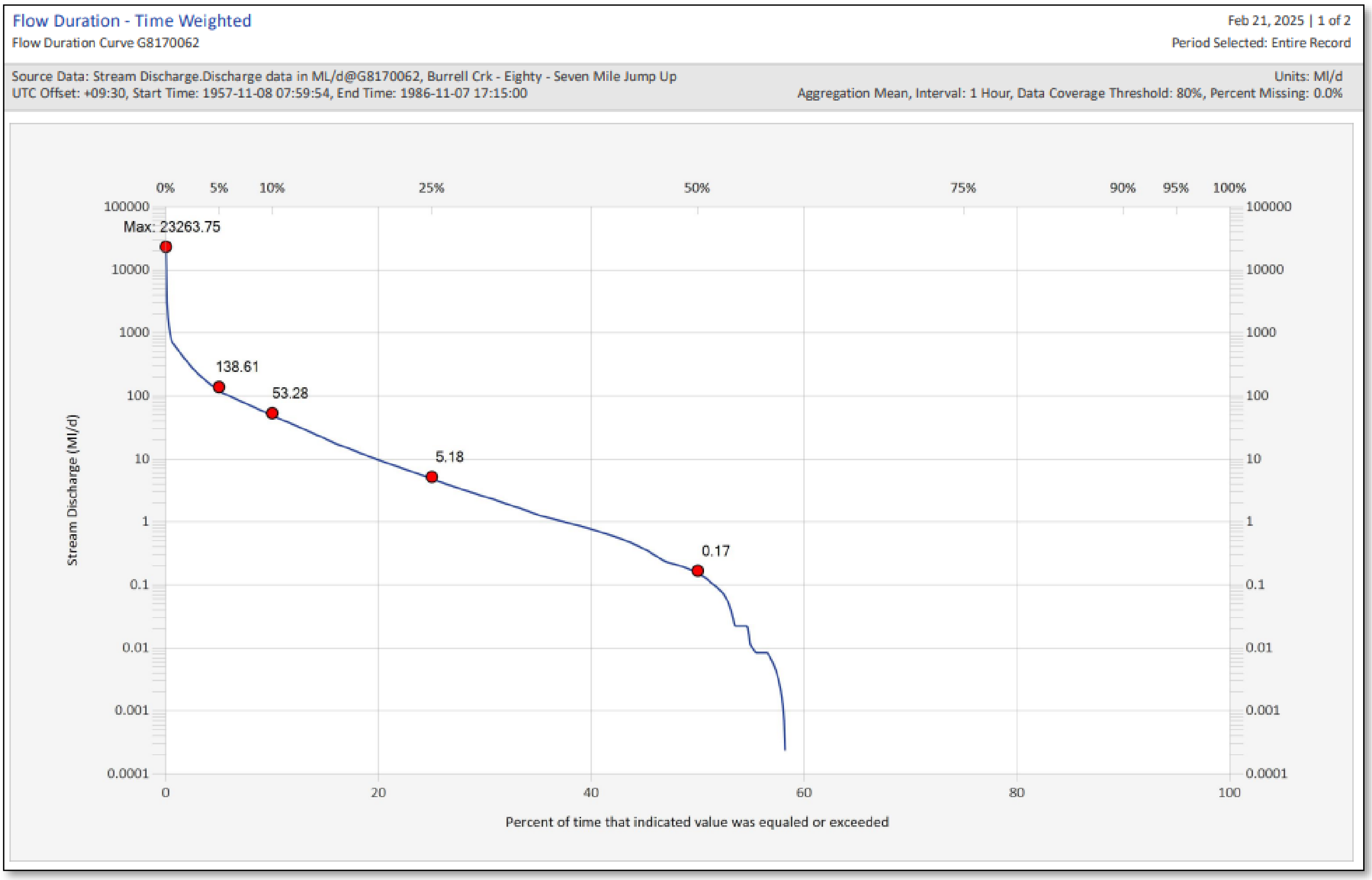


Figure 42. Flow duration curve for G8170062 in Burrell Creek catchment

The largest discharges in Burrell Creek occur in February, March and April. Figure 43 shows mean monthly discharge volume for each month throughout the year. The wet season months of October to April constitute 91% of total annual flow at G8170062.

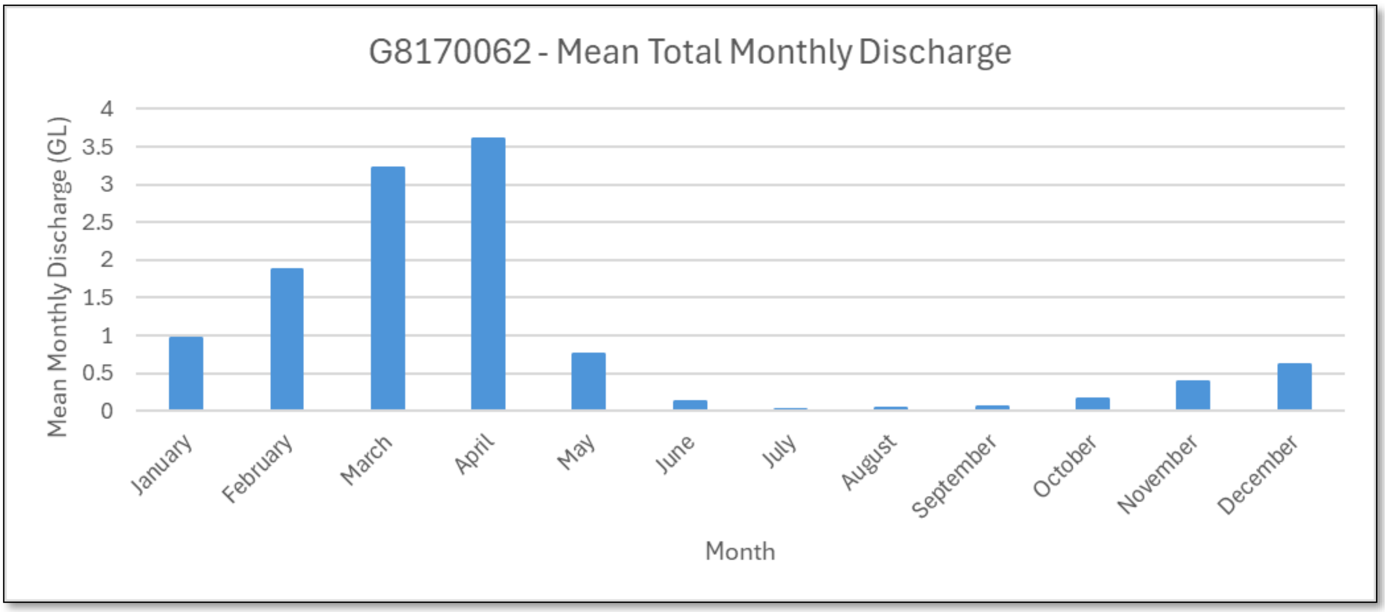


Figure 43. Mean monthly discharge at G8170062

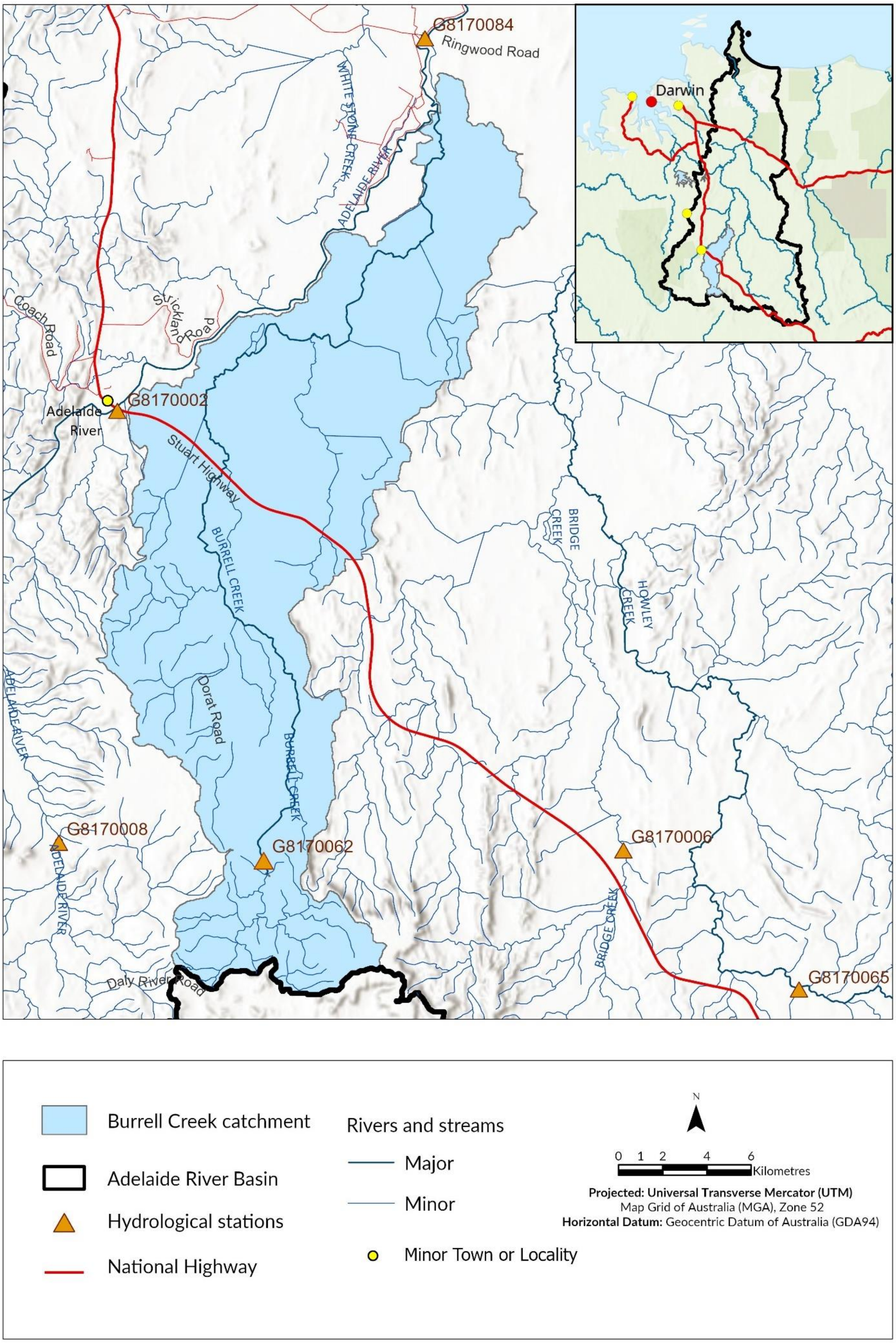


Figure 44. Burrell Creek catchment and the locations of hydrological stations within the catchment

4.4.3 Coomalie Creek

The Coomalie Creek catchment, situated on the mid-western side of the Adelaide River, covers an area of 340 km². The creek extends approximately 35.66 km before merging with the Adelaide River about 10.8 km downstream from gauging station G8170084. Figure 46 shows the Coomalie Creek catchment, including the locations of hydrological gauging stations.

Two main tributaries to Coomalie Creek – Glen Luckie Creek and White Stone Creek, drain most of the southern portion of the catchment and join Coomalie Creek in its lower reaches. The only long-term monitoring site in the catchment, G8170066 Coomalie Creek - Stuart Highway, is upstream of the confluence of Coomalie Creek with both main tributaries, and captures flow for 82 km^2, less than 25% of the total catchment (Figure 46). Table 13 lists the parameters and periods of record for data collected at each of the gauging stations.

Table 13. Current and historic hydrological monitoring stations in the Coomalie Creek catchment (source: NTG Aquarius database)

Name	Site ID	Parameter	Period of record	Label
Coomalie Creek – Stuart Highway	G8170066	Water Level	1958 to ongoing	Publish
		Discharge	1958 to ongoing	Publish
Coomalie Creek – Below Junction	G8170091	Water Level	1951 to 1960	Publish

Coomalie Creek is known to flow perennially due to discharges from groundwater. The catchment is underlain by the Whites Formation, a fractured rock formation known to host low yielding aquifers, and the Coomalie Dolostone, a karstic and fractured rock aquifer known to host high yielding aquifers. Annual baseflow contributions estimated from daily stream discharge data at G8170066 (Water Assessment Branch, 2024), range from 10.8% to 20.1%, while typically all flows from July to commencement of early wet season rains are considered to be discharged from groundwater.

Figure 45 shows the flow duration curve for G8170066. It shows that while Coomalie Creek flows all year round at this location, for half the period of record flow is below 12.45 ML per day. The minimum recorded flow is 0.17 ML per day, while flow remains below 25 L/s (2.17 ML per day) for 10% of the period of record.

Due to G8170066 capturing flow from less than 25% of the catchment, modelled flows from the NAM rainfall runoff model have been used to calculate discharge statistics for Coomalie Creek catchment. Site G8170066 was used to develop and calibrate the NAM model.

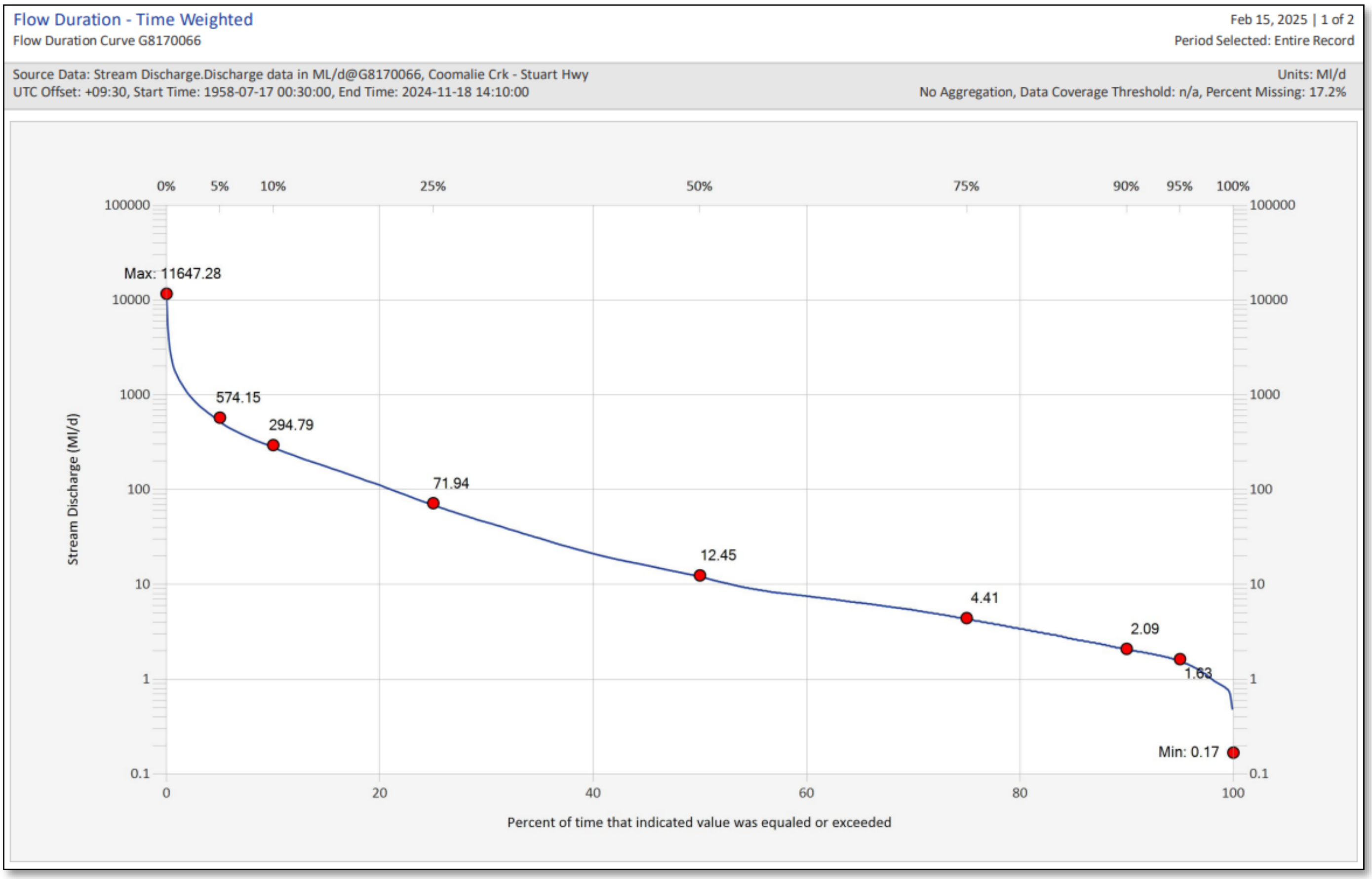


Figure 45. Flow duration curve at G81700066 (source: NTG Aquarius database)

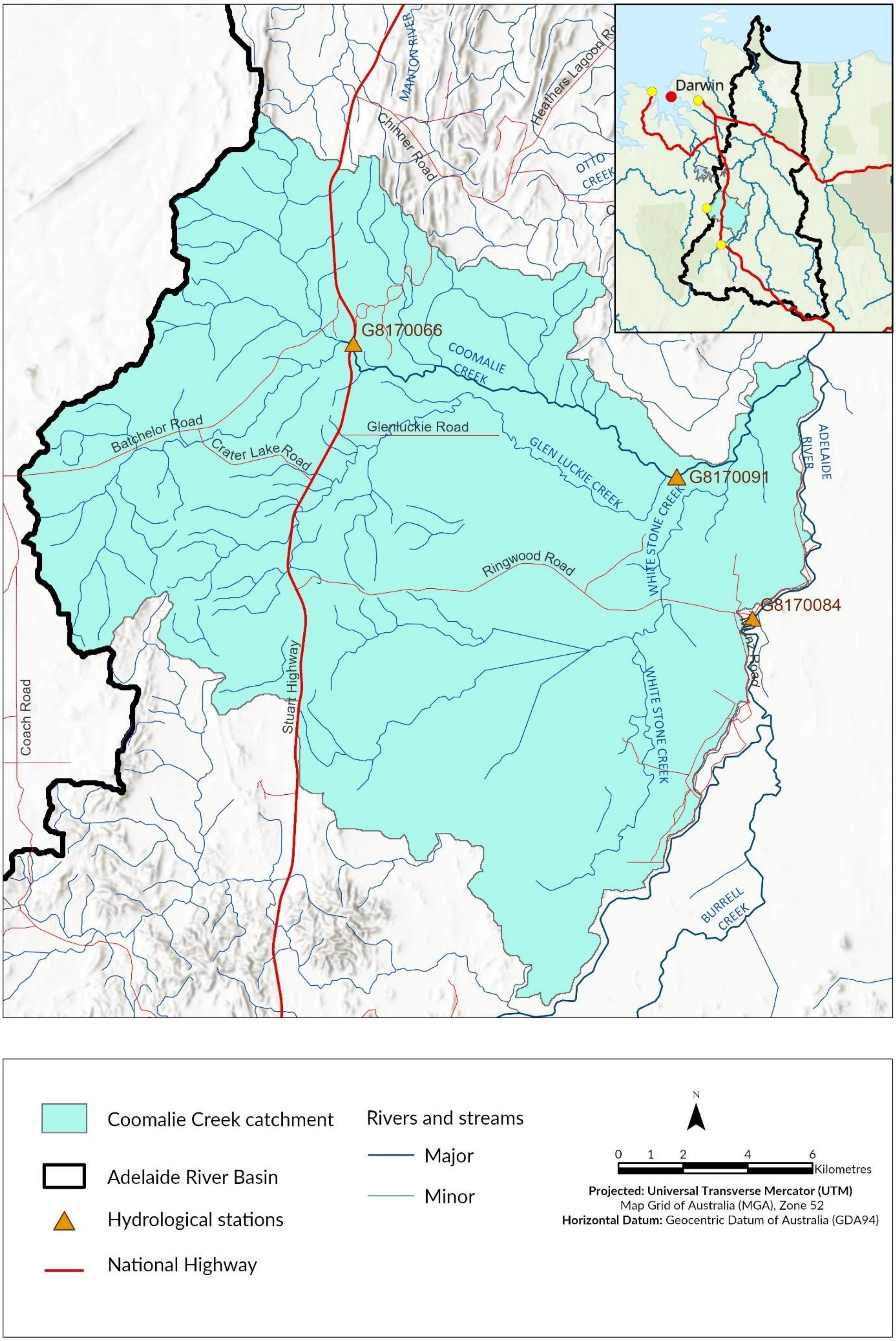


Figure 46. Coomalie Creek catchment and the locations of hydrological stations within the catchment

4.4.4 Howley Creek

Howley Creek is the largest tributary of the Margaret River and drains an area of 1,014 km^2 in the mid-south of the Adelaide River catchment. Bridge Creek is a major tributary to Howley Creek. The creek extends approximately 90 km in length before merging with Margaret River about 4.7 km upstream from the gauging station G8170095.

Figure 47 provides an overview of the catchment, including the locations of hydrological gauging stations and nearby mining operations.

Table 14 shows the parameters and period of record for monitoring sites in the Howley Creek catchment excluding Bridge Creek sites. Gauging station G8170065 is located approximately 2.7 km east of Stuart Highway and about 7 km downstream from the Cosmo mine site. Recording flow from just 10% of the Howley Creek catchment and for only 4 complete years, site G8170065 is not suitable for characterising whole of catchment flows. It does however show that flow ceased in all 4 years of record, usually by July.

Site G8170067 was installed in late 2023 and has insufficient record to analyse, however site G8170095 on the Margaret River downstream of the Howley Creek confluence also shows flow ceasing every year, also usually by July, which means no flows are discharged from Howley Creek after the early dry season.

Modelled flows from the NAM rainfall runoff model were used to estimate total catchment flow statistics from Howley Creek catchment. Data from sites G8170065 and G8170095 were used to help develop and calibrate the NAM model.

Table 14. Current and historic hydrological monitoring stations in the Howley Creek catchment (source: NTG Aquarius database)

Name	Site ID	Parameter	Period of record	Label
Howley Creek – D/S Brocks Creek Mine	G8170065	Water Level	1997 to 2002	Publish
		Discharge	1997 to 2002	Publish
Howley Creek – Ringwood Road	G8170067	Water Level	2023 to 2024	Publish (not available)

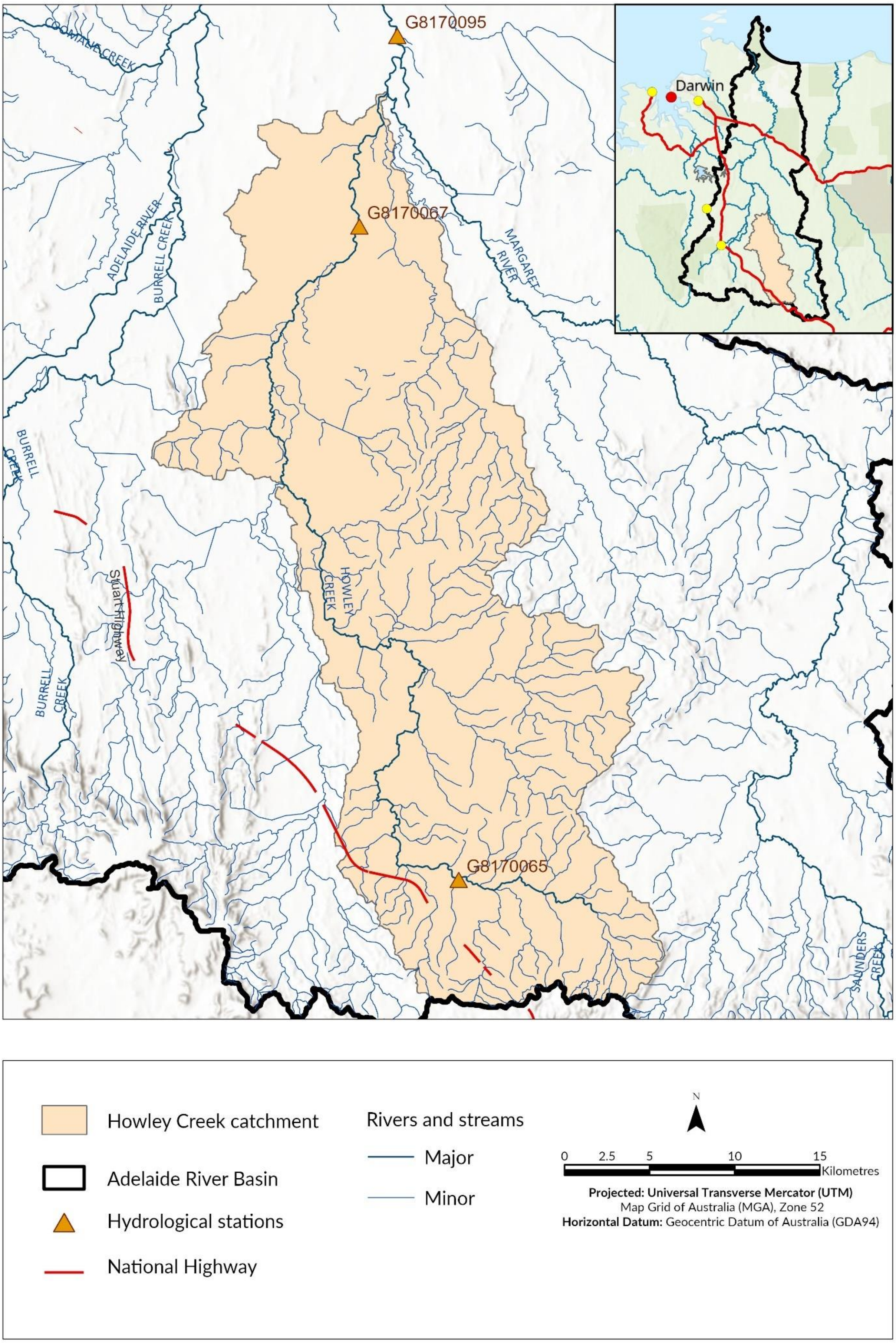


Figure 47. Howley Creek catchment and the locations of hydrological stations within the catchment

4.4.5 Manton River

The Manton River is a tributary to the Adelaide River, with a catchment area of 217 km^2 on the mid-western edge of the Adelaide River catchment. Its main tributary, Acacia Creek, drains the northern 78 km^2 of the catchment. The Manton River is approximately 31 km in length and flows north-east to its confluence with the Adelaide River in the tidally influenced zone downstream of Dirty Lagoon. Manton River is one of two regulated waterways in the Adelaide River catchment, with a concrete dam constructed in 1942 as a water supply for Darwin. Approximately one third of the Manton River catchment occurs upstream of Manton Dam. Downstream of Manton Dam, the Manton River receives inflows from a large tributary to the south, and from Acacia Creek to the north, before passing through Acacia Gap in range of low hills to its confluence with the Adelaide River. Figure 50 shows the Manton River catchment and the locations of hydrological gauging stations.

Manton Dam served as Darwin's primary fresh water supply from 1942 until its decommissioning in 1972, when it was repurposed for recreational use within a conservation area dedicated to native flora and fauna. Manton Dam is currently undergoing a 'return to service' to supplement Darwin's water supply starting in late 2026 and aims to provide an additional 7.3 GL annually to the Darwin region's water supply system.

