Boggy Brook

Baseline Aquatic Fauna Survey & Interim Site-Specific Guideline Values

Newmont Boddington Gold Pty. Ltd.

Prepared by:

SLR Consulting Australia

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Making Sustainability Happen

Revision Record

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Basis of Report

This report has been prepared by SLR Consulting Australia (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Newmont Boddington Gold Pty. Ltd. (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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Executive Summary

Newmont Boddington Gold (NBG) operates the Boddington Gold Mine (BGM), located 17 km northwest of the town of Boddington, and around 100 km to the southeast of Perth in Western Australia. During the oxide mining period and during the current mining period tailings have been stored in Residue Disposal Areas (RDAs). The active tailings facility will reach its current approved maximum capacity of 600Mt in mid-2025. In anticipation, in July 2023 NBG submitted approvals to increase the existing facility to 750Mt. Newmont is currently completing a feasibility study for tailings deposition into a second RDA facility once the 750Mt facility reaches capacity. The Boggy Brook creek line lies within the vicinity of the potential RDA 2 facility and hence an updated aquatic fauna and water quality survey is required to assess potential environmental impacts to Boggy Brook. In addition, the potential for discharge of excess water from mine operations to a nearby creekline may be explored as part of the RDA 2 feasibility studies. Boggy Brook is a small, ephemeral tributary to the Hotham River, and has been identified as a potential location to receive discharge water. Further environmental studies are required including the aquatic fauna and ecosystem values of Boggy Brook, including an updated aquatic fauna baseline (originally completed in 2011) and development of interim site-specific water quality guideline values (SSGVs). The operation needs an understanding of water quality required for discharge to inform water treatment investigations.

SLR Consulting were commissioned by Newmont Australia to document and assess the aquatic ecological values of Boggy Brook, in order to provide supporting documentation required under the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act) and Part IV of the WA Environmental Protection Act 1986 (EP Act). In addition, long-term data supplied by NBG from five locations on Boggy Brook were analysed to examine background concentrations of analytes for Boggy Brook, and to propose interim SSGVs where justified.

<u>Key findings of the baseline survey:</u>

Two sites were sampled on Boggy Brook in September 2023, which was otherwise dry during the survey.

- Water quality was generally good, however a salinity gradient occurred between the upstream forested reach (fresh) and downstream reaches adjacent to farmland (brackish), also reported in 2011 baseline surveys.
- The aquatic macroinvertebrate assemblage at Boggy Brook had low richness, and one native crayfish species was present.

Water quality in both reaches had circum-neutral pH, low turbidity and total suspended solids (TSS), and low concentrations nutrients and most dissolved metals, with exception of aluminium and copper. The salinity gradient identified between forested reaches (AL-1) and reaches adjacent to farmland (AL-8) is indicative of secondary salinisation in the lower reaches. Aluminium and copper were elevated at both sites, however it is unknown the proportion of which was bioavailable.

The aquatic faunal assemblage at Boggy Brook had low species richness, dominated by taxa with adaptations to an ephemeral hydroregime. A total of 18 invertebrate taxa were identified from Boggy Brook in 2023, with AL-1 recording 14 taxa and AL-8 recording eight taxa (including microcrustacean groups), with similar richness recorded during the 2011 surveys (WRM 2012a). Fish were not present during the survey (likewise no fish were present in 2011; WRM 2012a), however native crayfish *Cherax preissii* (koonacs) were present at AL-8. No taxa identified in the 2023 survey appear on conservation lists.

<u>Longer term patterns in water quality:</u>

Analysis of long-term monitoring data showed there was a clear divide in water quality attributes between upstream forested reaches and downstream cleared reaches on Boggy Brook, particularly salinity and hardness. Therefore, it was appropriate to assess water quality in the upper forested reaches against ANZG (2018) Default Guideline Values (DGVs) for 99% species protection. The lower reaches were assessed against the 95% DGVs, which are applicable for use in moderately disturbed systems.

Across both reaches, analytes that were frequently elevated against DGVs included aluminium, which is apparently released from the upper catchment with the onset of rainfall. This indicates naturally elevated background levels. Other analytes showing periodic elevations included cobalt, copper, nickel and zinc, however it is not possible to comment on the origin of these exceedances. Further analytes were locally elevated at site BGBK16 (including arsenic and lead), noting this site is in close proximity to the Gold Mine Road and therefore may not necessarily be representative of 'background' concentrations for Boggy Brook.

Water hardness is directly associated with the bioavailability of several toxicants, therefore hardness modified guideline values (HMGVs) are proposed for several analytes in the lower reaches of Boggy Brook. As well as differences in hardness, there are differences in levels of disturbance between the upstream and downstream reaches. It may therefore be inappropriate to apply one set of SSGVs to both upstream and downstream reaches, as levels that may be of little ecological consequence in the lower reaches may have deleterious impacts of the minimally disturbed upper reaches.

Table E1 summarises proposed interim SSGVs applicable to the lower reaches of Boggy Brook. Interim SSGVs were calculated for the forested upper reaches (see Section 5.3) however discharge of mine water to Boggy Brook reaches within the minimally disturbed forested sections is not recommended.

Recommendations to consider for Boggy Brook as a receiving environment for excess mine water discharge:

1. Given the upper reaches of Boggy Brook flow through native jarrah forest, with little/no evidence of invasive aquatic fauna, riparian weeds or other disturbances, it may be expected that the addition of mine discharge would fundamentally alter ecosystem attributes. It is therefore advised that if Boggy Brook is further considered to receive excess mine water, that the discharge point is located below the forested area (i.e. below site AL-8).
2. Should investigations into discharge into Boggy Brook continue, a hazard analysis for Boggy Brook and the Hotham River should be conducted once more information relating to the composition of discharge water is known (i.e. composition and concentration of potential analytes of concern).
3. In the interim, water quality monitoring at Boggy Brook should include hardness, nutrients (total N, total P, NOx, NO_3) and all toxicants listed in Tables 7, 8 & 9 for which there is insufficient data. Limits of reporting need to be sufficiently low for comparison against ANZG (2018) default guideline values for 95% and 99% species protection.
4. Monitoring should aim to achieve as much replication from across Boggy Brook monitoring sites as possible (i.e. rather than focussed on BGBK6 and BGBK16). This should include the full suite of analytes in each sample. Sampling should include all sites possible in both the forested and cleared sections of Boggy Brook.
5. Collection of dissolved organic carbon (DOC) data should commence as soon as surface water is present at Boggy Brook, to allow derivation of a site-specific guideline for copper. In the interim, laboratory LORs should be sufficiently low to compare

against ANZG (2023a) DGVs. Ideally, 24 months of data would be collected from sites in both the upper and lower reaches of Boggy Brook, acknowledging that monthly collection is constrained due to the ephemeral flow regime.

Table E1. Site-specific guideline values applicable to Boggy Brook, downstream of AL-8. They do not apply to reaches upstream of AL-8, which require more conservative limits. SSGVs defer to 95% DGVs unless specified. Analytes which have both and upper and a lower DGV (e.g. pH) the 20^{th} and 80^{th} percentile value is given. Refer to footnotes.

Analyte	unit	ANZG 95%	ANZG 99%	80th %ile	Interim SSGV
Al	mg/L	0.055	0.027	0.34	**0.34**
Alkalinity	mg/L	-	-	28.2	**-**
As (total)	mg/L	0.024	0.001	<LOR	**0.024**
B	mg/L	0.94	0.34	0.03	**0.94**
Ba	mg/L	-	-	0.08	**0.08**
Cd	mg/L	0.0002	0.00006	<LOR	**0.0002**[A]
Co	mg/L	0.0014	-	0.003	**0.003**
Cr (IV)	mg/L	0.001	0.00001	<LOR	**0.001**[A]
Cu	mg/L	0.00047	0.0002	0.014	**0.00047**[B]
Cyanide - free	mg/L	0.007	0.004	<LOR	**0.007**
DO	%	80 - 120	-	52 - 72	**60 - 120**
EC	(µS/cm)	250	-	9,236	**9,236**
Fe	mg/L	-	-	-	**1.0**[C]
Hardness	mg/L	-	-	271 – 1,456	**-**
Hg	mg/L	0.00006	-	N/A	**0.00006**
Mn	mg/L	1.9	1.2	0.21	**1.9**
Mo	mg/L	0.034	-	<LOR	**0.034**
N_NH_3	mg/L	0.72	0.27	<LOR	**0.72**[D]
N_NO_3 (T)	mg/L	2.4	1	-	**2.4**[E]
N_NO_X (E)	mg/L	0.2	-	0.18	**0.2**
N Total	mg/L	1.2	-	-	**1.2**
Ni	mg/L	0.011	0.008	0.03	**0.21**[F]
P Total	mg/L	0.065	-	-	**0.065**
pH	H+	6.5 - 8	-	6.7 - 7.5	**6.5 - 8**
Pb	mg/L	0.0034	0.001	0.0003	**0.0034**[A]
S_SO4	mg/L	-	-	181	**181**
Se	mg/L	0.011	0.005	<LOR	**0.011**
Temperature	C	-	-	11.2 - 17.5	**-**
TDS	mg/L	-	-	5,333	**5,333**
TSS	mg/L	-	-	17	**17**
Turbidity	NTU	20	-	-	**20**
U	mg/L	0.0005	-	0.0002	**0.0005**
V	mg/L	0.006	-	0.0008	**0.006**
Zn	mg/L	0.008	0.0024	0.03	**0.15**[F]

A – Hardness modification not recommended due to insufficient data (hardness and/or analyte)

B – ANZG (2023b) DGV at DOC =< 0.5 mg/L used, in absence of local DOC data. ANZG (2023b) is anticipated to supersede 2018 (current) DGVs.

C – Fe data not supplied for lower reaches (downstream of AL-8). SSGV is 80^{th} %ile recorded from upstream reaches, update recommended.

D - Calculated using 80^{th}%ile pH (7.1) and temperature (15ºC). See ANZG (2023a).

E - ANZG (2018) recommend use of ‘grading’ trigger values presented in Hickey et al., (2013) as 95% DGV, *in lieu* of updated guidance specific to Australia.

F – Background concentrations evident, therefore interim HMTV applied (hardness at 952 mg/L as $CaCO_3$). Hardness data for Boggy Brook is limited, therefore it strongly advised that further hardness data be collected.

Table of Contents

Tables in Text

Figures in Text

Appendices

Acronyms and Abbreviations

34MB	34 Mile Brook
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Guidelines
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BGM	Boddington Gold Mine
BOM	Bureau of Meteorology
CL	Carapace length
DBCA	Department of Biodiversity, Conservation and Attractions
DGV	Default guideline value
DPIRD	Department of Primary Industries and Regional Development
DWER	Department of Water and Environmental Regulation
EC	Electrical conductivity
EPA	Environmental Protection Authority
EWR	Ecological water requirement
HMGV	Hardness modified guideline value
IUCN	International Union for the Conservation of Nature
LoE	Lines of evidence
NBG	Newmont Boddington Gold
NWQMS	National Water Quality Management Strategy
RDA	Residue Disposal Area
SLR	SLR Consulting Australia
SSGV	Site-specific guideline value
SWWA	South-western Australia
TDS	Total dissolved solids
TL	Total length
TSS	Total suspended solids
WoE	Weight of evidence
WQMF	Water Quality Management Framework
WRM	Wetland Research and Management

1.0 Introduction

Newmont Boddington Gold (NBG) operates the Boddington Gold Mine (BGM), located 17 km northwest of the town of Boddington, and around 100 km to the southeast of Perth in Western Australia. Open pit oxide mining and stockpile processing was undertaken at the site from 1987 to 2002. After a period of care and maintenance, construction of a large scale open pit mining operation to exploit the hard rock ore body was commenced by Newmont in 2006. The current mining and processing operation was commissioned in 2009. During the oxide mining period and during the current mining period, tailings have been stored in co-located Residue Disposal Areas (RDAs). The active tailings facility is known as the F1/F3 RDA and will reach its current maximum capacity in mid-2025 at 600Mt (at stage 18). NBG submitted approvals to increase the existing facility to 750Mt in July 2023. Newmont is currently completing a feasibility study for tailings deposition into a second RDA facility once the 750Mt facility reaches capacity. The Boggy Brook creek line lies within the vicinity of the potential RDA 2 facility and hence an updated aquatic fauna and water quality survey is required to assess potential environmental impacts to Boggy Brook. In addition, the potential for discharge of excess water from mine operations to a nearby creekline may be explored as part of RDA 2 feasibility studies.

Boggy Brook is located south-east of the existing and proposed RDA facilities and is a small, ephemerally flowing creekline running predominantly through native jarrah forest. Boggy Brook has been identified as a potential discharge location for excess water from mine operations. Before considering approvals, further environmental studies are required including the aquatic fauna and ecosystem values of Boggy Brook, including an updated aquatic fauna baseline (originally completed in 2011; WRM 2012a) and development of interim site-specific water quality guideline values (SSGVs). The operation needs an understanding of receiving environment water quality to assess discharge water quality against, and to inform water treatment investigations.

SLR Consulting were commissioned by Newmont Australia to document and assess the aquatic ecological values of Boggy Brook, in order to provide supporting documentation required under the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act) and Part IV of the WA Environmental Protection Act 1986 (EP Act).

1.1 Scope of Works

The scope of work for the current project included a review of prior baseline studies at Boggy Brook and nearby ephemeral creeklines, and a repeat of 2011 baseline surveys of Boggy Brook to establish a contemporary aquatic ecosystem baseline. Boggy Brook has been identified as a potential receiving location for discharge water, thus the scope also includes development of Water Quality Guidelines/limits (i.e. SSGVs) for this system.

Specifically, the current study included:

- Systematic sampling of aquatic fauna (macroinvertebrates, fish and crayfish) and water quality (in situ, ions, nutrients and metals) for Boggy Brook.
- Assessing water quality data against the Australia New Zealand Guidelines (ANZG 2018), part of the National Water Quality Management Strategy (NWQMS). The NWQMS is an update of the previous Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) Water Quality Guidelines (ANZECC/ARMCANZ, 2000).
- Sampling design, methods and general approaches consistent with the following:
    - EPA (2018) Environmental Factor Guideline: Inland Waters. Environmental Protection Authority, Western Australia. 29 June 2018.

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018);
- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002); and,
- EPA Guidance No. 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004).

- All aquatic fauna to be identified to species level, where possible.
- Conservation status of each species recorded, and an assessment of any changes in distribution compared to previous baseline reports conducted in 2011.
- Development of interim SSGVs for the receiving environment in preparation for potential excess mine water discharge.

2.0 Environmental Setting

2.1 Climate and Rainfall

The south-west region of Western Australia has a mediterranean climate, typified by hot dry summers and mild winters. Rainfall tends to be highly seasonal, falling primarily in the winter- to early spring months (June through September), with little rainfall over the summer dry season with the exception of occasional summer storms. As such, many low order streams and rivers in the region tend to have seasonally intermittent flow regimes.

Rainfall in the study area is best represented by Bureau of Meteorology (BOM) stations Bannister (009507; approx. 9.5km from centre of study area) and Boddington North (109516; approx. 16.5km from study area). Annual rainfall for the catchment varies between 560 – 635 mm (Figure 1). As is typical for the region, rainfall predominantly occurs between June and September (Figure 2). When compared to long-term data, rainfall in the study area was below average for 2023, with an unusually dry May (**Error! Reference source not found.**). A continuing trend of declining winter rainfall has been observed across the south-west since approximately 1970, and is expected to continue to intensify as climate change progresses (McFarlane et al., 2020).

