

Surface Water Assessment, Brookton and Mid Central mining expansion areas

FINAL

16 January 2023

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Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for Country and the waterways within.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for CDM Smith under the contract titled 'South 32 Mining Extension Surface Water Assessment'.

Authors:	Vincent Li Creagh
Review:	Adyn de Groot
Approved:	Felix Egger
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1 Introduction

Overview

South32 Worsley Alumina (hereafter referred to as South32) are the current operators of the Worsley Bauxite Alumina Project, located near Boddington, Western Australia (WA). In 2005, South32 were granted approval to expand their mining operations to an additional five mining areas. Prior to commencing mining operations, however, additional environmental studies within the extended mining areas are required (as part of the 2005 Public Environmental Review). The studies required a range of flora to fauna investigations, characterisation of landforms, groundwater and surface water systems and impacts associated with climate change (South32, 2023).

This report provides an assessment of surface water quantity and quality at two of the proposed mining expansion areas, namely the Mid Central and Brookton locations (Extended Mining Area Boundaries) shown in Figure 1 and Figure 2 (for the rest of this assessment, the two areas will be referred to as "North mining expansion area", illustrated in green within Figure 1 and Figure 2). The prior surface water assessment has assessed the Existing Mining Lease Boundaries illustrated in Figure 1 and Figure 2. The scope for this assessment was to assess the historic and current conditions in terms of water quantity as streamflow and precipitation, and the historic and current water quality conditions in the relevant mining expansion areas using publicly available data. A main objective for this report was thus, to establish water quantity trends over the historic period to assess if water quantity (i.e. discharge and precipitation) are generally increasing or decreasing. For water quality, the objective was to establish pre-mining conditions at relevant locations. This report also addresses the data gaps exist in the available data sources. After establishing the trends, pre-mining conditions and locations of current monitoring, an additional objective was to assess the projected impact of mining, and to advise on additional monitoring locations and parameters. For this report, the two mining expansion areas will be grouped and referred to as the Northern mining expansion area (Mid Central and Brookton). In addition to the assessment of the current conditions, an impact assessment is undertaken, and future monitoring sites proposed to ensure any changes to water quantity and quality may be characterised following the commencement of mining operations in these areas.

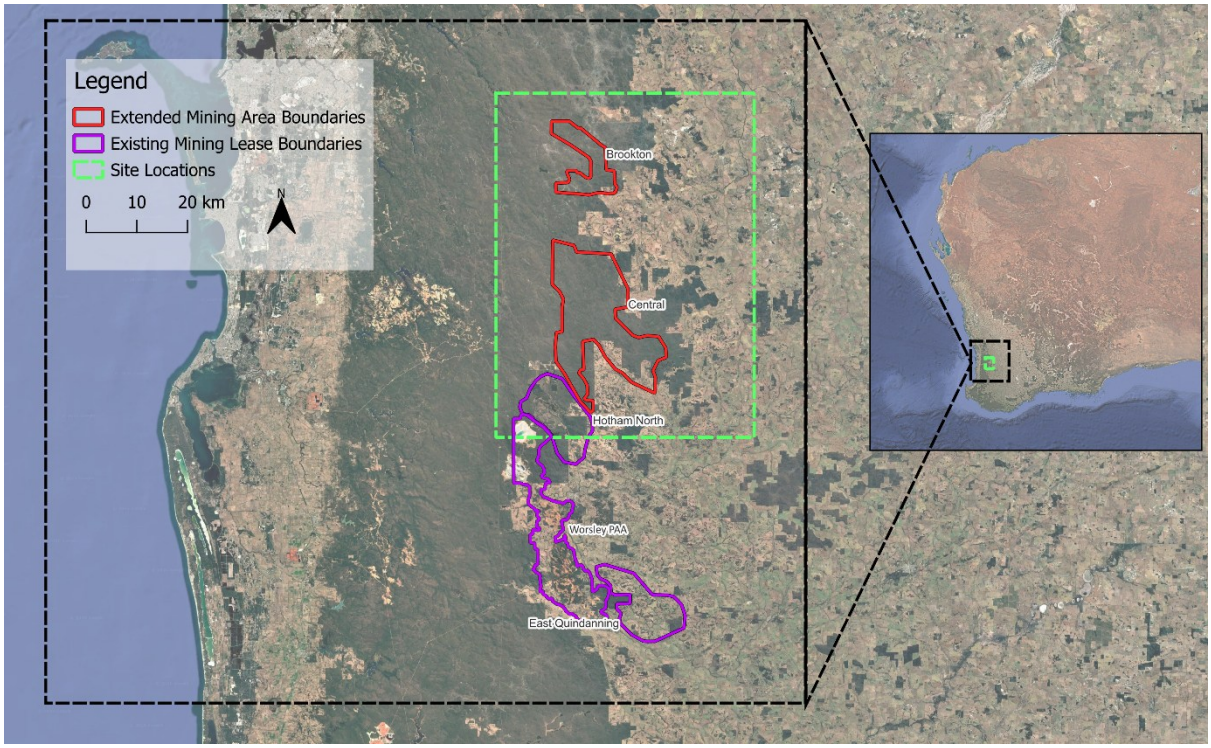

Figure 1. *Site overview for both the Extended Mining Area Boundaries as well as the Existing Mining Lease Boundaries.*

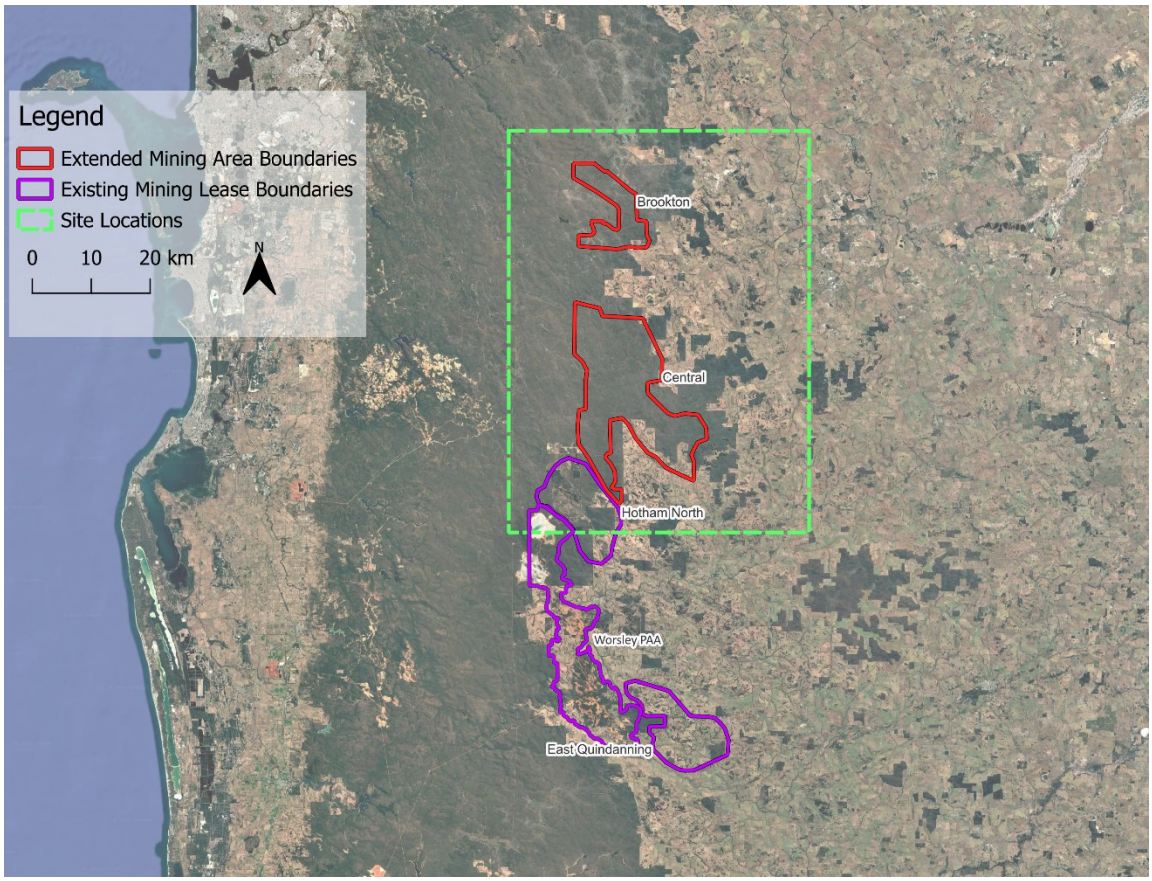

Figure 2. *Approximate location of Extended Mining Area Boundaries and Existing Mining Lease Boundaries.*

Understanding climatic conditions

Changes in climate (primarily related to Hadley Cell expansion) and in forcing factors (e.g. storm tracks) have resulted in significant declines in rainfall and even greater reductions in runoff in the Southwest of WA (Head et al. 2014, Water Corporation WA 2022). This has primarily occurred since the late 1970s, with estimates of a 20% reduction in rainfall volumes, leading to greater than 80% reduction in surface runoff. Characterising surface hydrology and resultant water quality under more recent rainfall and climate periods is essential in understanding the baseline state of surface water in the proposed mining expansion areas of Mid Central and Brookton.

We have previously provided a surface water assessment for the Quindanning and Hotham North expansion areas, noting a decline in surface water quantity in recent years (pre-mining) (Alluvium, 2023). The uniqueness of hydrology in the general area is also noteworthy, based on recent work we've undertaken to understand hydrology of the nearby Serpentine River, and a review of previous modelling of the Canning system. In particular, the variability and frequency of flow in those systems in recent years has resulted in limited surface runoff, having important implications for groundwater recharge. The Department of Water and Environmental Regulation, presents a relationship between decreasing surface water flows and decreasing groundwater storage (Western Australia Government, 2023). We have drawn on the insights gained from this work to aid in characterising surface water hydrology and water quality expected over the lifetime of any future mining operations. The method for annual trend analysis from the previous work was used as a basis for annual trend development within this surface water assessment.

Scope of Works

The main objective of this work is to assess surface water at the mining expansion sites. A desktop assessment was undertaken to describe the baseline surface water environment of the catchments falling into the mining expansion areas, detail potential impacts from this expansion on the surrounding surface water quality and quantity and provide recommendations on future monitoring regimes (including locations and program). The following presents the tasks undertaken. The scope for this assessment was similar to the scope of the previous surface water assessment for the Quindanning and Hotham North areas; however here the scope is expanded to two additional extended mining areas (EMAs).

The works are completed in a 4-stage process as outlined below:

- Stage 1: Collating data and setting the context.
    - Includes relevant legislation, historical climatic conditions for the catchments, and publicly available water data online.
- Stage 2: Impact assessment
    - Considering potential impacts on downstream users and the environment for both hydrological and quality values.
- Stage 3: Baseline Monitoring
    - Baseline monitoring established though previous stages 1 and 2, to propose areas of potential future water monitoring, providing further guidance into a monitoring regime.
- Stage 4: Reporting
    - Collating Stages 1-3 into a report and presenting the findings (this report).

1.1 Catchment characterisation

To gain an understanding of potential impacts, the North mining expansion area was characterised in terms of land use, topography, climate, streamflow trends and drainage directions. All of these are outlined in further detail below.

Land use

Land use data was retrieved at a national scale from the Australian Government Department of Agriculture, fisheries, and forestry (ABARES, 2016) captured over the FY2010/11 to FY2015/16 period, at a 250 m resolution. For the purposes of this assessment (and in lieu of additional data), we've assumed that land use data has remained consistent throughout the current period.