Four gauging stations are located within the Manton River catchment, G8170075 upstream of Manton Dam, G8170011 at the Manton Dam offtake tower, G8170033 just upstream of the confluence with the Adelaide River ("Acacia Gap") and G8170085 in the upper reaches of Acacia Creek. Table 15 summarises the parameters and period of record for monitoring sites within the Manton River catchment. Site G8170033 is well positioned to monitor total catchment flows from Manton River to the Adelaide River, although monitoring ceased at this location in 1986. Contributions from Manton River to the Adelaide River are assessed based on the limited flow records from site G8170033.

Table 15. Monitoring stations in the Manton River catchment (source: NTG Aquarius database)

Name	Site ID	Parameter	Period of record	Label
Manton River – U/S Manton Dam	G8170075	Water Level	1965 to current	Publish
		Discharge	1965 to current	Publish
		Rainfall	2019 to current	Publish
Manton Dam – Dam Intake Tower 2	G8170011	Water Level	1956 to 2003	Publish
		Discharge	1956 to 2003	Publish
Manton River – Acacia Gap	G8170033	Water Level	1959 to 1986	Publish
		Discharge	1959 to 1986	Publish
Acacia Creek – Stuart Highway	G8170085	Water Level	1963 to current	Publish
		Discharge	1963 to current	Publish

Discharge from the upper Manton River catchment is retained within Manton Reservoir. During the wet season, water spills when levels exceed the spillway at 38.1 mAHD. A small environmental flow, 0.6 ML per day is released from the reservoir during the dry season, however Manton River did not flow perennially to the Adelaide River prior to the construction of the dam (Water Resources Division, 2024). Site G8170075 upstream of the dam does show perennial flow in most years, indicating some discharges from the underlying Whites Formation and Coomalie Dolostone, however the flow duration curve (Figure 48) shows flow is less than 3.21 ML per day, 37 L/s for 50% of the record and less than 0.86 ML per day, 10 L/s for 21% of the record.

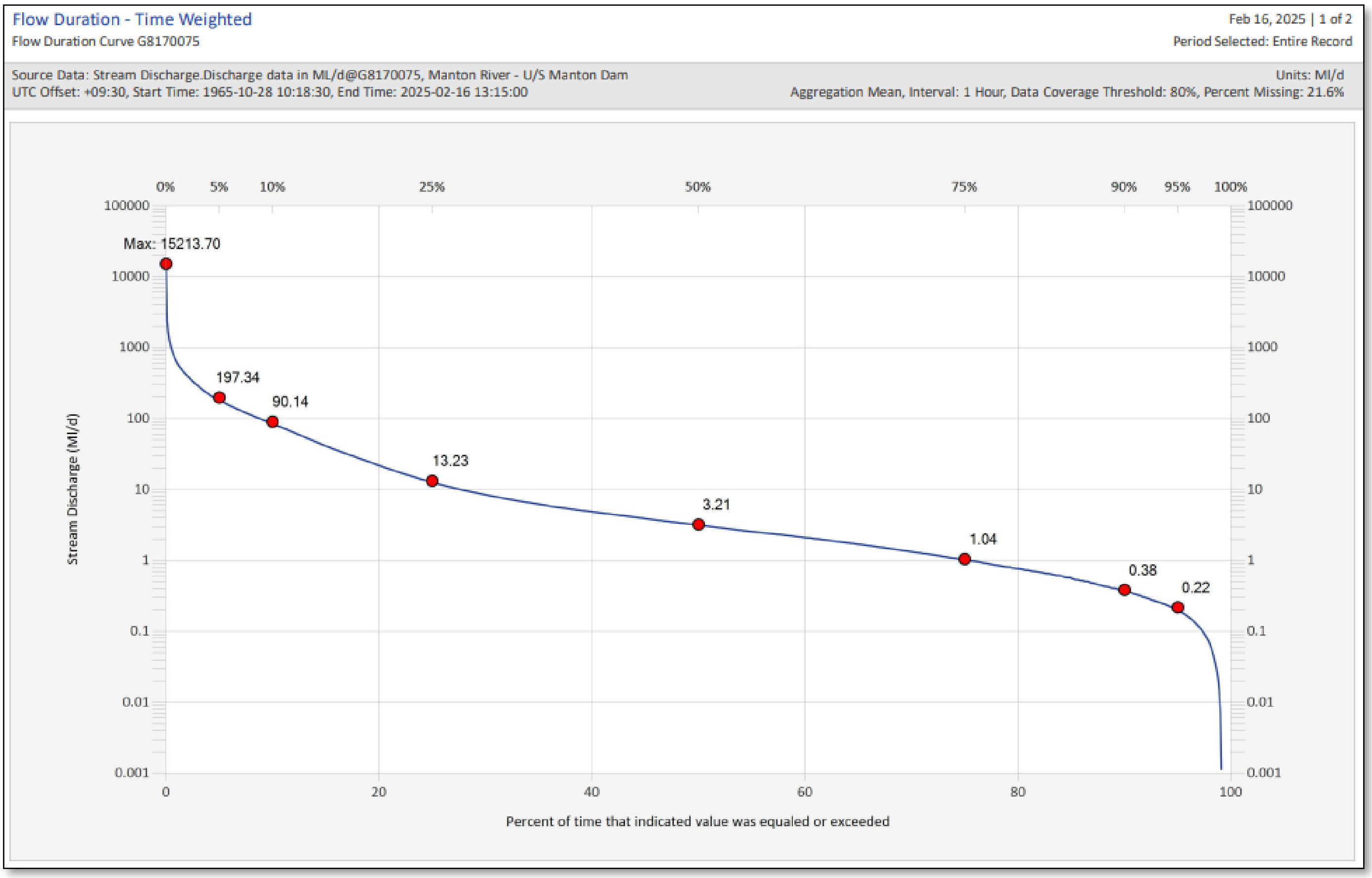


Figure 48. Flow duration curve for G8170075, Manton River - US Manton Dam

Site G8170033 was also built after construction of Manton Dam. Figure 49 below shows the flow duration curve for G8170033 and shows that the site ceases flowing for 35% of its period of record, indicating both Manton River and its major tributary Acacia Creek flow intermittently. Tickell (2000) found persistent discharges from the underlying Coomalie Dolostone into both the Manton River downstream of Manton Dam, and into the lower reaches of Acacia Creek supporting 32 hectares of rainforest (Water Resource Division, 2024). Discrete measurements undertaken in 1999 found groundwater discharges of 88 L/s in June, however discharge had ceased by September although groundwater levels remain near the surface throughout the dry season (Tickell, 2000).

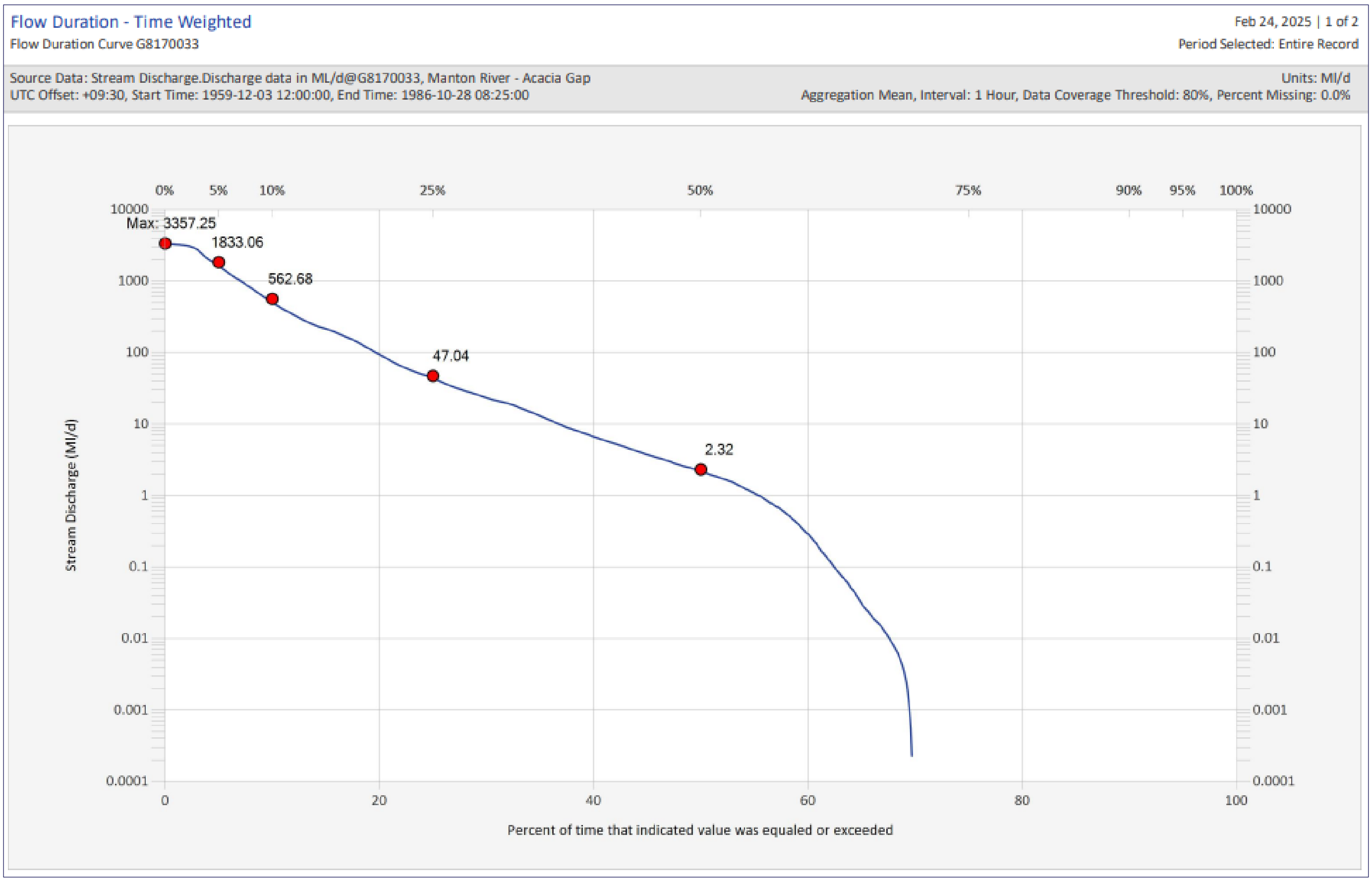


Figure 49. Flow duration curve for G8170033, Manton River at Acacia Gap

Maximum flow in flow duration curve for G8170033 is understated as the rating does not extend to the full gauge range. As such, total annual flow also cannot be calculated from the record of G8170033 due to the rating only extending to 3.03 m. Modelled flow from the NAM rainfall runoff model were used to determine flow characteristics for the Manton River catchment.

With the return to service of Manton Reservoir in 2026, spill flow that has entered the Adelaide River system since 1972 will be reduced by 20 ML per day or 7.3 GL per year.

Site G8170085 Acacia Creek – Stuart Highway monitors flow for a catchment area of just 11 km^2. This site is used for flood alerting for the Stuart Highway and is not suitable for characterising catchment flows other than to observe that it also ceases flowing by July each year.

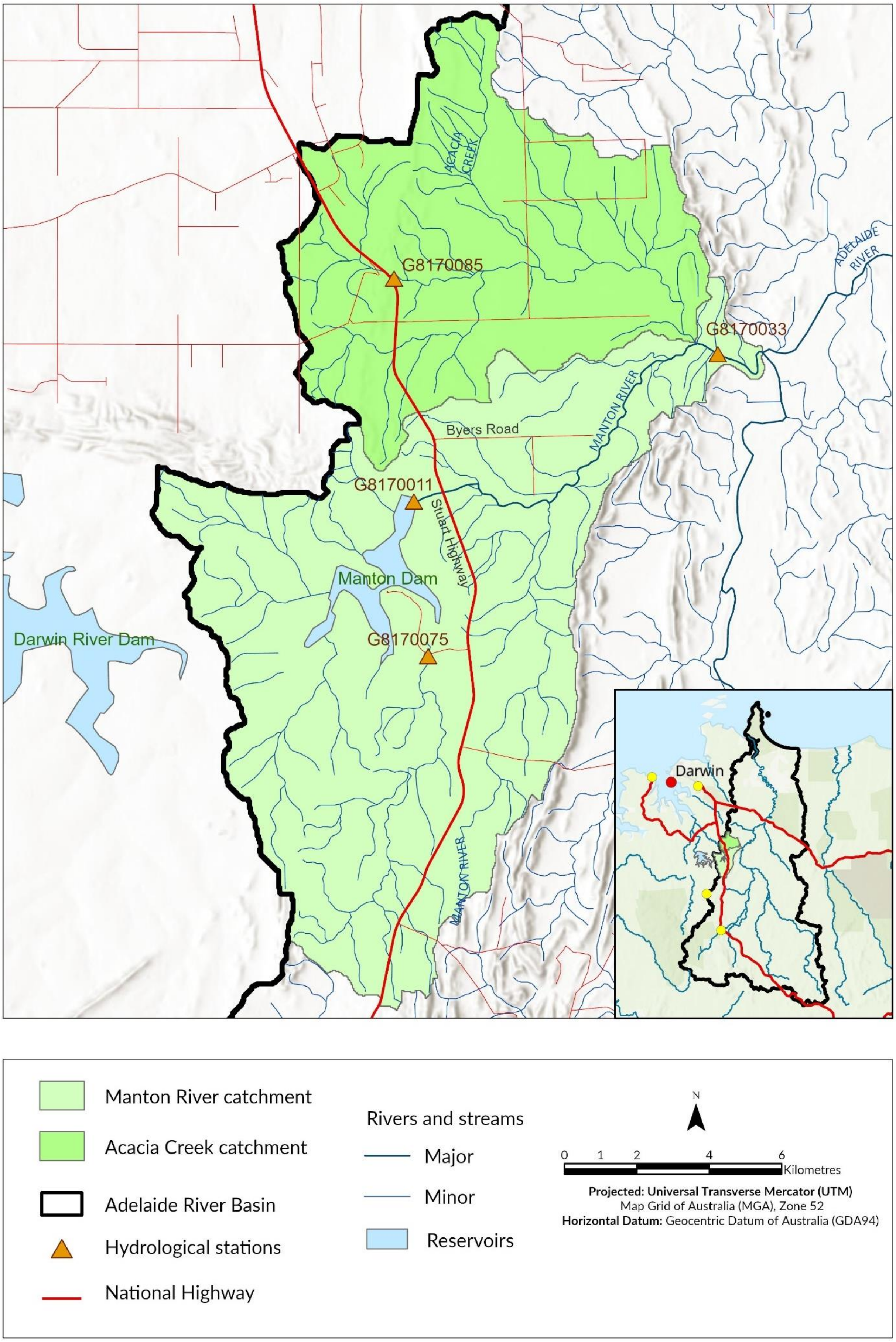


Figure 50. Manton River catchment and the locations of hydrological stations within the catchment

4.4.6 Otto Creek

Otto Creek is a small tributary in the mid-west of the Adelaide River catchment on the southern edge of the Manton River catchment. Covering an area of approximately 64 km² and includes Lake Bennett, a small artificial freshwater lake behind an earthen dam, making Otto Creek the second regulated catchment in the Adelaide River catchment. Otto Creek extends approximately 18.5 km before joining the Adelaide River about 1.8 km downstream of gauging station G8170020: Adelaide River at Dirty Lagoon. Figure 51 provides an overview of the catchment. No gauging station exists on Otto Creek. Estimated flows from the NAM rainfall runoff model have been used to characterise discharges from the Otto Creek catchment.

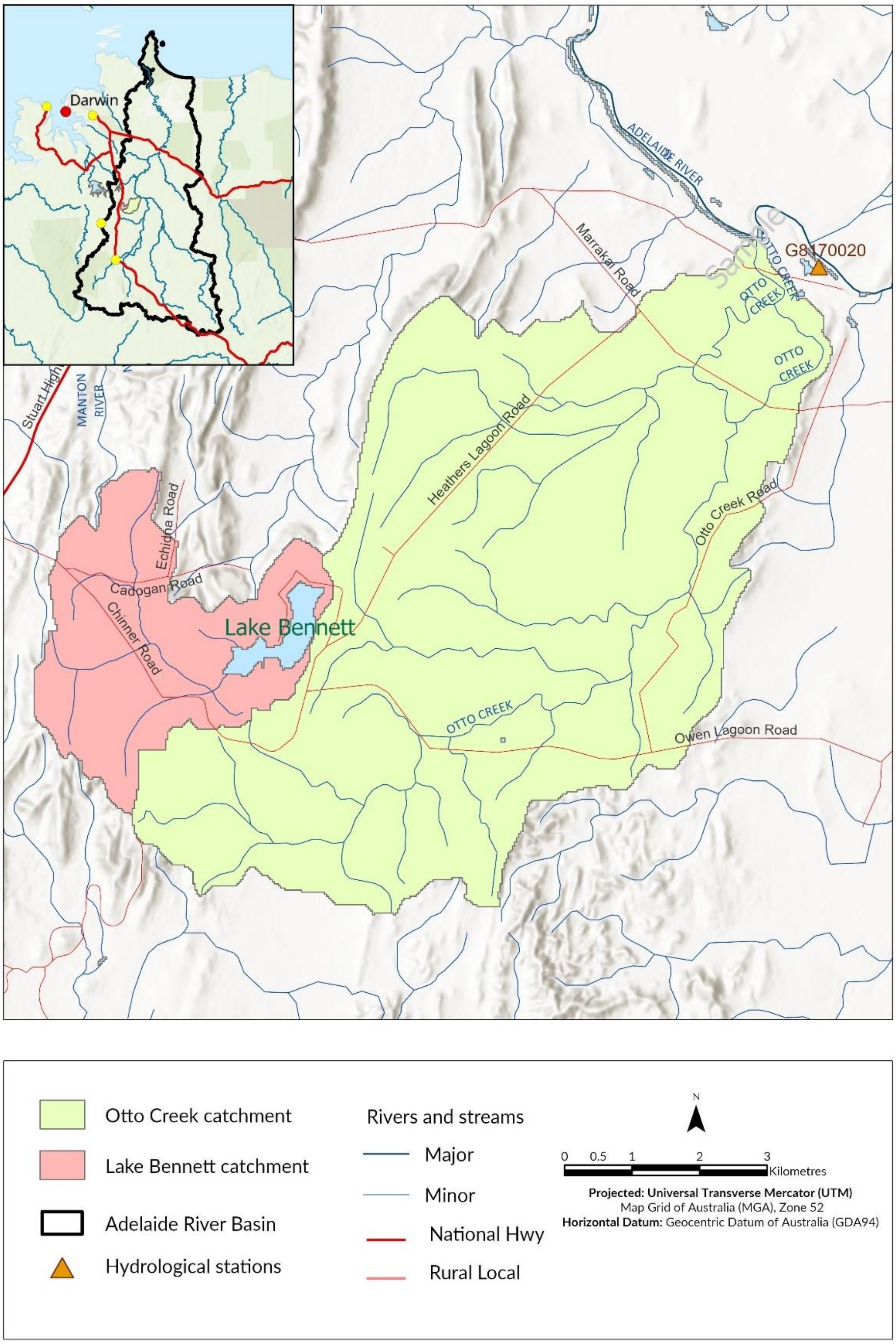


Figure 51. Otto Creek – Lake Bennett catchment location

4.4.7 Snake Creek

The Snake Creek catchment is situated in the south-west of the Adelaide River catchment and covers an area of approximately 51 km^2. A large part of the Snake Creek catchment lies within the Litchfield National Park. Snake Creek commences within Litchfield National Park and flows 18.7 km east to join the Adelaide River approximately 2 km downstream of Adelaide River township. Figure 52 shows the location of Snake Creek catchment, including the locations of key hydrological gauging stations.

Table 16 shows the details for gauging station G8170089. This site captures flows for an area of 37.5 km^2, however a large amount of missing record over wet and dry season means the flow record is insufficient for assessment purposes. The NAM rainfall runoff model was used to estimate streamflow records for Snake Creek to characterise flows in this catchment.

Table 16. Historic hydrological monitoring stations in the Snake Creek catchment (source: NTG Aquarius database)

Name	Site ID	Parameter	Period of record	Label
Snake Creek – Stuart Highway 3	G8170089	Water Level	1963 to 1969	Publish

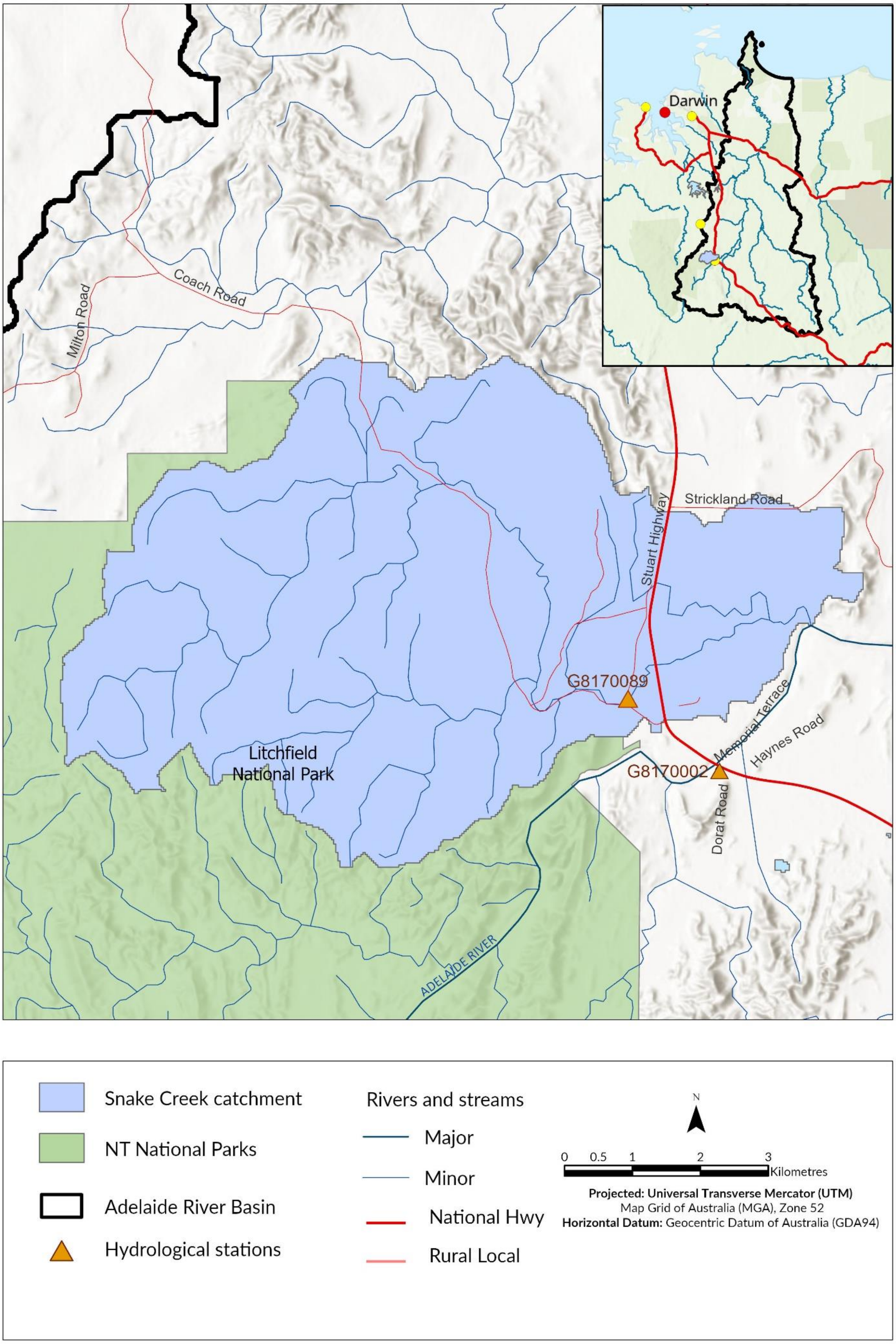


Figure 52. Snake Creek catchment and the locations of hydrological stations within the catchment

4.4.8 Stapleton Creek

The Stapleton Creek catchment is located in the south-west of the Adelaide River catchment and covers an area of approximately 130 km² to the north of Snake Creek catchment. The creek flows for 24.7 km before joining the Adelaide River approximately 17 km upstream of gauging station G8170084. Figure 54 shows the location of the Stapleton Creek catchment, including key hydrological gauging stations.

Table 17 lists the parameters and periods of record for data collected at site G8170076. Site G8170076 measured flows for an area of 50 km², less than half the total catchment area. While its record is not sufficient to determine catchment outflows, its record shows that the Stapleton Creek is ephemeral and typically ceases to flow by July each year, and often by June indicating it is rainfall driven with no persistent flows.

Table 17. Historic hydrological monitoring stations in the Stapleton Creek catchment (source: NTG Aquarius database)

Name	Site ID	Parameter	Period of record	Label
Stapleton Creek – Stuart Highway	G8170076	Water Level	1963 to 1981	Publish
		Discharge	1963 to 1981	Publish

Figure 53 shows the flow duration curve for G8170076. It shows no flow was recorded at the site for over 50% of the period of record. Flow at G8170076 usually ceases from June to November.

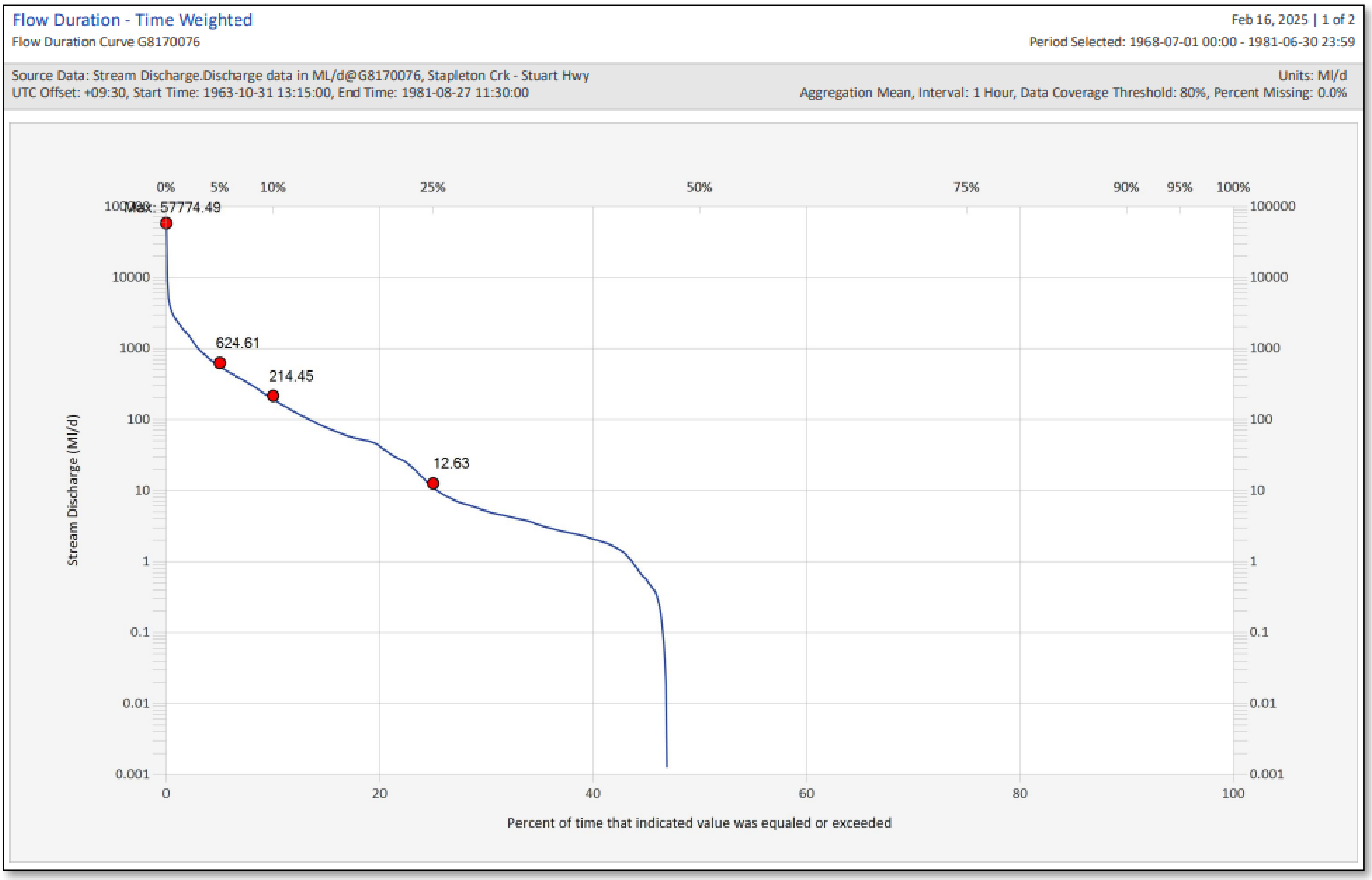


Figure 53. Flow duration curve for Stapleton Creek - G8170076

The NAM rainfall runoff model was used to estimate flows for assessment of whole of catchment flow conditions. Data from site G8170076 was used to develop and calibrate the NAM model.