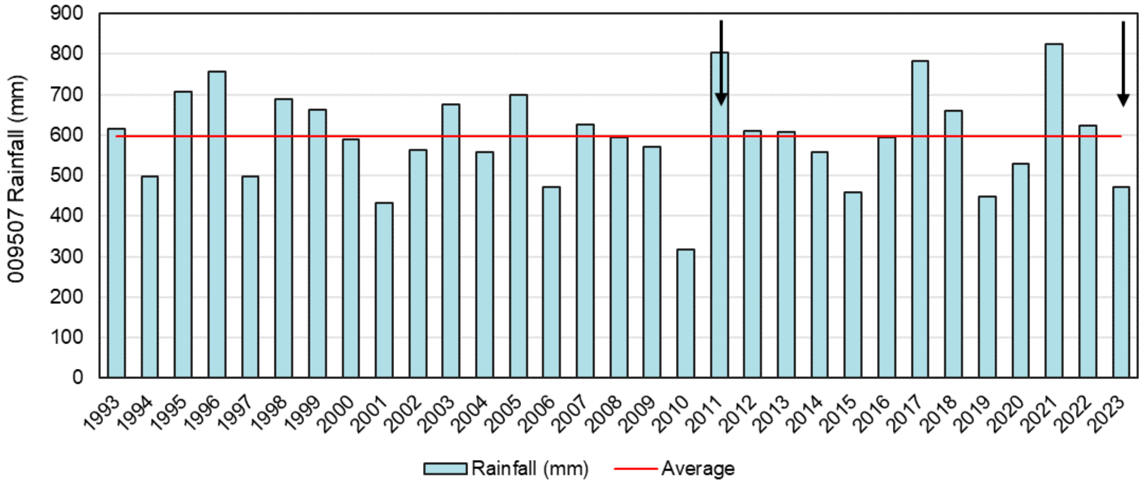

Figure 1. Annual rainfall recorded from Bannister between 1993 – 2023 (BOM 009507). Average (1993 – 2023) total is also given. Black arrows indicate timing of aquatic baseline surveys in 2011 and 2023.

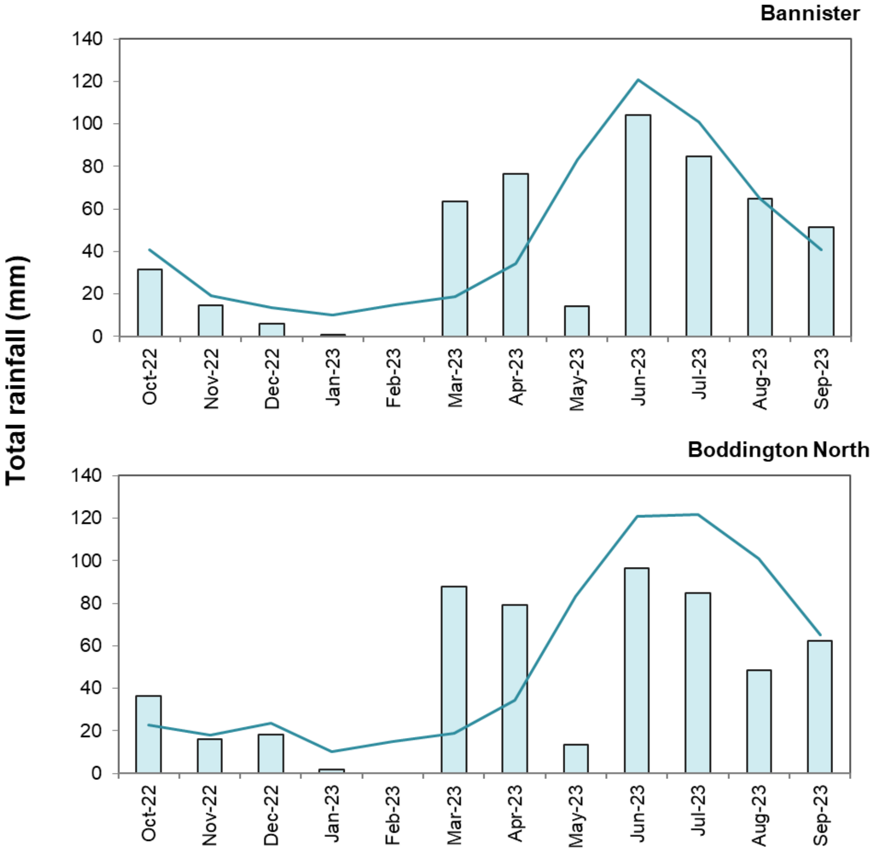

Figure 2. Total monthly rainfall (Oct-22 to Sep-23) overlain with long-term average rainfall for Bannister (1891 – 2023; BOM 009507) and Boddington North (2011 - 2023; BOM 109516) (BOM 2023).

2.2 Surface Hydrology

Boggy Brook is an ephemeral tributary to the Hotham River. Flow is typically short lived, following winter rainfall events, and drying occurs shortly following the cessation of winter rains.

Boggy Brook may be hydrologically separated into two sections, with the upper reaches flowing through forested upland catchment containing shallow ephemeral reaches, and small tea tree flats (Appendix 1). The lower reaches flow through cleared farmland, and have increased permanency, likely due to being lower in the catchment, but also receiving greater infiltration due to clearing. This is supported by observations of water quality, which show the upper reaches to be very fresh, typical of rainfall-fed headwater streams, whereas the lower reaches are brackish to saline, typical of waterways affected by secondary salinisation (WRM 2012a).

3.0 Summary of previous surveys

3.1 Methods and guidance

There are scant records of aquatic ecosystem values from Boggy Brook, with field surveys limited to the original baseline study conducted by WRM in 2011 (WRM 2012a). There have been several further surveys on nearby creeklines which may inform current baseline studies at Boggy Brook. Otherwise, the majority of available literature focusses in and around the Hotham River near Boddington and surrounds, which are unlikely to be substantively informative noting expected differences between large rivers (e.g. the Hotham River) and small ephemeral creeks (i.e. Boggy Brook). These studies are only considered if they provide further context on observations summarised below.

The conservation significance of all aquatic fauna recorded was assessed using established lists and databases, outlined below:

- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act),
- Western Australian *Biodiversity Conservation Act 2016* (BC Act) as Threatened or Priority species, as listed on the DBCA Threatened and Priority Fauna List (DBCA 2023),
- International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2023),
- Australian Society for Fish Biology Conservation List (ASFB 2018),
- Potential or known short range endemic (SRE) freshwater invertebrate species, that have naturally small distributions of less than 10,000 km^2 (after Harvey 2002), as described by the EPA (2016) for the purposes of environmental impact assessment.

All fauna recorded during the field surveys were also assessed using these conservation listings and databases (see sections 5.2, 5.3).

3.2 Summary of results

Several aquatic fauna and water quality surveys have been conducted on creeklines in vicinity of BGM, including Boggy Brook (sites AL-1, AL-6 and AL-8), House Brook (sites AL-3 and AL-4), and Wattle Hollow Brook (siteWHB1) (WRM 2012a), Jungellan Creek (WRM 2012b) and 34 Mile Brook (34MB; Bunn & Davies 1992; WRM 2012b,c) (Figure 3).

3.2.1 Water quality

The August 2011 Acquired Lands survey examined water quality and aquatic fauna on three ephemeral creeklines (Boggy, House and Wattle Hollow brooks) directly south of the BGM. All three creeklines were similar in terms of water quality, were characterized as fresh (EC 152 – 262 µS/cm), circum-neutral pH, low nutrients and low concentrations of most dissolved metals (WRM 2012a). The lowest site on Boggy Brook (AL-8) was an exception, with brackish EC (2,250 µS/cm). Elevated dissolved Al was detected at Boggy Brook (AL-1 and AL-6), but not at Wattle Hollow or House Brooks. High Cu was recorded at AL-3 (on House Brook) and Zn across most sites except AL-6. In addition, low alkalinity across creeks (<20 mg/L) suggested low buffering capacity to changes in pH. Similarly to WRM 2012a, water quality at Jungellan Brook was also found to have low EC, slightly acidic to circum-neutral pH, and low concentrations of metals and nutrients. Alkalinity was more variable, ranging from 6 to 45 mg/L (WRM 2012b). Alkalinity refers to the amount of bases in the water, which are able to buffer against changes in pH by absorbing hydrogen ions when water is acidic, and releasing them when water becomes basic (Riethmuller et al., 2001, Boulton et al., 2014).

In contrast to above, water quality at 34MB showed some influence of disturbance. 34 MB is ephemeral in the upper catchment, and semi-permanent in the lower catchment due to the influence of seepage from waste fines storage facilities and surface water storage (WRM 2012b) and altered groundwater hydrology as a result of clearing (Bunn & Davies 1992; Figure 3). A such, EC at 34MB was reported as brackish to saline (Bunn & Davies 1992; WRM 2012b,c), reflecting secondary salinisation that is prevalent across the wider Hotham River catchment (Bunn & Davies 1992; Sharafi et al., 2005; WRM 2012c). In addition, pH at 34MB was found to be significantly lower than nearby Jungellan Brook, and concentrations of sulphate, sulphur, and uranium were significantly higher (WRM 2012c). Altogether, observations of water quality attributes at nearby creeklines (and historic Boggy Brook observations) support the general expectation that differences would occur between least-disturbed, forested ephemeral streams, to creeks traversing cleared farmlands or those under direct influence of the mine.

3.2.2 Macroinvertebrates

A total of 35 macroinvertebrate taxa were recorded In the August 2011 surveys of Boggy, House and Wattle Hollow brooks (WRM 2012a). The faunal assemblage was dominated by Diptera (particularly chironomid *Parakiefferiella* sp., and larval mosquito *Aedes* sp.) and aquatic beetles, including an indeterminate *Paroster* sp. (*leai/ellenbrookensis*) at AL-1, likely a SWWA endemic (WRM 2012a). No fish or crayfish were recorded across any creekline, this along with 'low' macroinvertebrate richness was attributed to the ephemeral flow regime.

The 2012 surveys of 34MB and Jungellan Creek recorded higher taxa richness, and some key differences in assemblage composition (WRM 2012b). Although richness and assemblage composition were not statistically different between the creeklines, there were a number of sensitive taxa, including Ephemeroptera, Trichoptera and Plecoptera (EPT taxa) taxa identified at Jungellan Brook, which were absent from 34MB (WRM 2012b), and also the ephemeral creeklines studied by WRM (2012a). These included the stonefly Gripopterygidae sp., and caenid mayflies *Tasmanocoenis tillyardi*. Further studies of the macroinvertebrate fauna at 34MB also recorded several SWWA endemic taxa, including *Sternopriscus browni*, *S. multimaculatus*, the dragonfly *Nannophya occidentalis*, the damselfly *Archiargiolestes* sp. and the chironomids *Botryocladius bibulmun*, *Paramerina levidensis*, and *Paralimnophyes pullulus* (WRM 2012b,c). The SWWA endemic amphipod *Austrochiltonia subtenius* was numerically dominant across 34MB and the Hotham River (Bunn & Davies 1992; WRM 2012b,c). The composition of macroinvertebrate communities are determined (in large part) by the hydroregime of each creekline, with increasing ephemerality necessitating that taxa have traits to allow survival and persistence (Strachan et al., 2015). As a result, ephemeral creeklines are limited in the number of taxa they can support to those with specific adaptations to drying, therefore richness would be expected to be lower than nearby creeks with semi-permanent hydroregimes. Nevertheless, even ephemeral creeklines in the area (including Boggy Brook) were shown to support a number of SWWA endemic taxa.

3.2.3 Fish and crayfish

There are no prior records of fish or crayfish occurring in the ephemeral creeklines in proximity of BGM (including Boggy Brook; WRM 2012a).

Three crayfish species are known from 34MB, including native gilgies (*Cherax quinquecarinatus*) and koonacs (*C. preissii*), and the introduced invasive yabby (*C. destructor*) (WRM 2012b,c). The gilgie was also recorded at Jungellan Brook, and the smooth marron (*C. cainii*) is also known from the Hotham River and Gringer Creek (a seasonal tributary to the nearby Bannister River; WRM 2012d). The gilgie and koonac are known to disperse to seasonal creeks, and are able to construct burrows in which to over-summer, where there is shallow depth to groundwater (Austin & Knott 1996). Koonacs (particularly) frequently occur in all types of temporary waterbodies in SWWA, and are known to occur in systems where water tables fluctuate markedly (Austin & Knott 1996; Beatty et al., 2006).

Five species of fish were recorded from 34 Mile Brook and three from Jungellan Creek (WRM 2012b,c). Three small bodied native species are known from both creeks, including western minnow (*Galaxias occidentalis*), western pygmy perch (*Nannoperca vittata*) and nightfish (*Bostockia porosa*). These native fish species are all present in nearby river systems including the Hotham, and are known to migrate between rivers and tributaries during flow (WRM 2011; WRM 2012d; SLR 2024a), and have recently been reported in the upper reaches of Gringer Creek (SLR 2024b). In each of these species, breeding usually occurs in headwater tributaries during early to mid-winter (for western minnow Pen & Potter 1990a; and nightfish Pen & Potter 1990b) and spring (for western pygmy perch; Pen & Poter 1991). Therefore, connectivity between riverine and ephemeral stream habitats may be vital for maintaining populations in the local region. A fourth native fish, the south-western cobbler (*Tandanus bostocki*) was recorded at 34MB near the confluence with the Hotham River. The invasive mosquitofish (*Gambusia holbrooki*) was also common along 34MB, and alongside the yabby, were the only fish/crayfish found in reaches upstream of the pit area (WRM 2012b,c).

Patterns in the distribution of fish and crayfish across creeklines in vicinity of, and including Boggy Brook, suggest low likelihood that permanent populations of fish and/or would crayfish occur. This is especially true of fish, which may use the creekline as spawning habitat, although this appears improbable. However, there is some potential that burrowing crayfish (gilgies and koonacs) may occupy reaches of Boggy Brook, if there is suitable habitat present that is close to groundwater.

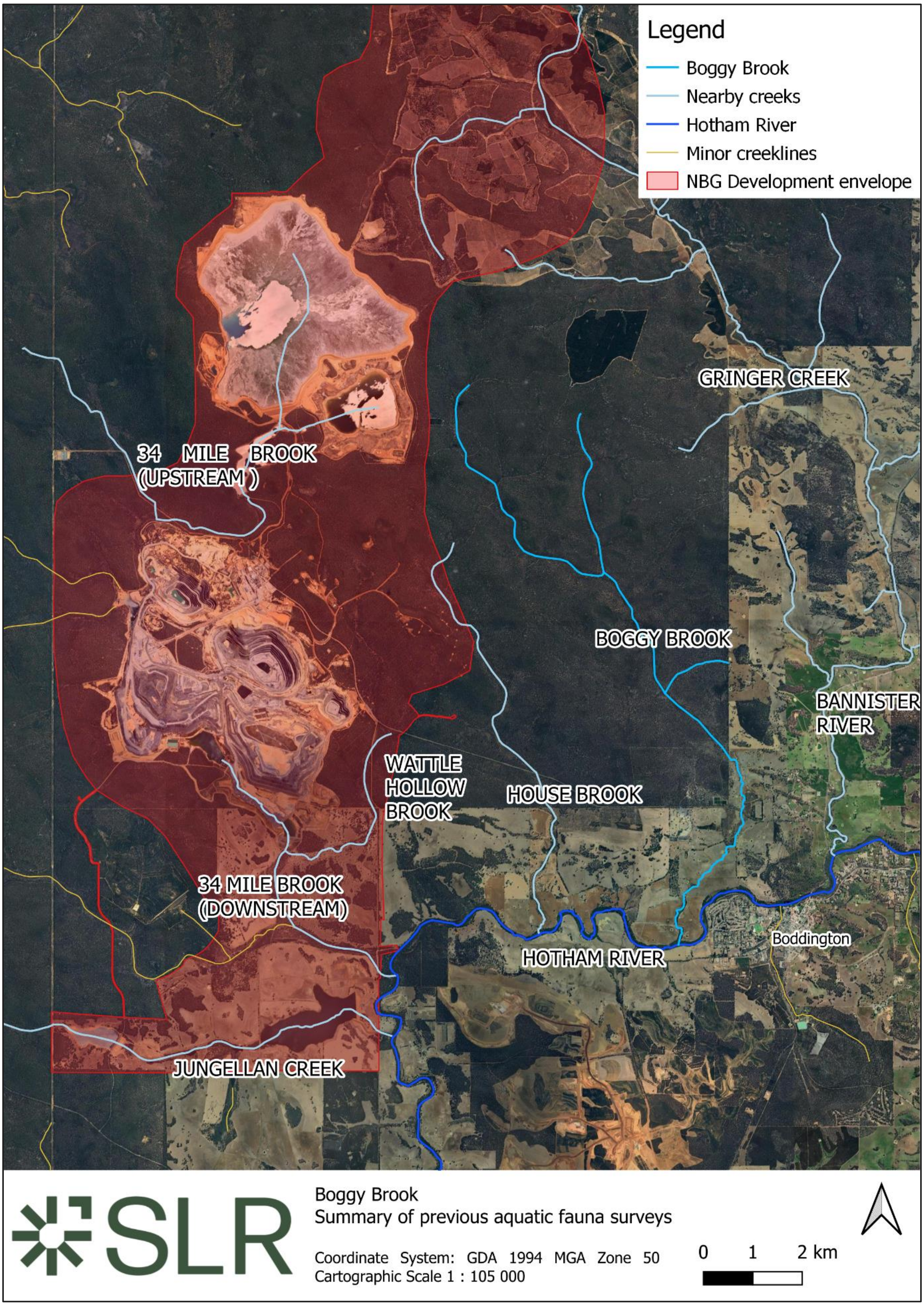

Figure 3. Creeklines in vicinity of Boggy Brook and the NBG mine, that have associated prior aquatic fauna and water quality survey data.