For this assessment a range of land use classifications have been grouped together as they have similar hydrological response, and negligible difference in impact for a rainfall runoff assessment. The land use classifications were grouped as follows:

- Plantations (including production native forests and plantation forests).
- Conservation (including nature conservation and managed resource protection)
- Grazing (including grazing modified pastures and grazing native vegetation)
- Cropping (including irrigated perennial horticulture, perennial horticulture, and cropping)
- Water (including marsh/wetland, river, reservoir/dam, and lake)
- Rural residential (including urban residential, rural residential and farmland)
- Industrial (including utilities, mining, waste treatment and disposal, transport and communication, manufacturing and industrial)

The North mining expansion area is predominantly classified as plantations (plantations land use class includes production native forests and plantation forests, however noting that production native forests presents a vast majority of this land use category for the North mining expansion area), a trend which is consistent with the remainder of the catchment area. Other major land uses in the catchment of the North mining expansion area include conservation, cropping and grazing (see Figure 3).

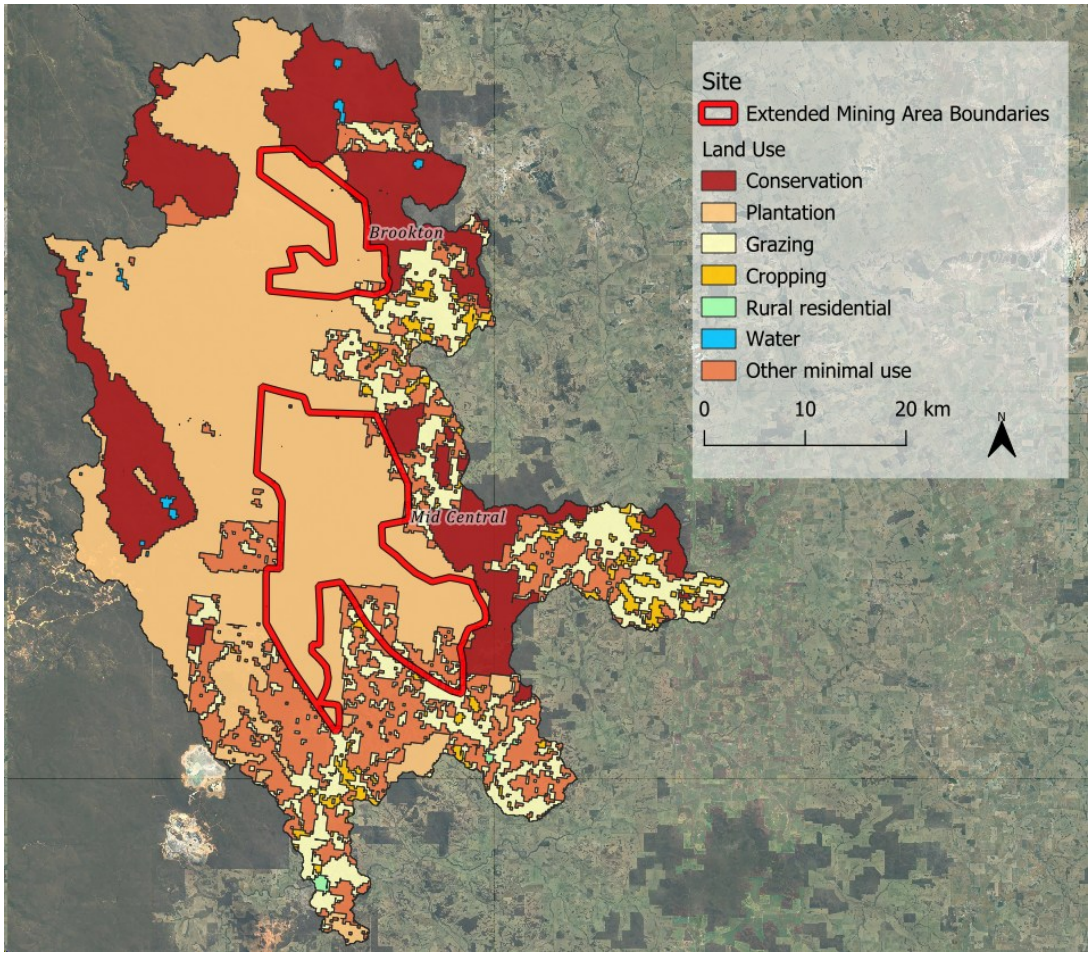

Figure 3. *North mining expansion area catchments land use data (ABARES, 2016).*

Topography

A digital elevation model (DEM) detailing catchment topography (topography covers the extent of the assessed catchments) of the North mining expansion area can be seen in Figure **4**. Elevations for the North mining expansion area range from 163 - 517 mAHD. Of note, the North mining expansion area is located on an apparent ridgeline, where a portion of the catchment in both mining expansion areas drain towards both the coast and inland.

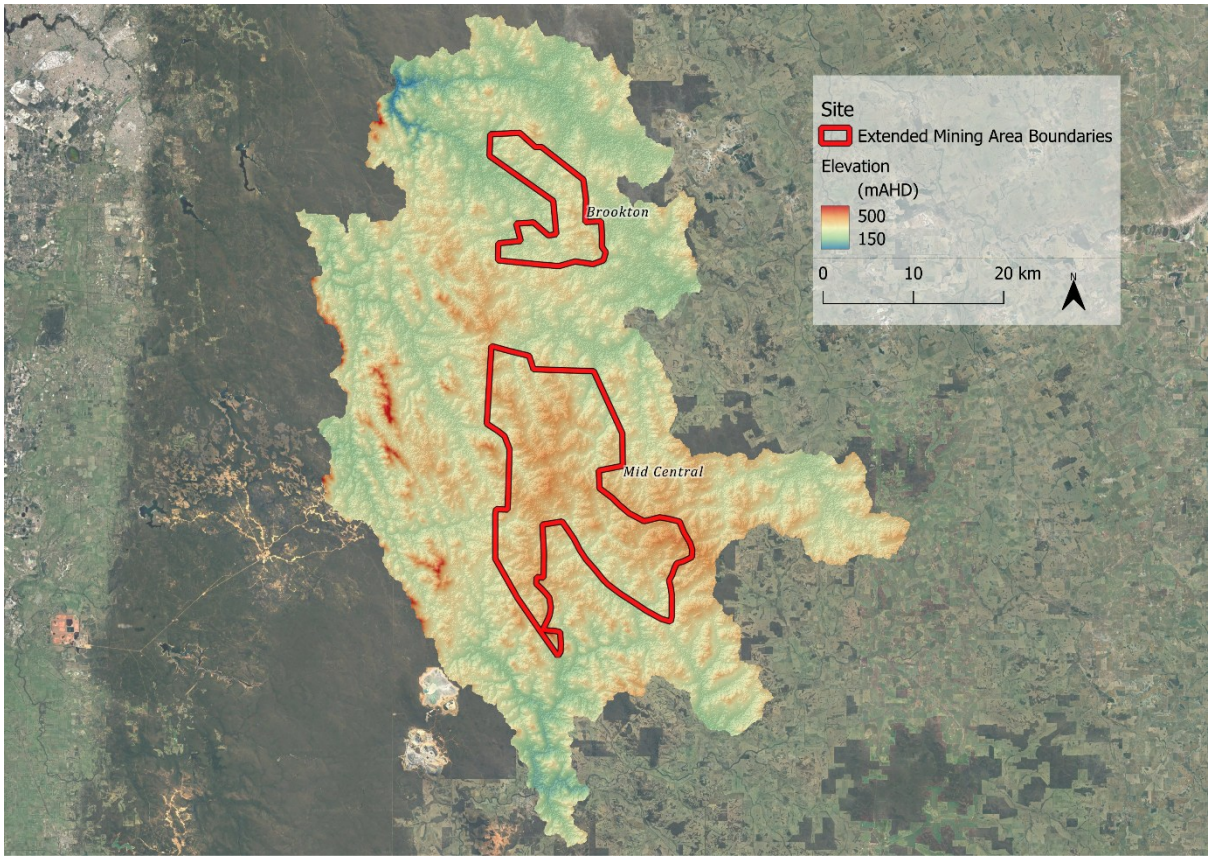

Figure 4. *Topography of the North mining expansion area's assessed catchments.*

Climate

The North mining expansion area experiences subtropical climate with a mean maximum winter temperature of 31.5 °C and summer temperature of 16.4 °C (based on Boddington Shire temperature) (BOM, 2023). The average annual rainfall for the North mining expansion area is 533.2 mm based on rainfall records at Boddington Shire station (Gauge ID: 9509, situated approximately equidistant to the two mining expansion areas, approx. 50 km from each outside boundary). Most rainfall occurs during the winter months of June to August. Figure 5 highlights the seasonality of the rainfall alongside the mean maximum temperature through the year.

Under the effects of climate change the climate for Western Australia is expected to rise between 1.2 °C to 2 °C under an intermediate emission scenario (RCP4.5), seeing a decrease of up to 25% rainfall (RCP4.5), with a increase in overall evapotranspiration rates (Western Australia Government, 2021).

The climate is somewhat variable between subcatchments within the mining site, with a high-level overview presented in Figure 6. This figure illustrates how much rainfall has occurred (as a percentile rank) in a particular year (2022) compared to the state's (Western Australia) long term average for any given grid square (where 1.0% means a significant amount of rainfall compared to the state's long term average).

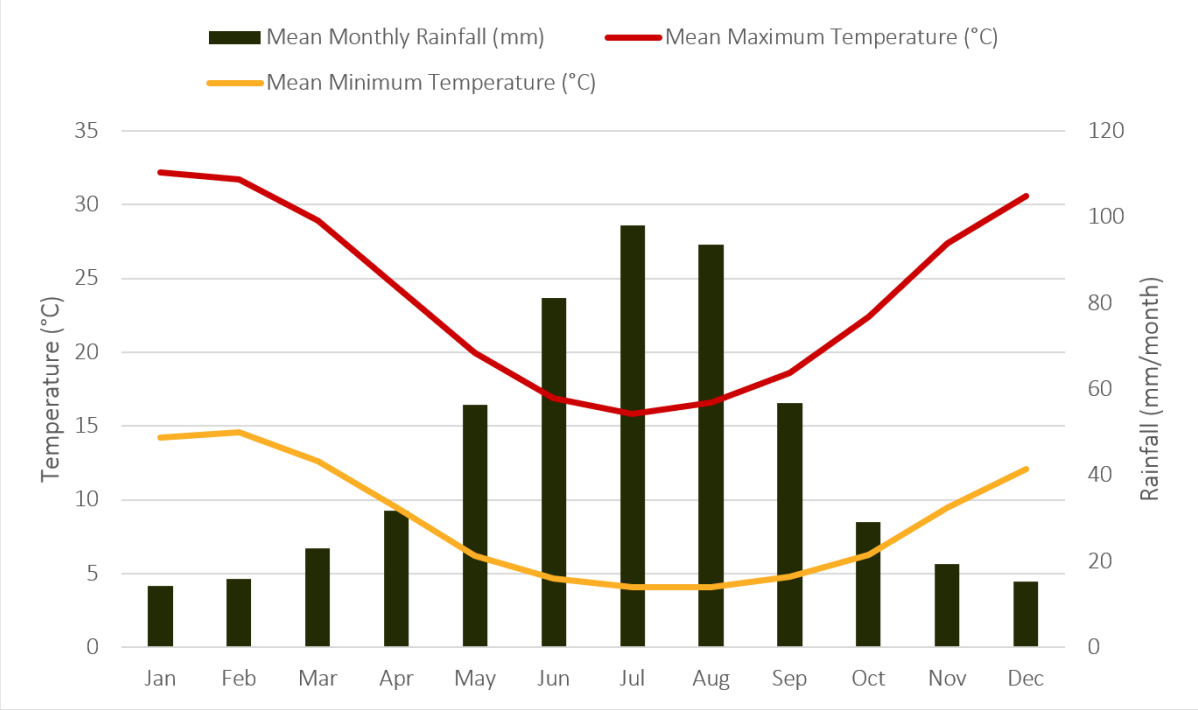

Figure 5. *Mean monthly rainfall and mean maximum and minimum temperatures at Bodington Shire (Site Name: Wandering).*