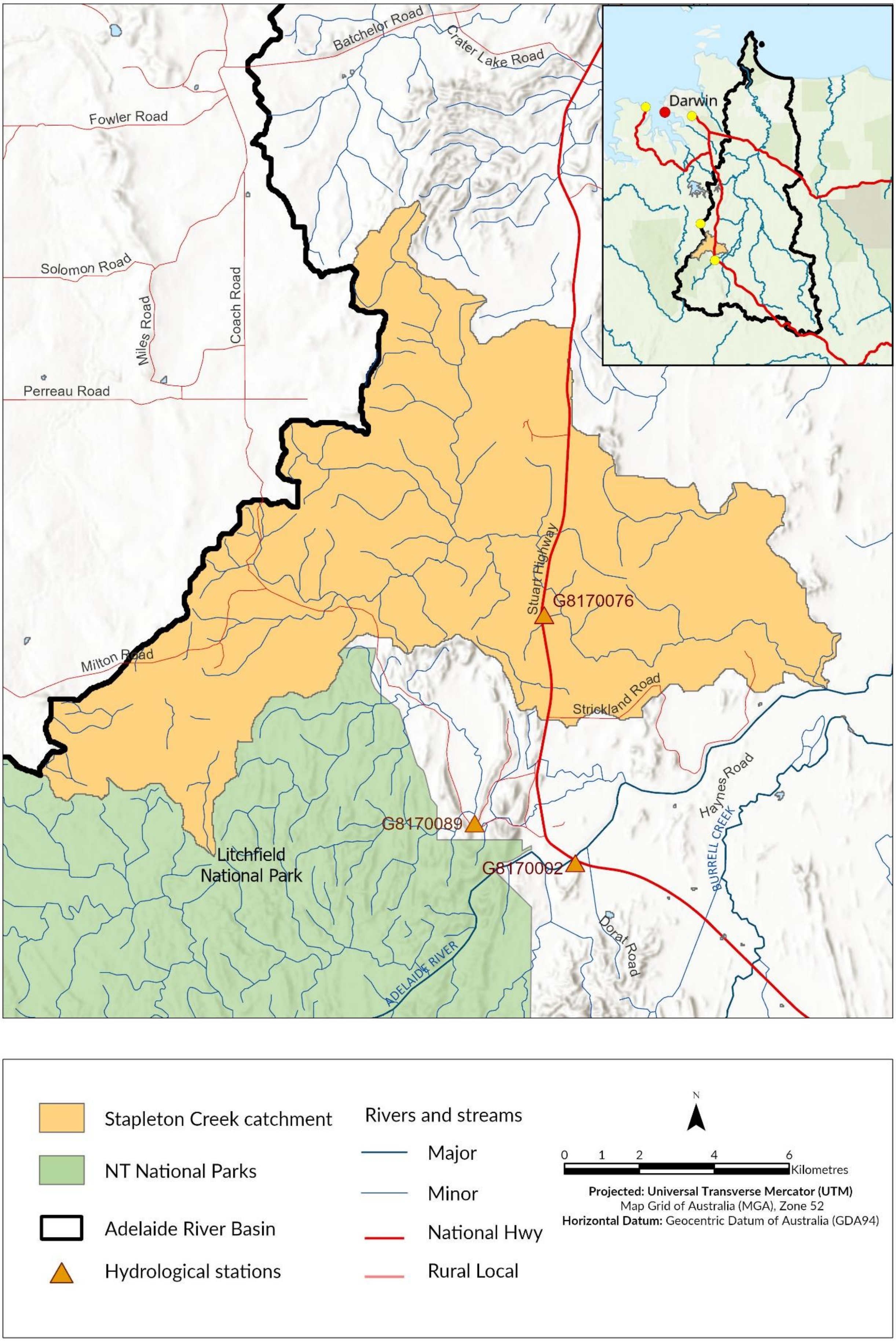


Figure 54. Stapleton Creek catchment and the locations of hydrological stations within the catchment

4.5 Surface water quality

4.5.1 Surface water quality monitoring

Water quality in the Adelaide River catchment is influenced by a complex interplay of spatial variability and seasonal fluctuations. Natural processes such as tidal movements, rainfall, and groundwater interactions shape the river's chemical and physical properties, with seasonal shifts between wet and dry conditions driving many of the observed changes. Human activities, such as agriculture and mining, and their associated impacts, are likely to impact water quality in the catchment.

Surface water quality monitoring in the Adelaide River catchment dates back to the 1950's, with data collection historically aligned to the flow monitoring gauge stations within Adelaide River and its tributaries (refer to Table 8 and Figure 26 for gauge station locations). Water quality sampling was conducted on an ad hoc basis until regular monitoring programs were recently established in response to the proposed development of the water resource.

Monitoring programs are documented in *Technical Note: Adelaide River Catchment Water Resource Monitoring Programs* 1950–2024 (Huxley et al, 2024) and in the *draft Water quality summary* (WAB, 2025 unpublished) report. These reports provide context around the data sources used to characterise surface water quality in the Adelaide River. There is notably less data representing the Margaret River catchment which is difficult to access in the wet season and ceases to flow during the dry season, and from the lower Adelaide River catchment due to limited access options across the floodplain. Additionally, there are significantly more samples representing water quality in the wet season.

Water quality data sources include:

1. DLPE historical data (1950–2022): collation of water quality data collected over a 70 year period, including single event data points at several sites.
2. DLPE baseline surface water quality monitoring (2023–2024): single-event instantaneous samples were collected during both the dry season of 2023 and the wet season recessional flows in 2024 to capture longitudinal and seasonal variations in water quality along the Adelaide River. This monitoring provides a snapshot of key water quality parameters and serves as the foundation for an ongoing monitoring program in the Adelaide River catchment.
3. DLPE in-situ water quality loggers (2023-2025): in-situ loggers were deployed throughout the catchment to capture real-time water quality data. Continuous data from these loggers enables a more comprehensive understanding of spatial and temporal water quality fluctuations, particularly across seasonal transitions.
4. Power and Water Corporation (2011–2022): monitoring is designed to assess the suitability of the source water for drinking water purposes. Surface water quality data has been collected at various sites in the catchment, with a greater number of data points captured upstream of the proposed public water supply extraction point between Marrakai Crossing and Dirty Lagoon.

The comparison of observed concentrations to ANZECC (2000) default guideline trigger values for protection of freshwater aquatic ecosystems is based on available data and should be considered preliminary. The Department of Lands, Planning and Environment has established an ongoing monitoring program for the Adelaide River catchment to continue to capture a baseline dataset to investigate and characterise water quality, as part of the development of the Adelaide River plan.

4.5.2 Physical and chemical

Salinity, measured by electrical conductivity shows spatial and temporal variation along the river, influenced by tidal conditions and rainfall. Tidal movements cause hourly fluctuations, particularly in the lower reaches, while rainfall leads to seasonal changes, with higher salinity during the dry season and lower salinity during the wet season as freshwater runoff dilutes dissolved minerals.

In the upper Adelaide River and Margaret River catchments, electrical conductivity values are generally low, ranging from 3–1200 µS/cm, reflecting freshwater dominance. Higher electrical conductivity values are typically observed during the dry season due to reduced flow and the concentration of dissolved minerals. In contrast, during the wet season, increased rainfall and runoff dilute the water, reducing salinity. At the Arnhem Highway, in the lower Adelaide River catchment, electrical conductivity values are much higher ranging from 329 to 5121 µS/cm during the dry season, reflecting increased seawater ingress with tidal movements. During the wet season, electrical conductivity values range from 37 to 736 µS/cm, reflecting the increased influence of freshwater runoff.

Specific conductivity results from in-situ water quality loggers illustrate the spatial salinity variation along the river (refer to Figure 55). The loggers recorded electrical conductivity longitudinally down the river system over a one year period from December 2023 to December 2024. Specific conductivity is the adjusted electrical conductivity measurement that accounts for temperature. At Dirty Lagoon, conductivity was low <500 µS/cm, indicating a predominantly freshwater environment, while loggers closer to the river mouth recorded high conductivity at around 55,000 µS/cm, consistent with seawater salinity (de Mellow et al., 2025). For the 2024 rainfall year, the transition zone, where freshwater transitions to brackish water, was identified downstream of Dirty Lagoon, at a place locally known as 'Goat Island' (Figure 55). Further work by the Department of Lands, Planning and Environment is underway to investigate how the transition zone shifts in response to rainfall and other environmental factors.

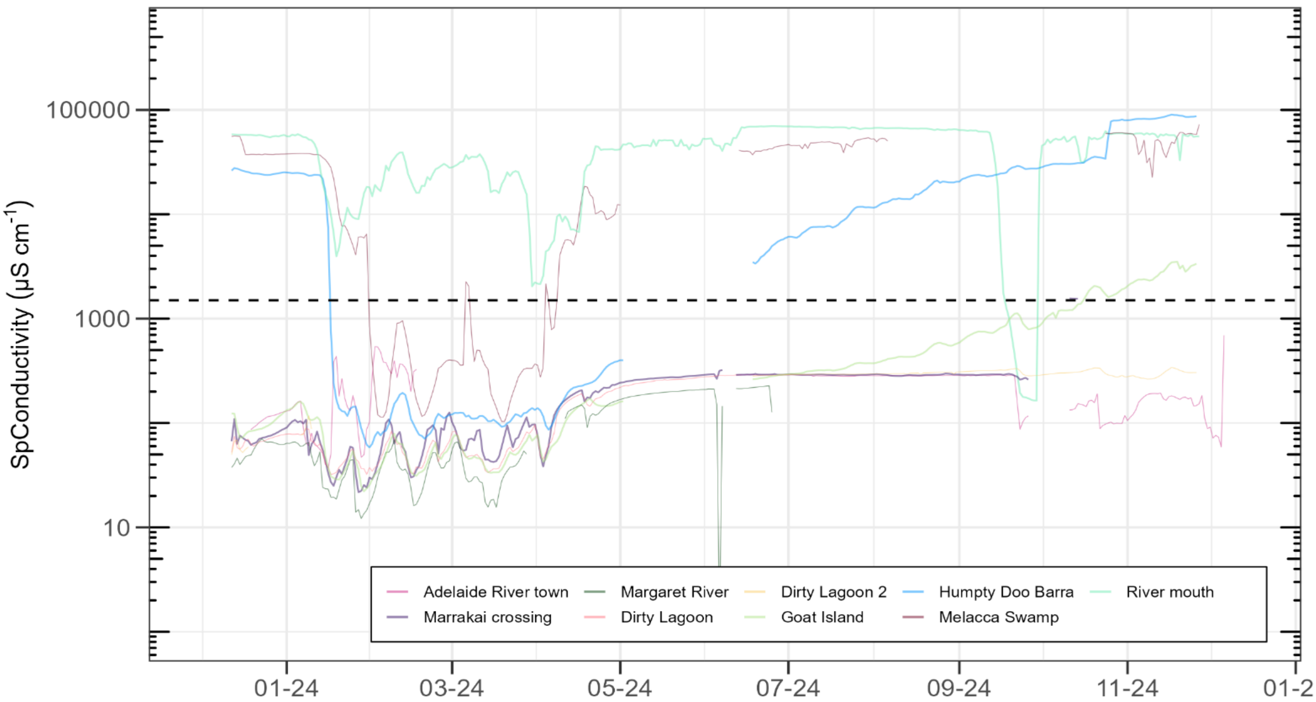


Figure 55. Daily mean values of specific conductance (µS/cm) data for in-situ water quality loggers

Water quality loggers located at: Adelaide River road bridge (Adelaide River town); Adelaide River/Marrakai Crossing; Margaret River/Marrakai Crossing; Dirty Lagoon; 1 km downstream Dirty Lagoon (Dirty Lagoon 2); 700 m downstream Goat Island; 4.5km downstream Humpty Doo; Barramundi; 4.5 km upstream Melacca Swamp Conservation Area; and River mouth. The dotted line represents the maximum specific conductance limit, 1,500 µS/cm for freshwater (de Mellow et al., 2025).

The significant temporal variation in conductivity is likely to be driven by tidal variation and seasonal changes. Conductivity dropped during the peak wet season, January to March 2024, particularly in the lower catchment, where the salinity temporarily shifted to a freshwater condition. Conductivity began to increase again in April, with a gradual increase during the dry season at loggers in the lower catchment, marking a transition from freshwater to brackish conditions. These fluctuations were influenced by tidal cycles and stream discharge, especially during peak wet season flow events (de Mellow et al., 2025).

pH levels across the catchment range from slightly acidic at 5.7 to slightly alkaline 8.8. The variation of pH is influenced by underlying geology, with areas containing high levels of carbonate minerals buffering acidity. In the upper catchment, pH is more variable and occasionally slightly acidic, while in the lower catchment, particularly near the river mouth, pH remains relatively stable and slightly alkaline due to the tidal ingress of seawater with high pH buffering capacity.

Dissolved oxygen levels in the Adelaide River were highly variable, ranging from 4% to 115% saturation, with limited data from the Margaret River or upper Adelaide River catchments.

Strong seasonal variability of turbidity is observed, with significant increases during the wet season. Wet season turbidity can exceed 500 NTU, while dry season turbidity can be as low as 0.1 NTU. The mean turbidity generally increases downstream, from 0.8 NTU at the Adelaide River East Branch to 166 NTU at the Arnhem Highway, reflecting the progressive accumulation of suspended sediments as water flows through the catchment.

Bicarbonate alkalinity in the Adelaide River is influenced by rainfall, groundwater inflow, and the geology of the surrounding catchment area. In regions with abundant carbonate minerals in groundwater, derived from limestone and dolostone, bicarbonate concentrations tend to be higher. Seasonal variations in bicarbonate levels are common, especially in areas with significant groundwater contributions. During the wet season, increased runoff and flow dilute bicarbonate concentrations, while in the dry season, reduced flow and increased proportion of groundwater inputs result in higher bicarbonate levels.

The ionic composition, as shown in the Piper diagrams (Figure 56), displays the relative concentrations of major ions. The dominance of calcium and magnesium suggests that freshwater sources in the catchment are strongly influenced by geological features, particularly carbonate formations. During the dry season, the upper Adelaide River is generally characterised by calcium-magnesium and chloride ions, typical of freshwater systems influenced by carbonate-rich geology. In the wet season, the water remains dominated by calcium-magnesium carbonates; however, the relative contribution of sodium and potassium ions increases. This shift is likely due to increased runoff, which introduces higher concentrations of sodium and potassium from soil and vegetation.

In contrast, in the tidal zone around Arnhem Highway, water chemistry reflects the influence of seawater, with high sodium-chloride concentrations common during the dry season. The presence of sodium-chloride salts in this area indicates the strong seawater influence in the tidal zone. During the wet season, the ionic composition remains more similar to upstream sites than the dry season, despite the seawater influence in the tidal zone. The increased sodium and potassium concentrations reflects the impact of rainfall runoff, which transports salts and minerals from the surrounding catchment during higher flow conditions.

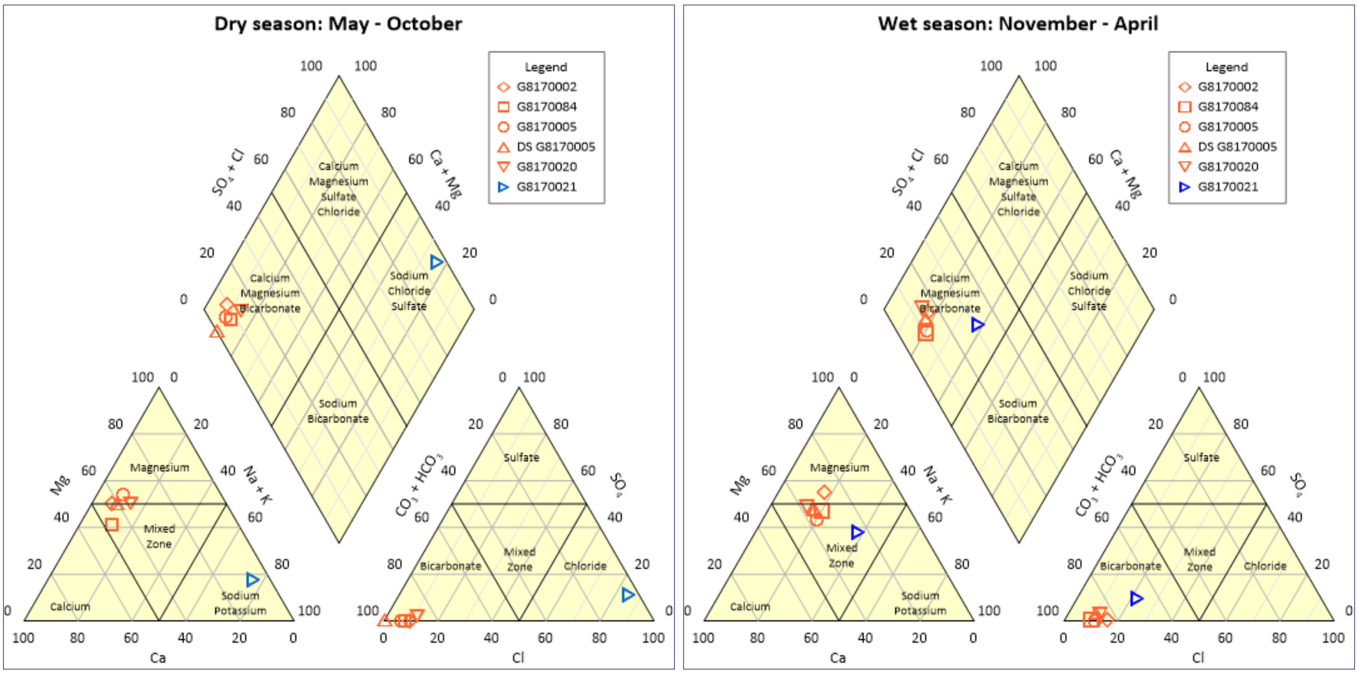


Figure 56. Piper diagram of water quality at the DLPE mainstream sites

4.5.3 Nutrients

Nutrient levels, particularly nitrogen and phosphorus, are key factors influencing water quality and ecosystem health.

Some nutrient concentrations exceeded default trigger values for aquatic ecosystems at times, particularly in the lower catchment around Dirty Lagoon and Arnhem Highway. Despite increased nutrient loading during the wet season from higher rainfall and runoff, dry season concentrations were at times higher than wet season. This can be attributed to the complex effects of factors including dilution related to rainfall and river flow, algal growth and nutrient cycling processes.

Total Nitrogen ranged from 0.03–10.0 mg/L, with higher concentrations in the wet season. Certain sites, such as Tortilla Flats, Marrakai road, and Dirty Lagoon, exhibited spikes in nitrogen concentrations, with the highest concentration recorded at Dirty Lagoon. The elevated spikes were likely due to localised runoff events, where nitrogen from terrestrial sources entered the river with rainfall. NO_2 + NO_3 in contrast, had higher concentrations recorded during the dry season, although noticeable increases were observed in the wet season, especially in the lower catchment, with a max of 0.82 mg/L recorded at the Arnhem Highway. Concentration in the catchment ranged from <0.002–0.82 mg/L. Ammonia concentrations ranged from <0.005–1.13 mg/L, with the higher values observed in the lower catchment during the wet season.

Total phosphorus concentrations showed similar seasonal fluctuations, with a range <0.005–0.360 mg/L. Phosphorus levels were higher during the wet season. Sites such as Tortilla Flats and Marrakai road had lower phosphorus concentrations than Adelaide River railway bridge and Dirty Lagoon, particularly during the wet season. Reactive phosphorus concentrations followed similar trends, ranging from <0.001–0.027 mg/L, remaining low at most sites. Fluctuations were observed at sites such as Tortilla Flats, Marrakai road, and Dirty Lagoon, particularly during the wet season, likely due to nutrient mobilisation from rainfall events. The Arnhem Highway site was an exception, with single samples consistently higher than the default trigger value for reactive phosphorus during the wet season.

Baseline chlorophyll a concentration in the dry season of 2023 and wet season of 2023-24 varied seasonally. Chlorophyll a, an indicator of algal biomass in the water column, ranged from 0.4 to 4.4 µg/L. In the dry season, concentrations ranged from 0.36 to 2.99 µg/L, while in the wet season, levels increased to 0.43 to 4.4 µg/L.

4.5.4 Metals

Metal concentrations in the Adelaide River catchment are of particular interest due to the potential impacts from various mining activities throughout the catchment. Active mines, exploration licences and sites with legacy mine features are located in the upper Adelaide River and Margaret River catchments. Legacy mines within the Margaret River and Howley Creek catchments have historically known to have acid metalliferous drainage issues, characterised by low pH and elevated metal concentrations.

Additionally, there are natural sources in the catchment that contribute to metal concentrations in the Adelaide River. Laterite formations and certain soils release aluminium and iron to water resources in the catchment. Elevated aluminium levels are also observed in other catchments across the Top End of the NT. Historical samples in the Water Resource Division database frequently exceeded guideline values across the region (Novak and Schult, 2015). Similarly, the adjacent Mary and Daly Rivers have reported aluminium concentrations to consistently exceed default trigger values for aquatic ecosystem protection, especially during periods of high flow. Investigations suggest that the elevated aluminium found in these rivers represent background ‘natural’ concentrations (Novak and Schult, 2015).

The baseline sampling results from 2023-24, recorded high aluminium with both total and soluble aluminium exceeding the default trigger value for pH<6.5. For all other metal analytes, while total concentrations were elevated at some sites, the concentrations of soluble metals remained below the ANZECC (2000) trigger values for 95% protection of aquatic ecosystems. While total concentrations provide an overview of the overall metal content, soluble concentrations are more indicative of the fraction that is bioavailable to aquatic ecosystems.

Historical data from the Department of Lands, Planning and Environment and Power Water Corporation datasets are more extensive, and show the soluble concentrations of aluminium, copper, and zinc to well exceed default trigger values at certain sites, during specific years. A significantly larger number of samples were collected in the lower Adelaide River catchment, between Marrakai Crossing to Dirty Lagoon, while data from the Margaret River and upper Adelaide River catchments was limited. Additionally, a greater number of samples were collected during the wet season.

Soluble aluminium was elevated at many sites, particularly during the wet season, with values exceeding default trigger values. Concentrations in the catchment ranged from 0.7 to 3,900 µg/L. The highest concentrations were recorded in the Margaret River catchment and Dirty Lagoon in the 2013. During the dry season, concentrations were lower, ranging from <0.3 to 230 µg/L, with occasional spikes exceeding the default trigger values. While natural sources such as laterite formations, contribute aluminium to the catchment, the influence of anthropogenic activities will continue to be monitored.

Iron concentrations also varied across the catchment, with higher levels observed during the wet season. Soluble iron levels ranged from <2 to 6,499 µg/L in the wet season and 3 to 550 µg/L in the dry season. Iron concentrations are likely influenced by seasonal effects on surface runoff and groundwater inflows. The Pine Creek Orogen underlies much of the southern half of the catchment and holds iron-rich sedimentary rocks that provide a natural source of iron.

Soluble copper and zinc values were well above trigger levels for aquatic ecosystem protection during historical wet season sampling events. Soluble copper concentrations ranged from <0.1 to 45.0 µg/L during the wet season and <0.4 to 0.7 µg/L in the dry season. All dry season samples complied with the default trigger values. Elevated copper concentrations were detected at several locations, particularly at Dirty Lagoon. Although copper was relatively low at some sites, like Tortilla Flats, occasional peaks exceeded the trigger value. Soluble zinc concentrations ranged from 0.3 to 4,372 µg/L in the wet season and 2 to 88 µg/L in the dry season. Concentrations were highest at Marrakai road and Dirty Lagoon.

There is some evidence to suggest that impacts from mines in the upper Adelaide River catchment could extend to the lower Adelaide River catchment. Schultz et al. (2002) reported that an inactive mine site in the upper Mary River catchment was potentially impacting in excess of 25 km of the river, with several metals (cadmium, copper, zinc) exceeding default trigger values. For the Adelaide River, understanding the natural background concentrations will help to identify natural or anthropogenic causes for the exceedances.

The Department of Mining and Energy, Legacy Mines Unit reported historically exceedances in cobalt, copper, manganese, nickel and zinc, well above the default trigger values for 95% species protection (ANZECC, 2000). Significant remediation activities at the Cosmo mine between 2020 and 2023 have addressed a primary source of contamination in the Margaret River catchment. In 2023, downstream monitoring of legacy mine reported improved metal concentrations with all analytes complying with the trigger values for 95% protection of aquatic ecosystems, as well as the drinking water quality guidelines (pers. comm. Director Legacy Mines, 7 March 2025).

4.5.5 Pesticides and herbicides

Pesticide and herbicide concentrations were sampled as part of the baseline sampling in 2023-24. Concentrations were below detectable levels at all sites, except for Tebuthiuron at Margaret River. Tebuthiuron, a herbicide used for vegetation control, was detected in the Margaret River during a single wet season sampling event at a concentration of 0.02 µg/L. While this concentration does not exceed guideline trigger level, it suggests that Tebuthiuron may be entering the system, likely through runoff or subsurface flow. This concentration does not appear to pose an immediate risk to aquatic health. Further monitoring will assist in identifying and characterising the risks associated with pesticide chemicals, for the purpose of managing these risks.