4.0 Field Survey

4.1 Methods

4.1.1 Guidance and general approach

4.1.1.1 EPA Environmental Factor Guideline: *Inland Water*

The baseline aquatic ecosystem survey at Boggy Brook was conducted in accordance with the EPA Environmental factor guideline *Inland Water,* broadly defined as encompassing "the occurrence, distribution, connectivity, movement, and quantity (hydrological regimes) of inland water including its chemical, physical, biological and aesthetic characteristics (quality)" (EPA 2018).

Inland waters are considered to include groundwater systems, wetlands, estuaries, and any river, creek, stream or brook (and its floodplain), including systems that "flow permanently, for part of the year or occasionally, and parts of waterways that have been artificially modified" (EPA 2018). Thus, the EPA factor is considered to include all inland waterways irrespective of duration, frequency or volume of flow or inundation. The objective of this factor is "to maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected" (EPA 2018). Environmental value is defined under the Environmental Protection Act 1986 as a beneficial use or an ecosystem health condition. Aquatic fauna and the ecological processes that support them are specifically listed in the revised Environmental Factor Guideline as one of the ecosystem health values that must be considered as part of the EIA process (EPA 2018).

4.1.1.2 Technical guidance

There are currently no prescriptive guidance statements at the state level outlining surface water quality and aquatic fauna sampling design, methods and general approaches / bioindicators. In alignment with current research however, field surveys conducted in 2023 were consistent with the following:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia (ANZG 2018);
- Australian Government 2018, Charter: National Water Quality Management Strategy (NWQMS), Department of Agriculture and Water Resources, Canberra, March. CC BY 3.0 (Aust. Govt. 2018);
- Batley, GE, van Dam, RA, Warne, MStJ, Chapman, JC, Fox, DR, Hickey, CW and Stauber, JL 2018. Technical rationale for changes to the Method for Deriving Australian and New Zealand Water Quality Guideline Values for Toxicants. Prepared for the revision of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra, ACT, 49 pp (Batley et al. 2018);
- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002);
- EPA Guidance No. 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004).
- Warne MStJ, Batley GE, van Dam RA, Chapman JC, Fox DR, Hickey CW and Stauber JL 2018. Revised Method for Deriving Australian and New Zealand Water Quality Guideline Values for Toxicants – update of 2015 version. Prepared for the revision of the Australian

and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra, 48 pp (Warne et al. 2018).

In addition, Australia's NWQMS provides authoritative guidance on the management of water quality in Australia and New Zealand (ANZG, 2018). To protect the community values of waterways (aquatic ecosystems and cultural and spiritual values), the Water Quality Management Framework (WQMF) applies a weight of evidence (WoE) process to collect, analyse and evaluate a combination of different qualitative, semi-quantitative or quantitative lines of evidence (LoE) to make an overall assessment of water quality and its associated management. Therefore, in accordance with the WQMF (ANZG 2018), water quality (physical and chemical stressors and toxicants) and aquatic fauna receptors (i.e. hyporheic fauna, microinvertebrates, macroinvertebrates, and fish) can be used to characterise and monitor ecosystem health condition.

Aquatic fauna sampling methods were also similar to the following:

- van Looj E, Storer T 2009. *Inception Report Volume 1*, Department of Water, Western Australia.
- Storer T, White G, Galvin L, O'Neill K, van Looj E, Kitsios A. 2010. *The Framework for the Assessment of River and Westland Health (FARWH) for flowing rivers of south-west Watern Australia: method development, Final report.* Water Science Technical Series, report no. 40, Department of Water, Western Australia.
- Storer T, White G, O'Neill K, Galvin L, van Looj E. 2020. *South-West Index of River Condition, Method Overview 2020*, River Science Technical Series 1, *Healthy Rivers* program, Department of Water and Environmental Regulation, Perth.

Fauna sampling was conducted under DBCA Fauna Taking (Biological Assessment) licence BA27000899 and DPIRD Fisheries Exemption 251151923.

Surveys were undertaken on the 8th of September 2023.

4.1.2 Survey sites

A total of five sites were surveyed on Boggy Brook in September 2023 (Table 1; Figure 4). Site selection aimed to revisit those used during original baseline surveys conducted by WRM in 2011 (WRM 2012a). Three of the five sites selected for sampling were dry (Appendix 1), with only the furthest upstream site AL-1 and the furthest downstream site AL-8 containing surface water. In addition, four NBG water quality monitoring sites on Boggy Brook were included in long-term monitoring datasets, but were not included in the baseline survey (Table 2; Figure 4).

Table 1. Summary of methods successfully used at each site.

Site	Type	Easting	Northing	WQ	Macro.	Box traps
AL-1	Aquatic fauna	444593	6378900	✓	✓	Insufficient depth
AL-5	Aquatic fauna	447229	6377152	DRY		
AL-6	Aquatic fauna	446774	6377524	DRY		
AL-7	Aquatic fauna	448273	6375088	DRY		
AL-8	Aquatic fauna	449382	6373915	✓	✓	✓

Table 2. NBG water quality monitoring sites used in long term data analysis.

Site	Type	Easting	Northing
BGBK6	NBG water quality monitoring	444081.7	6379881
BGBK16	NBG water quality monitoring	449722.6	6372761
BGBK17	NBG water quality monitoring	449665.9	6372347
BGBK18	NBG water quality monitoring	448490.9	6370098

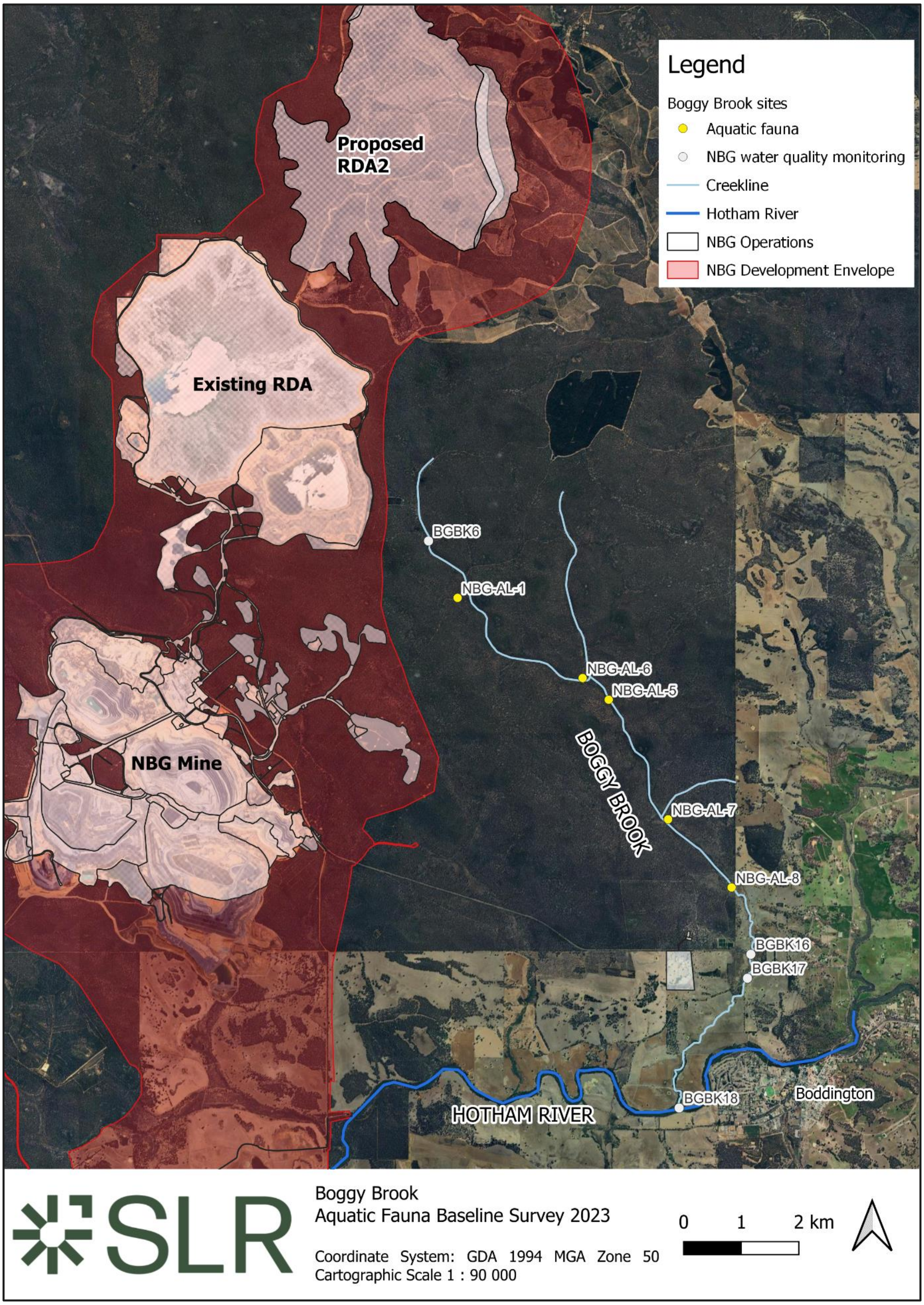

Figure 4. Survey sites on Boggy Brook, including NBG water quality only sites (BGBK6, BGBK16, BGBK17, BGBK18).

4.1.3 Field methods & data analysis

4.1.3.1 Water Quality

Water quality included *in situ* measurements of pH, conductivity, dissolved oxygen and temperature. At each site, undisturbed water samples were taken for laboratory analysis of hardness and alkalinity (as $CaCO_3$), total dissolved solids, total suspended solids, ions, nutrients (including total and dissolved forms) and dissolved metals. Field filtering for filtered samples was conducted through 0.45 µm Millipore filters. Water samples were immediately placed on ice in the field, and then refrigerated (general ions and filtered metals) or frozen (filtered nutrients) prior to transport to ChemCentre (a NATA-accredited laboratory).

Water quality data recorded in 2023 were compared to the ANZG (2018) default guideline values (DGV) for 99% and 95% species protection. The 99% DGVs are which are recommended for use in pristine-minimally disturbed systems (ANZG 2018) and are thus appropriate for Boggy Brook which runs through native forest throughout the study area. The 95% DGVs are provided for context.

4.1.3.2 Habitat characterisation

Qualitative data on aquatic habitat conditions at each site were collected using visual assessment. These data aid in interpretation of aquatic fauna diversity and abundance, given the known relationships between fauna and habitat conditions. Habitat characteristics recorded included percent cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation. Visual appraisal of substrate composition was also conducted, including percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt and clay. SLR have specific worksheets for this task so that recordings between sites remain as comparable as possible. General observations regarding the condition of site habitat and disturbance were also made, and site photographs taken. Site photographs are provided in Appendix 1, and habitat observations are provided in Appendix 2.

4.1.3.3 Macroinvertbrates

One composite macroinvertebrate sample was collected from each site. Macroinvertebrates were sampled using a 250 µm mesh D-frame dipnet. All habitats present (e.g. littoral areas, open channel, macrophyte, inundated riparian vegetation) were sampled, with the objective of maximising the number of species recorded by sampling across as many habitats as possible. All samples were preserved in the field in 100% ethanol for laboratory processing. In the laboratory, macroinvertebrates were removed from samples by sorting under microscopes. Specimens were then identified to the lowest taxonomic level (typically genus or species) and enumerated to $\log_{10}$ scale abundance classes (i.e. 1 = 1 - 10 individuals, 2 = 11 - 100 individuals, 3 = 101-1000 individuals, 4 = >1000).

4.1.3.4 Fish & Crayfish

At sites where water depth was sufficient, baited box traps were deployed overnight and collected the following morning. Fyke nets could not be used at any sites on Boggy Brook due to insufficient water depth.

4.2 Results

4.2.1 Water Quality

Generally, the water quality at AL-1 and AL-8 in September 2023 was good, with both sites having circum-neutral pH, low turbidity and total suspended solids (TSS), and low concentrations of most toxicants (Table 2). Dissolved oxygen was low at AL-8 (64.2%), however this was not unexpected given the tea-tree canopy (high detrital inputs, and inhibition of primary producers) and that sampling was conducted early in the day.

<u>Ionic Composition and Salinity</u>

Both upstream and downstream reaches were dominated by sodium (Na) cation and chloride (Cl) anion (Figure 5). Mg^{2+} and $HCO3^{2-}$ were sub-dominant at AL-8, whereas Mg^{2+} and Ca^{2+} cations were sub-dominant at AL-1.

As mentioned above, differences in ionic concentrations and salinity (EC) between AL-1 and AL-8 are most likely due to position in the catchment, proximity to cleared farmland, and differences in groundwater connectivity. Waters at AL-1 were fresh (154.1 µS/cm), reflective of the primarily rainfall driven hydroregime. Conductivity at AL-8 was greater (1,558 µS/cm), however noting this is lower than previously recorded (2,250 µS/cm in 2011; WRM 2012a) likely due to recent rainfall in the lead up to sampling in 2023. There is general acceptance that at conductivity greater than 1,500 µS/cm, freshwater ecosystems start to experience ecological stress (Horrigan et al., 2005).

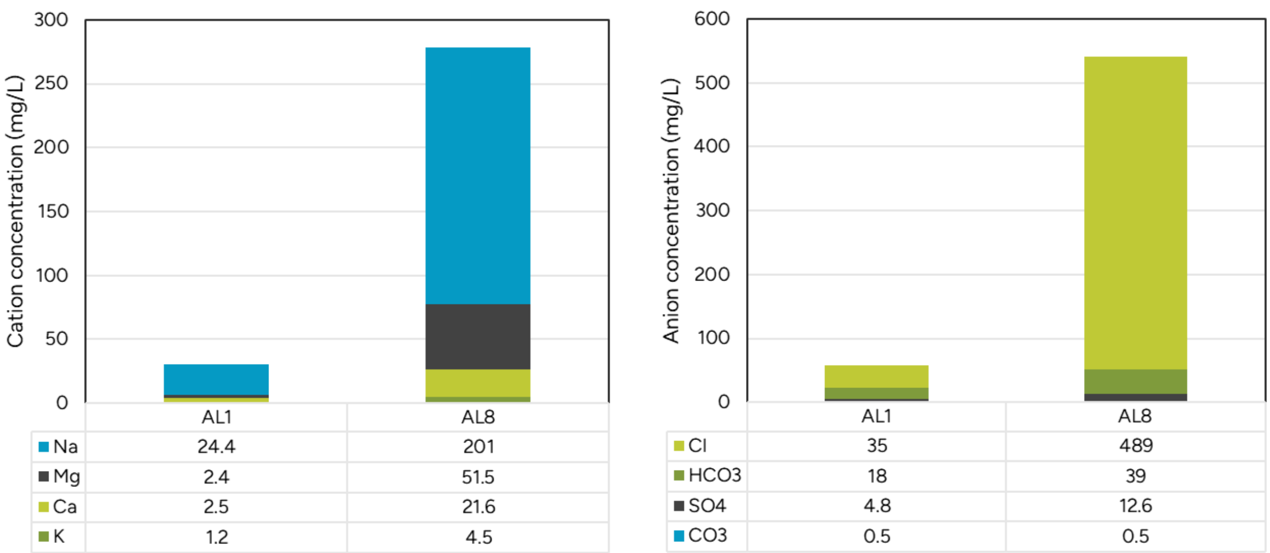

Figure 5. Ionic composition at AL-1 and AL-8, including cations (left) and anions (right).