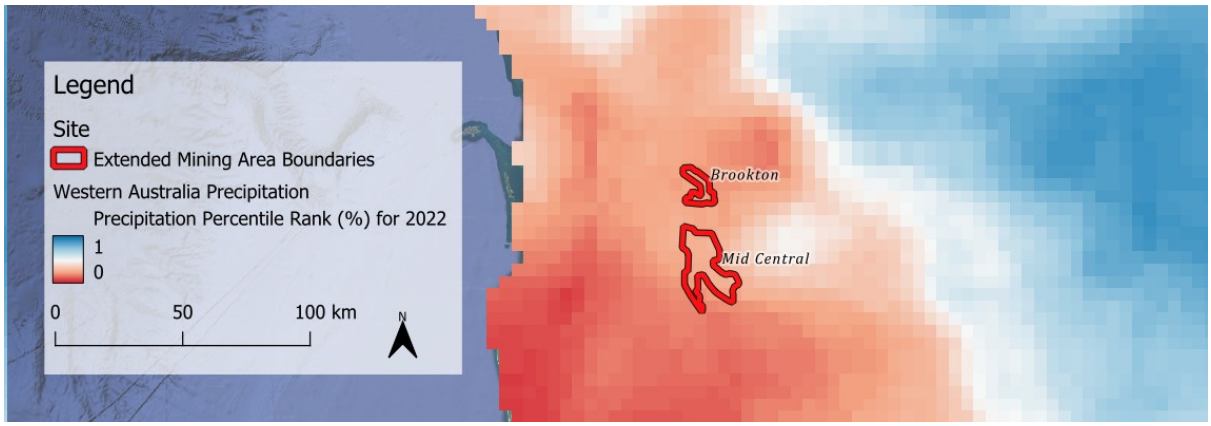

Figure 6. *Relative 2022 precipitation percentile rank over both of the mining expansion areas in South Western Australia (Australian Water Outlook via BOM, 2023). The mining expansion areas mostly received a low amount of precipitation (2022) compared to the states long term average. The North mining expansion area received slightly higher rainfall in the easterly region.*

Streamflow trends

The North mining expansion area is predominantly made up of non-perennial streams, illustrated in Figure 7. This means that most streams within or near the mining expansion area are either intermittent or ephemeral streams (sourced from BOM's Geofabric database (BOM, 2023)) (meaning they have been supplemented by groundwater for certain times of the year, or flow only for a short time after precipitation events (Virginia Places, 2020)).

Catchments

Site locations for the North mining expansion area were georeferenced based on the scope of works. Much of the North mining expansion area is seen to extend principally within the Hotham, Dale and Darkin River catchments. Although there are small portions of mining area that lie within the headwaters of the Mokine Brook and Kettlerock Gully catchments (Figure 7).

Notably, runoff potentially from the Hotham and Serpentine catchments is intercepted by the Serpentine dam catchment, which is a source of drinking water (Figure 15) (Western Australia Government, 2022). As such, these catchments have stringent catchment management plans and require water resource protection. Mining operations in these catchments would therefore need to comply with more stringent monitoring and regulations (NHMRC & NRMMC, 2011).

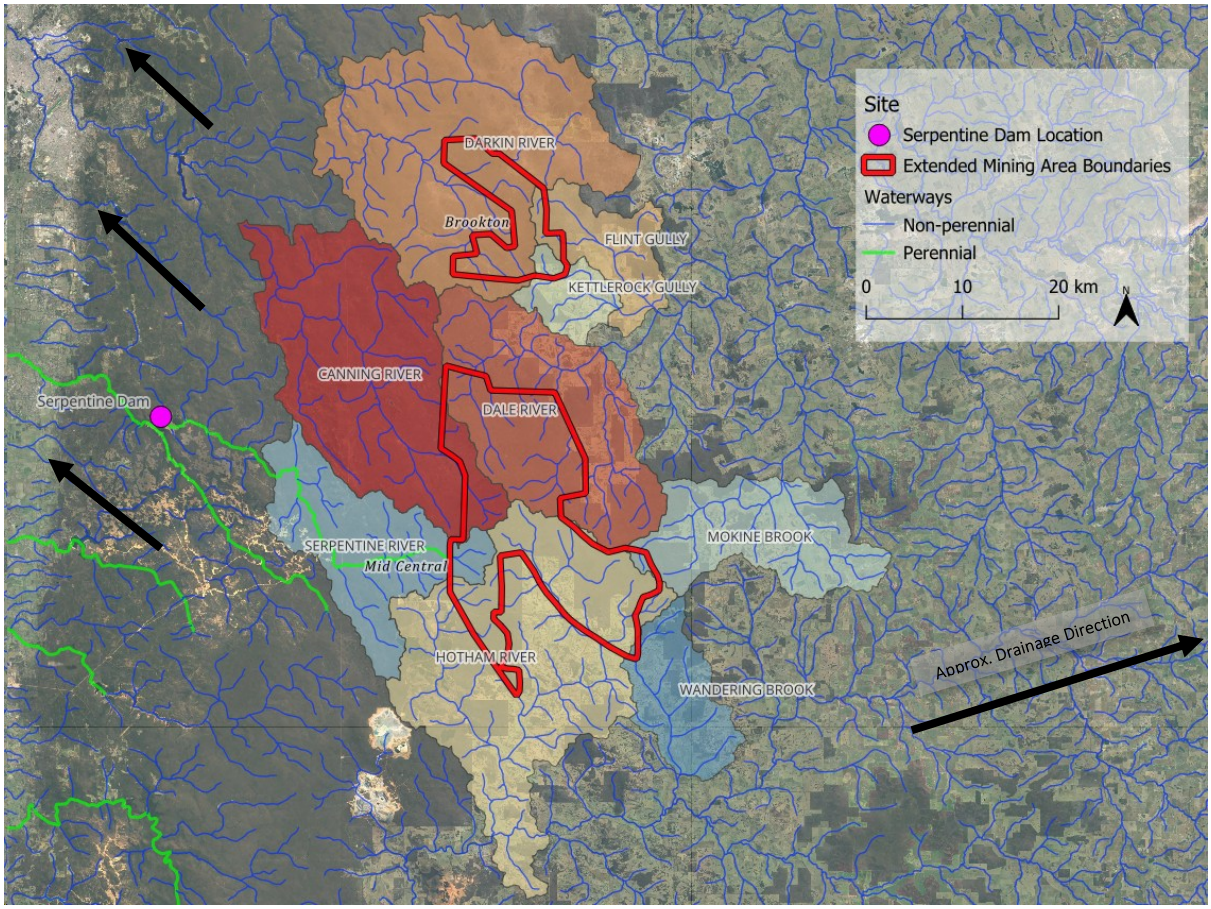

Figure 7. *Northern mining expansion area mining extent, indicating general drainage direction for some of the major catchments (black arrows). The proposed mining areas span catchments that drain in easterly and westerly directions.*

1.2 Legislative context

Inland waters are covered and considered by the Environmental Protection Authority (EPA) through the Environmental Factor Guideline: Inland Waters EPA, Western Australia (2018), which provides commentary on how inland waters should be considered in Environmental Impact Assessments. Clear quantitative objectives for flows and water quality within the state's waterways are not provided within the guideline.

In absence of quantitative water quality objectives in available guidelines, deriving site specific guideline values and comparing water quality against those site-specific values is best practice and should be adopted where possible. In lieu of specific site derived guidelines, water quality in the region should be evaluated against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) (ANZG, 2018). Trigger values are provided to protect aquatic ecosystems for irrigation and general water use, as well as for stocking use. As the current land use over the Extended Mining Area Boundaries is predominantly made up of forest and agricultural uses (mix of stocking and cropland), it may be necessary to ensure water quality from the future mining activities in these subcatchments complies with these guideline values.

Additional regulations are in place for the drinking water catchments of South Dandalup and Serpentine Dam. These include drinking water source protection plans for these catchments, which are intended to assist state and local governments with land use planning decisions in these catchments (Department of Environment, 2005 and 2007). Drinking water within these dams should also comply with the Australian Drinking Water Guidelines (NHMRC & NRMMC, 2011). Key headings of likely relevance for the Australian Drinking Water Guidelines are as follow:

- Part 1. Management of Drinking Water Quality
- Part 2. Description of Water Quality
- Part 3. Monitoring

An in-depth analysis of the Australian Drinking Water Guidelines should be undertaken as necessary.

2 Existing Monitoring and Impact Assessment

2.1 Available Monitoring Data

Table 1 presents a list of all water quality constituents assessed, and at which gauges they were monitored. Trigger values are shown for physical and chemical indicators which were retrieved from ANZG (2018) for slightly disturbed ecosystems in South-west-Australia. No site-specific monitoring data was available for the existing mining extents to be used in this analysis, and as such, publicly available water quantity and quality monitoring data from the Western Australian Water Information Reporting (WIR, 2023) was adopted.

Table 1. *List of water quality constituents considered.*

Constituent	Units	Gauges assessed	Trigger value	Source
Total Alkalinity (CaCO3)	(µg/L)	All gauges	-	-
Soluble Calcium (Ca sol)	(µg/L)	All gauges	-	-
Soluble Chlorine (Cl sol)	(µg/L)	All gauges	-	-
Colour	(Hu)	All gauges	-	-
Conductivity	(µS/cm)	All gauges	-	-
Total Hardness	(µg/L)	All gauges	-	-
Total Potassium (K tot)	(µg/L)	All gauges	-	-
Soluble Magnesium (Mg sol)	(µg/L)	All gauges	-	-
Soluble Sodium (Na sol)	(µg/L)	All gauges	-	-
Total Nitrogen (TN)	(µg/L)	Rivers gauges	<450	ANZG
Total Kjeldahl Nitrogen (TKN)	(µg/L)	Rivers gauges	-	-
NH4-N	(µg/L)	Rivers gauges	<60	ANZG
NOx-N	(µg/L)	Rivers gauges	<200	ANZG
DO Saturation	(%)	Rivers gauges	>90	ANZG
DO concentration	(mg/L)	Rivers gauges	-	-
Total Phosphorus (TP)	(µg/L)	Rivers gauges	<20	ANZG
Orthophosphate (PO4-P)	(µg/L)	Rivers gauges	<10	ANZG
pH	-	All gauges	6.5 – 8.0	ANZG
Salinity	ppt	Rivers gauges	-	-
Silicon Dioxide (SiO2)	(µg/L)	All gauges	-	-
Sulfate (SO4)	(µg/L)	All gauges	-	-
Total dissolved salts (TDSalts)	(mg/L)	All gauges	-	-
Total dissolved solids (TDSolids)	(mg/L)	Rivers gauges	-	-
Temperature	(°C)	All gauges	-	-

Constituent	Units	Gauges assessed	Trigger value	Source
Turbidity	(NTU)	All gauges	-	-

River gauges are specifically in riverine sites where further constituent readings are taken (they will typically include all other constituent readings too).

Northern mining expansion area

Daily water quantity data was sourced from the Bureau of Meteorology (BOM) as rainfall and from the Water Information Reporting (WIR) portal as streamflow (Table 2), in the relevant catchments (Figure 8). Some rainfall gauges just outside of the relevant catchments were also assessed. When selecting the gauges, the topographic effect (direction run off would likely go due to the topography) was considered to choose gauges where runoff from the mining site would be observed.