5. Ecological classification

An ecological mapping and classification project was undertaken throughout the Adelaide River catchment to determine, classify and quantify spatial extent of the main water dependant ecological communities within the catchment. The Department of Lands, Planning and Environment partnered with Charles Darwin University to develop the classification framework and to determine the spatial extent of each of the ecosystem types through analysis of the satellite imagery record between 1986 to 2022 (de Mello et al, 2024). Site visits were undertaken to train the image analysis algorithms and to verify image analysis results. A full description of the methodology and results can be found in the project report titled '*Ecological Assessment Adelaide River Catchment: Wetland mapping and preliminary fieldwork*' (de Mello et al, 2024).

Nine classification categories were established based on distinct ecosystem types that could be reliably detected through the image analysis. Of these, eight categories (Figure 57) are specific to aquatic ecosystems while one, 'Open Forest' represents the dominant non-wetland cover across the catchment. Distinction between the different categories was through vegetation type, for example, grasses, woody vegetation, mangroves etc. as well as likelihood of inundation, period of inundation, proximity to water bodies, topography, land use as well as previous ecosystem mapping projects such as mangrove monitoring etc. (de Mello et al, 2024).

System	*Category*	*Sub-category*	*Tidal influence*	*Land cover*
Estuarine	Floodplain Marsh	Salt marshes	YES	grass vegetation
	Salt flat	Samphire /salt flats	YES	bare, short vegetation
	Swamps	Mangroves	YES	trees or shrubs
	Water	Coastal lagoon	YES	water
	Water	Estuarine waters	YES	water
Lacustrine	Water	Lake	NO	water
Riverine	Water	River	NO	water
	Riparian Vegetation	Riparian vegetation	NO	trees
Palustrine	Swamps	Freshwater swamps	NO	trees
	Floodplain	Flooded open forest tree (Melaleuca, Eucalypt) and grass (freshwater marsh)	NO	trees and grass vegetation
	Water	Freshwater pools	NO	water
Man-made	Water	Reservoir/Dam	NO	water

Figure 57. Proposed wetland classification key (de Mello et al, 2024)

5.1 Class definitions

Vegetation communities across the classification categories are unlikely to be static. Different species are likely to dominate different areas of the same ecological classification due to minor differences within the physical environment throughout each classification category, and with transition zones between categories more likely represented by a gradual change in vegetation types rather than hard boundaries between categories. Classification of any natural system is problematic as it seeks to simplify complex relationships between terrain, climate, hydrology and ecology. However, it assists natural resource managers to broadly understand the type, location and extent of ecological communities within a study area, and where the satellite record is sufficient to study changes over time. It is a powerful tool to look at future changes over time and to monitor and assess potential changes due to land use change and other developments.

The results revel a general stability for all major wetland categories in the Adelaide River catchment, which suggests that wetlands in the catchment have not experienced severe degradation during the 36 years of the analysis.

5.2 Spatial variation of ecological classes

The project showed that some ecological classes appear to be increasing in extent over time (e.g. swamp, short mangrove) while others show a slight decrease in area (water, floodplain) with some seeming static. This may be due to variations in annual rain patterns as well as factors such as poor image capture, too much cloud cover, imagery not aligned with peak flood extent or confusion between two classes.

Figure 58 shows the 2022 coverage of the nine categories identified as part of the ecological mapping and classification project. The total area of each ecological classification is summarised in Table 18.

Table 18. Relative area of each classification class from 2022 imagery

Ecological class	2022 total area (km^2)
Water	106.5
Mangrove	91.9
Samphire/salt flat	78.4
Swamp	374.6

Ecological class	2022 total area (km^2)
Riparian vegetation	557.8
Short mangrove	79.6
Open forest	1576.4
Marsh grass	768.2
Green marsh	165.7

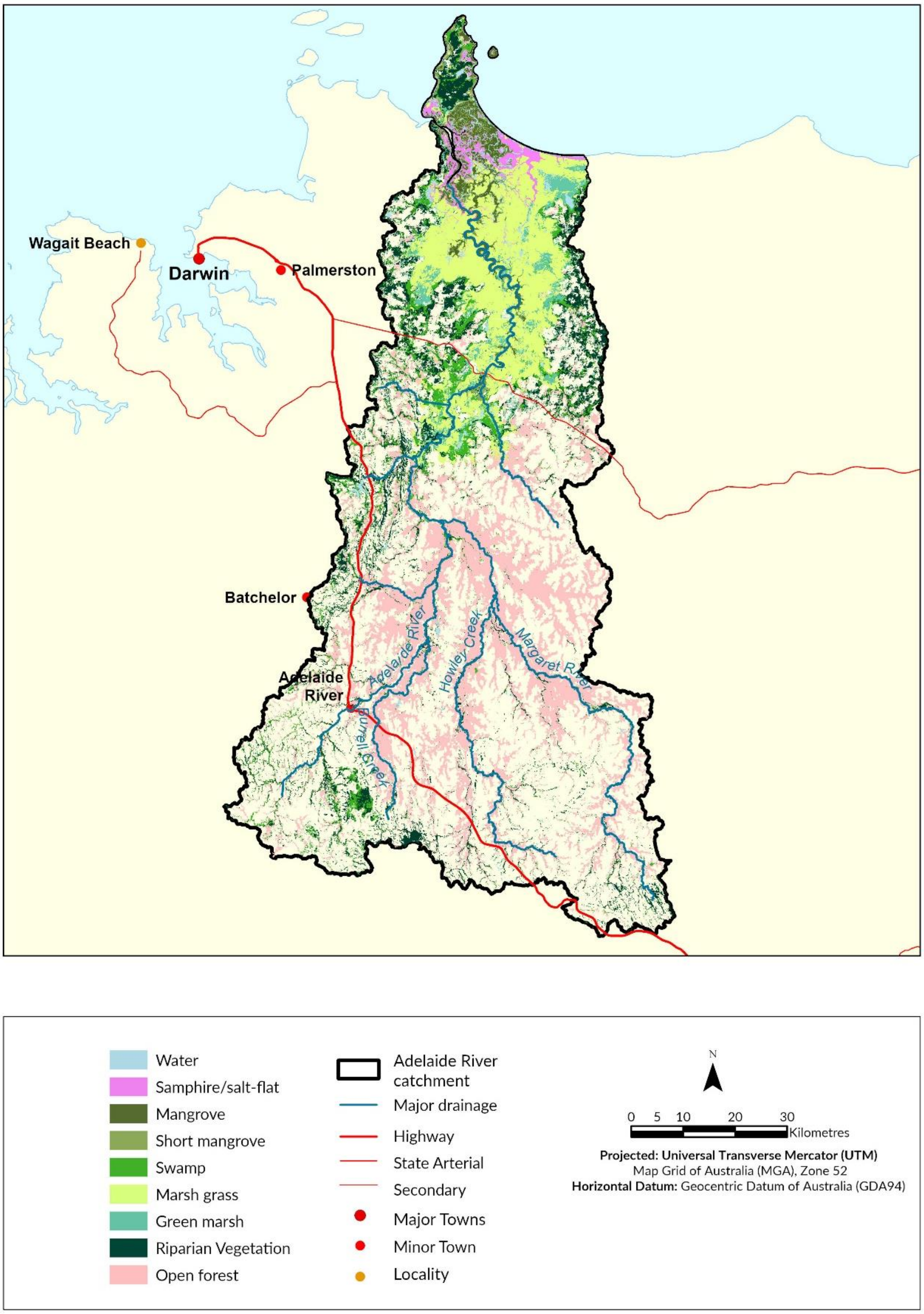


Figure 58. Category coverage identified as part of the ecological mapping and classification project

5.3 Seasonal variation of wetland extent

Wetlands are highly dynamic in nature, and the extent of a wetland can expand or contract in response to local hydrological and climate conditions, and human pressures. Among all wetland categories in the Adelaide River catchment, the floodplain, mostly covered by marsh, is heavily influenced by the wet and dry seasonal climate. Areas identified as wet during the dry season in the field were classified as floodplain (Figure 59). Although the maximum extent of the floodplain was stable over the years, the extent of wet areas during the dry season has varied, with a slight trend towards reduced wetted area (de Mello et al, 2024).

In general, January/February and November/December presented the highest water coverage.

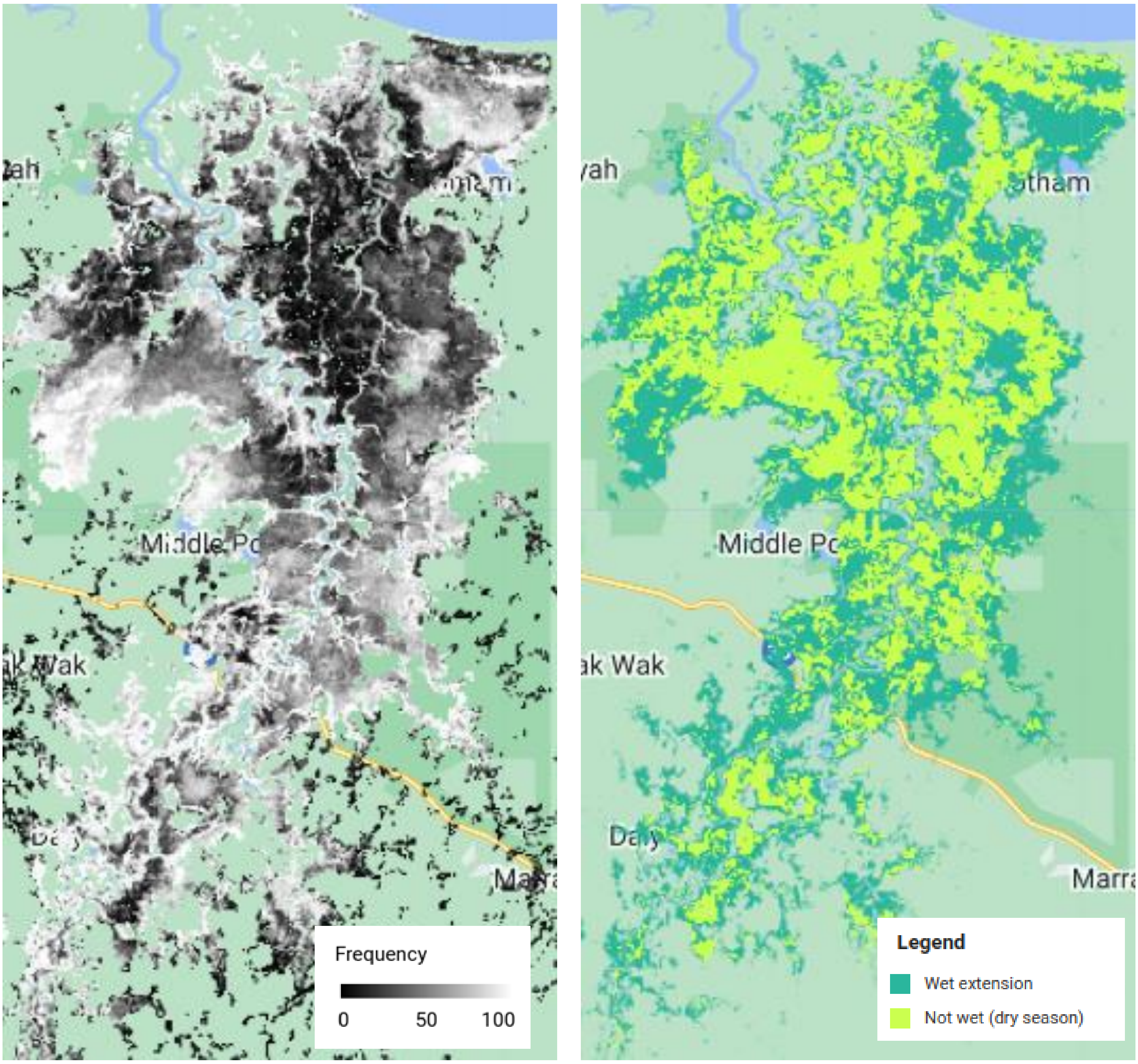


Figure 59. Wet extent during the dry season for floodplains (a) frequency (1886-2022), (b) wet extent for 2022 (de Mello et al, 2024)

5.4 Wetland condition change index results

The wetlands did not show high levels of alterations, though areas with higher numbers of cattle and buffalo such as the floodplain marsh near Black Jungle showed a negative condition trend. Field observations for correlation indicated soil pugging, which aligns with the values found on the map. Conversely, some undisturbed areas also exhibited a negative trend, which should be investigated as it could be a possible natural alteration. Roads and new rural areas were also identified on the trend change map. The mapping tool can identify cattle stations upstream of the catchment and rural areas such as those close to Lake Bennett. Riparian areas, in general, show neutral or positive trends in ecological condition indicating they have improved condition over the period of satellite record.

Some areas of positive trends were associated with new mango crops, since this type of land cover increases normalised difference vegetation index and wetness values compared to the former use of that land. Areas with positive trends should also be investigated to check for environmental condition improvement or land use and land cover change.

6. Water availability

6.1 Annual natural water balance

The natural water balance is an important concept in water resource management used to assess the average water availability within the management area. It describes all the inflows and outflows of water within the water management zone over a period of time, in this case the surface water catchments of the Adelaide River catchment for a water year. The natural water balance is expressed using a simple flux equation:

Inflow = outflow +/- Δ storage

Discharges from the Cambrian Limestone Aquifer into the Adelaide River catchment appear to be sourced from rainfall within the catchment and include negligible inflows from the Cambrian Limestone Aquifer outside the catchment (Yin Foo, 2018). Inflow from regional fractured formations such as Burrell Creek Formation are also considered to be negligible, while discharges from the karstic Coomalie Dolostone, Koolpinyah Dolostone and other formations originate largely from precipitation falling within the Adelaide River catchment.

As such, the components that make up the water balance can be simplified to:

Precipitation = total catchment discharge + ET + recharge (to groundwater) + lateral groundwater discharges

Figure 60 provides the overview of the natural water balance for Adelaide River catchment. The values of the individual components are likely to contain errors due to spatial lumping, parameter estimation and calculation assumptions (Knapton, 2020).

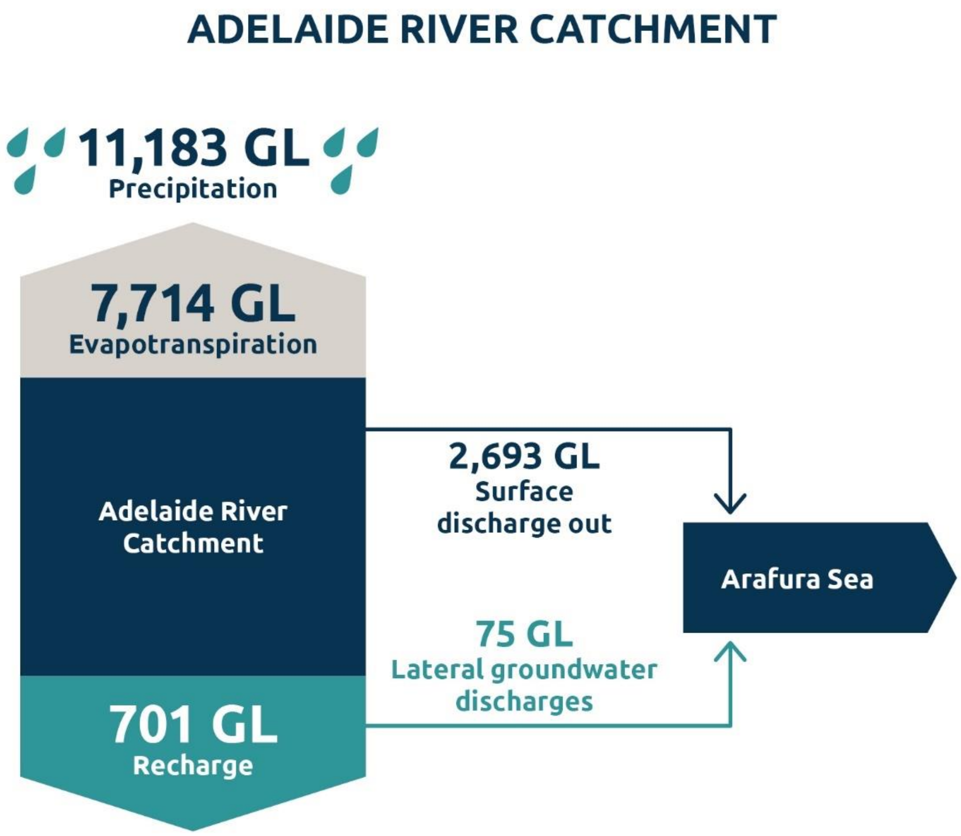


Figure 60. Natural water balance

The actual water balance will vary each year based on rainfall totals, intensity and duration as well as climate influences on evapotranspiration.

The components of the natural water balance have been estimated using:

- spatially averaged mean annual rainfall
- mean annual recharge
- spatially averaged mean annual actual evapotranspiration, based on estimated actual evapotranspiration at Howards Springs and Litchfield Shire
- modelled mean annual total catchment discharge (Petheram et al, 2018)
- modelled mean lateral groundwater discharge (Petheram et al, 2018).

Total catchment discharge is based on modelling undertaken by CSIRO for the NAWRA and includes runoff from the ungauged sections of Adelaide River catchment including the coastal floodplains.

Evapotranspiration was calculated based on average daily actual evapotranspiration estimates and ranges from 1.9 mm per day to 4.3 mm per day across the year. Actual evapotranspiration estimates are provided by TERN.

Mean annual recharge was calculated from the mean annual recharge estimates provided in Table 7, multiplied by the area for each formation.

Lateral groundwater discharge was estimated based on modelling undertaken by CSIRO, which aligned with groundwater discharge estimates for the Koolpinyah Dolostone (Knapton, 2017).

6.2 Wet season take

The Surface water wet season take policy (NTG, 2024) provides guidance for determining the volume of water that may be taken from wet season flows in a catchment while protecting ecological and cultural values. Under the policy, in the absence of scientific evidence to set waterway specific environmental flow requirements, a conservative contingent volume of water is made available for allocation. This volume is equal to 5% of the 25 percentile of the wettest three wet season months for a period of record of at least 50 years. This volume of take is proportional throughout the catchment as a percentage of catchment area upstream of the abstraction location.

For the Adelaide River catchment, analysis of records since 1970 indicates a volume of approximately 41 GL may be available to take from wet season flows using the allocation rules within the Surface water take policy at the upper extent of tidal influence at Dirty Lagoon. For context, this volume makes up 2.5% of median total annual discharge, 12.9% of the lowest recorded total annual discharge and 0.8% of the highest recorded total annual discharge. Table 19 shows several possible abstraction scenarios as a proportion of total annual discharge, however, does not take into account limitations on take due to license conditions restricting take at specific periods and discharge thresholds, or engineering limitations due to capacity of pumps or diversion structures.

Table 19. Variation of 2024 policy abstraction scenarios and proportion of various annual discharge volumes

Proportion of 25 percentile	Volume (GL)	Proportion of median annual total discharge (1637.7GL)	Proportion of minimum annual total discharge (318.7 GL)	Proportion of maximum annual total discharge (5069.5)
5% *	40.9	2.5%	12.9%	0.8%
10%	81.9	5.0%	25.7%	1.6%
15%	122.8	7.5%	38.5%	2.4%
20%	163.7	10%	51.3%	3.2%
25%	204.7	12.5%	64.2%	4%
30%	245.6	15%	77.1%	4.8%

* 2024 Surface water wet season take policy

Development of catchment specific environmental flow requirements will provide flow thresholds to protect key ecological and hydrological functions within waterways. These will restrict periods and rates of take and combined with engineering limitations, is likely to lead to substantially lower volumes being extracted than would be licensed under the higher proportional percentages of the abstraction scenarios shown in Table 19.

Flow regimes which will be protected by specific License Conditions may include:

- fully preserving ‘first flush’
- protecting a minimum net flow rate in the river at the extraction point or appropriate gauge
- limiting the percentage of instantaneous flow that can be extracted
- protecting flow regimes that result in downstream floodplain inundation if ecologically significant.

7. Conclusions

The Adelaide River catchment lies in the wet-dry tropics and experiences significant rainfall during the wet season months from October to April, followed by moisture deficits during dry season months from May to September when losses to evapotranspiration exceed precipitation. Rainfall across the catchment is fairly consistent, with a small gradient of increasing rainfall from the south of the catchment to the north. An underlying trend of increasing annual rainfall exists across the catchment from the mid 1960's, becoming more pronounced since 1995. Rainfall runoff is highly dependent upon antecedent conditions, intensity and duration of rainfall.

Flows in the Adelaide River catchment are dominated by the distinct seasonal polarity of the wet-dry tropics. While minor perennial flows do occur in the upper reaches of the Adelaide River catchment and Coomalie Creek, downstream reaches of the Adelaide River only flow perennially after larger wet seasons due to increased recharge to groundwater storages allowing groundwater discharges to persist until the onset of early rains the following wet season. Minor perennial flows in the upper Adelaide River occur in about 40% of years due to groundwater discharges. By contrast, insufficient storage capacity occurs within the Margaret River catchment so that the Margaret River and its tributaries cease flowing early in the dry season every year.

Over 99% of total catchment discharges from the upper Adelaide River and Margaret River occur during the wet season, with a median annual discharge of 1637 GL entering the Adelaide River estuary. Annual discharges are highly variable depending upon rainfall volume, intensity and duration during the wet season. The minimum total annual discharge entering the estuary is 319 GL while the maximum total annual discharge is 5,069 GL. Almost 40% of total catchment flow is generated from the ungauged portion of the lower Adelaide River along the estuary, with median total catchment discharge estimated at 2,354 GL (Petheram et al, 2018).

The lower Adelaide River catchment is macro-tidal, with the estuary extending 80 km inland. An extensive coastal floodplain of ecological and conservation significance has developed on the coastal plain extending 60 km inland and covering and area of approximately 1,300 ha. Wet season flows displace saline water to the river mouth during large wet seasons, while an extensive salinity profile develops from the river mouth to the upper estuary during the dry season. Extent and intensity of water quality variation through the estuary depends upon magnitude and duration of previous wet season and timing of commencement of the following wet season. Inundation of the floodplain appears to be predominately from localised rainfall and runoff within the lower Adelaide River catchments. Low relief and elevations allow localised runoff to be captured and stored on the floodplain creating a mosaic of wetland habitats of ecological and cultural significance. Lateral connectivity between the floodplain and the river occurs sporadically in the upper floodplain, with water levels exceeding bank levels infrequently, and not at all in 20% of years. When significant lateral connectivity is achieved, the duration of connectivity tends to be quite long (>10 days) due to the low hydraulic gradients.

The Adelaide River catchment has a complicated hydrology due to generally low relief throughout the catchment, and a significant hydraulic control at the upstream limit of the tidal estuary. This constriction at Dirty Lagoon regulates discharges from the upper catchments, however the natural storage capacity behind the constriction causes significant backwater effects on the lower reaches of both the upper Adelaide and Margaret Rivers, complicating monitoring activities. Monitoring difficulties are further compounded by relatively shallow channels through the upper catchments leading to diversion of significant flows from the primary channel into flood channels, flood conveyance areas and wetland storage.

Paucity of monitoring data in many of the subcatchments and across the Margaret River catchment complicates flow assessments, however this can be alleviated by development of hydrological and hydrodynamic models to provide a better overview of flow dynamics within the catchments.

Modelled flow records will produce discharge information and allow catchment flow assessment for the subcatchments across the Adelaide River catchment, while hydrodynamic models will allow impact assessment for planning activities and license applications, as well as testing development scenarios for ecohydrological assessment within the catchments and across the coastal floodplain.

Water quality in the Adelaide River catchment is shaped by a complex interplay of spatial variability and seasonal fluctuations. Natural processes, including rainfall, tidal movements, and the surrounding geology, influence the river's chemical and physical properties, with seasonal shifts between wet and dry conditions driving many of the observed changes. Human activities, such as agriculture and mining, and other forms of disturbance such as the presence of feral animals are also likely to impact water quality in the catchment. Ongoing baseline sampling efforts will help further understand the natural background concentrations, allowing for a clearer identification of natural or anthropogenic causes for exceedances.

Mapping and classification of ecological communities has identified eight broad aquatic ecosystem types across the Adelaide River catchment. Biological surveys undertaken to identify representative species composition of these classification will allow ongoing monitoring of ecosystem health, as well as identification of key species and their flow requirements to model impacts of hydrological change.

8. Recommendations

Recommendations are provided to improve upon existing understanding of the hydrology of the Adelaide River catchment.

Knowledge of Territory water resources is continually improving. The following recommendations will build on existing knowledge of the surface water resources in the Adelaide River catchment and will help support development of future water plans.

These recommendations include:

8.1 Short term recommendations

Based on current activities, the following items should commence or continue:

- A monitoring program to enhance our understanding of catchment hydrology and support model development has been proposed in Table 20. These sites include key locations on main waterways as well as outflow locations for the main subcatchments. Priority sites are underlined and will be regualroty reviewed to ensure the program is effective.

- Establish a monitoring location on the flood channel diverting flows from Margaret River to Adelaide River, to better understand magnitude of diversion and support model development.

- A floodplain inundation study should be undertaken to understand primary drivers in upstream and downstream components of the coastal floodplain. Installation of loggers at sites identified in **Error! Reference source not found.** will allow patterns of inundation to be analysed and assessed alongside localised rainfall and runoff, catchment flood discharges and impacts of tidal variation. Frequency and duration of lateral connectivity of the river channel to the floodplain should also be analysed. This study will support ecological studies and impact assessment of license applications. Loggers must include instream and floodplain locations and be tied into AHD.

Continue in-situ time series monitoring of electrical conductivity, turbidity, temperature, pH and dissolved oxygen at locations listed in These sites may be considered for future monitoring.

- including existing monitoring locations to further develop understanding of water quality fluctuations induced by tidal influences and to better understand natural variability associated with river flows. This data will be critical for future water quality model development.

Sample at sites listed in These sites may be considered for future monitoring.

- along the Adelaide River estuary, to better understand seasonal and annual variability on water quality due to wet season flooding and tidal forcing. This program will support water quality modelling to better understand tidal and seasonal dynamics on water quality.
- Continue collection of biannual water quality samples at locations identified in Table 20 for minimum of 5 years to establish a baseline dataset of water quality parameters and better understand seasonal and annual variability. Assessment of results after 5 years will determine whether further intensive baseline data should be collected, or whether lower intensity monitoring for changes to the baseline can be adopted.

8.2 Medium-term recommendations

The following recommendations are components of existing programs or will provide information to support future license application assessments.

- Reassess rating curves at G8170084 and G8170095 based on modelled discharges to incorporate flows diverting around the monitoring sites during higher flow periods. Determine whether a rating extension can be reasonably established or whether other locations for monitoring should be investigated.
- Review data for existing Adelaide River catchment monitoring sites listed in Table 20. The reviews should reinstate zero values for dry season data gaps for some cease to flow conditions, completing the record back to 1960 where possible. Where no monitoring data or field notes exist, modelled outputs should be used as a reference.
- Extend ratings for:
  - G8170008: Adelaide River East Branch
  - G8170084: Adelaide River at Tortilla Flats (if possible)
  - G8170095: Margaret River DS Howley Creek (if possible).
- Consider further hydraulic modelling scenarios of design storm events should be generated for all planning scenarios and license applications. Scenarios should be developed for flood frequencies of most significance to maintenance of ecological values in order to determine likely impact of water dependent development. Key flood frequencies should include the 63.3%, 50%, 20% and 10% AEP event.
- Consider extending bathymetric long section of the tidal estuary to profile thalweg (deepest line of the riverbed) to improve model performance.
- Consider salinity profiling along tidal estuary to understand stratification/mixing of tidal water and fresh water through the water column to support water quality modelling in the tidal region and changes as dry season progresses.