<u>Alkalinity and hardness</u>

Alkalinity is a measure of the capacity of water to neutralise acid, and is important for aquatic fauna as it can protect against fluctuations in pH. Alkalinity of less than 20 mg/L is typically considered low. Alkalinity at AL-1 was low (15 mg/L as $CaCO_3$), whereas it was higher (but not considered 'high') at AL-8 (32 mg/L). This indicates that for the upper reaches in particular, the buffering capacity against rapid changes in pH is low.

Water hardness (expressed as mg/L $CaCO_3$) has an ameliorating effect on a number of toxicants, including metals such as Cd, Cu, Cr, Ni, and Zn, and ammonia (ANZG 2018; Warne et al., 2018; ANZG 2023a,b). DGVs are typically applicable to water hardness =< 30 mg/L, above which hardness modification is typically applied (Warne et al., 2018). Hardness was very low at AL-1 (16 mg/L), whereas it was moderately hard at AL-8 (270 mg/L).

Nutrients

Total nitrogen at AL-8 (0.94 mg/L) was above the ANZECC/ARMCANZ (2000) guidelines for SWA 'upland rivers' (0.45 mg/L), but below the DGV for 'lowland rivers' (1.2 mg/L), noting such a distinction is not supported with local data (van Looj et al., 2009). Nitrate/nitrite (NOx) and total P were below ANZG (2018) DGVs (Table 2).

Metals

The majority of metal and non-metal toxicants were below both 99% and 95% DGVs (ANZG 2018), and often below detection. Aluminium and copper were elevated at both sites, however it is unknown the proportion of which was labile (i.e. bioavailable). The bioavailability of metals is affected by a number of factors including water hardness, alkalinity, salinity and pH, as well as the form (species) of metal present. Furthermore, recent updates to guidance on the toxicity of Cu (ANZG 2023a[1]) stipulates dissolved organic carbon (DOC) as a key determinant of toxicity, to due the tendency of Cu to readily complex with DOC and thus become unavailable. ANZG (2023a) recommend collection of local DOC data with which to determine a relevant trigger value, however in the absence of data for DOC, ANZG (2023a) provide very conservative 99%, 95%, 90% and 80% DGVs using a conservatively low DOC =< 0.5 mg/L. Without local, recent DOC data (ideally paired with Cu data) it is not possible to determine the toxicity of Cu at Boggy Brook.

[1] Currently in draft, but expected to be published in near future.

Table 3. Summary of spot measures of water quality analytes recorded at Boggy Brook in September 2023, compared against ANZG (2018) DGVs for 99% and 95% species protection. Units are mg/L unless specified.

ANALYTE	95% DGV	99% DGV	NBG-AL-1	NBG-AL-8
Al	0.055	0.027	0.076	0.1
Alkalinity	-	-	15	32
As	0.0024	0.0001	0.0001	0.00027
B	0.94	0.34	<0.02	0.04
Ba	-	-	0.006	0.082
Ca	-	-	2.5	21.6
Cd	0.0002	0.00006	<0.0001	<0.0001
Cl	-	-	35	489
Co	0.0014	-	0.0003	0.0021
CO_3	-	-	<1	<1
Conductivity (µS/cm)	120 - 300	-	154.1	1558
Cr	0.001	0.0001	<0.0005	<0.0005
Cu	0.0014	0.0002	0.0006	0.0009
DO (ppm)	-	-	9.29	5.96
DO%	80 - 120	-	105.4	64.2
Fe	-	-	0.2	4.8
Hardness	-	-	16	270
HCO_3	-	-	18	39
K	-	-	1.2	4.5
Mg	-	-	2.4	51.5
Mn	1.9	1.2	0.016	0.35
Mo	-	-	<0.001	<0.001
N_NH_3	0.9	0.32	<0.01	0.02
N_NO_2	-	-	<0.01	<0.01
N_NO_3	2.4	1	<0.01	<0.01
N_NO_X	0.2	-	<0.01	<0.01
N_total	0.45	-	0.28	0.94
Na	-	-	24.4	201
Ni	0.011	0.008	<0.001	<0.001
P_total	0.065	-	0.009	0.015
Pb	0.0034	0.001	0.0003	0.0002
pH	6.5 - 8.0	-	7.26	7.61
S	-	-	1.6	4.2
Se	-	-	<0.001	<0.001
Si	-	-	1.7	2.7
S_SO_4	-	-	4.8	12.6
Sr	-	-	0.016	0.26
TDS	-	-	94	910
TSS	-	-	<1	4
Turbidity (NTU)	10 to 20	-	14.49	4.59
U	-	-	0.0004	0.0002
V	-	-	0.0006	0.0016
Zn	0.008	0.0024	<0.001	0.002

4.2.2 Macroinvertebrates

A total of 18 macroinvertebrate taxa were identified from Boggy Brook in 2023, with AL-1 recording 14 taxa and AL-8 recording eight taxa (Table 3). Excluding microcrustaceans (not identified beyond Order), this total was 13 at AL-1 and five at AL-8. Similar patterns in richness were reported by WRM 2012a, with 13 macroinvertebrates recorded from AL-1 and seven taxa each from AL-6 and AL-8. None of the recorded taxa appear on conservation lists, however the majority could not be identified to species level due to immature forms, or lack of taxonomic information. Several locally endemic species (e.g. Coleoptera, Odonata) have been recorded from nearby streams (e.g. Gringer Creek, 34 Mile Brook; WRM 2012b,c,d, SLR 2024b), therefore there is potential that specimens identified here as immature belong to locally endemic species.

The assemblage at Boggy Brook was comprised of Diptera (eight taxa), of which non-biting midges Chironomidae were the most speciose. Three larval Coleoptera (beetles) were recorded, including *Necterosoma* sp. (L) and *Platynectes* sp., as well as immature damselflies at AL-8. Whilst a comparatively depauperate assemblage by comparison to nearby systems (e.g., a total of 72 taxa were identified at Gringer Creek in September 2023; SLR 2024 in prep.), the ephemeral hydroregime at Boggy Brook would necessitate specialised adaptations for aquatic invertebrates to survive, often involving desiccation resistance (e.g. desiccation resistant eggs, or anhydrobiosis) or strong resilience traits, such as the ability to develop rapidly, and recolonise during short winter flows (Strachan et al., 2015). This would preclude many species from surviving at Boggy Brook, whereas groups where these traits are common (e.g. microcrustaceans) were more abundant (Table 2). Nevertheless, larval beetles and damselflies were recorded, as well as the pupal stages of some Diptera. Regarding the insect larvae, it is not possible to conclude whether these individuals would survive to emergence (and thus be part of a permanent population at Boggy Brook) or are the result of adult vagrancy from nearby seasonal and permanent streams.

Table 4. Macroinvertebrate taxa recorded from Boggy Brook in 2023.

PHYLUM/Class	Order	Family	Lowest taxon	AL-1	AL-8
NEMATODA			Nematoda sp.	1	0
ANNELIDA			Oligochaeta sp.	1	0
ARTHROPODA					
Branchiopoda			Cladocera sp.	0	4
Maxillopoda			Copepoda sp.	3	4
Ostracoda			Ostracoda sp.	0	2
Collembola	Poduromorpha		Poduroidea sp.	0	2
Insecta	Coleoptera	Dytiscidae	*Necterosoma* sp. (L)	2	0
			Platynectes sp. (L)	1	0
		Scirtidae	Scirtidae sp. (L)	2	4
	Diptera	Ceratopogonidae	Cerapotopogonidae sp. (P)	2	2
		Chironomidae	Chironomidae sp. (P)	2	0
			Corynoneura sp. (V49)	1	0
			Dicrotendipes sp. (V47)	1	0
			Parakiefferiella sp. (VCD2)	1	2
			Paramerina levidensis	3	0
			Tanytarsus sp. (V6)	2	0
		Culicidae	*Culex* sp.	1	0
	Odonata		Zygoptera sp. (imm)	0	2
Total richness				**14**	**8**

4.2.3 Fish & crayfish

No fish were captured at Boggy Brook in 2023, and water depth was insufficient at AL-1 to deploy box traps.

Six koonacs *Cherax preissii* were captured at AL-8. Koonacs are a south-west endemic crayfish, and are common in many aquatic habitat types across their range (Austin & Knott 1996). Koonacs are able to construct burrows, opening in the edges of streams and extending down to the water table, where they are able to shelter over-summer (Beatty et al., 2006). This enables koonacs to survive and thrive in seasonally dry wetlands and streams.

Length is not a reliable estimate for age in crayfish, however, each individual was well within adult size ranges (between 32-60mm) (Figure 6).

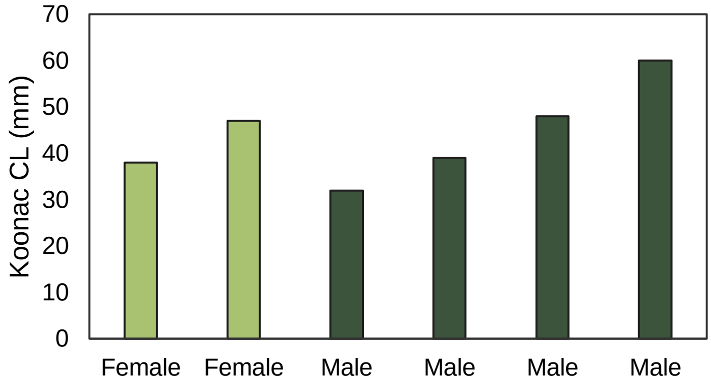

Figure 6. Sizes of koonacs *Cherax preissii* recorded at AL-8.

5.0 Longer-term water quality trends and interim SSGVs

5.1 Data compilation and methods

5.1.1 NWQMS approach

The NWQMS recommend the use of a weight of evidence approach when assessing the potential impacts to aquatic ecosystems from analytes of concern, involving multiple lines of evidence across the pressure-stressor-ecosystem receptor pathway (ANZG 2018). This may include assessment using SSGVs/ DGVs against distributions (or changes in distribution) of known sensitive receptors (e.g. macroinvertebrates, fish, zooplankton) as evidence of potential impacts and causal factors. However, in absence of direct toxicity analysis on local fauna, specific tolerances of fauna to levels of concentrations of analytes remain unknown and likelihood of impact can only be inferred. In circumstances where water quality attributes of a system persistently exceed established DGVs for 99% or 95% species protection (whichever is relevant; see footnote[2]) prior to an impact, then it is usually more informative to compare changes over time to site-specific guideline values derived from local data (ANZG 2018). SSGVs provide localised indication of changes in analyte concentrations from background

[2] ANZG recommend use of 99% DGVs for near-undisturbed systems, whereas the 95% DGVs are recommended for slightly to moderately disturbed systems (ANZG 2018).

condition. This is usually sufficient to infer likelihood of adverse impact occurring in receiving environments, in absence of direct toxicological assessment on local biota.

For the purposes of this analysis, each toxicant or stressor with sufficient data available were assessed based on the frequency of data exceeding the 99% DGV and/or 95% DGV as 'background' levels. The 99% DGV is appropriate for use in relatively undisturbed systems, and was applied to the forested upland reaches of Boggy Brook, unless specified. At AL-8 and downstream, the impacts of clearing on water quality are apparent, thus the 95% DGV for 'moderately disturbed' systems is used for comparison.

The method for deriving SSGVs recommended by Water Quality Australia for moderately disturbed systems is calculation of 80th percentile values (or 20th percentiles, for analytes for which low values are problematic, e.g. low pH or low oxygen) from a baseline or 'pre-impact' dataset, with suitable reference sites if available. For this purpose, monitoring data from Boggy Brook for physico-chemical stressors and toxicants were supplied by NBG (1987 to 2023) and baseline WQ data from WRM/SLR (2012a, 2024b) were used to calculate summary statistics including:

- Median, 20th and 80th percentiles,
- Minimum and maximum analyte concentrations,
- Proportion of data that exceeds 95% DGVs (as a percentage).

Using these lines of evidence, background concentrations of each analyte were then compared to 95% DGVs to determine whether the default guideline remains appropriate, or if baseline/pre-impact data regularly exceed the DGV and an interim SSGV is justified.

5.1.2 Data suitability

Prior to analysis, all data were screened for inclusion in calculating interim SSGVs. Data were either gathered in field (e.g. physical attributes DO, pH), or supplied from one of three NATA accredited laboratories: ALS or MPL (NBG data), or ChemCentre (WRM/SLR), over a 36 year period. For data to be useful, the laboratory limits of detection/limits of reporting (LORs) had to be lower than the DGVs, otherwise it was not possible to determine if actual concentrations were below the DGV. Unfortunately this introduced error in some datasets, where laboratory limits of detection/limits of reporting (LORs) were too high. Criteria for exclusion included: laboratory limits of detection/ limits of reporting (LORs) too high to be comparable to ANZG DGVs, erroneous/spurious values or units, malfunctioning equipment, or data derived from 'reliable estimates', and removal of duplicates. A summary of availability of cleansed data is provided in Table 4.

Table 5. Summary of water quality data from Boggy Brook, valid for use in calculation of SSGVs. Including data ranges and total number of samples (*n*) from NBG and WRM/SLR collections.

Analyte	NBG			WRM/SLR		
	Start	**End**	***n***	**Start**	**End**	***n***
Al	18-06-2022	07-09-2022	*34*	25-08-2011	08-09-2023	*5*
Alkalinity	03-05-2015	07-09-2022	*22*	25-08-2011	08-09-2023	*5*
As	27-15-1997	07-09-2022	*257*	25-08-2011	08-09-2023	*5*
B	-	-	-	25-08-2011	08-09-2023	*5*
Ba	08-06-1998	02-02-2000	*20*	25-08-2011	08-09-2023	*5*
Cd	02-09-2015	07-09-2022	*59*	25-08-2011	08-09-2023	*5*
Co	06-07-2010	07-09-2022	*62*	25-08-2011	08-09-2023	*5*
Cr (IV)	12-08-2020	07-09-2022	*9*	25-08-2011	08-09-2023	*5*
Cu	08-10-2004	07-09-2022	*64*	25-08-2011	08-09-2023	*5*
Cyanide (free)	03-09-2015	14-09-2018	*13*	-	-	-
DO	-	-	-	25-08-2011	08-09-2023	*5*
EC	06-08-1987	03-08-2023	*572*	25-08-2011	08-09-2023	*5*
Fe	12-08-2020	07-09-2022	*9*	25-08-2011	08-09-2023	*5*
Hardness	08-06-1999	04-09-2001	*13*	25-08-2011	08-09-2023	*5*
Hg	05-08-2014	21-08-2018	*5*	-	-	-
Mn	24-07-1990	07-09-2022	*147*	25-08-2011	08-09-2023	*5*
Mo	-	-	-	25-08-2011	08-09-2023	*5*
N-NH3	-	-	-	25-08-2011	08-09-2023	*5*
N-NO3	-	-	-	25-08-2011	08-09-2023	*5*
N-NOX	-	-	-	25-08-2011	08-09-2023	*5*
N Total	-	-	-	25-08-2011	08-09-2023	*5*
Ni	31-07-1990	07-09-2022	*97*	25-08-2011	08-09-2023	*5*
P Total	-	-	-	25-08-2011	08-09-2023	*5*
pH	04-02-1988	03-08-2023	*465*	25-08-2011	08-09-2023	*5*
Pb	06-10-2008	15-02-2017	*6*	25-08-2011	08-09-2023	*5*
Sb	12-08-2020	07-09-2022	9	-	-	-
S-SO4	08-06-1998	07-09-2022	*50*	25-08-2011	08-09-2023	*5*
Se	27-06-2011	07-09-2022	*52*	25-08-2011	08-09-2023	*5*
Temperature	14-07-2001	03-08-2023	*78*	08-09-2023	08-09-2023	*2*
TDS	06-08-1987	03-08-2023	*621*	25-08-2011	08-09-2023	*5*
TSS	-	-	-	08-09-2023	08-09-2023	*2*
Turbidity	14-07-2001	01-09-2010	*8*	25-08-2011	08-09-2023	*5*
U	-	-	-	25-08-2011	08-09-2023	*5*
V	-	-	-	25-08-2011	08-09-2023	*5*
W	12-08-2020	07-09-2022	9	-	-	-
Zn	06-08-1990	07-09-2022	*141*	25-08-2011	08-09-2023	*5*

5.1.3 Limitations of the current dataset

Although water quality data for Boggy Brook are available as far back as 1987 for some analytes, there were a number of issues with the datasets which reduced the confidence in some inferences about background analyte concentrations.