Table 2. *Northern mining expansion area stream and rainfall gauge Information*.

Gauge name	Gauge ID	Source	Type	Length of record
Bannister	09507	BOM	Rainfall gauge	1885-2023 (112 years)
Boddington Shire	09509	BOM	Rainfall gauge	1915-2022 (108 years)
Oakland	10620	BOM	Rainfall gauge	1912-2017 (104 years)
Culford	09769	BOM	Rainfall gauge	1967-2023 (53 years)
Hotham River – Pumphreys Bridge	614105	WIR	Streamflow gauge	1996-2018 (22 years)
Crossman River – Rivendale	614125	WIR	Streamflow gauge	2008-2023 15 years
14 Mile Brook – Congelin	614126	WIR	Streamflow gauge	2008-2017 (9 years)
Avon River – Beverley Bridge	615025	WIR	Streamflow gauge	1995-2023 (58 years)
Dale River – Waterhatch Bridge	615027	WIR	Streamflow gauge	1995-2023 (24 years)

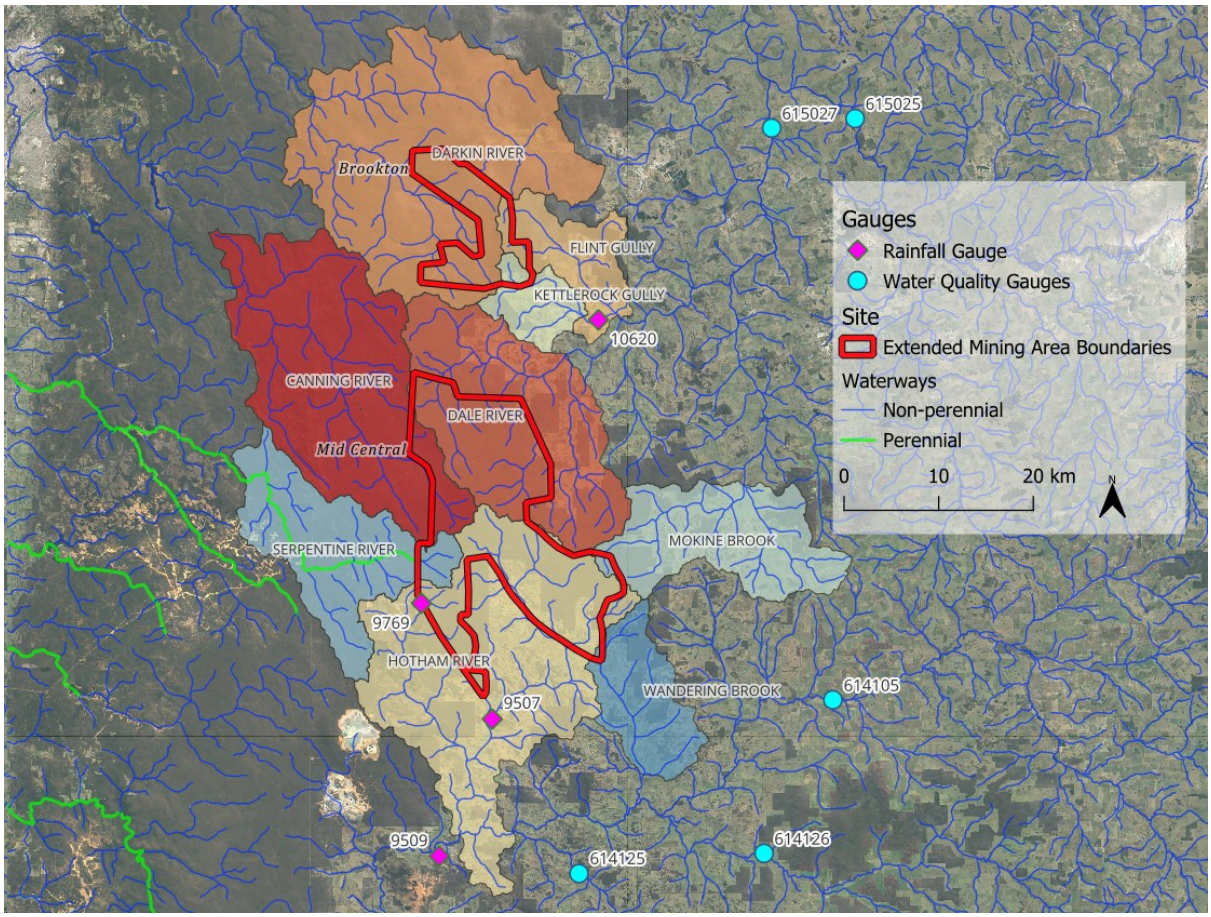

Figure 8. *Northern mining expansion area location of assessed rainfall and streamflow gauges over the Extended Mining Area Boundaries.*

Relevant water quality information was sourced from the WIR portal for the Northern mining expansion area (Table 3). Gauges were situated in the Dale, Avon, Hotham, Fourteen Mile Brook and Crossman catchment. A range of water quality constituents were monitored at these sites, though gauges 615025 and 615027 have a higher level of detailed monitoring data for the Avon and Dale rivers respectively.

Table 3. *Northern mining expansion area Water quality gauges and gauge locations.*

Gauge name	Gauge ID	Source	Type	Length of record
Hotham River – Pumphreys Bridge	614105	WIR	Streamflow gauge	1999-2010 (11 years)
Crossman River – Rivendale	614125	WIR	Streamflow gauge	2007-2021 (14 years)
14 Mile Brook – Congelin	614126	WIR	Streamflow gauge	2008-2017 (9 years)
Avon River – Beverley Bridge	615025	WIR	Streamflow gauge	1999-2022 (23 years)
Dale River – Waterhatch Bridge	615027	WIR	Streamflow gauge	2000-2023 (3 years)

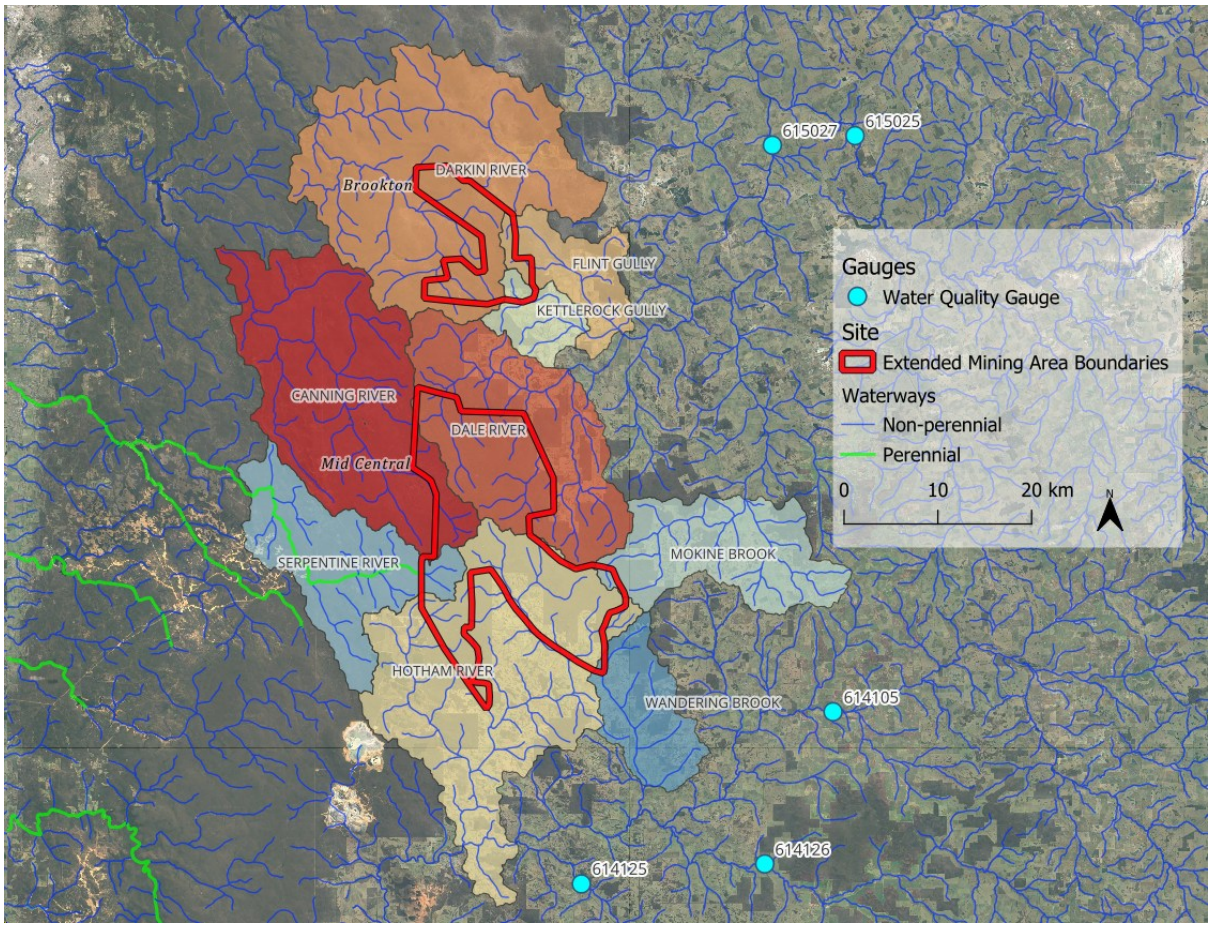

Figure 9. *Northern mining expansion area location of water quality gauges.*

2.2 Water Quantity

Climate Data Summary

Climatic data for daily rainfall in the North mining expansion area exhibits recording periods between 53 years to 112 years (Table 4). The rainfall data was selected at a range of rainfall stations in and around the proposed mining expansion areas to inform the climate variability for the two mining expansion areas.

The summary statistics for annual aggregated rainfall (shown in Table 4 **Error! Reference source not found.**), suggest a relatively consistent average annual rainfall (along with minima and maxima) in the North mining expansion area. This is observed through the average rainfall at near to twice the difference at some gauge locations. This could be an effect of rainfall gauge location in proximity to the low rainfall ridge seen in Figure 6.

Table 4. *North mining expansion area's rainfall summary statistics of aggregated annual data for total rainfall's (mm/year) mean, median, minimum and maximum at the observed gauges.*

Site ID	Number of years in record	Mean (mm/year)	Median (mm/year)	Minimum (mm/year)	Maximum (mm/year)
Bannister	112	637.4	640	294.91	1309
Boddington Shire	101	671.23	678.2	367.89	1139.32
Oakland	104	532.62	528.97	240.6	894
Culford	53	666.16	655.4	170.8	947.28

Summary Streamflow Data

Summary statistics for annual aggregated streamflow for the North mining expansion area is shown in

Table 5. The North mining expansion area experiences relatively consistent discharges within each independent gauge, however does show a high level of variability in the more ephemeral systems, with extremely large peaks relative to their median (likely during a flood event). For the North mining expansion areas, the gauges with a higher mean flow are seen to collect more water from the surrounding ephemeral streams (see Figure 8 and **Error! Reference source not found.**).

Table 5. North mining expansion area's streamflow summary statistics of aggregated annual data for total annual discharge's (GL/year) mean, median, minimum and maximum at the observed gauges.