8.3 Monitoring recommendations

Table 20 proposes an ongoing monitoring program within the Adelaide River catchment to build on baseline datasets, monitor change over time, support model development and to allow active management of future surface water licenses. Priority monitoring locations are underlined.

Table 20. Proposed monitoring program

Site name	Site ID	Parameter	Monitoring requirement
Adelaide River at railway bridge	G8170002	Water level Discharge Rainfall WQ field WQ samples	• baseflow assessment from TLA* • flood warning and management • SW license assessment • WQ baseline dataset
Adelaide River US Marrakai Crossing	G8170005 (new number for new site at crossing)	Water level Discharge Rainfall WQ field WQ samples	• low flow calculation for G8170020 • model development • SW licence assessment • WQ baseline dataset
Adelaide River DS Daly road	G8170008	Water level Discharge Rainfall	• baseflow assessment from TLA, BCF* • flood warning and management
Adelaide River at Dirty Lagoon	G8170020	Water level Discharge Rainfall WQ field	• total catchment flow from non-tidal catchments • model development • flood warning and management • SW license assessment • WQ baseline dataset
Adelaide River on Arnhem Highway	G8170021	Water level Rainfall	• flood warning and management
Margaret River US Marrakai Xing	G8170032	Water level Discharge WQ field WQ samples	• low flow calculation for G8170020 • model development • total flow from Margaret River catchment • SW licence assessment • WQ baseline dataset
Manton River at Acacia Gap	G8170033	Water level Discharge WQ field WQ samples	• total catchment flow For Manton River catchment • SW license assessment • WQ baseline dataset
Coomalie Creek at Stuart Highway	G8170066	Water level Discharge	• baseflow assessment • drainage from mining area • flood warning and management
Adelaide River at Tortilla Flats (consider relocation to capture high flows)	G8170084	Water level Discharge Rainfall	• SW license assessment
Acacia Creek on Stuart Highway	G8170085	Water level Discharge	• flood warning and management
Adelaide River downstream Red Bank Creek	G8170094	Water level Rainfall	• baseflow assessment • flood warning and management
Margaret River downstream Howley Creek	G8170095	Water level Discharge WQ field WQ samples	• SW license assessment • WQ baseline dataset

Site name	Site ID	Parameter	Monitoring requirement
Howley Creek DS Mt Ringwood Road	G8170016	Water level Discharge WQ sample	• SW license assessment
Burrell Creek US Adelaide River Confluence	G8170044	Water level Discharge	• SW license assessment
Snake Creek US Adelaide River Confluence (temp)	G8170015	Water level Discharge	• SW license assessment
Stapleton Creek US Adelaide River Confluence (temp)	New site	Water level Discharge	• SW license assessment
Coomalie Creek US Adelaide River Confluence	G8170029	Water level Discharge	• SW license assessment
Marrakai Creek Marrakai Homestead (temp)	G8170036	Water level Discharge	• assessment of floodplain inundation • SW license assessment
Scotch Creek US Woolner Rd	G8170050	Water level Discharge	• assessment of floodplain inundation • SW license assessment
Margaret River Flood Channel (temp)	New site	Water level	• SW flow system characterisation • model development
Adelaide River W Plains Beatrice Hill	G8170003	Water elevation	• assessment of floodplain inundation
Adelaide River E Plains Road Xing	G8170004	Water elevation	• assessment of floodplain inundation
Adelaide River Hoffman Plains	G8170022	Water elevation	• assessment of floodplain inundation
Adelaide River E Plains N	G8170037	Water elevation	• assessment of floodplain inundation
Adelaide River Koolpinyah Number 3 Fence	G8170039	Water elevation	• assessment of floodplain inundation
Adelaide River Point 1	G8175019	Water elevation	• assessment of floodplain inundation

* BCF = Burrell Creek Formation; SW = surface water = TLA = Tindall Limestone Aquifer and WQ = water quality

Table 21 lists the monitoring locations which were used to establish baseline water quality fluctuations from tidal influences. These sites may be considered for future monitoring.

Table 21. Tidal estuary water quality monitoring

Site name	Site location	Parameter	Monitoring requirement
CDU Site 5 Dirty Lagoon	-12.90538 131.22326	Water level WQ field	• characterise WQ variation • WQ model development
CDU Site 6 700 m Downstream Goat Island	-12.77961 131.2447	Water level WQ field	• characterise WQ variation • WQ model development
CDU Site 7 Upstream Arnhem Highway	-12.66966 131.3336	WATER level WQ field	• characterise WQ variation • WQ model development
CDU Site 8	-12.51187	Water level	• characterise WQ variation

Site name	Site location	Parameter	Monitoring requirement
4.5 km Downstream Humpty Doo Barramundi	131.3856	WQ field	• WQ model development
CDU Site 9 4.5 km Upstream Melacca Swamp Conservation Area	-12.38095 131.3147	Water level WQ field	• characterise WQ variation • WQ model development
CDU Site 10 River mouth	-12.22739 131.2485	Water level WQ field	• characterise WQ variation • WQ model development

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10. Appendices

10.1 Appendix A – Groundwater monitoring network

Count	Network name	Site	Latitude	Longitude	Started monitoring ground-water level (year)	Groundwater level logger (yes/no)	Water quality
1	Howard East	RN020248	-12.59	131.21	1981	yes	
2	Howard East	RN020967	-12.53	131.18	1983	yes	
3	Howard East	RN021396	-12.43	131.16	1983	yes	
4	Howard East	RN024716	-12.50	131.27	1987	yes	
5	Howard East	RN029425	-12.50	131.16	1994	yes	
6	Howard East	RN029426	-12.50	131.17	1994	yes	
7	Howard East	RN029427	-12.50	131.17	1994	yes	
8	Howard East	RN030345	-12.58	131.25	1996	yes	
9	Howard East	RN031326	-12.62	131.29	1997	yes	
10	Howard East	RN031975	-12.55	131.20	2006	yes	
11	Howard East	RN031976	-12.41	131.19	2009	yes	
12	Howard East	RN031977	-12.42	131.21	2006	yes	
13	Howard East	RN036538	-12.46	131.20	2009	yes	
14	Howard East	RN037416	-12.47	131.19	2012	yes	
15	Howard East	RN038194	-12.55	131.33	2014	yes	
16	Howard East	RN009266	-12.58	131.31	1978	yes	
17	Howard East	RN021047	-12.50	131.16	1983	yes	
18	Howard East	RN021048	-12.49	131.16	1983	yes	
19	Howard East	RN024671	-12.56	131.25	1987	yes	
20	Howard East	RN030346	-12.63	131.22	1996		
21	Howard East	RN037154	-12.48	131.19	2012	yes	
22	Howard East	RN037414	-12.47	131.19	2012	yes	
23	Howard East	RN037495	-12.47	131.16	2012	yes	
24	Howard East	RN041218	-12.48	131.16	2020	yes	
25	Howard East	RN041219	-12.48	131.16	2020	yes	
26	Howard East	RN024715	-12.52	131.27	1987	yes	
27	Howard East	RN020229	-12.52	131.20	1981		
28	Howard East	RN021395	-12.53	131.19	1983		

Count	Network name	Site	Latitude	Longitude	Started monitoring ground-water level (year)	Groundwater level logger (yes/no)	Water quality
29	Howard East	RN024717	-12.52	131.24	1987		
30	Howard East	RN030231	-12.57	131.24	1996		
31	Howard East	RN030232	-12.58	131.21	1996		
32	Howard East	RN030233	-12.61	131.21	1996	yes	
33	Howard East	RN030344	-12.56	131.24	1996	yes	
34	Howard East	RN031324	-12.63	131.29	1997	yes	
35	Howard East	RN031325	-12.64	131.28	1997		
36	Howard East	RN031327	-12.61	131.31	1997		
37	Howard East	RN031490	-12.55	131.35	1998	yes	
38	Howard East	RN033331	-12.55	131.24	2006	yes	
39	Howard East	RN037216	-12.43	131.22	2010		
40	Howard East	RN040784	-12.24	131.25	2018		
41	Howard East	RN031329	-12.56	131.37	1997	yes	
1	Marrakai	RN043550	-12.78	131.46	2023	yes	
2	Marrakai	RN043551	-12.75	131.45	2023	yes	
3	Marrakai	RN043552	-12.76	131.46	2023	yes	
4	Marrakai	RN043553	-12.78	131.49	2023	yes	
5	Marrakai	RN043554	-12.75	131.47	2023	yes	
6	Marrakai	RN043555	-12.75	131.46	2023	yes	
7	Marrakai	RN043556	-12.74	131.42	2023	yes	
8	Marrakai	RN043557	-12.73	131.44	2023	yes	
9	Marrakai	RN043558	-12.71	131.42	2023	yes	

10.2 Appendix B – SILO drill rainfall data

10.2.1 Adelaide River post office - monthly rain (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1900											105.4	184.7	290.1
1901	220.5	253.6	289.9	2.6	0	0	0	0	0.1	8.5	53.2	215.2	1043.6
1902	568.6	235.5	177	5.2	0	5.7	0	0	0	3	113.2	231.5	1339.7
1903	172.7	313.2	289.8	51.6	2.1	0	0	0	0.7	68.9	97.8	215.2	1212
1904	661.7	272.7	289.8	207.7	1.3	23.7	0	0	2.1	68.9	105.3	215.2	1848.4
1905	246.9	185.6	140.8	193.2	0.5	2	0	0.2	9.5	34.9	90.5	157.1	1061.2
1906	172.8	235.4	95.3	0.2	0	0	0	0.3	50.7	127.5	220.6	231.5	1134.3
1907	172.8	313.2	177	25.2	0	5.6	1.6	0.2	0.1	54.8	121.4	435.5	1307.4
1908	275.2	292.5	316.3	34.4	0	0	0.8	0	0.7	46.3	113.2	231.5	1310.9
1909	246.9	185.6	197.1	89.9	9.3	0	0	7.9	17.1	42.3	220.6	170.5	1187.2
1910	337.1	455.3	158.3	166.2	1	0	0.3	0	0.8	74	157.3	323.8	1674.1
1911	275.2	185.6	59.9	108.9	0	0	0	0.1	0	74	64.5	109.4	877.6
1912	305.2	334.6	436.5	21.2	0	0	0	0	23.6	46.4	121.4	132	1420.9
1913	444	357.1	344.3	0	0	0	0	0	0	2	58.6	170.6	1376.6
1914	568.7	185.7	264.7	25.2	34.7	0	0	0	0	22.2	121.3	199.7	1422.2
1915	406.6	272.6	218.2	0	14.6	0	0	0	68.9	64.1	166.9	485.6	1697.5
1916	305.2	334.6	177.1	14.4	0	0	0	0	14.2	64.1	83.6	366.2	1359.4
1917	246.9	218.1	240.8	29.6	0	18.9	0	12.4	31.3	35	147.8	284.8	1265.6
1918	305.2	272.7	95.3	0	0	0	0	0	0	6.8	38.4	248.5	966.9
1919	247	272.6	197.1	73.1	0	2.7	0	1.6	40.3	28.2	157.2	231.6	1251.4
1920	370.8	85.4	140.8	17.6	0	0	4.3	0	4.3	25.1	97.8	248.5	994.6
1921	305.3	404.3	373.6	0	0.2	0.1	0	0	7.5	50.5	147.8	157.1	1446.4
1922	406.5	201.4	373.7	11.6	1.3	0	0	0	2.1	179.2	64.5	199.7	1440
1923	275.2	218.1	289.9	51.6	0.3	4.5	0	0	0	34.9	97.8	323.8	1296.1
1924	195.7	170.5	197	0	0	0	0.3	0.5	23.6	74	157.2	248.5	1067.3
1925	305.3	272.7	344.4	89.9	0	0	0	0	0	34.9	58.6	144.2	1250
1926	370.8	129.8	158.3	39.8	9.3	0	0	0	0.1	5.4	220.5	304	1238
1927	195.7	185.7	218.3	11.7	1.7	0	0	0	2.1	46.3	138.6	215.2	1015.3
1928	172.7	272.6	218.3	3.7	0	0	4.9	0	56.5	31.6	47.9	215.2	1023.4
1929	195.8	292.6	316.3	45.4	0	0	0	0	0	25.1	113.2	231.5	1219.9

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1930	195.7	598.3	177	9.1	0	0	0	0.1	0	96.1	177	184.7	1438
1931	370.8	51.5	289.8	89.9	34.7	0	0	0	106.5	114.4	113.3	157	1327.9
1932	305.3	218	218.2	29.7	2.1	6.8	0	0	0	42.3	166.9	344.7	1334
1933	113.4	235.4	240.8	11.7	0.1	13	0	0	0	59.4	105.3	366.2	1145.3
1934	305.3	272.6	542	17.6	0	0	0	0	0	108.1	90.4	131.9	1467.9
1935	370.8	313.2	264.6	9.1	0	48	0	0	0	59.4	76.8	157	1298.9
1936	305.3	272.7	124.5	29.7	0	16.8	0	0	20.2	19.5	244.1	131.9	1164.7
1937	337.1	142.7	240.8	0	0	28.9	0	0	40.3	14.5	187.5	157.1	1148.9
1938	220.5	292.6	50.2	17.7	0	0.1	0.8	0	0.1	22.2	256.5	63.7	924.4
1939	525.2	334.7	82.5	17.6	0	11.2	0	0	9.5	25.1	76.9	170.6	1253.3
1940	483.7	334.7	470.1	0	0	0	0	0	0	0	70.6	120.3	1479.4
1941	525.1	235.5	264.6	25.2	3.8	8.1	0	0	0.1	19.5	220.5	120.3	1422.7
1942	305.3	429.3	82.5	65.4	0.5	0	0	0	45.4	59.4	187.4	323.9	1499.1
1943	220.5	380.2	197.1	179.5	0	0	0	0	11.7	50.5	105.4	157	1301.9
1944	305.3	142.6	470.1	14.5	0	0	0	0	1.3	12.3	147.8	215.2	1309.1
1945	195.8	218.1	177	11.7	0	2.7	0	0	62.5	50.5	83.5	323.8	1125.6
1946	406.6	801.5	82.4	0	0	0	0	0	5.8	22.2	22.7	131.9	1473.1
1947	195.8	170.6	316.4	51.6	0	2	0	16.6	11.7	120.9	121.4	144.1	1151.1
1948	151.4	404.4	158.3	141.6	0	0	0	0	0	0	147.8	248.5	1252
1949	172.7	292.6	218.2	11.6	0	0	0	0	1.3	10.4	244.1	157	1107.9
1950	568.6	455.3	436.6	0.9	0	0	0	0	98.3	230.4	129.9	303.9	2223.9
1951	220.6	455.2	140.8	0	0	0	0	0	1.3	59.5	83.6	157	1118
1952	305.3	185.7	140.8	17.6	0	0	0	0	0	25.1	177	144.1	995.6
1953	172.7	313.2	158.4	455.6	34.7	0	0	0	0	8.5	166.9	284.8	1594.8
1954	220.5	272.7	124.5	271.8	0	0	0	0	0	187.2	58.6	215.2	1350.5
1955	337.2	509.6	158.3	141.6	19.6	6.8	37.9	0	0	54.9	232.1	99.1	1597.1
1956	370.8	567.9	177	58.3	138.9	5.1	0	0	64.2	38.1	83.3	287.5	1791.1
1957	290.9	367.6	472.1	20.9	3.3	0.8	0	7.1	0	49.3	72.1	377	1661.1
1958	247.9	254.2	215.6	52.6	0	0	0.6	1.8	5.6	26.7	91.2	133.5	1029.7
1959	369.5	173	99.1	496	3.8	0	0	0	1	3.5	83.8	199.4	1429.1
1960	246.3	240.3	197.9	73	0	0	0	0	62.5	14.5	95.5	248.5	1178.5
1961	172.8	170.5	109.4	65.4	0	0	0	0	0	14.5	198.2	157	887.8
1962	458.8	380.2	50.3	0	0	0	0	0	0	46.3	174.5	161.5	1271.6

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1963	317.1	292.9	142.7	130.1	0	0	0	0	0	30.4	59.4	198.7	1171.3
1964	255.2	189.8	239.4	26.7	2.5	0.5	0	0	16	119.2	123.9	293.1	1266.3
1965	151.6	80.2	501.9	0	14	0.8	0	0	0	25.8	15.7	325.6	1115.6
1966	287.2	283.6	202.4	5.1	8.9	0.5	0	0	6.9	55	68.8	216	1134.4
1967	238	402.3	231.3	48.7	0	0	0	0	0	19.8	53.8	204	1197.9
1968	363.8	642.7	83.2	105.2	310	0	16.3	0	23.4	51	73.7	129.5	1798.8
1969	355.3	600.9	394.5	0	0	1.3	1	0	0	41.4	41	124.3	1559.7
1970	224.1	264.2	115.3	77.4	0	0	0	0	6.3	88.6	182.3	219.9	1178.1
1971	361.8	217.3	477.9	161.8	16.5	0	0	0	39.1	65	235.2	310.9	1885.5
1972	144.1	372.5	219	132.7	0	0	0	0	1.4	16.9	113.3	131.9	1131.8
1973	406.5	357	264.6	51.6	0	72.4	0	0	11.8	101.9	232.1	170.5	1668.4
1974	411	331.6	420.8	42.6	35	0	0	2	38.2	122.6	133.4	223.8	1761
1975	252	352.5	255	70.2	0	0	0	0	0	173.8	121.8	321	1546.3
1976	280.2	328.2	580	0	0	0	0	0	0	90.4	79.2	197.1	1555.1
1977	342.4	330.8	444.6	23.4	6.8	0	0	0	0	25	112.4	263.2	1548.6
1978	348.2	299.6	89	20.6	2.2	0	8.4	0	10	90.4	183.8	144	1196.2
1979	229	371.4	154.6	9.8	43	0	0	0	7.2	103	105.8	277.2	1301
1980	446.8	403	244.6	134.4	1	0	0	5.8	0	76.1	137.2	299.2	1748.1
1981	272	476.2	259.8	10.4	6.6	0	0	1	207.6	32.6	331.6	224	1821.8
1982	389.8	143.4	221.4	2.6	0	0	0	0	4	2.4	56.6	194.4	1014.6
1983	220.8	156.4	430.2	80.6	0	0	3	0	3	113.2	126.2	124.2	1257.6
1984	591	308.8	294.8	31.8	1.2	0	0	1.6	72	2	43	246.4	1592.6
1985	245.8	255	132.6	220	0	9	0	0	2.6	79.6	156.8	187	1288.4
1986	421.4	174	198.8	224.2	2.2	11.4	10.6	0	81.2	57.6	140.4	103.4	1425.2
1987	239.2	410.9	58	32.4	16	0	8	0	4	51.2	206	316.8	1342.5
1988	219.2	235.8	162.6	34.4	0	0	0	0	10.8	30.6	359	418.3	1470.7
1989	193	163.6	444.2	70	0	0	0	0	0	90.8	69.1	129.2	1159.9
1990	295	200.6	282.8	122	126.4	0	14	0	0	50	181.6	215.2	1487.6
1991	471.9	267.9	88.5	195.4	0	0	0	0	0	6.5	284.8	71.8	1386.8
1992	113.4	235.4	140.8	65.5	0.3	0	0	0.1	27.4	195.5	113.2	131.9	1023.5
1993	444.1	404.3	109.3	17.7	0	0	0	0.1	7.5	10.3	83.6	344.7	1421.6
1994	220.6	292.5	289.8	45.4	1.3	0	0	0	0	42.3	177	199.7	1268.6
1995	525.2	292.5	240.8	99.2	5.3	0	0	0	0	31.4	185.3	223.7	1603.4

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1996	189.8	221.6	130.2	218.6	0	0	0	18	0	116.4	117.9	460.2	1472.7
1997	699.7	297.2	255.4	0	2	0	0	0	0	61.8	136.8	294.1	1747
1998	590.6	191.8	202	98.6	0	0	0	9	10.6	110.8	99	461.6	1774
1999	241	275.2	422.8	197.4	0	0	0	0	2	99.2	301.2	233.8	1772.6
2000	287.8	317.6	445	135.4	10.8	0	0	0	8.8	102.4	124.6	221.2	1653.6
2001	326.4	592.8	270.8	117.2	0	0	0	0	0	53.6	227.4	221	1809.2
2002	155	428.8	109	22.8	1	0	0	0	20	0	113	151.4	1001
2003	147	465	172.6	8	0	0	0	0	0	9	99.6	450.6	1351.8
2004	264.8	355	238	44	26	9	0	0	0	29	185	216	1366.8
2005	435	204	122	59	0	0	0	0	1	135	181	247	1384
2006	470	160	290	443	0	0	0	0	1	0	100	232	1696
2007	342	288	653	4	17	0	0	4	1	38	177	373	1897
2008	395	557	314	29	0	0	0	0	14	88	165	400	1962
2009	253	404	102	2	12.6	0	0	0	5	64	46	583	1471.6
2010	636	211	88	141	104	0	4	0	16	151	94	378.9	1823.9
2011	527	513	367	328	0	0	0	0	0	87	189	170	2181
2012	383	275	513	12	23	0	0	0	28	38.4	231.8	114.6	1618.8
2013	133.6	323.3	319.1	41.7	56.7	1	0	2	8.7	97.9	298.6	300	1582.6
2014	459	613	33	60	19	0	0	0	0	5.4	85.7	349	1624.1
2015	487.6	229.8	150.4	23	0	2	0	0	1	23.3	103	695.1	1715.2
2016	239	187	199.9	6	58.5	0	9	0	38	30	105.5	595.1	1468
2017	294	271	314.5	59	0	0	0	0	0	54	124	212.8	1329.3
2018	711	242	159.5	57.5	0	0	0	0	0	99	398.5	90.5	1758
2019	311	163	158.5	59.5	92	0	0	3	0	1.5	139	95.3	1022.8
2020	321.9	376.5	132.2	64.5	2.5	0	0	0	29.9	73.9	136.6	445.1	1583.1
2021	314	374	261.1	34.5	0	3	0	0	19	32	101	431.5	1570.1
2022	343.6	298.5	162	82.6	0	4	13	0	92.4	123	248.5	433.5	1801.1
2023	259	333	163.5	76	0	0	0	0	0	14.5	228	247	1321
2024	715	161.5	335	94.2									1305.7
Mean	323.2	300.7	237.1	68.5	11.0	2.8	1.6	0.8	14.9	55.6	138.2	241.8	1393.2
Median	305.2	275.2	218.2	39.8	0	0	0	0	1.35	46.3	121.4	216	1350.5
Minimum	113.4	51.5	33.0	0	0	0	0	0	0	0	15.7	63.7	877.6
Maximum	715.0	801.5	653.0	496.0	310.0	72.4	61.0	18.0	207.6	230.4	398.5	695.1	2223.9

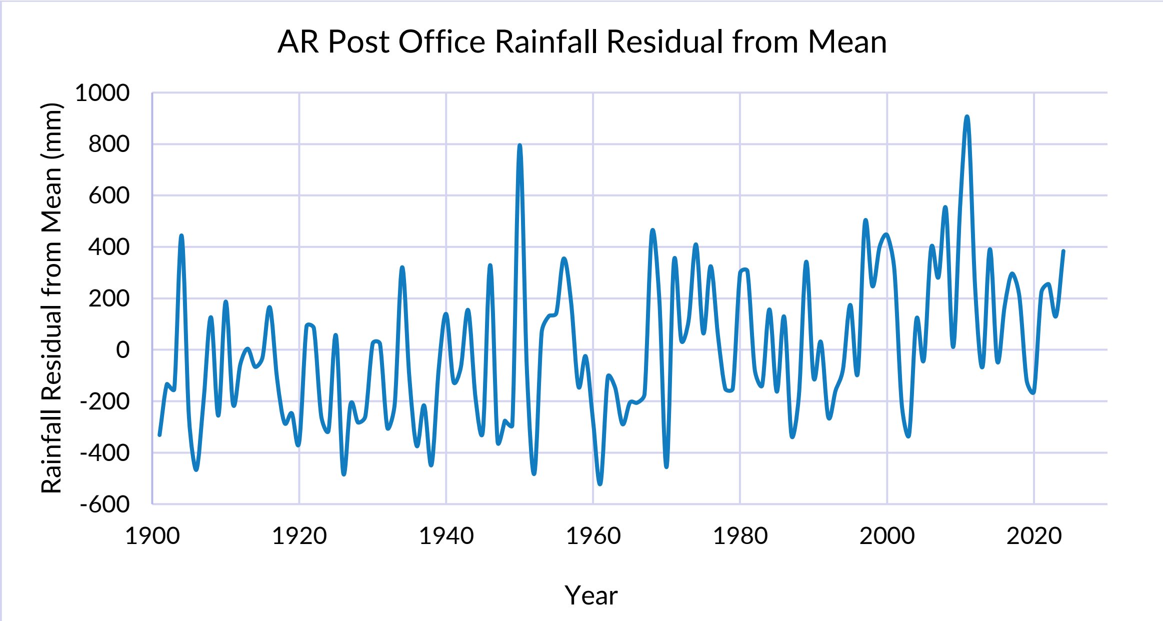

Figure 61. Rainfall residual from mean wet season rainfall 1901 to 2024 – AR post office

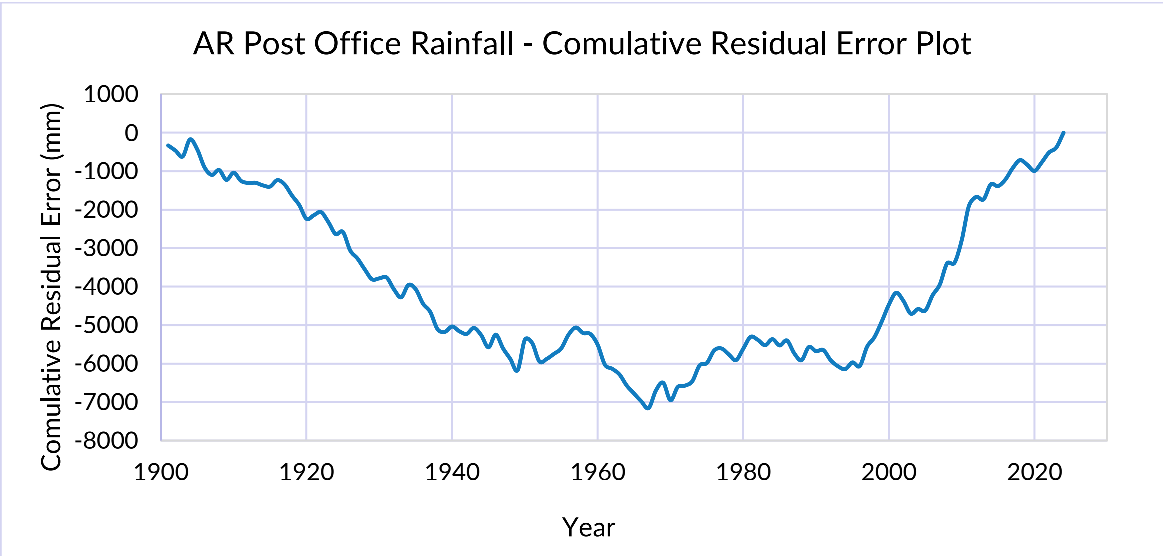

Figure 62. Rainfall cumulative residual from trendline - wet season rainfall 1901 to 2024 – AR post office