A number of analytes had levels of reporting (LORs) that were not suitable for comparison to ANZG (2018) freshwater ecosystem guidelines (99% or 95% species protection), such as Cd, Hg and Mo. Where the LORs are far higher than the DGVs it is not possible to determine if the actual concentration was above or below the DGV. Rather than use the LOR as the assumed concentration and thereby conclude numerous exceedances, the data were excluded on a QAQC basis. Some analytes had LORs suitable for recreational water quality guidelines (e.g. ANZECC/ARMCANZ 2000; section 5.0) including cyanide, but these guidelines are not protective of ecological values. Other analytes had LORs (for the majority of data) that were suitable for comparison to 95% DGVs, but not 99% DGVS (e.g. Al, As).

Analytes including dissolved oxygen, vanadium, uranium, and nutrients (including total N and total P, NOx, nitrate and ammonia) were not measured other than WRM (2012a) and the present survey.

In cases where the LOR is equal to or just above DGV (such as for the majority of Cu data) all detections (i.e. over LOR) by necessity exceed DGVs. This in effect removes all low values from statistical analysis, and skews the dataset toward exceedances. In this case, statistical analysis was conducted to provide context only, and were not used to inform interim SSGVs.

Data collection over time for the majority of analytes was not spatially or temporally even. The majority of measurements for many analytes were taken at BGBK16, which is adjacent to Gold Mine Road and thus potentially confounded by the road as a point source. Where analytes appear locally elevated at BGBK16, this site was excluded from analysis. Other than BGBK16, the greatest number of observations were from BGBK6 (furthest upstream, near the mine), with few data from any other sites (representative examples provided in Appendix 3).

Regular, consistent collection across all sites is the ideal to reduce spatial/temporal confoundment in the dataset for inclusion in calculations of full operational SSGVs. However, this is in acknowledgement that the hydroregime at Boggy Brook is highly ephemeral, and unpredictable, therefore datasets are always likely to be ‘patchy’ in terms of coverage. Because of this, a conservative approach was taken in deriving interim SSGVs for Boggy Brook, defaulting to the ANZG (2018) DGVs unless data were deemed sufficiently robust to justify an interim SSGV. Because of the temporal and spatial data gaps, and inconsistencies in long-term monitoring, it is only possible to provide interim SSGVs for Boggy Brook (rather than full operational SSGVs). Any ongoing data collection at Boggy Brook should aim to capture as many sites as possible at a given time, and include all analytes in each batch (i.e. all of those currently recorded, in addition to those outlined in section 8.0). Ideally sampling should include early, mid and late in the flow season for this ephemeral system each year, using LORs that allow comparison with 99% DGVs. Sampling should include sites within and outside the forested area, as water quality was distinctly different between the two areas, likely reflecting groundwater contribution to the creek flowing through cleared areas, and therefore separate SSGVs are required for forested and cleared lands.

5.1.4 Updated ANZG guidance

Since the ANZG (2018) guidelines were published, there has been further updated guidance regarding the ameliorating effects of some water quality attributes on the bioavailability of some toxicants. Recent draft guidance for toxicants including Cu and total ammonia is based on improved understanding of interactions between these toxicants and hardness, pH, temperature (for total ammonia) or dissolved organic carbon (DOC) (for Cu), in determining actual bioavailability to aquatic organisms (ANZG 2023a; ANZG 2023b). These updated guidelines are still in draft form, but are expected to be published in the near future and thus are included in the derivation of interim SSGVs for Boggy Brook.

The requirement for paired toxicant, hardness, pH and temperature (for total ammonia) and DOC (for Cu) data to assess the actual toxicity of these analytes at Boggy Brook is a limitation in the current dataset, which can be addressed using approximations given in ANZG (2023a & 2023b) (see below). In particular, hardness (defined as the aqueous concentration of calcium and magnesium ions, and expressed as mg/L $CaCO_3$) in freshwaters has an ameliorating effect on further metal toxicants, including Cd, Cr, Ni and Zn, to which hardness-modified trigger values (HMGVs) are applied in waters with hardness > 30mg/L $CaCO_3$ (Warne et al., 2018; ANZG 2018). High hardness is also indicated in amelioration of toxicity effects of nitrate (NO_3) in Pilbara waterways (defined as >160 mg/L; van Dam et al., 2022), however specific guidance beyond that region is yet to exist.

There is a small dataset with which to assess water hardness at Boggy Brook, including WRM/SLR measurements and sporadic measurements from BGBK6 and BGBK16 supplied by NBG (n = 18 in total). Furthermore, there is a clear divide in hardness data between upstream and downstream reaches (see section 5.1.1), giving n = 6 at sites upstream of AL-8, and n = 12 at AL-8 and BGBK16. Given the importance of hardness in calculating specific toxicity values for a number of analytes, this omission in regular monitoring is a limitation in the current dataset. Collection of these data prior to commencement of discharge should be undertaken to address these gaps, to assist formalisation of interim SSGVs to full SSGVs for ongoing use at Boggy Brook if required.

Ammonia:

Updated guidance is available based on new ecotoxicity data for total ammonia-N (hereafter TAN) in freshwaters (ANZG 2023b). The guidelines take into account the effects of both pH and temperature on the relative proportions of un-ionised NH_3 and ionised NH_4^+ in total ammonia-N. Un-ionised NH_3 readily diffuses across cell membranes of aquatic animals and is thus more toxic than ionised NH_4+, and occurs in higher proportions as pH and temperature increase, thereby increasing toxicant uptake by biota. ANZG (2023b) provide 95% and 99% DGVs[3] for ammonia at pH 7.0/20ºC and pH 8.0/20ºC, however adjusted DGVs are recommended where local pH and temperature data are available. Adjusted DGVs for TAN mg N/L are provided for a range of pH and temperatures (ANZG 2023b [Appendix D]). Generally, the laboratory derived total ammonia (expressed as NH_3-N) is directly comparable to the DGVs for total ammonia[4].

The SSGV for Boggy Brook was derived using the whole dataset of pH and temperature, applying the 80th percentile values for each (pH 7.5, temperature 17ºC) to the table provided in ANZG (2023b). Should the distribution of pH and or temperature change substantively following commencement of discharge to Boggy Brook, then the toxicity of ammonia present would also change, and a new interim SSGV would need to be calculated and applied.

Copper:

Hardness modification (as in Warne et al., 2018) is no longer recommended for Cu, as DOC and pH are now understood to have a greater effect on the bioavailability of Cu. In absence of local DOC data, adoption of the 95% DGV, at the standardised conservative DOC of =<0.5 mg/L is the recommended approach. These values are applicable at pH 6.5 – 8.0 and hardness of 2 – 200 mg/L (which applies to the upper reaches of Boggy Brook). Ideally, future water quality monitoring would include regular collection of DOC data with which to derive actual toxicity of Cu in Boggy Brook[5], as the default values are likely to be overly conservative.

Hardness modified guideline values (HMGVs) for heavy metals:

Default guideline values for Cd, Cr, Ni and Zn are standardised at hardness of 30 mg/L $CaCO_3$, and again corrections are applied to these guidelines to account for hardness (Warne et al., 2018). The default values are applicable to reaches above AL-8. However, reaches below AL-8 (inclusive) have higher hardness (see section 5.1.1). To derive an interim SSGV applicable to the lower reaches, the median hardness value recorded (12 samples = 952 mg/L) was used. The lowest value (110 mg/L; BGBK16 – 15/10/1999) directly proceeded a substantial rainfall event and likely reflects dilution.

[3] Bivalves are the most sensitive group to ammonia toxicity, therefore where bivalves are present 99% DGVs should be used.

[4] Confirmed by liason with ChemCentre (a NATA accredited laboratory).

[5] Where Cu concentrations remain well below the DGV (DOC =<0.5 mg/L), then an adjusted DGV is unlikely to be necessary (ANZG 2023a, pg. 29). However, in situations where dissolved Cu exceeds the DOC adjusted guideline values, then copper speciation should be conducted and the 'bioavailable' Cu tested against the non-adjusted DGV (i.e. DOC=<0.5 mg/L; ANZG 2023a).

5.2 Results of long-term analysis

Key analytes in exceedance of ANZG (2018) 99% and 95% DGVs are summarised in sections below. Several key spatial and temporal patterns in analyte concentrations were apparent when analysing long-term NBG monitoring data alongside baseline survey water quality data:

- Spatial differences between upstream forested reaches and downstream reaches traversing cleared farmland (particularly EC and ions);
- Strong seasonal fluctuation, indicating release from natural catchment sources with onset of rains (e.g. Al);
- Exceptional exceedances at BGBK6 on the 15-02-2017 (Al, Co, Cu, Zn), associated with a significant rainfall event. A total of 152mm recorded at Bannister 009507 between the 09-02-17 to the 12-02-17, with 115mm on the 10-02-17 (BOM 009507). 116mm was recorded at Boddington 109516 over the same period.
- Several metal analytes elevated at site BGBK16 (e.g. As, Co, Cu, Pb, Zn), indicating a point source of toxicants, potentially associated with proximity to the road or a groundwater source.

5.2.1 Water quality differences between upstream and downstream reaches

<u>Electrical conductivity</u>

In congruence with observations from the present baseline survey and WRM (2012a), conductivity at sites below AL-8 were saline, in contrast to the low conductivities recorded in the forested headwaters (Figure 7). Salinities recorded throughout the lower, cleared reaches of Boggy Brook are above those known to cause osmotic stress to freshwater fauna (Hart et al., 1991; Horrigan et al., 2005).

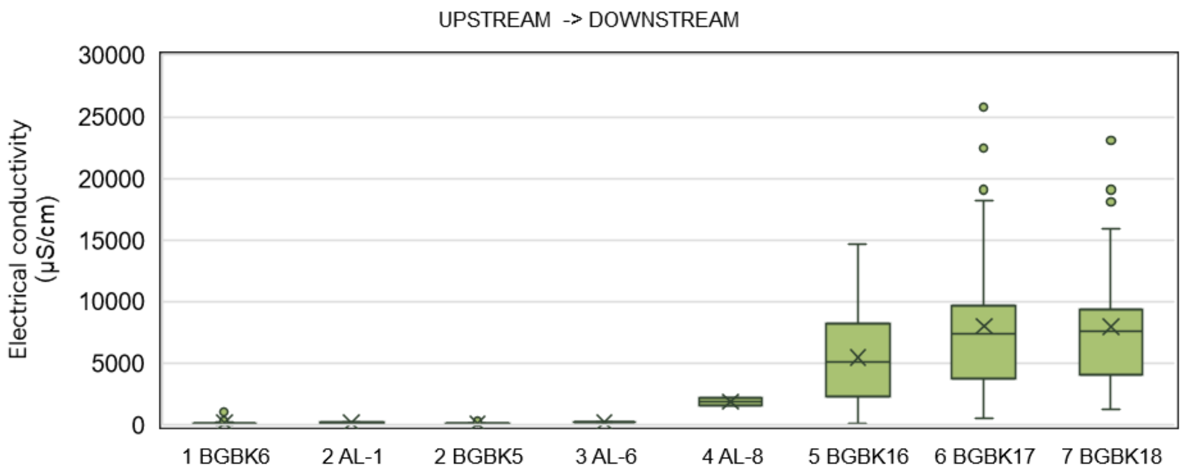

Figure 7. Distribution of conductivity data (µS/cm) recorded across Boggy Brook sites (06-08-1987 to 08-09-2023).

Hardness & alkalinity

Very few data points were available with which to assess hardness at Boggy Brook. However, examination of available data showed that a clear divide in hardness occurs between upstream sites (BGBK6, AL-1, Al-6) and downstream sites (AL-8, BGBK 16 & 17; Table 5). Water hardness is directly associated with the bioavailability of several toxicants, with higher hardness having an ameliorating effect. As such, toxicant DGVs applicable to waters with a hardness of over 30 mg/L as $CaCO_3$ are recommended to undergo hardness modification[6] (as per Warne et al., 2018; ANZG 2018) to produce HMGVs as the default guidelines for soft waters are usually overly conservative in these systems.

It is likely that the higher hardness of downstream sites is attributable to greater connectivity to groundwater, which has higher ionic concentrations than the rainwater-fed upper reaches. As such, it is recommended that for some analytes, the interim SSGVs incorporate hardness modification for the lower reaches on Boggy Brook (i.e. below AL-8).

Similarly, few datapoints were available to assess alkalinity, and the majority of data were collected from upstream sites (all NBG data from BGBK5 and BGBK6; *n* =22). Alkalinity was low (median = 15 mg/L, maximum = 32 mg/L) indicating a poor buffering capacity to changes in pH.

Table 6. Records of water hardness (mg/L as $CaCO_3$) from Boggy Brook sites. Average is given in years with *n* > 1 measurement.

	Site	Year	*n*	Hardness (mg/L)
UPSTREAM	BGBK6	1999	3	41
	AL-1	2011	1	24
		2023	1	16
	AL-6	2011	1	32
DOWNSTREAM	AL-8	2011	1	320
		2023	1	270
	BGBK16&17	1999	7	821
		2000	1	1520
		2001	2	1350

Ionic concentrations

Several ions were in higher concentrations at lower Boggy Brook sites than the upper forested reaches closer to the mine. In particular, differences in concentrations of Mg and SO_4_S were noted between upstream AL-1 to downstream AL-8 during current and historic baseline surveys (Figure 8), and there were clear differences in the concentrations of SO_4_S on downstream reaches, at concentrations higher than may be expected. Elevated concentration of ions Mg and SO_4_S are often hallmarks of neutral mine drainage, and commonly occurs in creeklines exposed to mine seepage. However, it is more likely that the ionic concentrations of the lower reaches of Boggy Brook are a reflection of the composition of regional groundwater, as similar concentrations were recorded at nearby Gringer Creek in September 2023 (SLR 2024b). Partly due to the spatially and temporally sparse data from Boggy Brook, it is not possible to speculate on the source of Mg SO_4_S, nor rule out another point source or seepage.

[6] Hardness modification allows calculation of HMGVs for 99%, 95%, 90% and 80% species protection.

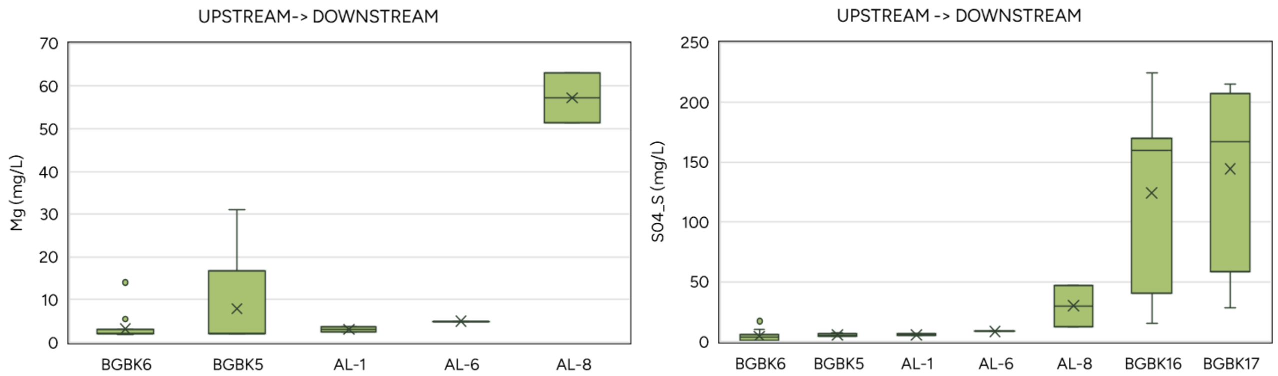

Figure 8. Distribution of Mg (left) and SO_4_S (right) data between Boggy Brook sites. NBG Mg data were limited to upstream sites, and WRM sites AL-1 to AL-8; SO_4_S data included a number of measurements from sites further downstream (BGBK16 and BGBK17).