Site ID	Number of years in record	Mean (GL/year)	Median (GL/year)	Minimum (GL/year)	Maximum (GL/year)
614125	17	15.37	12.93	4.38	34.87
615025	30	48.91	20.79	1.99	291.36
615027	30	36.50	28.86	5.82	107.20
614126	11	6.83	4.01	1.32	27.33
614105	23	17.41	12.91	1.84	55.43

Trend Analysis

Understanding continual changes in climate observed over the last 30 years throughout South-west Western Australia is the first step in a surface water assessment for the proposed mining extension. For this purpose, we have analysed trends in rainfall and streamflow at relevant rainfall and streamflow gauging stations via annual aggregation of data and subsequent linear regression assessment.

Northern mining expansion area

Daily rainfall data collected at stations in Hotham and Flint catchment (Table 2) were aggregated to yearly data (Figure 10) and analysed via linear regression.

All gauges except the Culford gauge show a clear downward trend in rainfall over the historic record. The downward trend is especially noticeable after 1970 (Figure 10 (Bannister, Oakland)), likely a step-change due to emergence of climate change (see end of section 2.2, subsection "Climate Change"). The downward trend is statistically significant for all rainfall gauges ($P < 5\%$, significant), except for the Culford gauge, which indicate rainfall may be stationary ($P > 5\%$, not significant). However, the amount of data recorded at the Culford rainfall gauge was much less than the other gauges, with recording starting in 1967 when a decrease in rainfall was observed in all other gauges which may indicate a step change in rainfall after 1970.

The observed decrease in rainfall across the region has led to a decreased streamflow at various streams in the Hotham catchments (Figure 11) and various streamflow summarised in Table 5. Gauge 614105 has a pronounced decrease in streamflow with the linear model not describing the high streamflow at the start of the record, indicating a non-linear response to rainfall. For gauge 614105 the decreasing streamflow trend could be due to a drier catchment leading to more rainfall percolating into the ground and being lost to evapotranspiration, causing less runoff even for the same levels of rainfall previously observed. A similar response has been observed in Victorian catchments following the Millennium drought (Peterson et al., 2021). Gauges 615025 and 615027 both show only a slight but consistent decrease in streamflow over the recorded period, decreasing at a rate of 0.00178 and 0.0004 mm/year respectively. This shows a linear decrease in streamflow; however, the decrease was not statistically significant at either gauge ($P > 5\%$). Gauges 614125 and 614126 both show an increase in streamflow but can both be categorised as ephemeral streams compared to the other gauge sites, which may result in higher variability of the gauged streamflow. These streams can also be considered more variable. For example in 2018, there was much less discharge recorded in these smaller ephemeral streams (around 12 – 15 GL/year) whereas the range of discharge in the larger streams was observed at 40 – 50 GL/year (Table 5 and Figure 11).

Key information for the Northern mining expansion area's rainfall and streamflow data:

- Rainfall sees a clear decrease through most rainfall gauges.
- Most gauges show a decrease in streamflow through the assessed time periods.
- The variation in streamflow rates may be somewhat insignificant as the data was not statistically significant.
- Larger streams saw a more consistent decrease in streamflow.

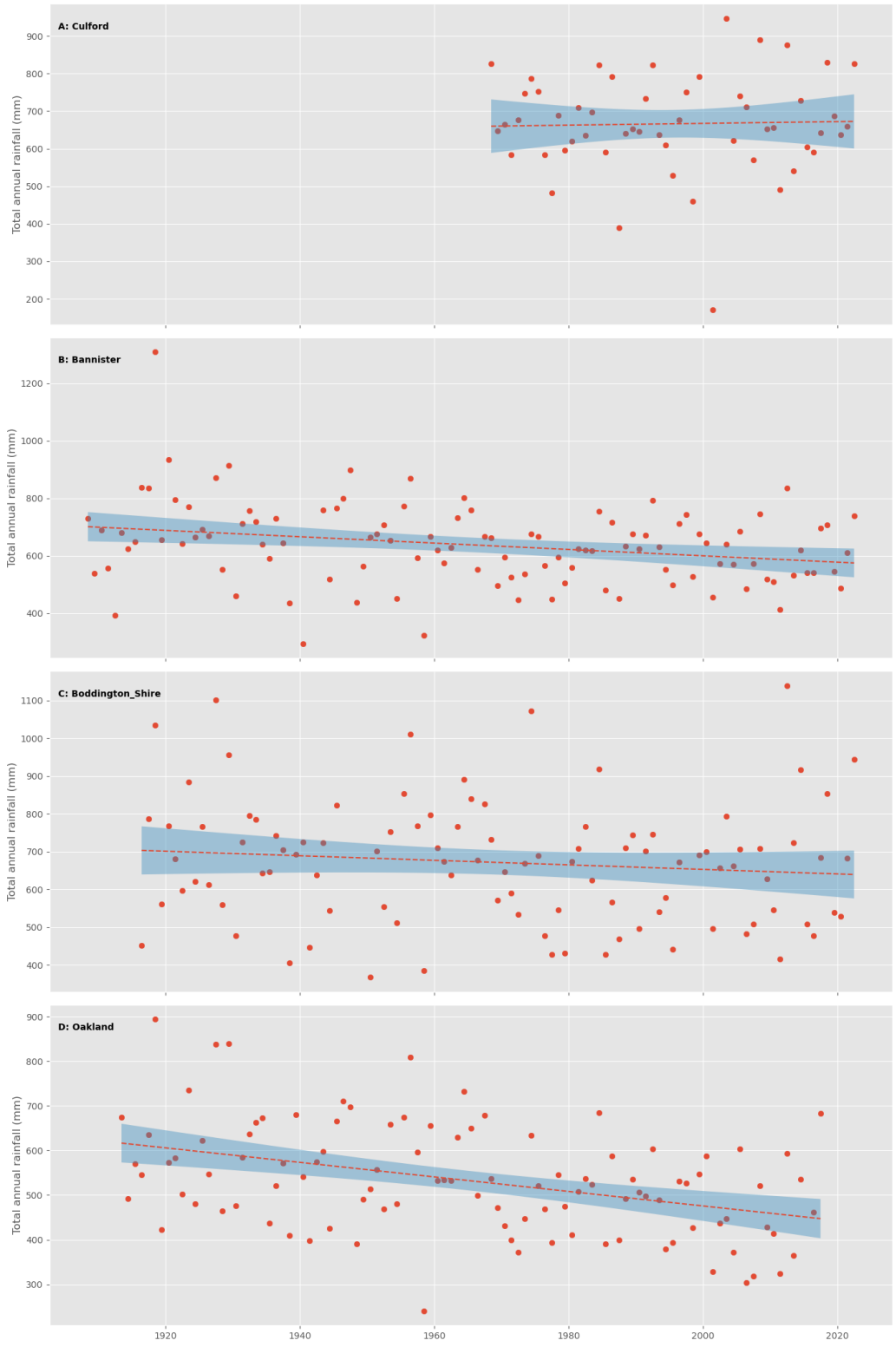

Figure 10. *Northern mining expansion area rainfall trends at the Culford (A), Bannister (B), Boddington Shire (C) and Oakland (D) in the Hotham Catchment. The daily rainfall data was aggregated to annual rainfall (red dots) and a linear regression applied to visualise the long-term trend in the data (red-dashed like including model confidence area in blue). The analysis is showing a long-term decrease in annual rainfall for Bannister, Boddington Shire and Oakland, whereas the data at the Culford gauge indicates stagnant or slightly increasing rainfall.*

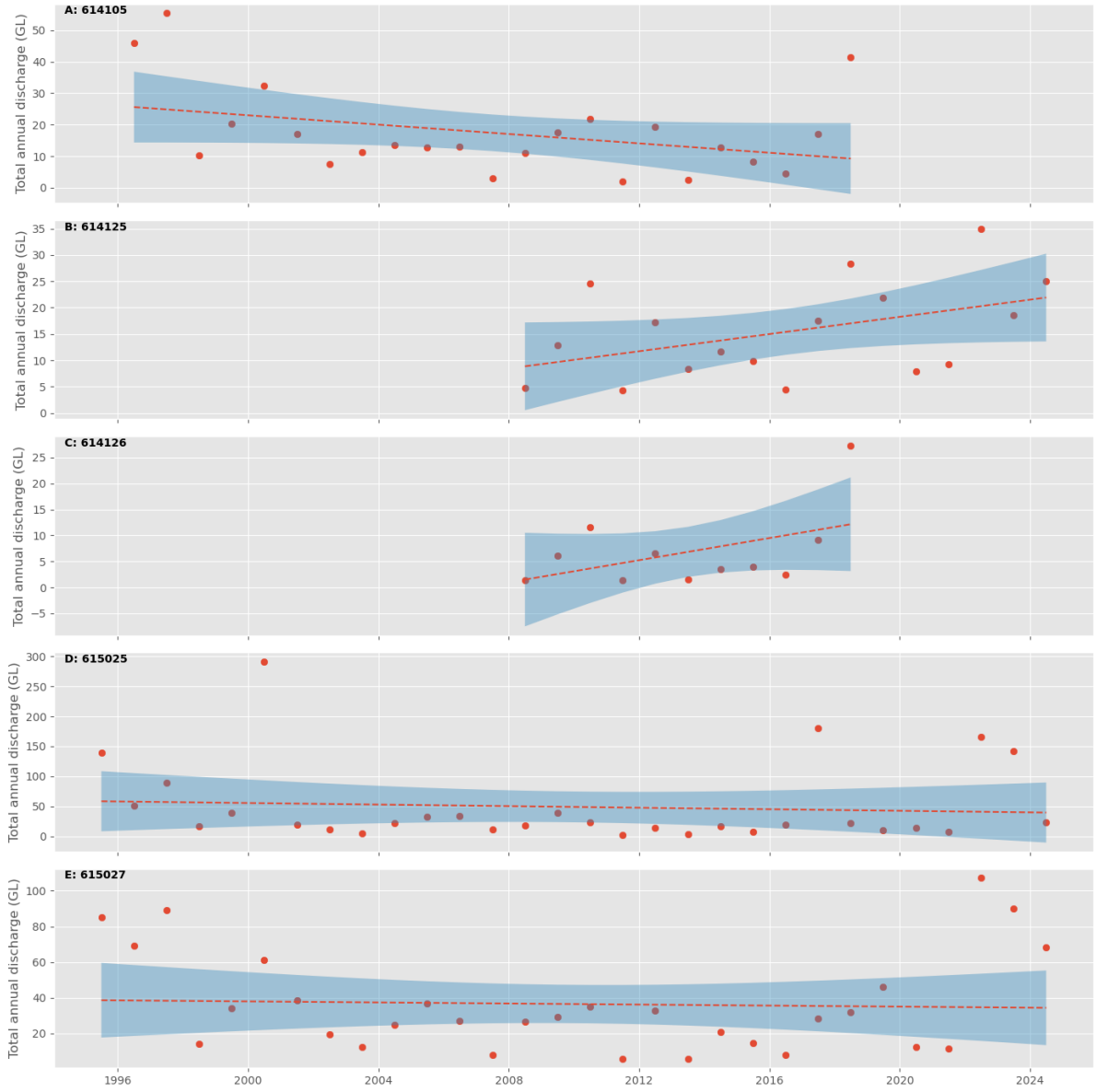

Figure 11. *Northern mining expansion area's total annual streamflow quantities at (A) Hotham River – Pumphreys Bridge (614105), (B) Crossman River – Rivendale (614125), (C) 14 Mile Brook – Congelin (614126), (D) Avon River – Beverley Bridge (615025), (E) Dale River – Waterhatch Bridge (615027). The daily data was aggregated to annual streamflow (red dots) and a linear regression applied to visualise the long-term trend in the data (red-dashed like including model confidence area in blue). The analysis is showing a long-term decrease in annual streamflow for Hotham, Avon and Dale River, whereas the data at the Crossman river and 14 Mile Brook indicate an increase in streamflow.*

Climate Change

Assessment of climate change projections over the mid- and long-term show that the decreasing trend observed in the hydrologic records in all catchments, which is likely to continue in the future under a changing climate (Department of Water, 2015). Predicted percentage changes to rainfall and potential evapotranspiration (PET) across South-west Western Australia are presented in Table 6 across four future period time horizons. Scenarios representing 'dry', median, and 'wet' modelling results are presented. Rainfall is expected to decrease regardless of the scenario selected across all future time periods. The largest decreases are reported by the end of the century under the dry scenario (as expected). At the same time, PET is expected to increase across all scenarios and time periods.