10.2.2 Beatrice Hill - monthly rain (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1900											120.4	139	259.4
1901	192.2	334.8	136.4	20.7	0.2	0	0	0	0.2	17.7	65.6	208.8	976.6
1902	601.2	170.6	118.9	7	0	18.3	0	0	0	8.6	60	228.9	1213.5
1903	192.3	265.7	245.4	87	9.6	0	0	0	5.3	107	145.8	295.8	1353.9
1904	696.9	287.6	220.5	215.3	0.9	25.4	0	0	0.2	60.2	128.5	250.1	1885.6
1905	473	187.6	74.9	230.4	2.8	2.6	0	0.1	1.9	30.3	97.8	74.1	1175.5
1906	130	205.6	102.9	0.2	0	0	0	1.1	46.8	81.9	250.1	229	1047.6
1907	242	287.6	175.5	63.5	4.1	12.5	0	1.4	0	41.7	120.5	560.4	1509.2
1908	298.9	334.8	245.4	50	0	0	0	0	0	55.2	154.9	208.8	1348
1909	242.1	125.1	197.2	136.8	2.8	0	0	22.5	11.3	41.7	238.3	171.8	1189.6
1910	397.6	360	155.1	215.3	6.4	0	0	0	5.4	55.3	173.8	493.1	1862
1911	298.8	187.6	33.8	200.8	0	0	0.2	0.3	0	94.1	77.6	110.2	1003.4
1912	362.9	334.8	428.8	56.5	0.1	0.1	0.2	0.1	27.5	55.2	145.8	154.9	1566.9
1913	397.6	310.7	360.9	7	0.2	0	0	0.1	0	3.9	120.5	250.1	1451
1914	513.7	139.3	299.9	63.4	34.9	0	0	0.3	0.2	20.6	77.6	124.2	1274.1
1915	397.6	154.5	271.8	14.2	0.7	0	0	0	23.6	30.2	84	401.3	1377.9
1916	330	386.2	155.1	24.6	0.1	0	0	0	23.6	100.4	112.5	320.5	1453
1917	362.9	170.6	245.4	1	0	1.9	0	2.1	36.4	55.2	145.7	272.5	1293.7
1918	434.3	265.7	118.9	24.6	6.5	0	0	0.7	3.9	37.7	84	295.9	1272.2
1919	362.8	205.6	300	125.8	2.8	0.8	0	5.7	2.7	17.8	154.8	139	1317.8
1920	362.8	224.7	136.3	87	0	4.4	2	0.1	16.8	55.2	164.2	320.4	1373.9
1921	362.9	442	360.9	0.2	0	0.1	0	0	0	76.1	77.7	295.9	1615.8
1922	397.6	265.6	271.8	87	0.1	0	0	0	0	151	120.4	228.9	1522.4
1923	329.9	187.7	360.9	63.4	19.8	5.3	0	0	0	26.7	112.6	320.5	1426.8
1924	216.4	187.6	102.9	2.6	0	0	0	0	0	81.8	164.2	272.5	1028
1925	298.9	265.6	271.9	186.7	0	0	0	0	0	17.7	65.6	110.2	1216.6
1926	397.7	244.6	245.4	50.1	1.8	0	0	0.6	0.2	2.7	137	250.1	1330.2
1927	216.3	111.7	175.5	33.5	0.8	0	0	0	0	50.6	274.8	155	1018.2
1928	242	224.6	300	11.4	0.8	0	0	0	23.6	55.2	36.2	171.8	1065.6
1929	242	310.7	465.5	17.3	0	0	0	0	0	0.1	28.6	189.8	1254
1930	362.9	749.9	299.9	0	0	0	0	0.1	0	87.9	274.7	208.8	1984.2

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1931	473.1	66.8	329.6	78.7	0.4	0	0	0	104.2	128.1	145.7	208.8	1535.4
1932	330	224.6	361	44.1	0	0.2	0	0	0	70.5	145.7	295.8	1471.9
1933	96.2	205.6	329.6	9.1	0.8	0	0	0	0.2	46	173.8	373.1	1234.4
1934	298.9	310.7	503.7	96	10.7	0	0	0	0	1.9	105	63.9	1390.8
1935	298.9	187.6	585.8	50.1	0	16.2	0	0	52.6	60.1	137.1	124.1	1512.5
1936	216.4	154.5	329.7	24.7	27.8	0.1	0	0	0.2	37.7	77.6	155	1023.7
1937	269.5	244.6	300	44.1	0	12.5	0	0	7	15.1	104.9	208.8	1206.5
1938	397.7	502.3	74.9	50	2.8	0	8.4	0	0	37.8	215.5	171.8	1461.2
1939	362.8	287.6	220.6	63.4	0	7.8	0	0	0	100.3	65.6	154.9	1263
1940	397.6	244.6	428.8	50	0.1	0	0	0	0	0	97.7	85.2	1304
1941	601.1	244.7	271.8	38.6	6.4	25.4	0	0	0	5.2	183.7	139	1515.9
1942	269.5	334.8	74.9	95.9	2.3	0	0	0	46.8	60.1	128.5	272.5	1285.3
1943	149.1	334.9	220.5	230.4	0	0	0	0	2.7	113.8	183.7	139.1	1374.2
1944	269.5	244.7	245.4	38.6	0	0	0	0	27.5	33.8	164.1	346.3	1369.9
1945	330	154.5	299.9	87.1	0	0.5	0	0	16.8	76.1	90.7	295.9	1351.5
1946	242	534.1	136.3	2.6	0	0	0	0	0	33.8	105	189.8	1243.6
1947	169.8	224.6	271.8	17.3	0	0	0	49.3	36.4	41.7	104.9	228.9	1144.7
1948	169.8	287.6	220.6	215.3	0	0	0	0	0.5	10.5	112.5	208.8	1225.6
1949	129.9	287.6	271.8	105.4	0	0	0	0	2.7	15.1	194	272.4	1278.9
1950	362.8	224.7	271.9	1	0	0	0	0	11.3	159.1	137.1	461.1	1629
1951	216.3	265.7	118.9	2.6	0	0	0	0	0	10.5	154.8	64	832.8
1952	329.9	99.2	197.2	38.6	0	0	0	3.7	4	46.1	226.7	110.3	1055.7
1953	269.5	154.6	102.9	315.9	0	0	0	0	0	33.8	71.5	155	1103.2
1954	330	224.6	271.9	396.2	0	0	0	0	0	241.5	120.4	272.4	1857
1955	169.8	360.1	271.8	136.9	37.5	6.5	22.4	0	0	55.3	154.8	124.1	1339.2
1956	216.3	673.1	197.2	200.7	55.4	0	6.1	0	16.8	106.9	71.5	346.3	1890.3
1957	300.3	496.3	557.2	23.9	8.7	0.1	0	3.8	0	34.2	56.7	201.5	1682.7
1958	159.3	137.2	215.8	60.2	3	7.4	0.5	0	0	52.3	141.2	276.4	1053.3
1959	395.2	52.5	166.7	151.8	0	0	0	0	3.3	14	64.9	320.1	1168.5
1960	224.7	275.7	263.6	45.7	21.9	0	0	0	19.1	43.5	65.4	181	1140.6
1961	204.4	180.9	72.5	58.2	0	0	0	0	1.1	17.7	238.2	85.2	858.2
1962	310.4	386.3	74.9	28.8	0	0	0	0	16.8	41.7	154.8	228.9	1242.6
1963	329.9	244.6	299.9	95.9	0.8	0	0	0	0	30.2	112.5	171.8	1285.6

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1964	269.5	224.6	394	50	4.1	1.3	0	0	20.1	87.8	300.7	250.1	1602.2
1965	192.2	154.6	543.9	1.7	8.4	0.8	0	0	1.8	37.7	128.5	493	1562.6
1966	397.6	154.6	175.5	3.8	19.9	3.3	0	0	7	100.3	104.9	346.2	1313.1
1967	269.5	413.6	329.7	50	0	0	0	0	0	37.7	164.1	85.2	1349.8
1968	397.6	502.3	155.2	50.1	179.3	0.5	3.7	6.5	13.9	41.7	40.4	110.3	1501.5
1969	269.6	442.1	394	0.2	0	0	0	0	5.3	143.2	60	189.9	1504.3
1970	242	244.6	175.5	28.8	3.4	18.3	0	0	23.6	87.8	164.1	401.2	1389.3
1971	269.6	205.6	220.5	173.5	0.6	0	0	7.7	13.9	143.1	154.8	346.2	1535.5
1972	216.3	265.6	428.8	136.8	3.4	0	0	0	20.1	12.7	54.7	225.8	1364.2
1973	443.5	247.1	483.8	68.1	8.1	26.2	0	0	2.8	23.1	160.9	287.7	1751.3
1974	405	353.4	502.8	53.2	14.9	0	0	11.8	23.6	70.5	77.6	63.9	1576.7
1975	216.3	534.1	428.8	87	1.1	0	0	0.3	0.2	161	216.6	138.6	1784
1976	294.6	301.3	333.8	42.1	0	0	0	0	0	2.6	113	145.2	1232.6
1977	278	348.7	453.4	73.8	15.6	0	0	0	0	9.8	120.6	192.2	1492.1
1978	240.7	218.2	129	55.2	0	0	2.8	0	0.2	80	164.6	129.2	1019.9
1979	295.2	250.4	131.3	0	1.4	0	0	0	14	32.6	48.9	153.6	927.4
1980	613.8	372.6	137.4	15.7	0	0	0	37	0	38.7	34.2	146.4	1395.8
1981	363	244.7	391.5	64.4	0	0	0	0	15	55.4	179	277	1590
1982	251.2	250.2	95.8	10.2	0	0	0	17.4	0	0	60.6	63.9	749.3
1983	67.6	145.9	364.4	34.6	22.4	0	0	0	2.8	119.4	107.4	23.6	888.1
1984	432.9	494	442.7	88.2	15.2	0	0	5.1	17.4	16.7	16.9	170.4	1699.5
1985	187.9	252.6	198.2	183.8	0	0	0	0	5.2	21.4	80.6	145.7	1075.4
1986	457.8	189.2	124.8	131.8	0	0	33.6	0	8.2	210	68.8	92.6	1316.8
1987	232	240.6	54.8	34.2	56	0	0	0	5.4	25	117.2	300.4	1065.6
1988	305.4	168.8	230.2	48.1	0	0	0	83	0	102.4	238.2	341.2	1517.3
1989	209.6	216.2	506.8	77	0	0	0	0	0	107.8	8.2	122	1247.6
1990	321.6	72	169.6	47.2	45	0	0	0	0	13.4	104.2	309.8	1082.8
1991	396.4	263.4	109	68.2	0	0	0	0	12.6	0	177.2	40	1066.8
1992	93.8	215.8	70.2	61.4	21.8	0	0	1	76	46.4	56	227.2	869.6
1993	258.8	263.4	136.6	15	3.2	0	0	0	6.8	24	147.4	297.6	1152.8
1994	182.2	189.6	292	72.6	16.2	0	0	0	0	16.8	44.6	231.8	1045.8
1995	519.2	330	288	61.2	6.6	0	0	0	0	87.8	188	175.8	1656.6
1996	333.8	115.8	374.4	140	0	0	0	0	0	170.2	114.6	304.8	1553.6

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1997	886.6	320.4	245.4	1	0	0	0	0	0	38.2	122.3	252.3	1866.2
1998	304.2	251	292.6	40.6	0.8	0	0	0.2	40.6	115.8	90.5	461	1597.3
1999	339.4	232.8	478.5	129.3	0	0.4	0	0	0	102.6	259.4	202.9	1745.3
2000	259.6	408.4	294	294.2	5	0.2	0	0	2.6	133.8	145	249.7	1792.5
2001	267	385.6	317.8	80.8	1	0.5	0	0	16.1	39.1	152.7	225.9	1486.5
2002	162.8	565.9	169.9	68.5	6	0	0	0	37.8	11	144	123.5	1289.4
2003	316.2	582	196	3	0	0	0	0	10.1	16	157.3	425.5	1706.1
2004	315.9	314.9	445.3	13.2	82.7	4.1	0	6	28	9.5	115.4	331.1	1666.1
2005	310.7	167	151.2	45	0	0	0	0	24.2	40.3	241.9	307	1287.3
2006	348.9	130.9	420.2	1000.5	35	0	0	0	0	0	342.8	216	2494.3
2007	182.4	437	646.5	24.3	24.6	0.2	0	1.6	29.4	48.8	111.1	342.2	1848.1
2008	327.1	555.9	330.5	37	0	0	0	0	9	55.5	96.5	499.4	1910.9
2009	290.7	278.1	181	17	0	0	0	0	6	5	130.6	369.2	1277.6
2010	308.5	209.2	106.7	218	24	0	3.2	0	13.9	184.6	71.6	401.2	1540.9
2011	362.8	673.1	428.9	297.5	0	0	0	0	0	127.9	137.1	406	2433.3
2012	389	192.1	442.7	21.5	13.4	0.5	0	0	31.8	41.8	60	139	1331.8
2013	269.6	180.8	271.9	33.5	58.7	0	0	4.7	3.9	46	298.1	264	1431.2
2014	598	295.5	105	186.8	23.6	2.5	0.1	0	1	6.8	104.9	139	1463.2
2015	362.8	287.7	197.3	44.1	3.4	0.5	0	0	3	8.5	43	430.7	1381
2016	68.4	187.6	175.5	56.5	99.4	0	0.2	0	69.9	107.1	219.5	335.2	1319.3
2017	341.2	343.4	406.5	105.3	0	0	0	0	0	147	130.2	110.2	1583.8
2018	747.9	386.2	197.2	70.8	0	0	0	0	1.8	37.7	112.6	124.1	1678.3
2019	362.9	99.2	155.2	78.6	21.7	0	0.1	0	0.2	41.7	105	74.1	938.7
2020	298.8	265.6	245.4	70.8	1.4	0	0	0	46.8	70.5	84	401.2	1484.5
2021	434.3	265.6	299.9	70.8	0	2.5	0	6.1	2.8	23.5	112.8	320.4	1538.7
2022	434.6	359.8	118.9	126	1	0.8	0.9	0	5.3	100.2	215.5	295.8	1658.8
2023	129.8	224.4	245.5	78.8	0	0	0	0	0	0.1	90.7	139	908.3
2024	556.4	334.8	360.9	56.5									1308.6
Mean													
Median													
Minimum													
Maximum													

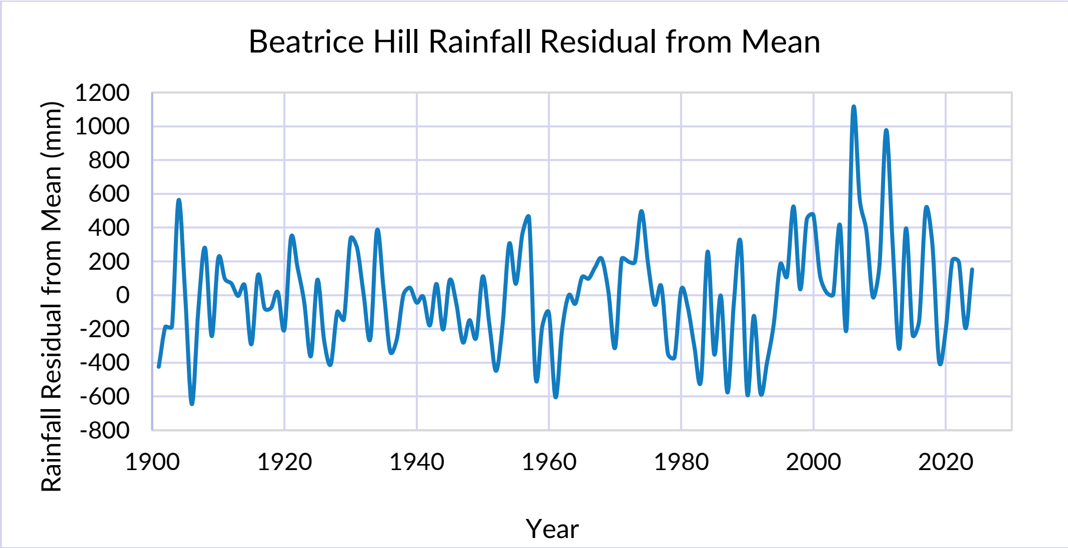

Figure 63. Rainfall residual from mean wet season rainfall 1901 to 2024 – Beatrice Hill

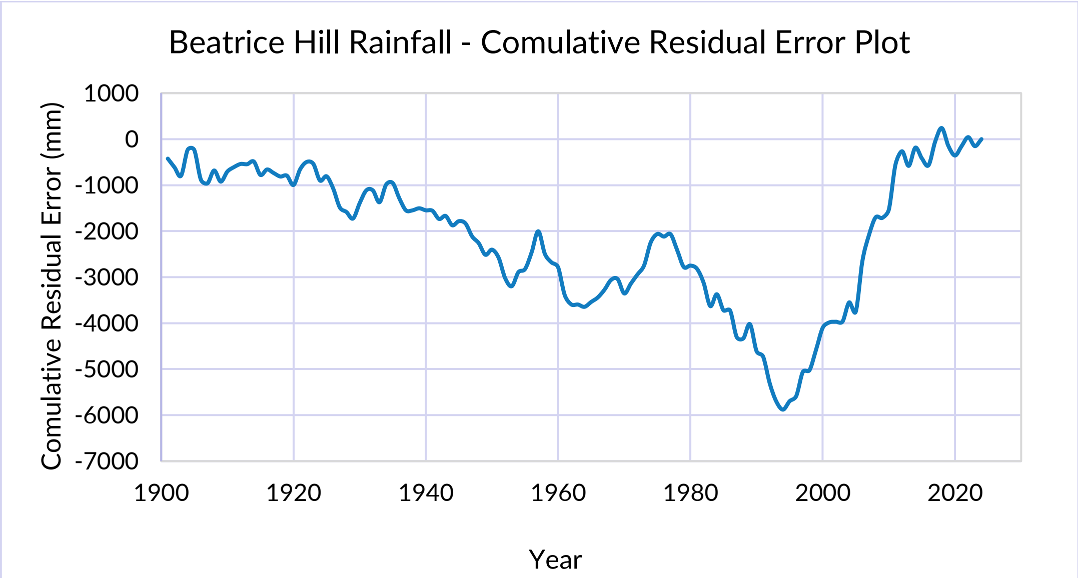

Figure 64. Rainfall cumulative residual from trendline - wet season rainfall 1901 to 2024 – Beatrice Hill

10.2.3 Koolpinyah- monthly rain (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1900	280.7	232.4	201.6	58.9	9.3	21.4	50.8	0	54.5	24	95.4	136.9	232.3
1901	203.7	408.6	60.6	35.6	0	0	0	0	0	20.5	74.3	197	1000.3
1902	652.2	174	118.9	10.2	0	21.4	0	0	0.2	12	40.8	197	1226.7
1903	203.6	276.8	252.9	108.3	19.8	0	0	0	9.3	102.7	146.9	290.9	1411.2
1904	652.2	325.8	201.6	218.2	1.6	26.6	0	0	0	67.8	146.9	214.1	1854.8
1905	562.9	254	60.6	233.3	5.3	3.5	0	0.1	0.2	35.9	88	69.8	1313.6
1906	122.8	254.1	118.9	0.7	0.2	0	0	1.7	37.7	87.8	290.4	214.2	1128.5
1907	280.7	276.7	178.5	81.3	9.3	16.9	0	2.6	0	50.5	111.2	546.7	1554.4
1908	280.8	408.6	226.4	52.4	0.2	0	0	0	0.2	67.8	146.9	232	1415.3
1909	340.5	156.8	201.6	151.4	2.6	0	0	25.5	17.4	50.5	236.3	150.7	1333.3
1910	443.4	379.7	201.7	249.2	14.8	0	0	0	11.7	45.4	188.6	487.9	2022.4
1911	280.7	232.3	23.9	249.2	0	0	0.6	0.6	0	95.1	74.3	111.7	1068.4
1912	373	352.3	376.9	81.3	0.7	0.1	0.7	0.2	24.4	56	156.8	165.4	1587.8
1913	434.4	348.1	276	6.4	1.3	0	0	0	0	3.3	135.3	281.8	1486.6
1914	434.4	140	328.5	82.7	31.7	0	0	0.6	0	20.5	56.1	177.4	1271.9
1915	359.6	134.7	289.9	38.6	0	0	0	0	26.9	25.1	33.4	212.4	1120.6
1916	333.8	502.6	131.2	20.6	0	0	0	0	31.8	130.3	199.8	319.4	1669.5
1917	514.9	336.5	317.8	158.3	0	0	0	0	51.3	86.1	163.1	202.2	1830.2
1918	438.5	258.7	128.3	65.3	18.1	0	0	1.3	9.9	70.6	102.9	309	1402.6
1919	376.1	211.8	330.1	145.6	12.7	0.3	0	10.2	0	9.9	164.2	113.6	1374.5
1920	425.4	337.5	154.9	167.8	0	15	3.1	0	37.5	109.6	231.1	295	1776.9
1921	245.9	426.7	338.4	12	3.5	6.7	0	0	5.1	49.6	171.3	237.9	1497.1
1922	521.2	273.5	316.8	120.5	7.2	0	0	0	0	85.4	96	184.1	1604.7
1923	319.6	197.3	589.7	107	18.1	0	0	0	0	83.3	79.4	359.2	1753.6
1924	251.3	277.4	211.1	5.3	0	0.3	3.8	0.5	6.4	26.6	128.5	211	1122.2
1925	379.3	330.3	350.2	375.3	0	0	0	0	0	69.3	69.1	132.9	1706.4
1926	537.8	159.7	221.9	52.8	10.2	0	0	1.5	22.6	4.9	134.7	243.1	1389.2
1927	258.5	172.2	190.1	69.4	6.3	0	0	0	1.8	58	310.9	174.6	1241.8
1928	163.7	347.5	415.8	36.8	0	0	0.5	0	5.4	16.6	88.7	119.3	1194.3
1929	386	305.9	422.5	95	0	0	0	0	0	16.6	152.7	333	1711.7
1930	167.3	640.7	454.4	11.7	0	0	0	3	2	97.7	302.2	163.1	1842.1

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1931	303.6	67.1	328.1	58.6	0.5	0	0	0	38.1	122.1	146.8	202.3	1267.2
1932	292.5	152.7	356.8	51.8	4.3	2.3	0	0	0.3	29.2	263.3	407	1560.2
1933	126.3	330.7	386.2	15.4	0	1	0	0	35.4	37	184.2	400.5	1516.7
1934	400.8	311.7	469.9	33.9	0	0.5	0	0	1.5	95.6	114.1	100.9	1528.9
1935	261.6	280.2	512.1	84.5	0	6.1	0	0	56.4	81.9	220	151.3	1654.1
1936	224.8	365.7	254.2	19.3	3	3.3	1.3	0	21.9	49.6	168.5	174.9	1286.5
1937	404.2	75.7	535.6	50	0	8.9	0	0	8.6	33.6	93.4	436.6	1646.6
1938	283.4	463.4	83.9	86.4	16.3	0.5	3.3	0	0.5	44.1	302.4	114.1	1398.3
1939	600.3	462.2	296.4	38.5	0.3	12	1.5	0	16.3	54.6	170	102.8	1754.9
1940	504.9	664.8	309.1	76.6	9.7	0	0	0	0	1.8	175.3	115.6	1857.8
1941	699.8	352.8	297.6	80.8	6.1	23.7	0	0	0	1.5	202.6	103.8	1768.7
1942	344.4	297.4	66.2	53.6	59.7	0	0	0	33.8	75.2	197.1	365.4	1492.8
1943	272.1	459.8	265.5	164.9	0	0	0	0	30.2	69.1	291	104.1	1656.7
1944	333	302.8	309.3	42.2	0	0.3	0	0	1	47.8	150.9	289.1	1476.4
1945	311.3	303.3	512.6	75.6	9.1	0	12.2	0	4.6	56.4	126.1	333	1744.2
1946	298.3	462.8	165.7	4.6	0	1	0	0	5.6	1.1	156.6	212.3	1308
1947	144.2	422.1	387.2	45.8	0	1	0	43	11.1	91.5	145.3	257	1548.2
1948	214.7	262	259.5	314.2	0	0	1	0	2.3	0.5	84.9	161.1	1300.2
1949	141.4	337.6	295.8	117.9	0	0	0	0	2	76	156.5	258.6	1385.8
1950	356	189.9	185	0	4.1	0	0	0	5	97.1	199.1	500.7	1536.9
1951	189.8	262.1	246.9	38.9	0	0	0	0	2.3	14.2	210.2	199.5	1163.9
1952	241.4	150.3	89.9	21.6	6.4	0	0	0	0.5	53.9	128.6	101.8	794.4
1953	386.3	267	149.3	240.9	2.3	0	0	0	0	0.3	186.6	211.3	1444
1954	441.4	195.8	265.1	483.1	2.3	0	0	3.3	0	163.7	123.2	357.5	2035.4
1955	186.1	638	358	109	27.7	3.5	12.2	0	0.5	4	182.7	193.8	1715.5
1956	269.5	679.4	275.4	329.7	78.8	0	18.8	4.3	87.4	40.6	149.6	355.4	2288.9
1957	665.7	302.6	529	36.1	7.7	0.8	0	0	1.3	2.1	67.1	309.2	1921.6
1958	195.8	262.2	198.7	171.7	7.1	0	14	0	0	58.1	125.1	260.2	1292.9
1959	273.4	171	79.5	531.5	9.4	0	0	0	0	2.5	200.4	343.1	1610.8
1960	408.9	275.2	307.5	77.9	62.8	0	0	0	2.8	2	112	319.6	1568.7
1961	452.9	259	65.7	55.4	0	0	0	0	0	38.7	166.7	261.8	1300.2
1962	550.5	392.4	116.7	84.4	0	2.8	0	0.5	8.6	7.1	151.7	161.1	1475.8
1963	295.2	214.7	221.3	179.3	0	0	0	14.2	0.5	55	112.9	332.9	1426