5.2.2 Comparisons against ANZG (2018) guideline values and summary statistics

Aluminium

There were numerous exceedances of the ANZG (2018) 95% DGV at Boggy Brook, with the majority of suitable data above DGV. The median (0.5 mg/L) was an order of magnitude above the 95% DGV of 0.5 mg/L, and the 80^{th} %ile was 2.0 mg/L (Table 6). Sites on the upper reaches had higher Al than downstream (Figure 9).

Examination of a timeseries of Al data indicates exceedances are greatest with the beginning of winter rain, with the exception of the maximum value (23.8 mg/L) recorded on the 15-02-2017 associated with a summer storm (Figure 10). It is likely the source of Al is attributable to natural enrichment within the catchment, which is dominated by laterite typically high in bauxite ores.

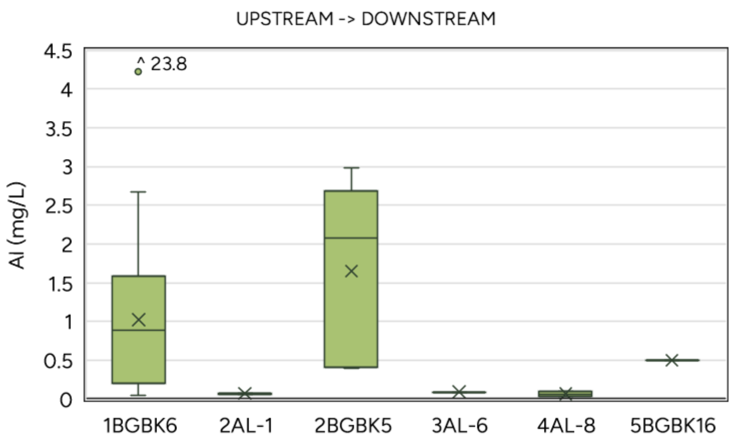

Figure 9. Distribution of Al data at each site on Boggy Brook. Sites are ordered from most-upstream to furthest-downstream. An extreme outlier (BGBK6; 15-02-2017) is labelled. The 99% DGV (0.027 mg/L) and 95% DGV (0.055 mg/L) not shown.

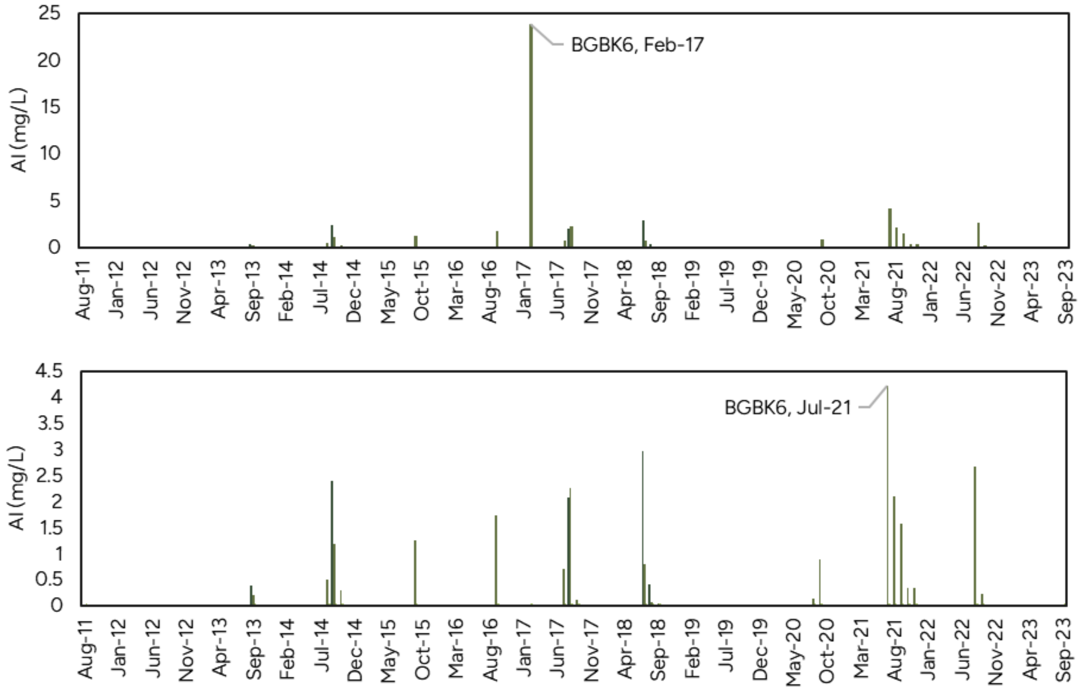

Figure 10. Records of dissolved Al over time at Boggy Brook, showing seasonal 'pulses' of Al and exceptional exceedance on the 15-02-2017 associated with a summer storm. All data presented (top), and data excluding 15/02/2017 (bottom). The 99% DGV (0.027 mg/L) and 95% DGV (0.055 mg/L) not shown.

Arsenic

There were multiple exceedances of the 95% DGV at BGBK16, to a maximum of 0.149 mg/L (09-06-1997; Figure 11). Excluding BGBK16, there were no exceedances of the 95% DGV, and two exceedances of the 99% DGV (0.001 mg/L) at BGBK6 (Figure 12; Table 6).

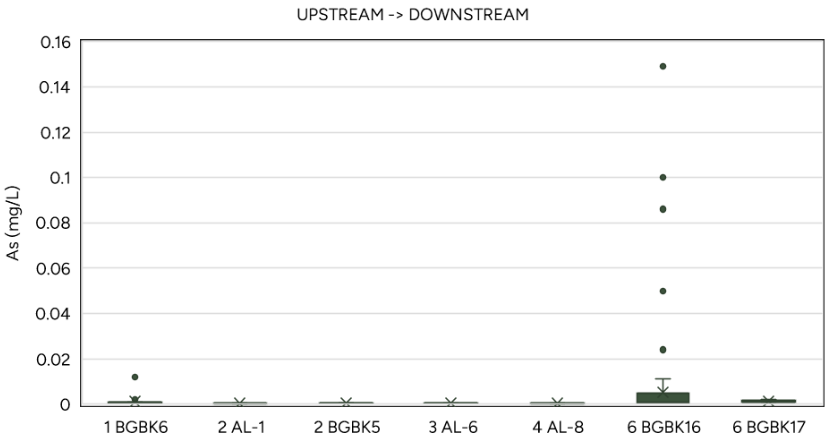

Figure 11. Distribution of As data recorded at Boggy Brook. Sites are ordered from most-upstream to furthest-downstream. The 99% DGV (0.001 mg/L) and 95% DGV (0.0024 mg/L) not shown.

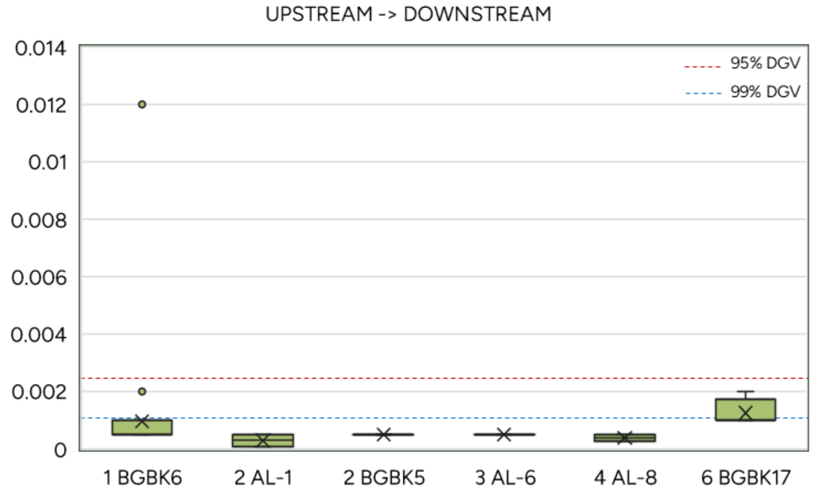

Figure 12. Distribution of As data recorded at Boggy Brook, excluding BGBK16. Sites are ordered from most-upstream to furthest-downstream. Overlain are the ANZG (2018) DGV for 95% protection (0.024 mg/L), and 99% protection (0.001 mg/L).

Cobalt

There were numerous exceedances of the ANZG (2018) DGV (0.0014 mg/L) at Boggy Brook, with the majority of suitable data above DGV, with the median (0.002 mg/L) and the 80th %ile value (0.006 mg/L) above DGV. There were several outliers recorded at BGBK16, and one exceptionally high value recorded at BGBK6 on the 15-02-2017 (Figure 13; Table 6).

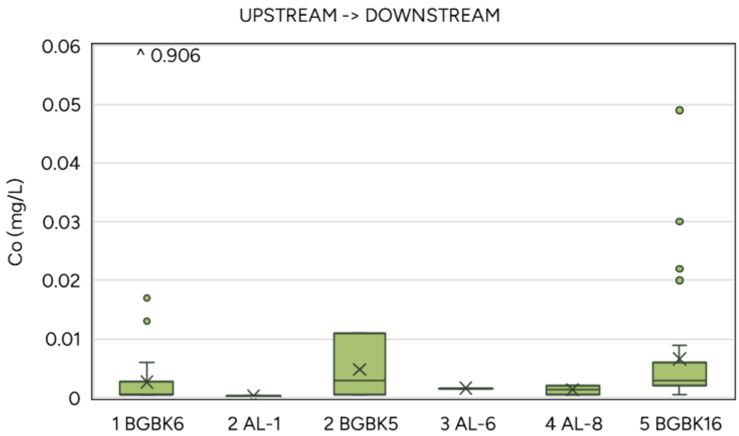

Figure 13. Distribution of Co data recorded at Boggy Brook. Sites are ordered from most-upstream to furthest-downstream. The DGV is 0.0014 mg/L, noting this is an unknown level of protection and a low reliability trigger value (not shown).

Copper

Statistical analysis of Cu data from Boggy Brook was hampered by high LORs, which were frequently above ANZG 95% and 99% DGVs (0.0014 mg/L and 0.001 mg/L respectively), meaning that of the available records, 78% were >95% DGV (Table 6). There were notable exceedances at BGBK6, to a maximum of 40.2 on the 15-02-2017, with the median value across sites of 0.004 mg/L and 80th%ile of 0.015 mg/L (Figure 14; Table 6). Current LORs are far too great for use against updated ANZG (2023a) draft guidance for DOC =<0.5 mg/L (95%

and 99% DGVs 0.00047mg/L and 0.0002 mg/L, respectively). It is recommended that further sampling for Cu use a better LOR that allows comparison to DGV for 99% species protection, and analyses include dissolved organic carbon (DOC), to enable development of relevant SSGVs for use at Boggy Brook. In the interim, it is advised that the default value (0.00047 mg/L) is used, and analysis is conducted at LOR suitable for this trigger value.

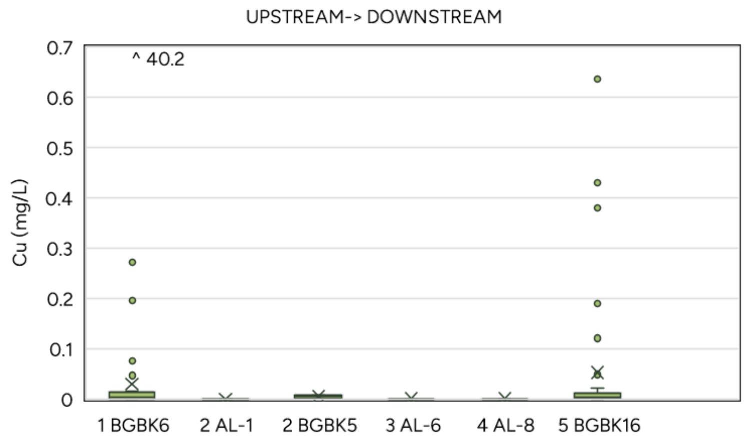

Figure 14. Distribution of Cu data recorded at Boggy Brook. Sites are ordered from most-upstream to furthest-downstream. The current 95% DGV is 0.0014 mg/L, and 0.001 mg/L for 99% species protection (ANZG 2018). Draft updates are expected to be published imminently, advising a 95% DGV of 0.00047 mg/L at DOC =< 0.5 mg/L (not shown).

Lead

The majority of exceedances of Pb were recorded at BGBK16, with the exception of one exceedance at BGBK6 recorded on the 15-02-2017, associated with a rainfall event. All other observations were well below 99% DGV (Figure 15).

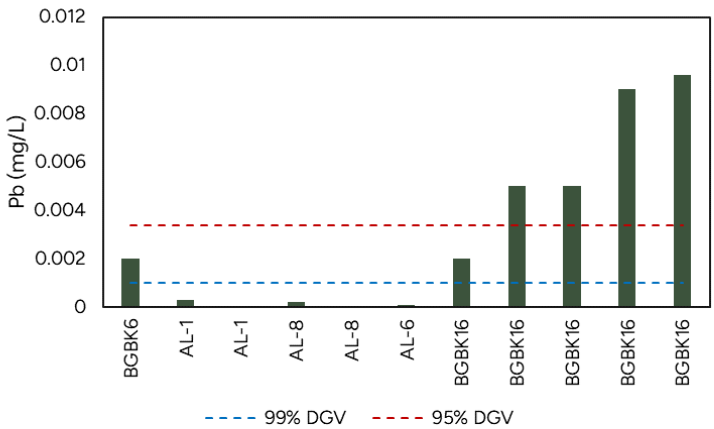

Figure 15. Concentrations of Pb recorded at Boggy Brook (unique records), compared against ANZG 99% DGV (0.001 mg/L) and 95% DGV (0.0034 mg/L).

Nickel

Because of differences in hardness between upstream and downstream reaches, analysis was conducted separately and exceedances were compared to default guidelines (upstream) or hardness-modified guidelines (downstream sites). Upstream sites recorded several exceedances in dissolved Ni, to a maximum of 1.26 mg/L (15-02-2017; Figure 16). The 80th%ile was however much lower (0.012 mg/L) and the median was <LOR (Table 6). Downstream sites (primarily from BGBK16) widely exceeded the 95% DGV (33 out of 74 records), however there were no exceedances of the 99% HMGV (0.21 mg/L; Table 6).

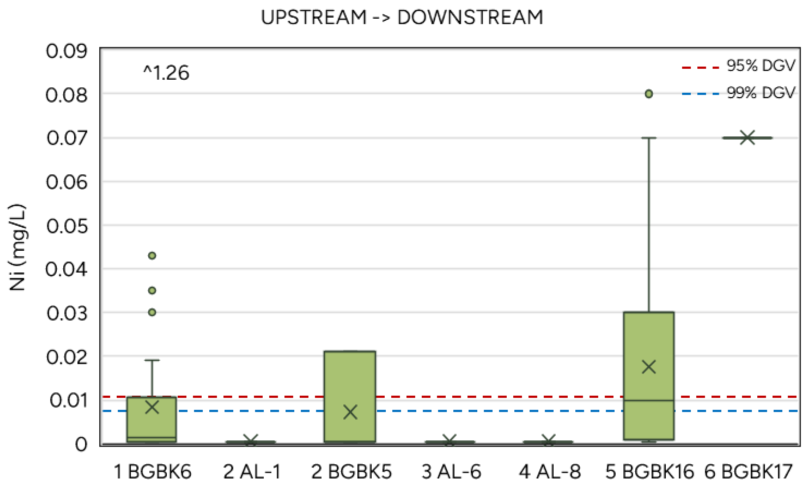

Figure 16. Distribution of Ni data recorded at Boggy Brook. Sites are ordered from most-upstream to furthest-downstream. The ANZG (2018) DGV for 95% protection is 0.011 mg/L, and 99% protection 0.008 mg/L, however hardness modification is recommended for hardness >30 mg/L as $CaCO_3$.