A non-linear response between rainfall and streamflow was noted in the historical trend analysis, with a more pronounced decreasing trend for streamflow shown. Under climate change, the combination of decreased rainfall and increased PET will act to amplify the decreases in streamflow non-linearly, with surface water flows expected to decrease more strongly than the expected decrease in rainfall. This effect will increase the number of no-flow days for the region's ephemeral streams (Barron et al., 2012). On the other hand, the intensity of extreme rainfall events may increase in the future, which potentially increases the risk of inundation and risk of exceeding water quality targets after extreme rainfall events.

Table 6. *Percentage change in rainfall and potential-evapotranspiration (Department of Water, 2015) in four future time periods compared to a baseline period (1961-1990).*

	Median percentage change to rainfall (%)			Median percentage change to potential-evapotranspiration (%)		
Year	Dry	Median	Wet	Dry	Median	Wet
2030	-14%	-5%	-2%	3%	2%	3%
2050	-25%	-9%	-4%	5%	3%	5%
2070	-36%	-13%	-5%	8%	5%	6%
2100	-47%	-17%	-7%	10%	6%	9%

2.3 Water Quality

Summary Data

Summarised data for the observed riverine gauges constituents with stated median, mean, minimum and maximum values shown against their relevant limit/trigger values (based on Table 1 if applicable) found below in Table 7. A complete list of observed constituents' medians, minimums, and maximums measured at each gauge is shown in Appendix A, Table A1.

Table 7. *North mining expansion area summarised water quality data showing median, mean, minimum and maximums for all observed riverine constituents.*

Constituent	Median	Mean	Minimum	Maximum	Number of observations	Limit/ trigger
N (sum sol ox) {NOx-N, TON} (µg/L)	5	144.1	2.5	2500	144	200
N (tot kjel) {TKN} (µg/L)	1700	2124.8	150	13140	159	-
N (tot) {TN, pTN} (µg/L)	1500	1828	250	10000	324	450
NH3-N/NH4-N (sol) (µg/L)	40	434.1	2.5	10500	184	60
O2-{DO %sat} (%)	98.95	106.5	3.1	281	378	-
O2-{DO conc} (mg/L)	9.28	14	0.2	2016	471	-
P (tot) {TP, pTP} (µg/L)	50	99.5	2.5	2500	349	20
PO4-P (sol react) {SRP, FRP} (µg/L)	5	12.9	1.5	240	187	10
Salinity (ppt)	10.8	18.8	0.1	99.95	135	-
TDSolids (calc) (mg/L)	23250	25565.3	3020	64100	32	-

Key data gaps

Due to data scarcity all available water quality monitoring data from all the gauges shown in Figure 9 were taken into consideration (even when the gauges were located in ephemeral systems). This choice of including all data may have skewed the water quality distributions which is one of the key drawbacks with the available data.

When assessing available water quality data, gauges where the total number of samples is less than 30 are not considered reliable enough for statistical inference; however, the data distributions are shown, nonetheless. Generally, too few data points were available at water quality gauge sites to establish long-term trends, so instead overall distributions are presented here to show overall behaviour at each available site.

Further, the water quality samples were displayed as a total dataset instead of yearly data, as in some years there may have only been one recording for a constituent, if there was a recording at all.

Summary Data

Northern mining expansion area

The overall data distributions of water quality constituents situated within the subcatchments impacted by the Northen mining extension areas, the Mid Central and Brookton sites (gauge IDs: 614105, 614125, 614126, 615025 and 615027) are shown in **Error! Reference source not found.** and Figure 13. All sites within the area measured comparable magnitudes in water quality constituents despite the difference in more water quality samples available for the riverine gauges (gauge IDs: 615025, 615027). Comparing the two riverine gauges, gauge 615025 exhibited higher concentrations in major cations and anions (sulphate, chloride, carbonate, calcium, and magnesium) and physical indicators (pH and temperature); however, this could be due to the discrepancy in sample sizing for this data set (Figure 13).

The length of the monitoring record varied between the assessed gauges (Table 3), with a difference of years for monitoring records of the riverine sites compared to the local subcatchments. There was often limited data available for many of the gauges as seen with the number of samples taken opposed to the total length of recording (if samples were taken at all) (Figure 12 to Figure 13).

There was no monitoring data available for nutrients, heavy metals, metalloids, and dissolved oxygen at the North mining expansion area. Nutrient and dissolved oxygen concentrations were available at the riverine sites as presented in Figure 14, but heavy metals and metalloid concentrations were not available from the publicly accessible monitoring data.

The data from the assessed gauges within the North mining expansion areas all showed similar concentrations of nutrients, dissolved oxygen, and salinity, with mean values generally below the recommended guidelines (Figure 14). TN and TP at these sites often exceeded the trigger values for slightly disturbed ecosystems in south-west Australia (ANZG, 2018) (Figure 31). A slightly disturbed ecosystem is one where the aquatic biological diversity may have been affected to a relatively small but measurable degree of human activity (ANZAG, 2018).

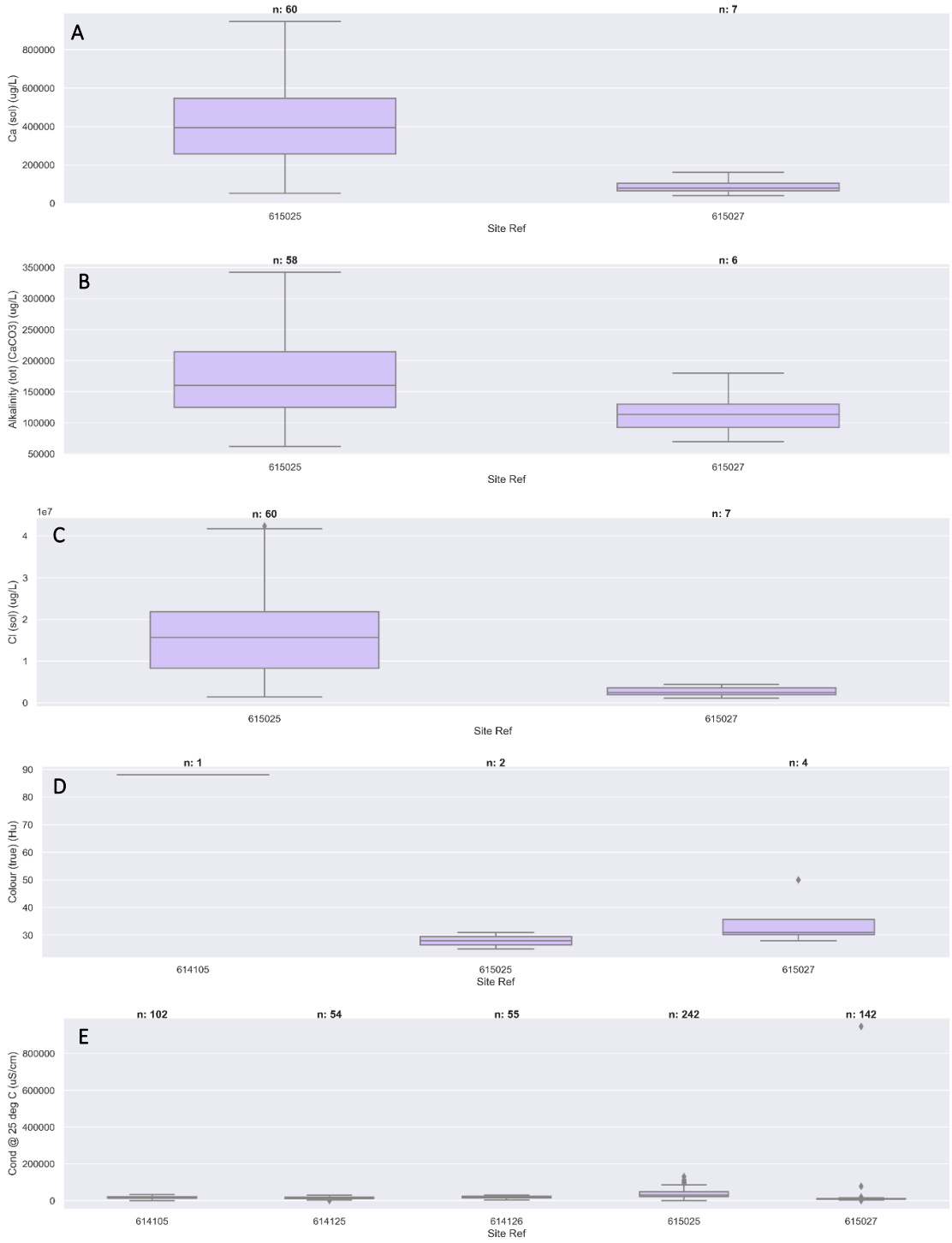

Figure 12. *Northern mining expansion area observed water quality values (with number of observations) for (A) soluble calcium, (B) total alkalinity, (C) soluble chlorine, (D) colour, and (E) conductivity for assessed gauges with data. Due to the scarcity of observations the data was analysed as a distribution to indicate the general tendency for water quality parameters at each observation site. At site 615027 an influential outlier in conductivity was observed. Site 614105 shows a higher colour value than other assessed sites, however, only one observation was made.*

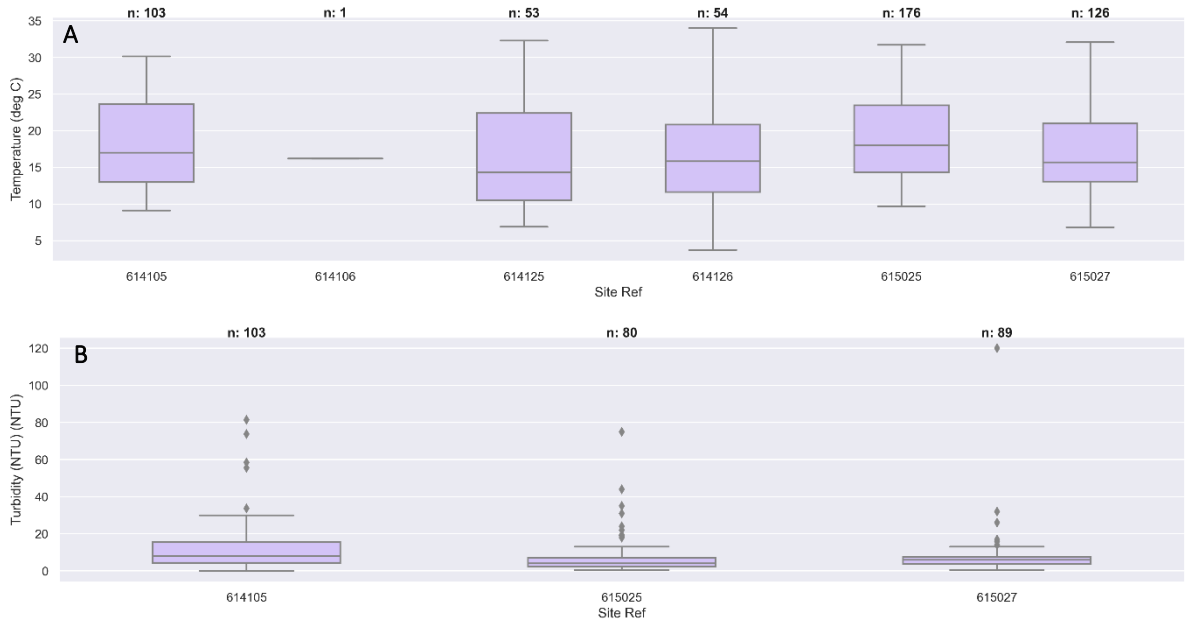

Figure 13. *Northern mining expansion area observed water quality values (with number of observations) for (A) temperature and (B) turbidity for assessed gauges with data. The median temperature across all assessed sites was similar (15 - 18 °C), with a large data spread, which is expected due to daily and seasonal variability. The turbidity showed some data points beyond the 99th percentile (top whisker in the box and whisker plot), indicating some large turbidity values, which are likely due to high flow events.*