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1964	239.2	100.1	399.4	65.3	5.8	3	0	0	21.3	37.7	238.5	187.2	1297.5
1965	253.7	148.2	641.1	33.6	18	8.6	0	0	8.2	21.3	104.7	357.6	1595
1966	374.4	260.5	42	29.7	2.5	2.1	0	0	0	7.3	113.2	382.2	1213.9
1967	367.3	606.3	278.6	41	0.5	0	0	0	0	45.8	74.9	150.5	1564.9
1968	596.4	648.6	211.7	106	287.5	0	12.2	7.6	28.2	106.1	64.2	205.3	2273.8
1969	398.2	750.4	399.6	20.3	0.3	0	0.8	0	0	88.1	54.3	101.3	1813.3
1970	230.4	326.8	82	34.8	0	16	0	0.8	43.5	222.7	100.9	490.4	1548.3
1971	445.7	222.9	348.3	107.5	0.8	0	0	0	4.1	224.4	98.3	300.5	1752.5
1972	129.6	312.6	389.6	84	7.1	0	0	0	7.6	4.8	132.1	130.7	1198.1
1973	452.4	132	565.2	76.8	8.4	76.2	0	0	11.4	32.7	225.2	245.4	1825.7
1974	644.4	408.5	412.4	65.9	8.2	0	0	15.4	24.4	61.7	119.5	407	2167.4
1975	181.1	536.3	412.4	89.8	4.6	0.2	0	0	0.2	136.3	111.1	214.1	1686.1
1976	373	438.6	489.6	46.4	0.2	0	0	0	0.2	14.6	67.8	137	1567.4
1977	373.1	408.6	667.6	163.6	37.8	0.2	0	0	5.6	24	128.3	214.1	2022.9
1978	388.7	273.8	119	58.9	23.6	0.2	4	0	7.2	142.2	199.9	232	1449.5
1979	340.6	276.7	252.9	22.4	11.9	0	0.2	0	1.8	45.4	61.8	232	1245.7
1980	521.2	438.6	253	22.4	0.8	0	5.9	40.2	0	45.4	137.5	197	1662
1981	469.8	316.1	185	52	14	3	3	7	82.6	56	188.6	232	1609.1
1982	443.4	254.1	311.3	35.5	0	0	0	8.9	14.3	0	56.1	150.8	1274.4
1983	203.7	192.4	667.6	118.3	70.8	0	0	0.1	11.7	165	249.2	165.3	1844.1
1984	407.3	607.9	343.1	52.4	8.2	0.2	0	0.5	67.8	12.1	87.9	165.3	1752.7
1985	203.6	325.8	311.2	189.7	0	0	0	0	17.4	40.5	111.1	165.4	1364.7
1986	606.7	156.8	311.2	163.7	18	2.6	11.1	0	17.5	118.9	103	100.1	1609.6
1987	280.7	502.4	87	30.8	70.8	0	1.2	0	7.3	20.5	167	459.9	1627.6
1988	160.1	325.9	343.2	35.5	0.3	0	0	12.7	37.7	95.1	223.9	488	1722.4
1989	253.3	192.5	531.1	189.8	0.7	0.2	0	0	0	50.5	36.3	150.7	1405.1
1990	340.5	156.8	253	98.7	74.8	0.2	0.3	0	0	9.6	177.6	250.7	1362.2
1991	521.2	438.6	281.2	139.9	2.1	0.1	0	0	4	0.2	188.6	53.1	1629
1992	253.3	254	178.6	218.2	4.5	0	0	2.3	11.7	102.7	87.9	312.2	1425.4
1993	481.5	300.8	201.6	18.8	1.3	1.9	0	5.7	4	27.7	147	488	1678.3
1994	181.1	571.5	343.1	58.9	8.2	0.2	0	0	1.8	31.8	67.8	214.1	1478.5
1995	699.8	352.2	667.7	98.7	18	0.1	0	2.1	1.8	95.2	111.1	250.7	2297.4
1996	280.7	232.4	311.2	218.3	0.2	0.5	0	3.7	2.8	87.9	111.1	459.9	1708.7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1997	801.2	571.4	450.1	6.2	16.3	0.5	0	5.3	1.1	127.4	147	312.2	2438.7
1998	481.5	438.6	281.2	46.3	2.6	0	0.2	4	20.7	110.8	95.3	711.4	2192.6
1999	443.5	502.5	376.8	151.4	0	0.8	0	0	0	110.7	199.9	334.6	2120.2
2000	373	607.9	311.3	282.5	28	0.5	0	0	0.2	67.8	103	270.4	2044.6
2001	373	408.5	252.9	50.6	14.7	0.8	6.6	0	1.8	90.9	189.7	97.2	1486.7
2002	306.8	574	153.2	72.8	2.6	0	0	0	25	5.8	172.7	133.2	1446.1
2003	631.8	772.6	231.6	6.1	3.2	1.9	0	1.7	17.4	31.7	147	546.7	2391.7
2004	340.5	438.6	376.9	22.4	92.2	16.9	0	1.3	28.5	5.9	81	250.7	1654.9
2005	280.7	140.6	178.5	22.4	0	0.2	0	0.8	20.7	45.4	211.7	232.1	1133.1
2006	407.4	140.7	489.5	465	9.3	0	0	0	1.1	1.1	137.5	165.3	1816.9
2007	309.7	379.7	879.4	46.3	35.1	0.2	0	0.5	11.7	27.8	111.2	381.9	2183.5
2008	309.7	645.7	226.5	35.5	0	0	0	0	5.5	80.8	80.9	357.9	1742.5
2009	340.5	438.6	137.3	18.9	11.8	0	0	0	4	14.5	146.9	487.9	1600.4
2010	481.5	438.5	178.6	118.3	40.6	0	0.4	0.3	37.7	185.5	128.4	312.2	1922
2011	691.2	901.5	376.9	218.3	0.2	0	0	0	0.5	80	151	321.2	2740.8
2012	334.9	100	476.2	138	19	0.5	0	0	28.5	56	128.4	111.6	1393.1
2013	280.7	276.8	412.5	98.7	40.5	0	0	10.8	1.8	80.9	290.4	312.3	1805.4
2014	652.3	379.8	102.2	218.2	18	0	0	0	0.5	1.9	147	165.3	1685.2
2015	481.4	438.6	226.5	73.4	10.5	1.3	0	0.4	7.2	7.6	74.2	546.7	1867.8
2016	181.2	285.3	182.5	50.8	28.7	0	3.4	0	98.6	101.2	219.2	262.2	1413.1
2017	443.4	469.9	376.8	139.8	0	0	0	0	0.6	127.7	136.4	164.4	1859
2018	753	300.7	253	98.7	0	0	0	0	1.1	56	147	111.7	1721.2
2019	340.5	174	137.2	151.4	19.7	0	0	0	0	31.7	95.4	100	1049.9
2020	407.3	325.8	226.4	118.2	4.5	0	0	0	37.7	102.8	87.9	381.9	1692.5
2021	481.4	352.2	252.9	108.2	0	0	0	14.3	0.5	27.7	147	381.8	1766
2022	407.3	379.7	118.9	163.7	1.3	4.4	0.1	0.1	24.3	80.8	156.7	433	1770.3
2023	305.7	502.4	178.4	176.4	0.3	0	0	0	1.8	1.1	61.9	165.4	1393.4
2024	652.2	352.2	489.5	46.3									1540.2
Mean	373.5	343.6	292.3	102.4	12.8	2.6	1.4	2.1	12.6	56.6	141.4	255.0	1594.9
Median	356.0	325.8	276.0	75.6	3.0	0	0	0	4.0	49.6	141.7	232.0	1568.7
Minimum	67.1	23.9	0	0	0	0	0	0	0	0	33.4	53.1	794.4
Maximum	801.2	901.5	879.4	531.5	287.5	76.2	50.8	43.0	98.6	224.4	310.9	711.4	2740.8

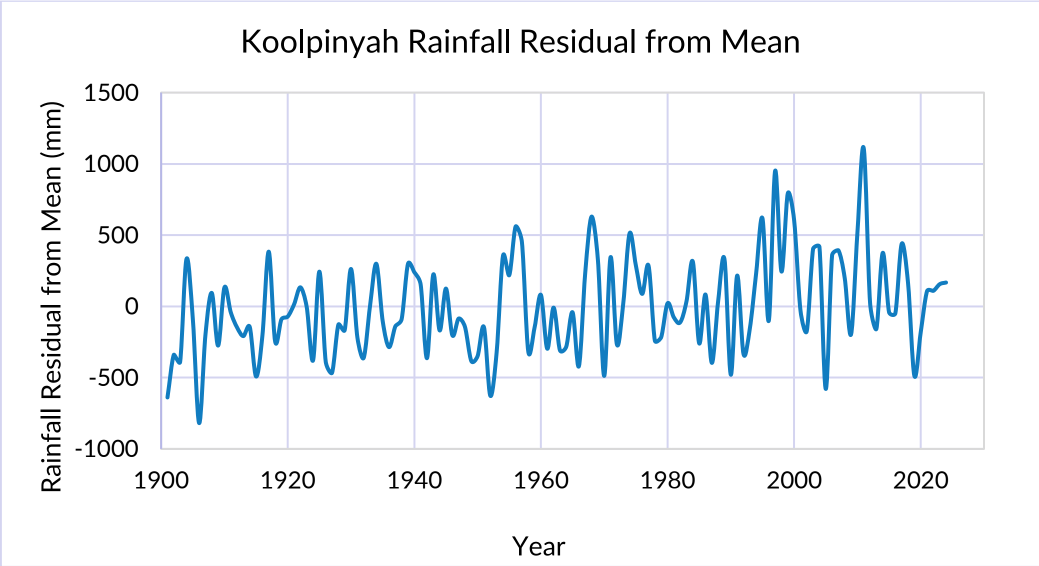

Figure 65. Rainfall residual from mean wet season rainfall 1901 to 2024 – Koolpinyah

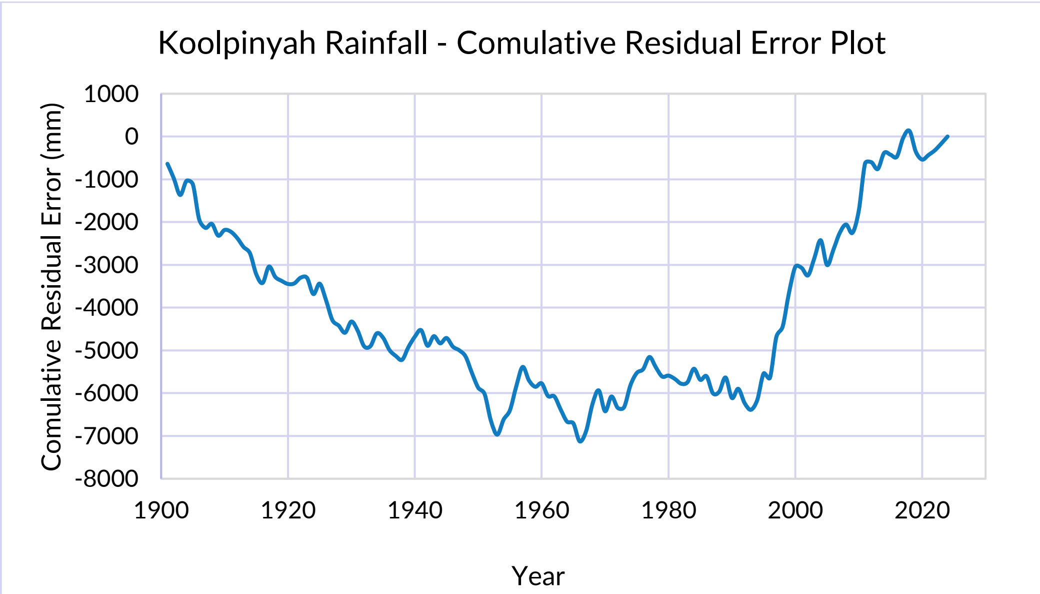

Figure 66. Rainfall cumulative residual from trendline - wet season rainfall 1901 to 2024 – Koolpinyah

10.2.4 Middle Point Rangers - monthly rain (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1900											112.5	138.6	251.1
1901	195.5	336.9	118	21.1	0.2	0	0	0	0.2	18.2	71.3	207.7	969.1
1902	603.3	171.6	117.9	7.4	0	18.6	0	0	0	10.8	54.5	207.7	1191.8
1903	195.5	267.3	246.8	96.3	11.2	0	0	0	5.4	103.9	145.9	293.9	1366.2
1904	698.4	289.5	221.4	214.9	0.9	25.7	0	0	0.2	57	128.6	248.6	1885.2
1905	475.8	206.9	73.4	230	2.9	2.6	0	0.1	1.2	31.1	97.6	74.2	1195.8
1906	115.2	206.9	101.7	0.2	0	0	0	1.1	47.5	84.7	263.3	227.7	1048.3
1907	245.3	289.4	175.4	63.8	5	12.7	0	1.7	0	43	112.6	590.9	1539.8
1908	302.1	337	246.8	50.5	0	0	0	0	0	57	155.1	207.7	1356.2
1909	272.8	125.8	197.6	137	2.9	0	0	23.2	11.5	43	239.1	171	1223.9
1910	437.3	362.2	175.4	214.9	7.7	0	0	0	7.2	52.2	174.2	489	1920.1
1911	302	188.8	24.9	214.9	0	0	0.2	0.4	0	90.9	77.5	123.7	1023.3
1912	365.9	336.9	399.3	63.9	0.2	0.1	0.3	0.1	24	57	145.8	154.2	1547.7
1913	400.6	312.6	365.3	7.3	0.4	0	0	0.1	0	4	120.4	270.7	1481.4
1914	516.3	140.1	302.6	71.2	36	0	0	0.4	0.2	21.2	71.2	123.7	1282.9
1915	400.6	155.4	274	17.6	0.4	0	0	0	24	31.1	71.2	370.5	1344.8
1916	333	416.2	154.8	25	0.1	0	0	0	24	103.9	128.5	318.3	1503.8
1917	400.7	188.8	246.8	7.4	0	1.3	0	1.5	42	57	145.8	270.7	1362
1918	437.2	267.4	118	29.3	7.7	0	0	0.8	5.4	38.8	83.8	318.3	1306.7
1919	365.9	207	302.7	126	4.3	0.8	0	6.1	1.1	18.2	155	138.5	1325.6
1920	365.9	226.1	135.7	96.2	0	6.6	2.1	0.2	20.3	62.1	174.1	318.3	1407.6
1921	333	444.8	365.3	0.6	0.2	0.5	0	0	0.2	72.9	90.6	270.7	1578.8
1922	437.2	267.3	274	96.2	0.2	0	0	0	0	140.6	120.5	207.7	1543.7
1923	333.1	188.8	399.2	63.9	18.7	4.4	0	0	0	31.2	105	318.4	1462.7
1924	219.6	188.7	117.9	2.8	0	0	0.1	0.1	0.2	72.9	164.4	248.7	1015.4
1925	333.1	267.3	273.9	214.9	0	0	0	0	0	21.1	65.5	110	1285.8
1926	437.3	226.1	246.8	50.5	2.5	0	0	0.8	1.2	2.8	137	248.6	1353.6
1927	219.6	125.7	175.4	39	1.1	0	0	0	0	52.1	276	154.2	1043.1
1928	245.3	226	302.6	14.5	0.4	0	0	0	20.3	47.5	44.8	154.2	1055.6
1929	272.9	312.7	472.6	25	0	0	0	0	0	1.2	40.2	207.7	1332.3
1930	302	715.5	333	0.6	0	0	0	0.3	0	84.7	276	207.7	1919.8

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1931	437.3	67.1	333.1	71.2	0.4	0	0	0	88.5	117.9	145.8	207.7	1469
1932	333.1	206.9	365.3	44.6	0.2	0.2	0	0	0	62.1	155	318.4	1485.8
1933	115.3	206.9	365.3	9.4	0.4	0.1	0	0	1.2	47.5	174.1	370.5	1290.7
1934	333.1	312.6	512.1	79	6.7	0.1	0	0	0	5.5	104.9	74.1	1428.1
1935	302.1	188.7	596.5	50.5	0	14.5	0	0	53.3	62.1	145.8	138.6	1552.1
1936	219.6	171.6	302.6	25	22.3	0.2	0	0	1.1	38.8	90.5	171.1	1042.8
1937	302	206.9	333	44.5	0	11	0	0	7.2	15.5	97.6	248.6	1266.3
1938	365.9	505.6	73.4	56.9	4.3	0.1	7.8	0	0	38.8	227.5	171.1	1451.4
1939	400.6	312.7	221.4	56.9	0	7.9	0	0	0.6	91	77.5	138.6	1307.2
1940	400.6	289.5	399.2	56.9	0.4	0	0	0	0	0.2	112.5	97	1356.3
1941	603.3	246.1	273.9	39	6.7	28.4	0	0	0	2.8	174.1	138.6	1512.9
1942	272.9	336.9	73.4	87.4	5.1	0	0	0	42	62.1	137	294	1310.8
1943	173.1	336.9	221.4	214.9	0	0	0	0	4	110.8	194.5	123.7	1379.3
1944	272.8	267.3	274	39	0	0	0	0	20.3	34.8	155	343.8	1407
1945	302.1	171.6	333	87.4	0.1	0.5	0.2	0	14.1	72.9	90.5	293.9	1366.3
1946	245.3	505.6	154.7	2.8	0	0.1	0	0	0	27.5	112.6	207.8	1256.4
1947	173	246.1	274	17.6	0	0.2	0	48.5	32.2	47.5	112.5	248.6	1200.2
1948	173	289.4	221.4	230.1	0	0	0	0	1.1	8.8	104.9	207.7	1236.4
1949	132.9	289.5	273.9	105.6	0	0	0	0	1.8	21.1	184.1	270.7	1279.6
1950	366	207	246.9	0.7	0.1	0	0	0	9.2	148.6	145.8	457.5	1581.8
1951	195.4	267.3	135.6	5.5	0	0	0	0	0	8.8	164.4	74.1	851.1
1952	333	99.7	175.4	39	0.1	0	0	3.1	4	43	216.2	110	1023.5
1953	272.8	155.4	118	296.6	0	0	0	0	0	27.5	83.8	154.2	1108.3
1954	333	226	274	373.5	0	0	0	0.2	0	230.8	120.4	270.7	1828.6
1955	152.2	362.2	302.7	105.6	33.3	6.6	21.5	0	0	47.5	155.1	123.7	1310.4
1956	219.6	640.7	197.6	214.9	53.4	0	7.1	0.2	20.3	90.9	83.8	293.9	1822.4
1957	366	416.3	553.4	44.5	5.8	1.3	0	2.9	0	21.1	65.4	188.8	1665.5
1958	173	155.4	175.4	79	1.9	0	0	0	0	33.6	105.4	207.7	931.4
1959	288.9	113.4	99.5	488.2	6.1	0	0	0	6.1	21.8	117.3	264.8	1406.1
1960	284.8	224.1	407.2	15.3	43.7	0	0	0	30.4	22.1	34.4	229.9	1291.9
1961	280.1	307.3	97.1	54.4	0	0	0	0	3.6	46.8	193.4	100.1	1082.8
1962	324.4	314	60	23.4	0	0.3	0	0	7.9	22.9	165.1	188.9	1106.9
1963	303.5	262.2	250.9	104.5	0	0	0	0	0	64.1	114.8	194.5	1294.5

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1964	232	232.3	431.6	56.8	13.8	0.3	0	0	18.5	143.1	192	224.3	1544.7
1965	243.9	119.5	552.9	4.9	5.3	2.3	0	0	1.3	26.5	113.4	484.3	1554.3
1966	471.9	247.4	157	21.6	11.9	0.5	0	0	22.1	64.9	60.3	364.4	1422
1967	394.2	398.4	304.7	93.8	0	0	0	0	0	14.4	104.8	128.5	1438.8
1968	409.7	512.4	182.4	84.8	298.4	0	2.5	0.8	26	53.8	31.8	123.4	1726
1969	285	408.9	387.2	0.8	0.8	0	0	0	0.3	73.5	111.4	171	1438.9
1970	323.2	267.3	115.5	25.4	3.1	30	0	0	0	102.4	174.8	431.1	1472.8
1971	243.7	237.2	228.9	160.9	3.3	0	0	5.6	6.6	145.2	179.7	329.2	1540.3
1972	196.8	177.6	498.9	112.8	1.3	0	0	0	14.8	31	72.1	234.5	1339.8
1973	521.8	274.4	476.2	64.8	16.7	29.2	0	0	26.9	26.5	153.8	321.4	1911.7
1974	506.5	479.9	427	67.6	16.8	0	0	13.6	20	56.6	67.1	38.6	1693.7
1975	221.6	537.5	435	87.4	1.5	0.1	0	0.2	0.2	136.6	89.8	167.9	1677.8
1976	258.5	487.7	308.3	38	0	0	0	0	0.8	18.2	128.3	105.6	1345.4
1977	250.4	352.4	306.6	146.2	18.6	0	0	0	0	11.8	128.7	163	1377.7
1978	286.9	204.1	145.8	55.8	7.2	0	4.4	0	0.2	148.7	215.7	87.8	1156.6
1979	367.3	298	219.2	16.6	14.8	0	0	0	23	46.8	79.3	155	1220
1980	562.8	418.6	179	33	0	0	2.6	38.5	0	44.5	73.2	144.2	1496.4
1981	443.1	199.7	286.9	49.6	10.1	0	0.6	9	51.1	56.3	235.6	192	1534
1982	322.4	209.6	167.6	11	0	0	0	1.6	17	0	42.8	102.9	874.9
1983	135	161	363.2	55.8	42.2	0	0	0.2	3	119	209.6	87.9	1176.9
1984	375.6	522.5	339.4	88.2	15.2	0	0	8.8	67.8	11.2	66.6	131.4	1626.7
1985	261.5	208	221.1	207.1	0	0	0	0	0.2	39.8	134.2	164.4	1236.3
1986	484.8	157.4	247	107.8	18.6	0.2	22.4	0	19.4	162.6	89.6	121.8	1431.6
1987	196.8	360	44.4	50.8	75.4	0	0.4	0	0.2	17	235.4	324.6	1305
1988	273.4	306.2	264.4	27.6	6.8	0	0	7.8	1.6	61	215.8	483.8	1648.4
1989	303.2	172.2	446.6	205	0	0	0	0	0	77.2	29	157.2	1390.4
1990	346.8	78	178.8	82.4	49.8	0.2	0	0.4	0	11.4	152.2	302.6	1202.6
1991	378	319.8	174.2	129.6	0.4	0	0.2	0	14.8	0	191.2	63.4	1271.6
1992	191.8	204.4	90.6	117.4	3.4	0	0	1	21	26.4	127.2	313.8	1097
1993	340.4	312.6	165	15.8	1.4	0	0.4	2.6	7.4	29	162.2	379.8	1416.6
1994	189.2	218.8	263.2	58	21.4	0	0	0	0.8	66.8	53	304.8	1176
1995	589.2	367.6	340.2	81.8	19	0	0	1.2	20	105	171.8	254	1949.8
1996	359.8	175.4	253.6	204	0	0	0	0.4	0.6	86	136.6	294.4	1510.8

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand total
1997	865.8	349.4	340.4	7.4	23	0	0	4.2	0	122.2	141.5	331.8	2185.7
1998	498	296.2	183.1	63.4	0.4	0	0	1.1	53.3	84.7	137.1	489	1806.3
1999	272.8	388.7	435	200.5	0	0	0	0	0	110.8	251.1	188.9	1847.8
2000	302.1	474.6	273.9	214.9	24.4	0	0	0	0	125.2	97.7	248.7	1761.5
2001	272.9	312.7	365.3	105.7	3.5	0	2.4	0	7.2	62.1	137	110	1378.8
2002	84.2	474.7	154.8	71.2	0	0	0	0	42	7	112.6	97	1043.5
2003	302	505.6	175.5	2.8	0	0	0.2	6.1	14.1	47.7	183.9	386.7	1624.6
2004	342.8	269.3	348	17.4	129.3	3.5	0	0	65.7	3.8	63.9	274.1	1517.8
2005	313.1	70	130.5	19.3	0	0	0	3.6	11.7	42.5	155	343.8	1089.5
2006	365.9	88	365.2	416.1	24.3	0	0	0.2	2.8	0	251.2	293.9	1807.6
2007	245.4	289.4	596.5	25	17	0.8	0	2.9	11.5	34.8	112.5	248.6	1584.4
2008	282.6	538.3	317.4	39	0	0	0	0	11.5	52.1	83.8	318.3	1643
2009	302	362.2	221.4	50.5	0.8	0	0.2	0	32.2	2.8	139.9	439	1551
2010	365	259.5	154.5	260.7	79.8	0	2.9	0.2	55.8	229.5	76.8	334.9	1819.6
2011	356.4	638.8	461.8	279.8	0	0	0	0	2	70.6	130	258.9	2198.3
2012	463.4	166.4	458	54	17	2.9	0	0	26.8	61.8	68.7	94.5	1413.5
2013	254.3	166.4	273.7	59.8	107.4	0	0	11.2	22	63.7	237.6	331.4	1527.5
2014	575.8	350.1	76.4	168.4	6.6	0.4	0	0	2.2	3.8	105	128.6	1417.3
2015	408.2	338.1	241.2	43.6	4.5	1.2	0	0	5.8	9.1	70	372.7	1494.4
2016	84.4	172.4	115	70.7	114.8	0	0.2	0	40.3	122.8	300.8	366.5	1387.9
2017	368.2	300.5	347.6	148.6	0	0	0	0	0.2	75.9	127.3	121.2	1489.5
2018	942.1	342.9	208.7	89.6	0	0	0	0	2.8	52.8	175.8	113.9	1928.6
2019	299	117.3	25.6	87.5	26.6	0	0	0	1.7	50.6	111.6	80	799.9
2020	264.4	289.6	239.5	107.8	3.6	0	0	0.1	71.8	76.5	46	320.5	1419.8
2021	477	248.3	253	104.6	0	0.6	0	4.5	3.8	36.2	121	349.3	1598.3
2022	441.6	345	100.2	112.6	0.5	1	1.8	0	0	95.6	160.7	313.2	1572.2
2023	119.8	341.8	180.6	96.6	0	0	0	0	0	0	79.3	180.9	999
2024	502.4	336.9	365.2	63.8									1268.3

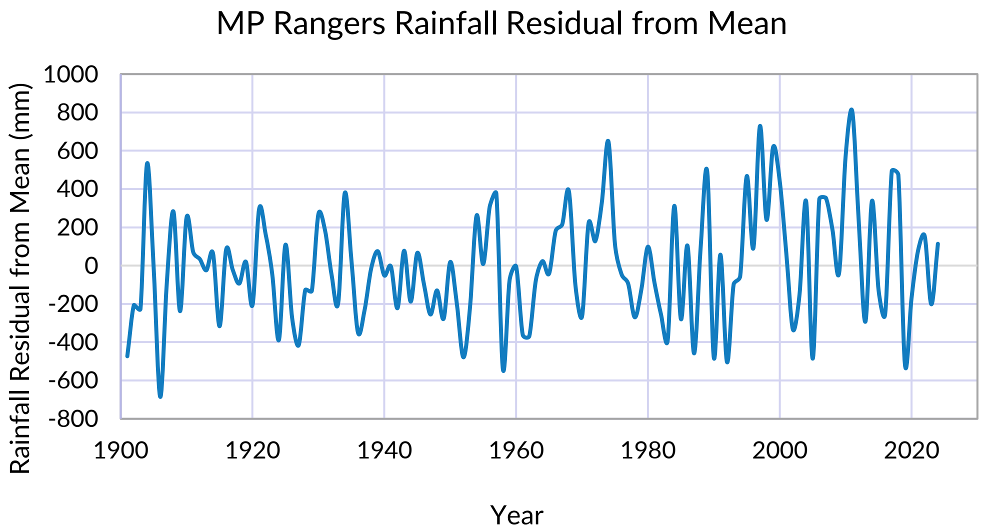

Figure 67. Rainfall residual from mean wet season rainfall 1901 to 2024 – MP Rangers