Zinc

Because of differences in hardness between upstream and downstream reaches, analysis was conducted separately and exceedances were compared to default guidelines (upstream) or hardness-modified guidelines (downstream sites). Upstream sites recorded frequent exceedances of dissolved Zn, to a maximum of 2.87 mg/L (15-02-2017; Figure 17). The median value (0.006 mg/L) was above the 99% DGV (0.0024 mg/L) and the 80th%ile (0.017 mg/L) well above the 95% DGV (0.008 mg/L; Table 6). Downstream sites also recorded frequent exceedances at the default values, however only a single elevation against the 95% HMTV (BGBK16; 06-10-2015 – 0.189 mg/L).

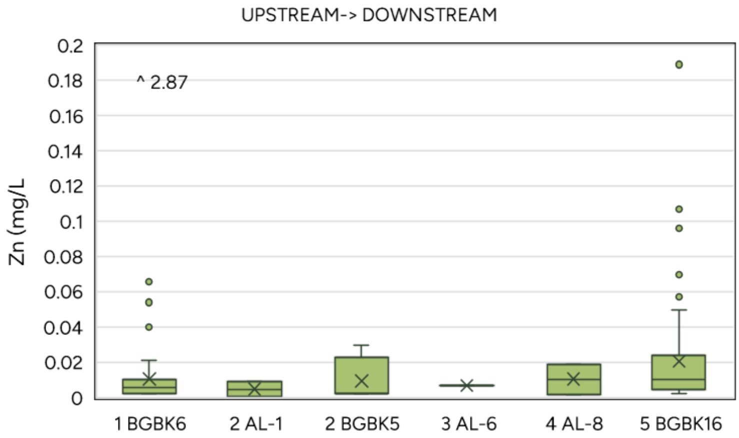

Figure 17. Distribution of Zn data recorded at Boggy Brook. Sites are ordered from most-upstream to furthest-downstream. The ANZG (2018) DGV for 95% protection is 0.008 mg/L, and 99% protection 0.0024 mg/L, however hardness modification is recommended for hardness >30 mg/L as $CaCO_3$.

Table 7. Summary of statistical analysis conducted for each analyte of interest at Boggy Brook, as part of investigations into site-specific guideline values.

Analyte	unit	*N*	ANZG 95%	ANZG 99%	Median	80th %ile	Maximum	% Exceedances		Comments
								95% DGV	99% DGV	
Al	mg/L	39	0.055	0.027	0.5	2	23.8	95%	97%	Frequently elevated in upper reaches. Lower reaches insufficient data
Alkalinity	mg/L	27	N/A	N/A	12	15	32	-	-	NBG data restricted to BGBK5 and BGBK6
As (total)	mg/L	194	0.024	0.001	0.001	0.002	0.149	2%	27%	
As (total) ex. BGBK16	mg/L	94	0.024	0.001	<LOR	0.001	0.012	0%	11%	
B	mg/L	5	0.94	0.34	0.026	0.03	0.04	0%	0%	
Ba	mg/L	25	N/A	N/A	0.034	0.076	0.26	-	-	
Cd	mg/L	64	0.0002	0.00007	<LOR	<LOR	0.012	6%	<LOR	LORs too high to compare to 99% DGV.
Co (ex. BGBK16)	mg/L	29	0.0014	-	<LOR	0.0034	0.906	41%	N/A	Outlier (max value) excluded from SSGV calculation. ANZG default is a low reliability DGV.
Co (BGBK16)	mg/L	39	0.0014	-	0.003	0.006	0.049	79%	N/A	Frequent exceedances of DGV. 62% of the data exceeds 2x DGV. Exclude from SSGV calculations
Cr (IV)	mg/L	11	0.001	0.0001	<LOR	<LOR	<LOR	N/A	N/A	
Cu[7]	mg/L	31	0.0014	0.001	0.004	0.015	40.2	78%	78%	Statistical results to be treated with caution, as for most measurements LOR was too high, skewing data to high values. Requires DOC data to update DGVs to SSGVs (ANZG 2023b).
Cyanide - free	mg/L	13	0.007	0.004	<LOR	<LOR	<LOR	0%	0%	LOR too high
DO	%	5	80 - 120		59.4	52 - 72	38 - 105	80%	N/A	
EC - US sites	(µS/cm)	142	120-300	N/A	151	240	1,076	0%		
EC- DS sites	(µS/cm)	435	120-300	N/A	5,580	9,236	25,800	100%		
Fe	mg/L	14	N/A	N/A	0.46	1.5	4.8	N/A	N/A	BGBK6, AL sites only
Hardness - US	mg/L	6	N/A	N/A	21.5	32	75	N/A	N/A	Low hardness
Hardness - DS	mg/L	12	N/A	N/A	952.5	1456	2070	N/A	N/A	High hardness - use HMTVs (Warne et al., 2018)
Hg	mg/L	5	N/A	0.00006	N/A	N/A	0.0003	N/A	40%	Majority of data LOR too high. Two exceedances at BGBK5 (0.0001) and BGBK6 (0.0003) on the 21-08-18
Mn	mg/L	152	1.9	1.2	0.039	0.21	3.1	0.6%	1.3%	
Mo	mg/L	5	0.034	N/A	<LOR	<LOR	<LOR	<LOR	N/A	NBG data LOR too high
$N-NH_3$	mg/L	5	0.72	0.27	<LOR	<LOR	0.02	-	-	Recommend using ANZG 2023a DGVs for pH 7.1 temperature 17C
$N-NO_3$ (T)	mg/L	5	2.4	1	<LOR	<LOR	<LOR	-	-	
$N-NO_X$	mg/L	5	0.2	-	0.01	0.176	0.2	0%	N/A	

[7] The updated guidance on toxicity of Cu in freshwater requires guideline values be adjusted according to dissolved organic carbon (DOC). In absence of local DOC, the default guideline for 95% and 99% species protection is 0.00047 and 0.0002 mg/L Cu at DOC =< 0.5 mg/L, respectively. This is likely to be overly conservative, but until DOC data is available, it is recommended that these new values be adopted.

Analyte	unit	N	ANZG 95%	ANZG 99%	Median	80th %ile	Maximum	% Exceedances 95% DGV	% Exceedances 99% DGV	Comments
N Total	mg/L	5	0.45	-	0.64	0.78	0.94	60%	-	Zero exceedances at DGV 1.2
Ni - US	mg/L	29	0.011	0.008	<LOR	0.02	1.26	24%	24%	
Ni - DS	mg/L	74	0.21	0.15	0.0085	0.03	0.08	0%	0%	HMTV at hardness = 952 mg/L.
P Total	mg/L	5	0.065	0.02	<LOR	0.01	0.015	0%	0%	
pH	H+	470	6.5 - 8	N/A	7.1	6.7 - 7.5	5.4 - 8.7	13%	N/A	
Pb ex. BGBK16	mg/L	11	0.0034	0.001	0.0001	0.0003	0.002	0%	9%	BGBK16 much higher than other sites
Sb	mg/L	9	0.009	-	<LOR	<LOR	<LOR	0%	-	Further data collection recommended if Sb is likely to be an issue
S-SO_4 (ex. BGBK16)	mg/L	39	-	-	4	7	46.9	-	-	BGBK16 data 1-2 orders of magnitude greater than other sites. AL-8 markedly higher than AL-1, Al-6 and BGBK6
Se	mg/L	57	0.011	0.005	<LOR	<LOR	0.07	3%	1%	Two records >LOR; BGBK16 (05-10-2011; 0.005 mg/L) and BGBK6 (15-02-2017; 0.07 mg/L)
Temperature	C	80	-	-	13.5	11.2 - 17.5	4 - 28.3	-	-	
TDS - US reaches	mg/L	175	-	-	78	110	664	-	-	
TDS - DS reaches	mg/L	451	-	-	3,107	5,333	16,676	-	-	
TSS	mg/L	224	-	-	7	16	270	-	-	
Turbidity – US	NTU	2	10 to 20	-	N/A	N/A	14.5	0%	-	
Turbidity – DS	NTU	8	10 to 20	-	17.5	45	60	37%	-	Recommend further data collection
U	mg/L	5	0.0005	-	0.0002	0.00024	0.0004	0.0%	-	Insufficient data
V	mg/L	5	0.006	-	0.0004	0.0008	0.0016	0.0%	-	Insufficient data
W	mg/L	9	-	-	<LOR	<LOR	<LOR	-	-	Consider further investigation at lower LOR if Tungsten potentially in discharge water
Zn - US	mg/L	47	0.008	0.0024	0.006	0.017	2.87	30%	98%	1 exceptional outlier (2.87 mg/L on the 15-02-2017)
Zn - DS	mg/L	100	0.15	0.045	0.01	0.03	0.189	1%	11%	HMTV at hardness = 952 mg/L. 1 exceedance of 95% HMTV: BGBK16 06-10-2015 (0.189 mg/L).

5.3 Interim SSGVs

Water quality at Boggy Brook differs between the upstream, forested reaches (primarily rainfall dominated) to the downstream reaches that traverse cleared farmland (rainfall and likely groundwater influence). Furthermore, the upstream reaches sit within natural jarrah forest with little apparent direct influence of the mine or other potential disturbance factor. In contrast, the lower reaches show water quality changes typical of secondary salinisation. Therefore, separate interim SSGVs are proposed for the two separate sections of Boggy Brook. Where a site-specific guideline is not justified, the upstream reaches defaults to the 99% DGV (Table 7), recommended for minimally disturbed systems, and for the downstream reaches defaults to the 95% DGV (Table 8) recommended for slightly to moderately disturbed systems (ANZG 2018).

5.3.1 Boggy Brook upstream section

Table 8. Site-specific guideline values applicable to Boggy Brook, upstream of site AL-8. They do not apply to AL-8 or downstream on Boggy Brook. SSGVs defer to 99% DGVs unless specified. Analytes which have both and upper and a lower DGV (e.g. pH) the 20th and 80th percentile value is given. Refer to footnotes.

Analyte	unit	ANZG 95%	ANZG 99%	80th %ile	Interim SSGV
Al	mg/L	0.055	0.027	2.0	**2.0**
Alkalinity	mg/L	-	-	15	**-**
As (total)	mg/L	0.024	0.001	0.001	**0.001**
B	mg/L	0.94	0.34	0.03	**0.34**
Ba	mg/L	-	-	0.006	**0.006**
Cd	mg/L	0.0002	0.00006	<LOR	**0.00006**
Co	mg/L	0.0014	-	0.003	**0.003**
Cr (IV)	mg/L	0.001	0.00001	<LOR	**0.00001**
Cu	mg/L	0.00047	0.0002	0.014	**0.0002**[A]
Cyanide - free	mg/L	0.007	0.004	<LOR	**0.004**
DO	%	80 - 120	-	52 - 72	**60 - 120**
EC	(µS/cm)	250	-	240	**250**
Fe	mg/L	-	-	1.0	**1.0**
Hardness	mg/L	-	-	19 - 32	**32**
Hg	mg/L	0.00006	-	N/A	**0.00006**
Mn	mg/L	1.9	1.2	0.21	**1.9**
Mo	mg/L	0.034	-	<LOR	**0.034**
N-NH_3 (T)	mg/L	0.72	0.27	<LOR	**0.27**[B]
N-NO_3 (T)	mg/L	2.4	1.0	-	**1.0**[C]
N-NO_X (E)	mg/L	0.2	-	0.18	**0.2**
N Total (E)	mg/L	1.2	-	0.78	**1.2**
Ni	mg/L	0.011	0.008	0.02	**0.02**
P Total	mg/L	0.065	-	-	**0.065**
pH	H+	6.5 – 8.0	-	6.7 - 7.5	**6.5 – 8.0**
Pb	mg/L	0.0034	0.001	0.0003	**0.001**
S_SO4	mg/L	-	-	7.0	**7.0**
Se	mg/L	0.011	0.005	<LOR	**0.005**
Temperature	C	-	-	11.2 - 17.5	**11.2 - 17.5**
TDS	mg/L	-	-	110	**110**
TSS	mg/L	-	-	7.0	**7.0**
Turbidity	NTU	20	-	-	**20**
U	mg/L	0.0005	-	0.0002	**0.0005**
V	mg/L	0.006	-	0.0008	**0.006**
Zn	mg/L	0.008	0.0024	0.017	**0.017**

A - ANZG (2023b) DGV at DOC =< 0.5 mg/L used, in absence of local DOC data. ANZG (2023b) is anticipated to supersede 2018 (current) DGVs.

B - Calculated using 80th%ile pH (7.1) and temperature (15ºC). See ANZG (2023a).

C - ANZG (2018) recommend use of 'grading' trigger values presented in Hickey et al., (2013) as 95% DGV, *in lieu* of updated guidance specific to Australia.

5.3.2 Boggy Brook downstream section

Table 9. Site-specific guideline values applicable to Boggy Brook, downstream of AL-8. They do not apply to reaches upstream of AL-8, which require more conservative limits. SSGVs defer to 95% DGVs unless specified. Analytes which have both and upper and a lower DGV (e.g. pH) the 20th and 80th percentile value is given. Refer to footnotes.

Analyte	unit	ANZG 95%	ANZG 99%	80th %ile	Interim SSGV
Al	mg/L	0.055	0.027	0.34	**0.34**
Alkalinity	mg/L	-	-	28.2	**-**
As (total)	mg/L	0.024	0.001	<LOR	**0.024**
B	mg/L	0.94	0.34	0.03	**0.94**
Ba	mg/L	-	-	0.08	**0.08**
Cd	mg/L	0.0002	0.00006	<LOR	**0.0002**[A]
Co	mg/L	0.0014	-	0.003	**0.003**
Cr (IV)	mg/L	0.001	0.00001	<LOR	**0.001**[A]
Cu	mg/L	0.00047	0.0002	0.014	**0.00047**[B]
Cyanide - free	mg/L	0.007	0.004	<LOR	**0.007**
DO	%	80 - 120	-	52 - 72	**60 - 120**
EC	(µS/cm)	250	-	9,236	**9,236**
Fe	mg/L	-	-	-	**1.0**[C]
Hardness	mg/L	-	-	271 – 1,456	**-**
Hg	mg/L	0.00006	-	N/A	**0.00006**
Mn	mg/L	1.9	1.2	0.21	**1.9**
Mo	mg/L	0.034	-	<LOR	**0.034**
N_NH_3	mg/L	0.72	0.27	<LOR	**0.72**[D]
N_NO_3 (T)	mg/L	2.4	1	-	**2.4**[E]
N_NO_X (E)	mg/L	0.2	-	0.18	**0.2**
N Total	mg/L	1.2	-	-	**1.2**
Ni	mg/L	0.011	0.008	0.03	**0.21**[F]
P Total	mg/L	0.065	-	-	**0.065**
pH	H+	6.5 - 8	-	6.7 - 7.5	**6.5 - 8**
Pb	mg/L	0.0034	0.001	0.0003	**0.0034**[A]
S_SO4	mg/L	-	-	181	**181**
Se	mg/L	0.011	0.005	<LOR	**0.011**
Temperature	C	-	-	11.2 - 17.5	**-**
TDS	mg/L	-	-	5,333	**5,333**
TSS	mg/L	-	-	17	**17**
Turbidity	NTU	20	-	-	**20**
U	mg/L	0.0005	-	0.0002	**0.0005**
V	mg/L	0.006	-	0.0008	**0.006**
Zn	mg/L	0.008	0.0024	0.03	**0.15**[F]

A – Hardness modification not recommended due to insufficient data (hardness and/or analyte)
B – ANZG (2023b) DGV at DOC =< 0.5 mg/L used, in absence of local DOC data. ANZG (2023b) is anticipated to supersede 2018 (current) DGVs.
C – Fe data not supplied for lower reaches (downstream of AL-8). SSGV is 80th %ile recorded from upstream reaches, update recommended.
D - Calculated using 80th%ile pH (7.1) and temperature (15ºC). See ANZG (2023a).
E - ANZG (2018) recommend use of 'grading' trigger values presented in Hickey et al., (2013) as 95% DGV, *in lieu* of updated guidance specific to Australia.
F – Background concentrations evident, therefore interim HMTV applied (hardness at 952 mg/L as $CaCO_3$). Hardness data for Boggy Brook is limited, therefore it strongly advised that further hardness data be collected.