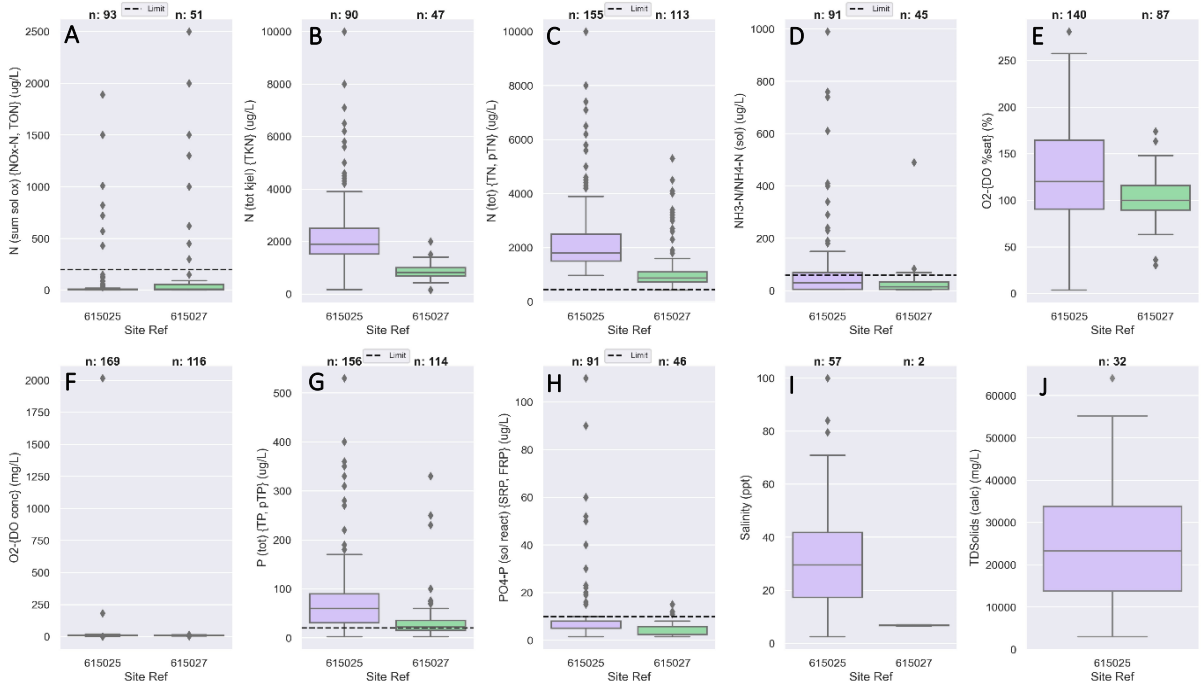

Figure 14. *Northern mining expansion area observed water quality values (with number of observations) for (A) oxidised nitrogen, (B) total Kjeldahl nitrogen, (C) total nitrogen, (D) ammonia, oxygen ((E) saturation and (F) concentration), (G) total phosphorus, (H) orthophosphate, (I) salinity, and (J) total dissolved solids at the riverine gauges assessed. Black dashed lines show the trigger values (ANZG, 2018). All water quality parameters with trigger values in the ANZG guidelines were exceeded. Some exceedances were only above the 99th percentile of the distribution (oxidised nitrogen and orthophosphate), while the other parameters with trigger values were exceeded substantially, especially total nitrogen and phosphorus, indicating a notable contribution or organic nitrogen and phosphorus at the assessed sites.*

2.4 Impact Assessment

Due to the scarcity of data received for water quality, the statistical analysis was very limited (as stated in Section 2.3). Also, as mining operations cannot be precisely located in the Extended Mining Area Boundaries prior to this investigation, specific details about streamflow and load of constituents and thus location of the constituent's potential impacts are difficult to predict (assuming that mining operation can occur anywhere within the potential mining expansion area). As such, the quantitative analysis conducted above was used in this impact assessment generalising the available information to qualify potential downstream impact of mining activity (at any location relative to the mining expansion areas for both streamflow and water quality constituents), to establish a fit-for-purpose surface water monitoring regime.

The available monitoring data has been used to develop an understanding of the historic climatic, streamflow, and water quality conditions within the Extended Mining Area Boundaries and potential impacts on downstream catchments. Additional monitoring within the North mining expansion areas is paramount as poor management of constituents may impact downstream users if constituent loads are too high. While the mining expansion areas do not directly discharge into perennial streams (Figure 7), the non-perennial streams can still carry constituents through to major waterways, especially via groundwater flow (Work undertaken by CDM Smith); causing potentially adverse effects for downstream land users (cropping, grazing or drinking water). For this reason, the impact assessment conducted here considered spatial location of mining impact and potential downstream users which was used to inform the location of monitoring sites as described in Section 3. As the mining has not yet started, impact cannot be assessed quantitatively.

The historical monitoring data at the water quality gauges was assessed to understand the current constituent loads flowing in the waterways and compare the medians of the data to each other and the ANZG guidelines where applicable (ANZG, 2018). The constituents were chosen based on the available recorded data and those constituents that can cause adverse effects to downstream users (Table 1). To understand the impact of the constituent loads, a monitoring process is outlined in Section 3, which will ideally aid in highlighting elevated excess constituent loads that the mining expansion areas may contribute to the water ways (and thus enable mitigative measures).

Available monitoring from the subcatchments impacted by the North mining expansion area suggests that water is of a better quality for all constituents assessed except for turbidity (sediments) compared to the receiving water at the riverine sites.

Drinking water impact

The North mining expansion area is within a Priority 1 (P1) catchment area. A P1 area is defined as "assigned over crown land covered with native vegetation and are managed to avoid water quality risks. Most land uses and activities are inappropriate in P1 Areas" (Department of Water and Environmental Regulation, 2020). The Brookton boundary for the North mining expansion area has the Darkin River catchment intersecting with the Mundaring Weir drinking water catchment area. While the Mid Central boundary has the Canning River and Serpentine River catchments partially intersecting the Canning Dam and Serpentine Dam drinking water catchments shown in in Figure 15. Details on the area of the drinking water catchments taken from the Western Australia Government, public drinking water source area mapping tool (Western Australia Government, 2022).

It is assumed the appropriate legislative documents have been pre-approved for mining within a P1 area, if not the appropriate steps to obtaining these legislative documents should be taken. To note, from an aerial imagery analysis it is seen there are previous/current mining operations within these P1 areas.

Northern mining expansion area

Available water quality monitoring data for the Northern mining expansion area is somewhat limited, as none of the water quality monitoring gauges are within the Extended Mining Area Boundaries . Also, the water quality gauges in the Northern mining expansion area have limited years of monitoring only assessing primarily between the years 1975 and 1996. It is unknown if there were other leases for mines during the timeframe of observation over the region, although it is unlikely.

While it seems apparent that water quality from these subcatchments (at least prior to 1996) was better than that from the rivers, it is not known whether it has degraded compared to similar slightly disturbed subcatchments. Comparisons between impacted subcatchments and riverine monitoring sites are difficult as the riverine site is subject to the influence of the whole upper catchment, with impacts primarily from agricultural land use. The influence of smaller tributary streams is masked by runoff from areas with agricultural land use, whereas the mining sites appear to be mostly forested (at least prior to mining), and thus lower concentrations of water quality constituents are expected. Forested catchments generally show much better water quality compared to agricultural catchments.

Portions of the Northern mining expansion area overlap with the headwaters of the Serpentine and South Dandalup drinking water catchments (Western Australia Government, 2022). Any mining activities in these catchments could impact these drinking water dams and would therefore need to comply with regulations to ensure water resource protection (NHMRC & NRMMC 2011) (Western Australia Government, 2022). If possible, it would be recommended that mining in these areas be avoided (approximate area shown inFigure 15).

3 Proposed Monitoring Regime

Given the constraints and data gaps of the current monitoring data outlined in Section 2.3 and Section 2.4, we propose a water quantity and quality monitoring regime be set up, which focuses on the Extended Mining Area Boundaries. A control-impact approach is proposed, which will allow for comparisons between sites that are impacted by mining activities and those that are not but will see an impact from mining activities. Both the impact and control sites will be subject to similar climatic conditions and land use prior to mining, allowing for the impacts of the mining activities to be discerned through comparison. The monitoring regime should begin prior to the commencement of the mining activities such that the pre-existing baseline conditions of the subcatchments (prior to mining) can be established, if possible. Collection of monitoring data before and after mining, and from a control and impact site will allow for implementation of statistical analyses to quantify the changes as a result of mining (e.g. Before After Control Impact (BACI) design) (Conner, 2016). A list of proposed variables to be monitored is provided in Table 8. Importantly, the list of constituents to be monitored includes both heavy metals and metalloids, which have not been monitored in the existing data.

Monitoring Frequency

It is recommended that monitoring for water quality should occur monthly at all current gauge sites seen in Table 3, and all additional recommended gauges seen in Table 9 until a baseline of 30 samples is reached (30 months); this baseline monitoring regime should capture the seasonality of all associated gauges (at least two seasons). The monitoring regime for baseline establishment is required to adhere to any additional stipulations posed by the Western Australia water quality guidelines for mining (Western Australia, 2000). The baseline monitoring establishes the water quantity and water quality thresholds for the distributed environment after mining has commenced.

After baseline establishment, monitoring should occur monthly and reactively (after spills or flow events at the mining's discretion); also, if monitoring shows an abnormally high result, a further test should be completed immediately to check its validity. If results remain elevated, investigations into causes, and potential mitigative activities should be undertaken. For a total monitoring time period, after the mine has shut down monitoring should continue until stationary water quality parameters are observed.

Table 8. *Recommended parameters to be monitored at the proposed mining sites.*

Type	Variables to monitor
Water quantity	Streamflow
Nutrients	Total nitrogen and total phosphorus
Sediments	Turbidity and total suspended solids
Heavy metal	Cadmium, chromium, copper, nickel, lead, and zinc
Metals and metalloids	Aluminium, iron, and manganese
Physical	Total dissolved solids, temperature, dissolved oxygen, and pH

Major cations and anions	Sulphate, chloride, carbonate, calcium, magnesium, and potassium

Monitoring Locations

The location of the proposed monitoring sites are presented for the Northern mining expansion area in Figure 15 and Table 9. The selected sites have been positioned near main roads (where possible) to ensure that they are easily accessible. Further monitoring of existing Northern mining expansion area is also recommended (gauge IDs: 614058 and 614011) to better ascertain the current conditions, though not necessarily required.

To note, for the Northern mining expansion area we are not recommending monitoring at the Mundaring Weir because water quality at that location will likely be masked by all incoming tributaries not impacted by the mining site.

