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Integration of surface and groundwater studies to support closure planning at the legacy Hercules Mine, Tasmania

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Abstract

MMG Limited owns and operates the Rosebery Mine in Rosebery, on the west coast of Tasmania. When the company purchased the mine in 2009, it also inherited the Hercules Mine legacy site located in the headwaters of Baker Creek on Mount Hamilton, approximately 8 km south of the Rosebery Mine.

The Hercules site is remote and located in challenging mountainous terrain, with steep slopes, unstable ground, limited level areas and high rainfall. The mined area is drained by the steeply sloping Baker Creek, which receives inputs of highly acidic (pH 2–3) metalliferous drainage (AMD) from several adits draining poorly mapped mine workings, and runoff from disseminated surface deposits of sulfidic waste rock. It has thus been a major challenge to apportion the contribution from different contaminant sources to the acid and metal load reporting to Baker Creek.

MMG is investing substantial effort to enhance its understanding of the primary sources of AMD, the relative contribution from each key source, and the key transport pathways in the system to better define rehabilitation and closure options and closure completion criteria for the site. Integrated studies of surface and groundwater quality and flows are currently underway to better understand the interaction between the various surface and underground sources, the behaviour of contaminants within them and the key drivers that need to be managed to reduce post-closure loads of contaminants to the downstream aquatic environment.

Keywords: *legacy mine, acid and metalliferous drainage, study integration*

1 Introduction

The Hercules site is remote and located in challenging mountainous terrain (Figure 1), with steep slopes, unstable ground, limited level areas and high rainfall, which occurs seasonally above the snow line. During mining, due to insufficient level area to create a waste rock dump in the steep topography, overburden and sulfidic waste rock were pushed down slope, creating scree slopes of waste rock, and a distributed rock dump within the Baker Creek valley.

Figure 1 View of Hercules Mine from the northwest

In addition to the steep terrain, a network of poorly mapped underground workings, including adits draining acidic and metalliferous drainage (AMD), ore passes and glory holes (a mining method that creates large, conical openings to the underground areas), has added to the complexity of identifying the contribution from different contaminant sources, and the transport pathways to Baker Creek (Figure 2).

The mineralisation at Hercules contains significant sulfidic material (pyrite (FeS2), sphalerite (ZnS), galena (PbS) and chalcopyrite (CuFeS2)), which, when exposed to atmospheric conditions, oxidises to produce AMD (EGi, 2018). The AMD at Hercules is highly acidic (typically, pH 2.5–3) and contains elevated concentrations of sulfate and dissolved metals, such as zinc, lead, copper, manganese and iron, that has led to environmental impacts downstream of the mine (Freshwater Systems, 2017). The AMD-impacted water in Baker Creek enters the Ring River downstream of the site, from where it travels a further 20 km past the Renison Bell tin mine tailings storage facility before entering Lake Pieman, an impoundment that was created in the Pieman River to provide feed to a hydroelectric power station (Figure 3).

The combination of the adverse physical and geochemical factors described above has resulted in an extremely challenging situation for the conceptualisation, selection and planning of potential rehabilitation works to reduce the current level of environmental impact.

As a part of the investigations being undertaken to understand the Hercules system for input to closure planning, a contaminant source study and hydrogeological assessment commenced in 2020, with a program of supplementary surface and groundwater studies (Phase 2 studies) currently in progress to address key uncertainties identified by the initial work. Close consultation with regulators and an independent peer-review panel have influenced the design of the studies.

Figure 2 Key Hercules Mine features including (a) 4 Level A1 open cut and adit; (b) 6 Level adit; (c) 5 Level adit (main); (d) 7 Level adit and weir; (e) Top of Baker Creek waste rock dump with outflow from 5 Level daylight adit to the left of upper Baker Creek; (f) Scree slopes at 6 Level