5.4 Testing against SSGVs under discharge operations

The interim SSGVs proposed are intended to detect exceedances of water quality toxicant and stressors in future monitoring data for Boggy Brook. The definition of “exceedance” adopted is in line with guidance from the ANZG[8], which recommend data analysis approaches for post-impact monitoring of toxicants and stressors. For toxicants, the 95th percentile of monitoring data is compared with the DGV/SSGV, that is, an exceedance is deemed to have occurred if the 95th percentile of the monitoring data exceeds the guideline value. Because the toxicant DGVs are based on actual biological effects data, and the proportion of the values required to be less that the guideline is very high (95%), in most situations a single observation greater than the guideline would be legitimate grounds for determining that an exceedance has occurred. For stressors, the median values of the monitoring data should be below the 80th percentile value of suitable reference sites (or above 20th percentile where low values are a problem; e.g. dissolved oxygen or pH). Exceedances are determined to have occurred if the median monitoring data is greater than the 80th percentile reference data (or less than the 20th percentile, where applicable) (ANZG 2018). For most stressors, occasional spot measurements above the DGV are not considered an exceedance, rather a consistent change in monitoring data compared to baseline or reference condition needs to be demonstrated to have occurred.

6.0 Summary

This report summarised the findings of contemporary baseline surveys of Boggy Brook conducted in 2023, building on previous baseline studies conducted in 2011. Below summarises the findings of the baseline survey, and development of water quality interim SSGVs for upper and lower reaches of Boggy Brook, should this creekline be further considered for discharge of excess mine process water.

6.1 September 2023 baseline survey

Of the five sites selected for sampling on Boggy Brook, two sites held water and were sampled, with other sites dry during the survey. This reflects its highly ephemeral hydroregime, particularly in the forested upper reaches. Key findings of the field survey included:

- Water quality at AL-1 and AL-8 was generally good, with circum-neutral pH, low turbidity and total suspended solids (TSS), and low concentrations of nutrients and most dissolved metals.
- Electrical conductivity at AL-8 was greater than that at AL-1, likely due to the sites’ proximity to cleared farmland.
- Other key differences between sites included alkalinity and hardness, which were low at AL-1 and higher at AL-8
- Aluminium and copper were elevated at both sites, however it is unknown the proportion of which was bioavailable.

[8] https://www.waterquality.gov.au/anz-guidelines/monitoring/data-analysis/derivation-assessment

- A total of 18 macroinvertebrate taxa were identified from Boggy Brook in 2023, with AL-1 recording 14 taxa and AL-8 recording eight taxa (including microcrustacean groups), with similar richness recorded during the 2011 surveys (WRM 2012a). None of the taxa present appear on conservation lists.
- The native crayfish *Cherax preissii* (koonac) was captured at AL-8. Koonacs are well adapted to ephemeral flow regimes, present in temporary systems with shallow depths to groundwater.

6.2 Long-term water quality analysis and interim SSGVs

This report compiled and analysed water quality data from Boggy Brook from NBG monitoring (1987 to 2023) and WRM/SLR baseline surveys (2011 and 2023), to determine whether background levels of analytes exceed ANZG (2018) default guidelines. In cases where background levels were determined to be above default guidelines, an interim SSGV is proposed (*cf.* Warne et al., 2018).

Analytes that recorded frequent exceedances at Boggy Brook included aluminium, which is apparently released from the upper catchment with the onset of rainfall. This indicates naturally elevated background levels. Other analytes showing periodic exceedances included cobalt, copper, nickel and zinc, however it is not possible to comment on the origin of these exceedances. Further analytes were locally elevated at site BGBK16 (including arsenic and lead), which is in close proximity to the Gold Mine Road and therefore not necessarily representative of 'background' concentrations at Boggy Brook.

In agreement with observations from WRM (2012a) and the current survey, there was a clear divide in water quality attributes between upstream forested reaches and downstream cleared reaches on Boggy Brook, particularly salinity and hardness. Water hardness is directly associated with the bioavailability of several toxicants, therefore HMGVs are proposed for several analytes in the lower reaches of Boggy Brook. As well as differences in hardness, there are differences in levels of disturbance between the upstream and downstream reaches. It may therefore be inappropriate to apply one set of DGVs/SSGVs to both upstream and downstream reaches, as levels that may be of little ecological consequence in the lower reaches may have deleterious impacts of the minimally disturbed upper reaches, however, more stringent guideline values for the headwaters would fail for the lower reaches.

As well as the potential to alter water quality attributes through changing concentrations of stressors and toxicants, discharge of excess mine water to creeklines is associated with other alterations to the ecology of streams. The flow regime determines the ecosystem values of a creekline, including biotic assemblages, nutrient cycling and productivity, and artificial alteration of flow regimes will invariably alter the ecosystem receiving discharge (Poff et al., 1997; Bunn & Arthington 2002; Acuña et al., 2017). Organisms existing in ephemeral streams have life history adaptations to life in temporary waters (Williams 2006; Strachan et al., 2015). Artificially increased permanency of flow will invariably disrupt life history cues for these organisms, and allow other invertebrates typical of more permanent systems to establish, altering the assemblage composition. Excess mine water discharge has been shown to alter the physiology of riparian and floodplain trees (Argus 2018) which would be expected to suffer when the tap is 'turned off' at some point in future. Furthermore, unnatural flow regimes often encourage the establishment and proliferation of invasive biota (Bunn & Arthington 2002). The increase in primary productivity accumulates significant organic carbon, which can be recalcitrant (in the case of plants) once ephemeral flow regime returns.

7.0 Recommendations

1. Given the upper reaches of Boggy Brook flow through native jarrah forest, with little/no evidence of invasive aquatic fauna, riparian weeds or other disturbances, it may be expected that the addition of mine discharge would fundamentally alter ecosystem attributes. It is therefore advised that if Boggy Brook is further considered to receive excess mine water, that the discharge point is located below the forested area (i.e. below site AL-8).
2. Should investigations into discharge into Boggy Brook continue, a hazard analysis for Boggy Brook and the Hotham River should be conducted once more information relating to the composition of discharge water is known (i.e. composition and concentration of potential analytes of concern).
3. In the interim, water quality monitoring at Boggy Brook should include hardness, nutrients (total N, total P, NOx, NO_3) and all toxicants listed in Tables 7, 8 & 9 for which there is insufficient data. Limits of reporting need to be sufficiently low for comparison against ANZG (2018) default guideline values for 95% and 99% species protection. Ideally, 24 months of data would be used, however this may not be achievable due to the ephemeral flow regime.
4. Monitoring should aim to achieve as much replication from across Boggy Brook monitoring sites as possible (i.e. rather than focussed on BGBK6 and BGBK16). This should include the full suite of analytes in each sample. Sampling should include all possible sites both within the forested and cleared sections of Boggy Brook.
5. Collection of dissolved organic carbon (DOC) data should commence as soon as surface water is present at Boggy Brook, to allow derivation of a site-specific guideline for copper. In the interim, laboratory LORs should be sufficiently low to compare against ANZG (2023a) DGVs.

8.0 References

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Appendix 1 Site photographs

AL-1 (1)

AL-1 (2)

AL-5

AL-6

AL-7

AL-8 (1)

AL-8 (2)

Appendix 2 Habitat and substrate characteristics

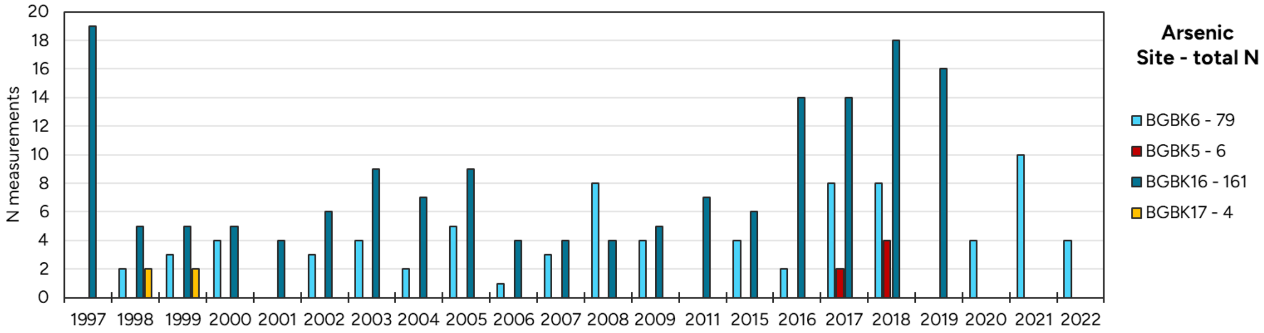
Table A2.1. Composition (as percentage) of substrate characteristics (top) and in-stream habitat types (bottom) estimated at each Boggy Brook site in 2023.

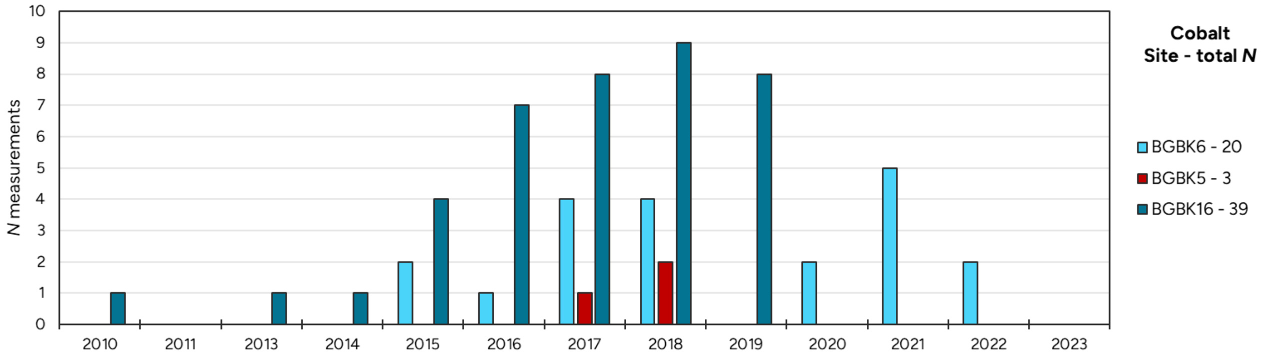
SITE	Substrate particle size								Substrate Diversity Score
	Bedrock %	Boulders %	Cobbles %	Pebbles %	Gravel %	Sand %	Silt %	Clay %	
	>256mm	64-256mm	16-64mm	4-16mm	01-Apr	1-4mm	<1mm		
NBG-AL-1	0	0	5	2	40	48	5	0	5
NBG-AL-8	0	0	0	0	0	90	10	0	2

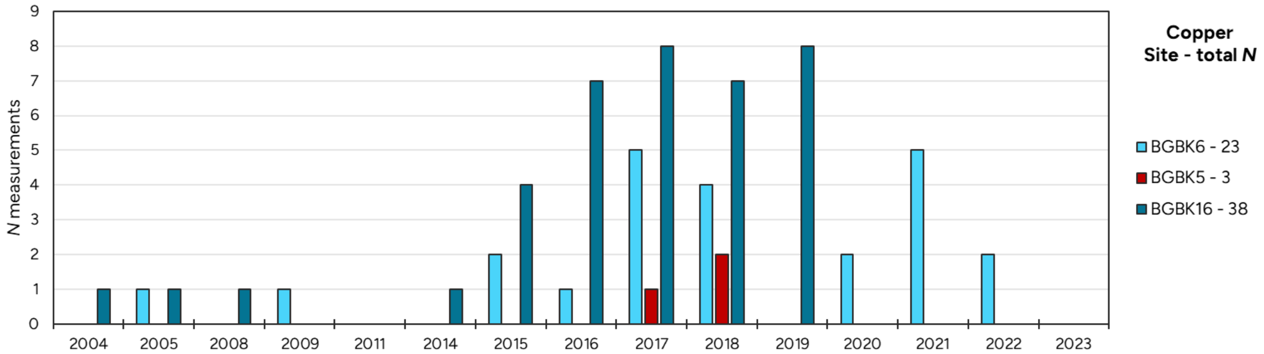
SITE	Habitat Types								Habitat Diversity Score
	Mineral %	Emergent veg %	Submergent veg %	Floating Veg %	algal cover %	Detritus %	Trailing veg %	LWD %	
NBG-AL-1	40	0	20	0	20	10	0	10	5
NBG-AL-8	69	0	1	0	0	20	5	5	5

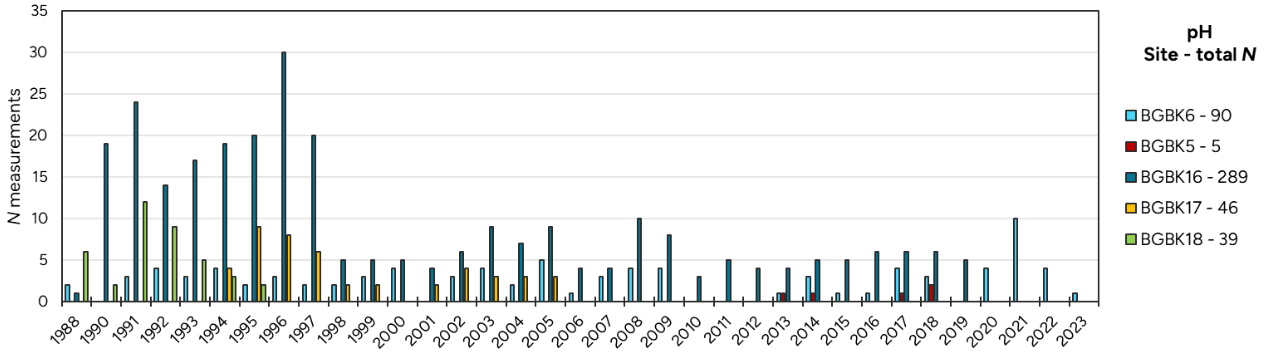
Appendix 3 Data availability

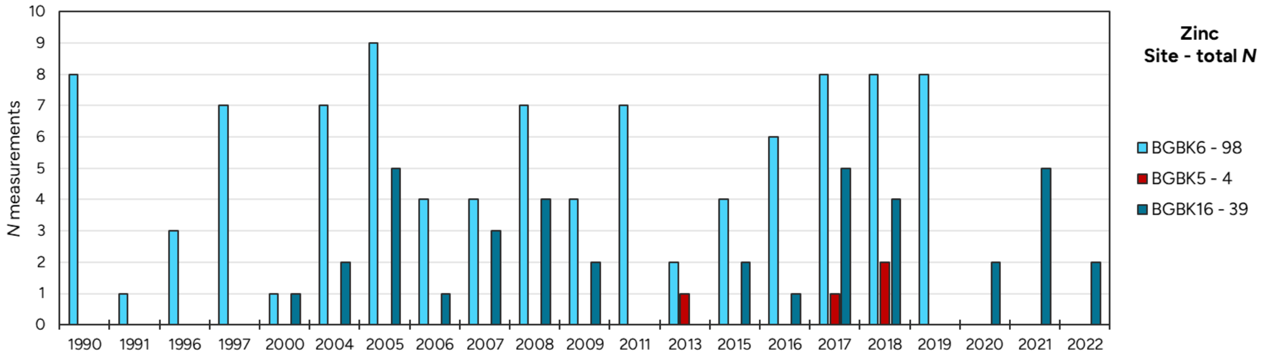
Figure A3.1 (overleaf). Plots of representative analytes Al, Co, Cu, pH and Zn, showing the number of samples per year, per site, at NBG monitoring sites on Boggy Brook.


Arsenic
Site - total N
BGBK6 - 79
BGBK5 - 6
BGBK16 - 161
BGBK17 - 4
N measurements
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2011 2015 2016 2017 2018 2019 2020 2021 2022


Cobalt
Site - total N
BGBK6 - 20
BGBK5 - 3
BGBK16 - 39
N measurements
2010 2011 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023


Copper
Site - total N
BGBK6 - 23
BGBK5 - 3
BGBK16 - 38
N measurements
2004 2005 2008 2009 2011 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023


pH
Site - total N
BGBK6 - 90
BGBK5 - 5
BGBK16 - 289
BGBK17 - 46
BGBK18 - 39
N measurements
1988 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023


Zinc
Site - total N
BGBK6 - 98
BGBK5 - 4
BGBK16 - 39
N measurements
1990 1991 1996 1997 2000 2004 2005 2006 2007 2008 2009 2011 2013 2015 2016 2017 2018 2019 2020 2021 2022

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