Both impact and control gauges are placed in river systems (no minor streams/creaks), at a confluence point for major subcatchments only (not a gully). Furthermore, impact sites were generally chosen in the upper catchment areas to determine the source impacts from the mining. While control sites were chosen in the lower reaches of a catchment at confluences in large river systems to gather as much information on constituents from a range of different catchments potentially impacted by the mining.

Table 9. *Northern mining expansion area, details of the proposed monitoring sites.*

Gauge site	Type	Existing Site	Mining Area	Latitude	Longitude
Bannister River – Albany Hwy	Control	No	Mid Central	-32.67608	116.51481
Dale River – York-Williams Rd	Control	No	Brookton	-32.25923	116.79202
Thorpe Rd	Control	No	Mid Central	-32.47352	116.26845
Canning River – Canning River Rd	Control	No	Mid Central	-32.33779	116.33914
Yarra Rd*	Control	No	Brookton	-32.18025	116.42982

**Gauge should be assessed to see if any flows pass through this point, if so can be used as a close impact monitoring gauge.*

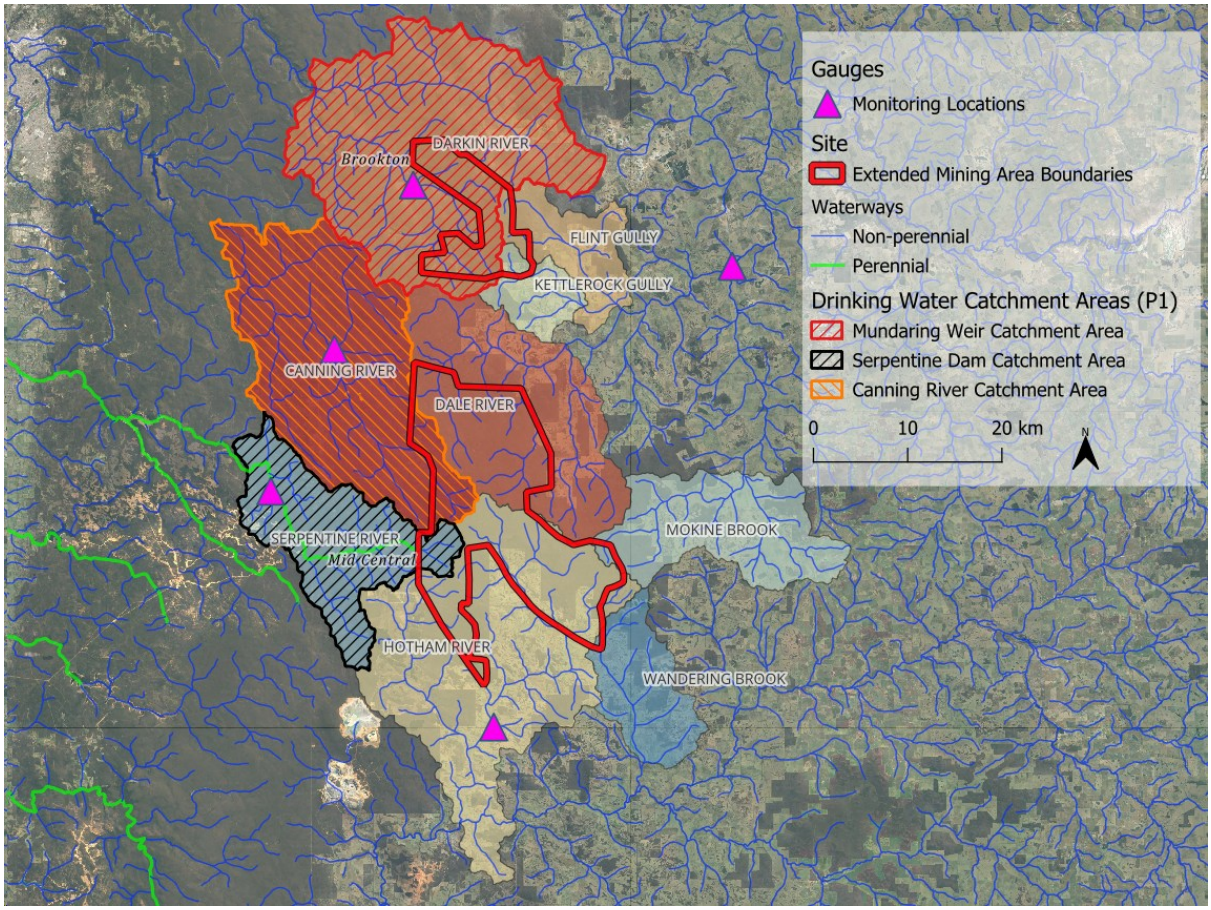

Figure 15. *Northern mining expansion area proposed monitoring locations. Drinking water catchment areas are based on catchments of interest for this assessment, the full drinking water catchment area may extend beyond what is shown here, refer to the Western Australia drinking water mapping tool for more information (Western Australia, 2022).*

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WIR – see Department of Water and Environmental Regulation

Appendix A

Table A1. *North mining expansion area's list of gauged water quality constituents with their relative observations, minimums and maximums*

Site Ref	Variable	Median	Minimum	Maximum	Number of observations
615025	Alkalinity (tot) (CaCO3) (µg/L)	160000.00	62000.00	342000.00	58.00
615027	Alkalinity (tot) (CaCO3) (µg/L)	113500.00	70000.00	180000.00	6.00
615025	Ca (sol) (µg/L)	393500.00	52000.00	946000.00	60.00
615027	Ca (sol) (µg/L)	78000.00	40000.00	160000.00	7.00
615025	Cl (sol) (µg/L)	15650000.00	14000000.00	42400000.00	60.00
615027	Cl (sol) (µg/L)	2500000.00	1100000.00	4400000.00	7.00
614105	Colour (true) (Hu)	88.00	88.00	88.00	1.00
615025	Colour (true) (Hu)	28.00	25.00	31.00	2.00
615027	Colour (true) (Hu)	31.00	28.00	50.00	4.00
614105	Cond @ 25 deg C (uS/cm)	16535.50	24.00	31681.00	102.00
614125	Cond @ 25 deg C (uS/cm)	16133.00	16.00	29176.00	54.00
614126	Cond @ 25 deg C (uS/cm)	19889.00	3290.00	31124.00	55.00
615025	Cond @ 25 deg C (uS/cm)	31477.00	19.87	130083.00	242.00
615027	Cond @ 25 deg C (uS/cm)	9535.00	111.00	946188.00	142.00
615025	Hardness (tot) (CaCO3) {Ca+Mg} (µg/L)	7115000.00	2410000.00	19300000.00	22.00
615025	Mg (sol) (µg/L)	1220000.00	109000.00	4120000.00	60.00
615027	Mg (sol) (µg/L)	250000.00	100000.00	510000.00	7.00
615025	Na (sol) (µg/L)	8645000.00	716000.00	28200000.00	60.00
615027	Na (sol) (µg/L)	1300000.00	590000.00	2200000.00	7.00
614105	pH (no units)	8.00	6.50	9.06	104.00
614106	pH (no units)	7.50	7.53	7.53	1.00
614125	pH (no units)	7.70	6.49	8.59	55.00
614126	pH (no units)	8.20	6.80	8.99	55.00
615025	pH (no units)	8.40	4.80	10.24	236.00
615027	pH (no units)	8.00	6.90	8.50	136.00
615025	SiO2 (sol react) (µg/L)	5700.00	5700.00	5700.00	1.00
615027	SiO2 (sol react) (µg/L)	8800.00	5100.00	9900.00	3.00
615025	SiO2 (sol react) (µg/L)	5700.00	5700.00	5700.00	1.00
615027	SiO2 (sol react) (µg/L)	8800.00	5100.00	9900.00	3.00
614105	Temperature (deg C)	17.00	9.10	30.13	103.00
614106	Temperature (deg C)	16.20	16.20	16.20	1.00
614125	Temperature (deg C)	14.30	6.90	32.30	53.00
614126	Temperature (deg C)	15.80	3.70	34.00	54.00

Site Ref	Variable	Median	Minimum	Maximum	Number of observations
615025	Temperature (deg C)	18.00	9.70	31.70	176.00
615027	Temperature (deg C)	15.70	6.80	32.10	126.00
614105	Turbidity (NTU) (NTU)	8.00	0.00	81.40	103.00
615025	Turbidity (NTU) (NTU)	4.10	0.50	75.00	80.00
615027	Turbidity (NTU) (NTU)	5.90	0.50	120.00	89.00
615025	N (sum sol ox) {NOx-N, TON} (µg/L)	5.00	2.50	1890.00	93.00
615027	N (sum sol ox) {NOx-N, TON} (µg/L)	11.40	2.50	2500.00	51.00
614105	N (tot kjel) {TKN} (µg/L)	2349.00	250.00	13140.00	22.00
615025	N (tot kjel) {TKN} (µg/L)	1900.00	170.00	10000.00	90.00
615027	N (tot kjel) {TKN} (µg/L)	820.00	150.00	2000.00	47.00
614105	N (tot) {TN, pTN} (µg/L)	1391.00	250.00	5888.00	51.00
614125	N (tot) {TN, pTN} (µg/L)	1340.00	980.00	1700.00	2.00
614126	N (tot) {TN, pTN} (µg/L)	2000.00	1500.00	2700.00	3.00
615025	N (tot) {TN, pTN} (µg/L)	1800.00	970.00	10000.00	155.00
615027	N (tot) {TN, pTN} (µg/L)	870.00	430.00	5300.00	113.00
614105	NH3-N/NH4-N (sol) (µg/L)	50.00	50.00	10500.00	48.00
615025	NH3-N/NH4-N (sol) (µg/L)	30.00	5.00	990.00	91.00
615027	NH3-N/NH4-N (sol) (µg/L)	15.00	2.50	490.00	45.00
614105	O2-{DO %sat} (%)	84.20	15.60	188.00	74.00
614125	O2-{DO %sat} (%)	89.90	3.10	153.00	43.00
614126	O2-{DO %sat} (%)	95.00	24.50	197.10	34.00
615025	O2-{DO %sat} (%)	120.20	3.80	281.00	140.00
615027	O2-{DO %sat} (%)	100.00	30.30	174.00	87.00
614105	O2-{DO conc} (mg/L)	7.70	1.11	15.71	99.00
614125	O2-{DO conc} (mg/L)	8.90	0.21	12.01	47.00
614126	O2-{DO conc} (mg/L)	9.80	1.72	16.40	40.00
615025	O2-{DO conc} (mg/L)	10.30	0.20	2016.00	169.00
615027	O2-{DO conc} (mg/L)	9.60	2.70	15.40	116.00
614105	P (tot) {TP, pTP} (µg/L)	200.00	50.30	2500.00	74.00
614125	P (tot) {TP, pTP} (µg/L)	12.00	11.00	13.00	2.00
614126	P (tot) {TP, pTP} (µg/L)	21.00	20.00	29.00	3.00
615025	P (tot) {TP, pTP} (µg/L)	60.00	2.50	530.00	156.00
615027	P (tot) {TP, pTP} (µg/L)	22.00	2.50	330.00	114.00
614105	PO4-P (sol react) {SRP, FRP} (µg/L)	10.50	5.00	240.00	50.00
615025	PO4-P (sol react) {SRP, FRP} (µg/L)	5.00	1.50	110.00	91.00
615027	PO4-P (sol react) {SRP, FRP} (µg/L)	2.50	1.50	15.00	46.00
614105	Salinity (ppt)	8.40	0.10	18.50	76.00
615025	Salinity (ppt)	29.60	2.50	99.95	57.00
615027	Salinity (ppt)	6.80	6.50	7.00	2.00
615025	TDSolids (calc) (mg/L)	23250.00	3020.00	64100.00	32.00