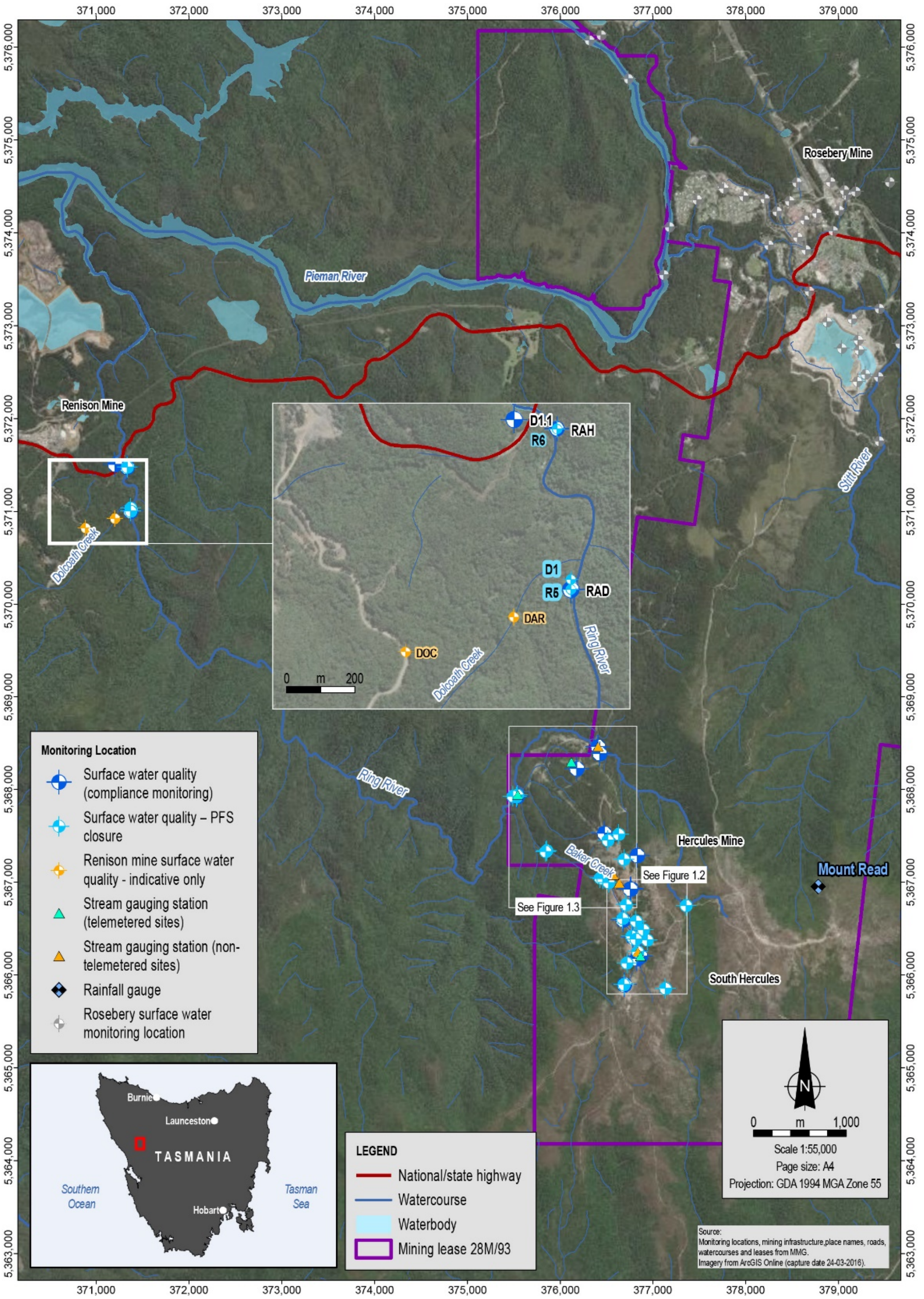


Figure 3 Hercules Mine overview

2 Contaminant source study

In the contaminant source study, a variety of assessment methods were used to investigate and quantify the key sources of contamination (with reference primarily to the adits on the four main levels: 4 Level, 5 Level, 6 Level and 7 Level). These included a review of continuous monitoring (flow, pH and electrical conductivity (EC)) data, water quality data (from routine and targeted grab samples), geochemical fingerprinting, calculation of metal loads using the continuous monitoring data, as well as further data validation exercises to reconcile the load calculations at the various monitored sites. A review of historical data and previous load calculation studies was also undertaken to provide context for the current study. Figure 4 shows a simplified schematic representation of the flow paths for the major sources of contamination.

MMG and previous owners of the site have progressively installed continuous monitoring of flow, pH and EC at a number of key locations in the impacted catchments. This was in recognition of the limited efficacy of routine grab samples to estimate loads in catchments being driven by episodic events in a high rainfall/precipitation regime and given the safety issues involved with obtaining spot samples for analysis under these extreme weather and terrain conditions. Collection of reliable continuous flow monitoring data is critical for enabling robust estimates to be made of both metals and sulfate loads (i.e. rate of delivery of total metals and sulfate as mass per unit time) to Baker Creek and the Ring River, and for providing the baseline against which the success of future implemented mitigation options can be assessed.