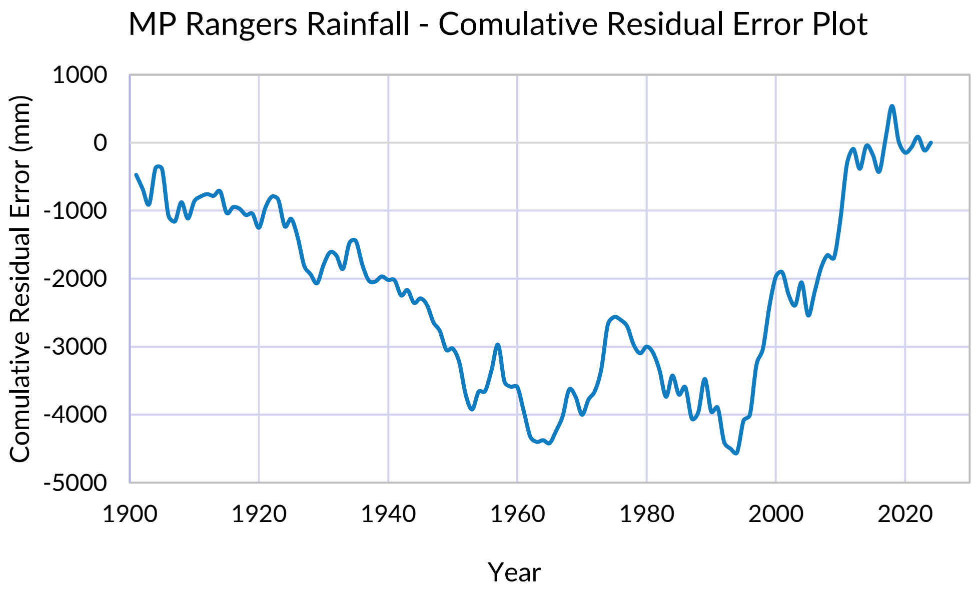

Figure 68. Rainfall cumulative residual from trendline - wet season rainfall 1901 to 2024 – MP Rangers

10.3 Appendix C – Hydrological analyses

10.3.1 Annual total discharge and rainfall

Dirty Lagoon annual flow record (water year) 1970 to 2024

Water year commencing	Water year discharge (GL)	Total rainfall Adelaide River post office (mm)	Rainfall - CRM from mean – ARPO (mm)	Total rainfall Koolpinyah (mm)	Rainfall - CRM from mean Koolpinyah (mm)
1970	*265.68**	1732.4	205.2	1983.5	259.3
1971	1163.27	1518.5	196.5	1550.2	85.3
1972	1535.10	1415.6	84.9	1586.2	-52.7
1973	1634.53	1757.3	315	2054.1	277.2
1974	3154.21	1449.7	237.5	1852.4	405.4
1975	1812.94	1805	515.3	1809.5	490.7
1976	2890.06	1514.7	502.8	1870.5	637
1977	1975.96	1160.2	135.8	1236.2	149
1978	801.84	1244.4	-147	1489.8	-85.4
1979	960.13	1723	48.8	1577.2	-232.4
1980	1679.42	1543.3	64.9	1465.9	-490.7
1981	1628.31	1554	91.7	1613.5	-601.4
1982	1388.33	1145.4	-290.1	1482.9	-842.7
1983	505.53	1597.2	-220.1	2010.4	-556.5
1984	2095.84	1227.4	-519.9	1363.9	-916.8
1985	655.22	1458	-589.1	1593.4	-1047.6
1986	615.32	1149.7	-966.6	1322.3	-1449.5
1987	740.05	1238	-1255.8	1520.9	-1652.8
1988	524.60	1689.5	-1093.5	2025	-1352
1989	1408.58	1315.9	-1304.8	1161.5	-1914.7
1990	318.68	1484.5	-1347.5	1821.3	-1817.6
1991	1504.93	918.5	-1956.2	1154.5	-2387.3
1992	436.32	1443.5	-2039.9	1522.7	-2588.8
1993	1640.84	1295.8	-2271.3	1835.4	-2477.6
1994	1203.53	1582	-2216.5	2152	-2049.8
1995	2115.57	1200.6	-2543.1	1504.2	-2269.8
1996	473.12	1966.8	-2103.5	2511.1	-1482.9
1997	3744.15	1575.7	-2055	1843.2	-1363.9

Water year commencing	Water year discharge (GL)	Total rainfall Adelaide River post office (mm)	Rainfall - CRM from mean – ARPO (mm)	Total rainfall Koolpinyah (mm)	Rainfall - CRM from mean Koolpinyah (mm)
1998	2249.59	1827.4	-1754.8	2417.4	-670.7
1999	2006.45	1832.8	-1449.2	2248.4	-146.5
2000	3219.11	1764.2	-1212.2	1541.9	-328.8
2001	2654.72	1218.6	-1520.8	1495.6	-557.4
2002	1292.62	1077	-1971	1983.9	-297.7
2003	933.94	1496	-2002.2	2032	10.1
2004	2319.84	1250	-2279.4	989.8	-724.3
2005	972.51	1927	-1879.6	2022.6	-425.9
2006	2913.69	1637	-1769.8	1955.4	-194.7
2007	2248.05	1888	-1409	1750.5	-168.4
2008	2687.31	1440.6	-1495.6	1472.2	-420.4
2009	1932.93	1878	-1144.8	1910.8	-233.8
2010	2032.64	2378.9	-293.1	2852.6	894.6
2011	5069.47	1652	-168.3	1621.3	791.7
2012	2145.29	1288.2	-407.3	1433.7	501.2
2013	461.81	1891.2	-43.3	2066.7	843.7
2014	2980.54	1332.9	-237.6	1546.4	665.9
2015	803.77	1512.8	-252	1364.6	306.3
2016	865.77	1716.1	-63.1	2114.5	696.6
2017	2621.16	1560.8	-29.5	1834.5	806.9
2018	2989.28	1372	-184.7	1138.6	221.3
2019	457.07	1136.4	-575.5	1309.3	-193.6
2020	890.26	1672.1	-430.6	1805	-112.8
2021	1759.44	1474.2	-483.6	1646.6	-190.4
2022	1344.58	1741.9	-268.9	1858.2	-56.4
2023	2287.12	1795	-1.1	1781.1	0.5

* not a full year of discharge record

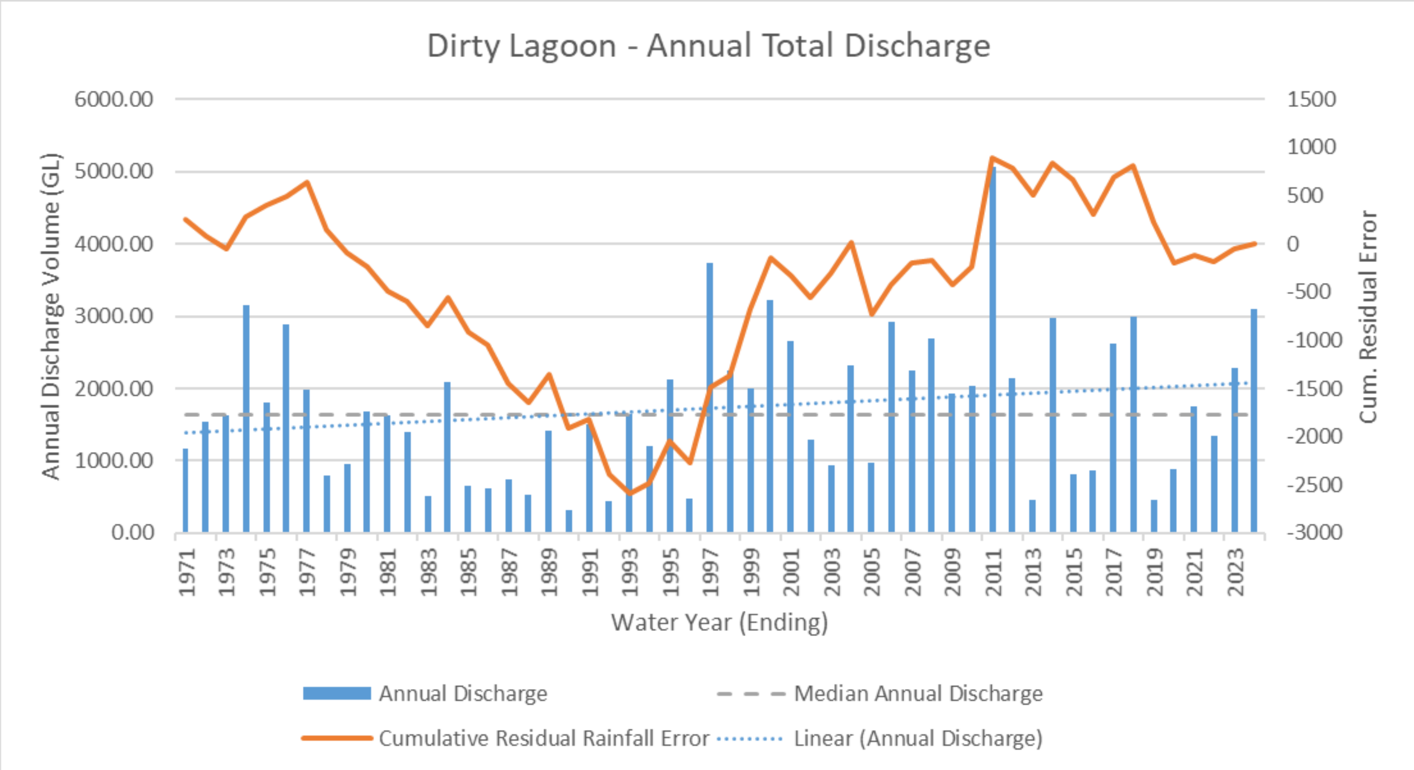

Figure 69. Annual total discharge (water year) at Dirty Lagoon and rainfall cumulative residual error from the mean at Koolpinyah

10.4 Appendix D – Flow duration curves

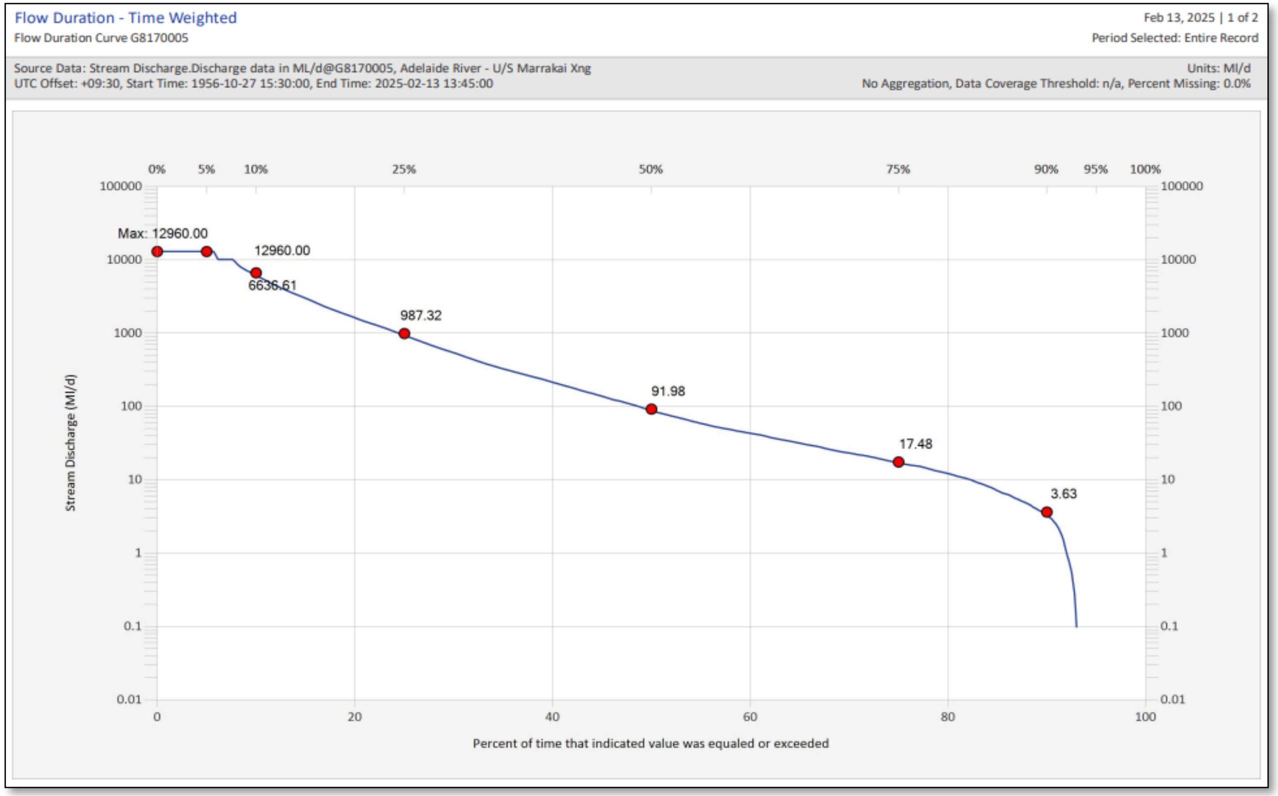

Figure 70. Flow duration curve for G8170005

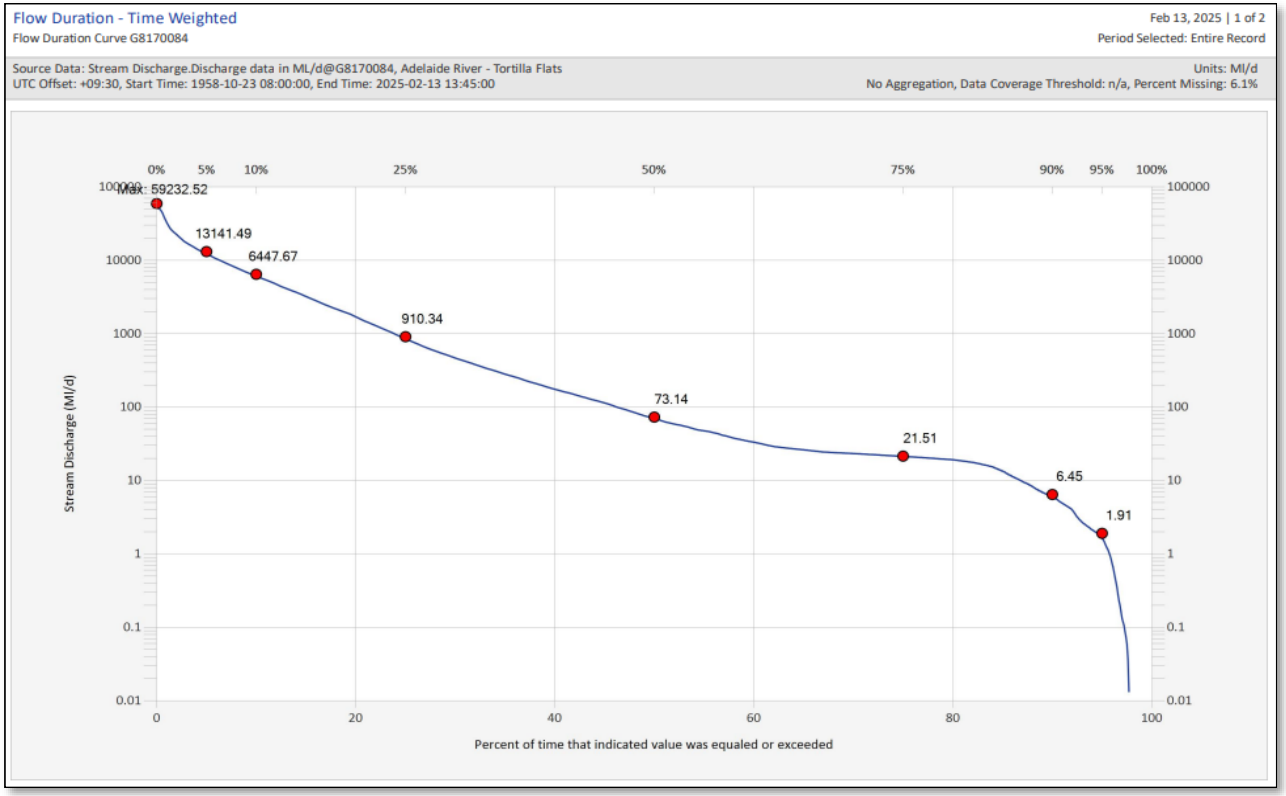

Figure 71. Flow duration curve for G8170084

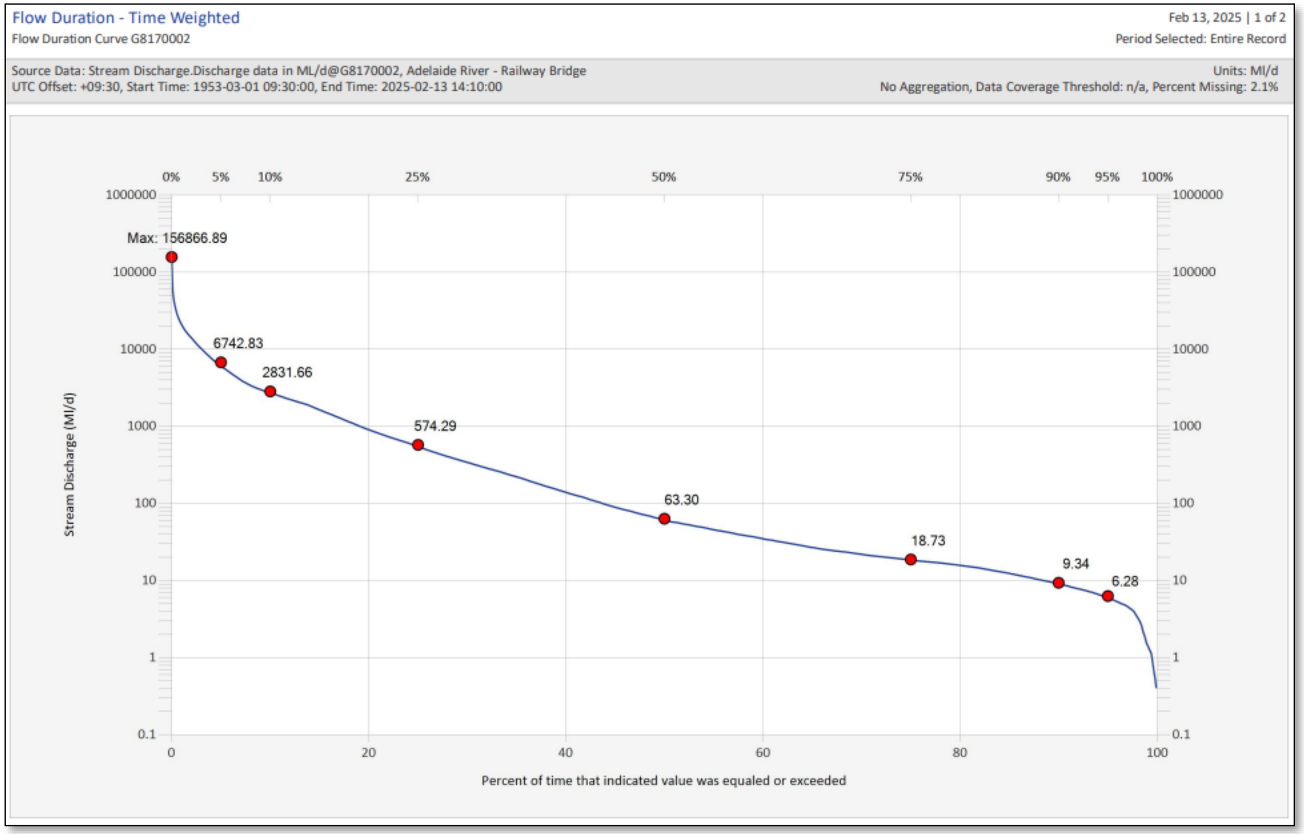

Figure 72. Flow duration curve for G8170002

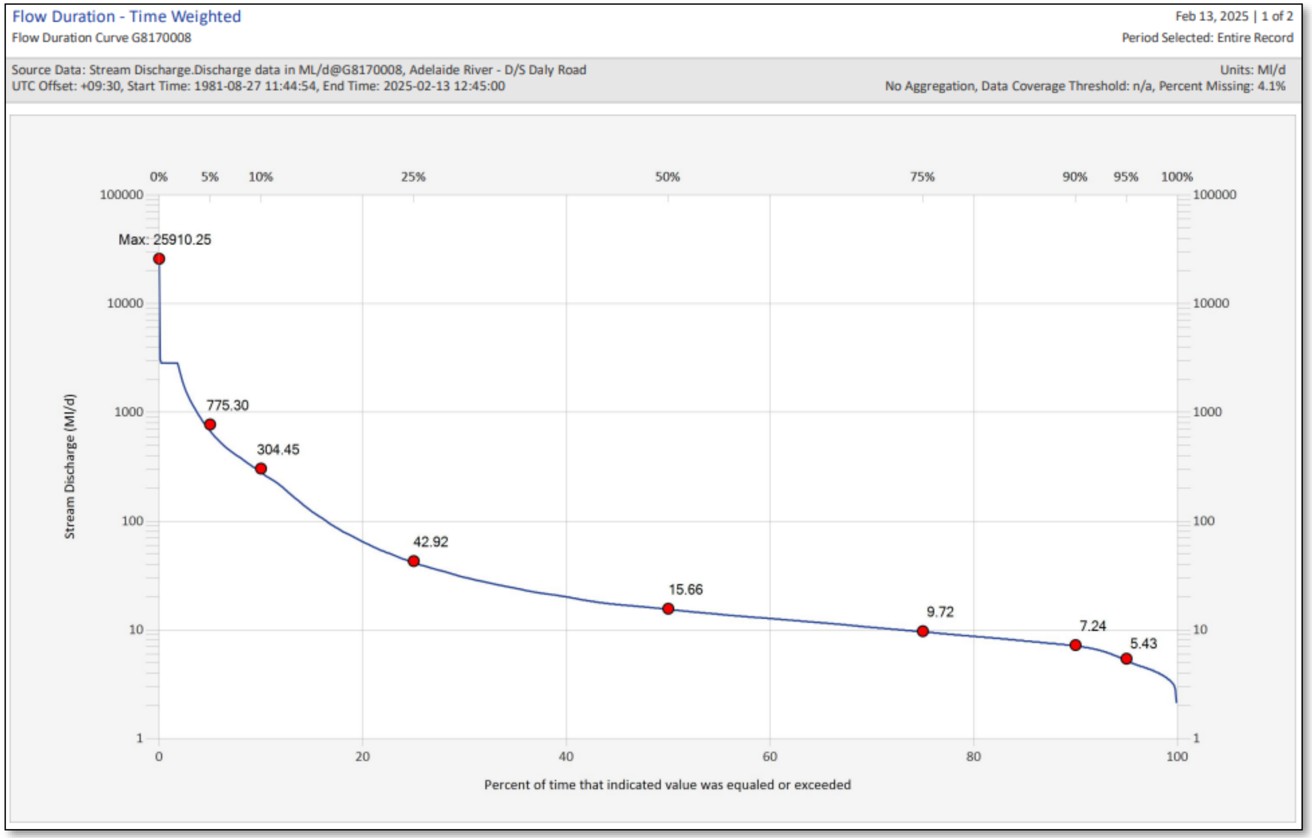

Figure 73. Flow duration curve for G8170008

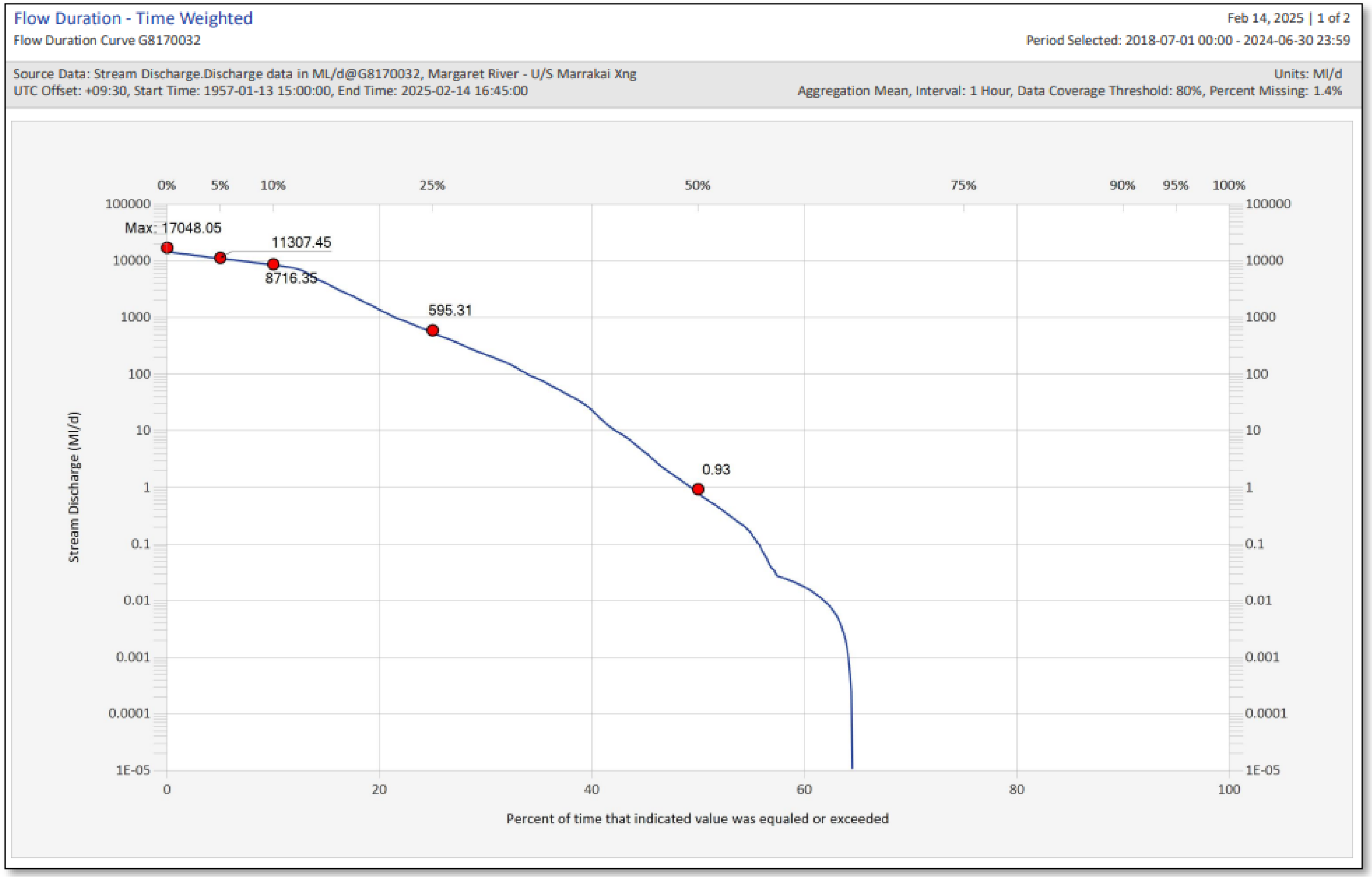

Figure 74. Flow duration curve for G8170032