The locations of grab sampling points and continuous monitoring equipment (shown as stream gauging stations) are shown in Figures 3, 5, and 6.

A summary of the key contaminant source study findings is provided below.

2.1 Geochemical fingerprinting

A rare earth element (REE) geochemical fingerprinting exercise was undertaken with the aim of distinguishing contributing sources in the event that these sources have a significantly different geological provenance; for example, different parts of a mineral province having been formed at different times with different ratios of entrained elements. In this context, the suite of REEs has often been used to distinguish different contributions to groundwater flow paths (Wood et al. 2006).

Where measurable, the REEs occurring at the highest concentrations at Hercules were gadolinium, lanthanum, praseodymium, samarium and yttrium. As there was no significant difference in the signatures of the REEs between the various sources that were sampled, it was concluded that this approach could not be used to attribute the sources of metal inputs to Baker Creek.

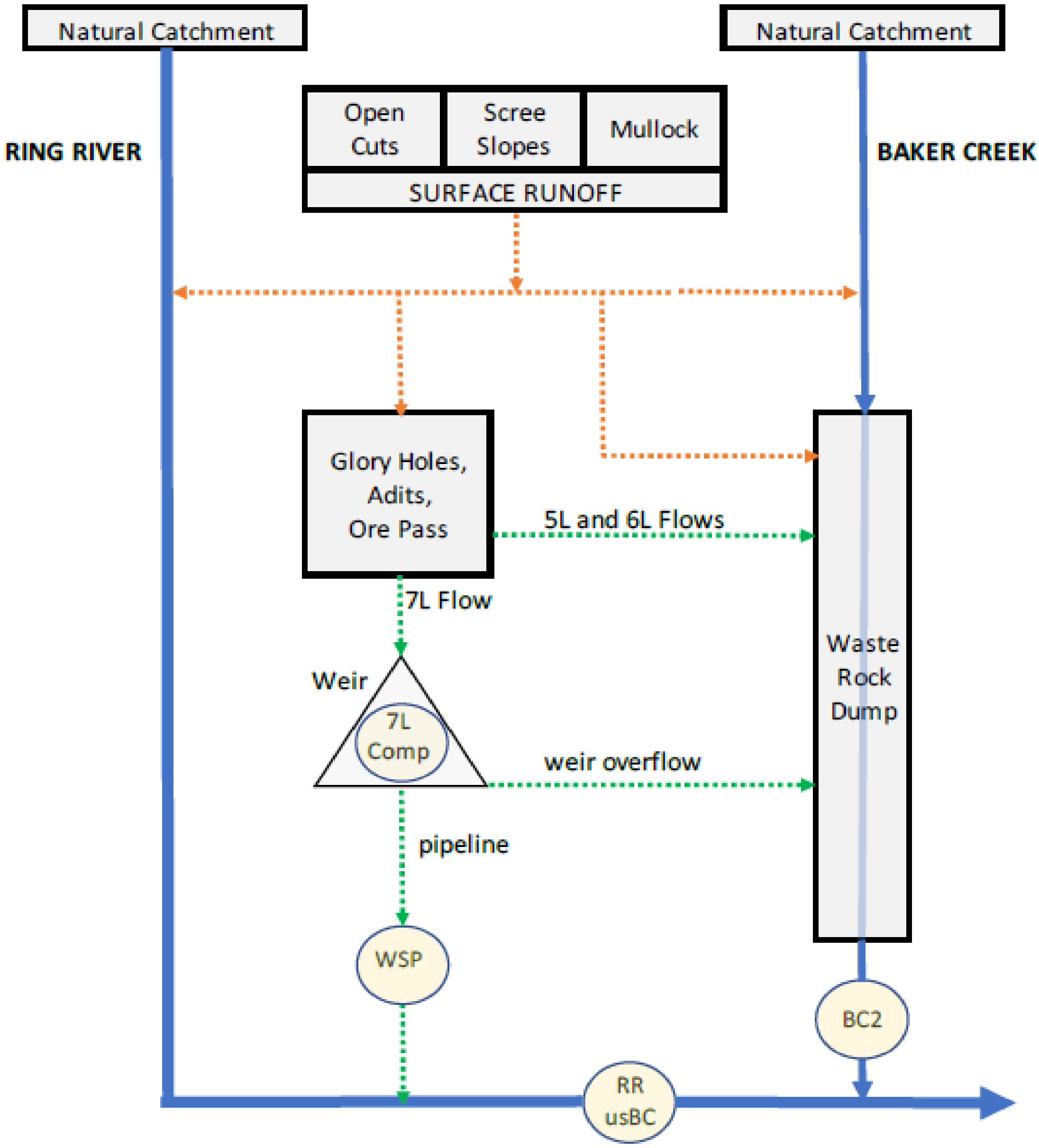


Figure 4 Overview of flow paths for major sources of AMD and metals (source: EGi 2018)

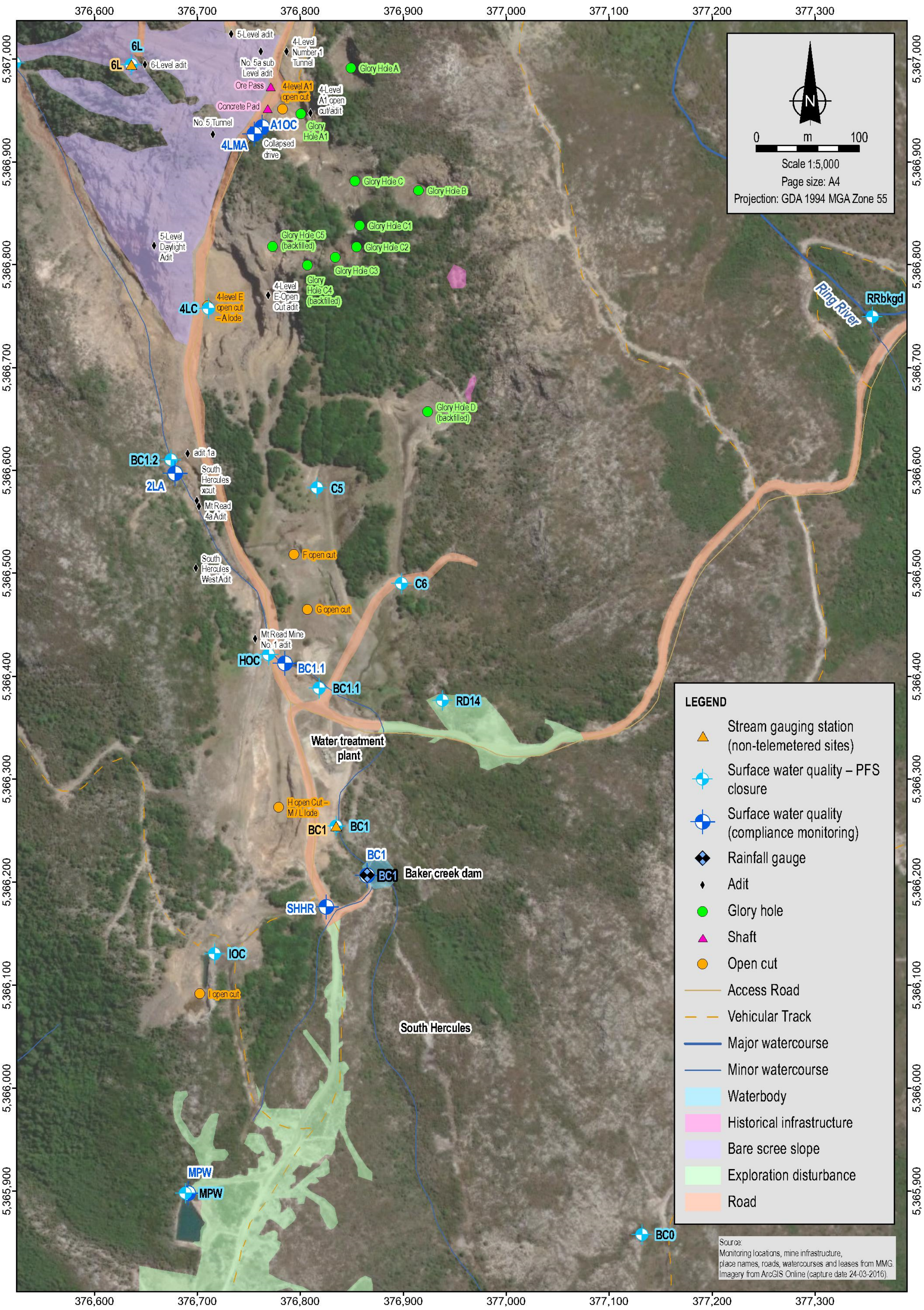


Figure 5 Hercules Mine southern portion

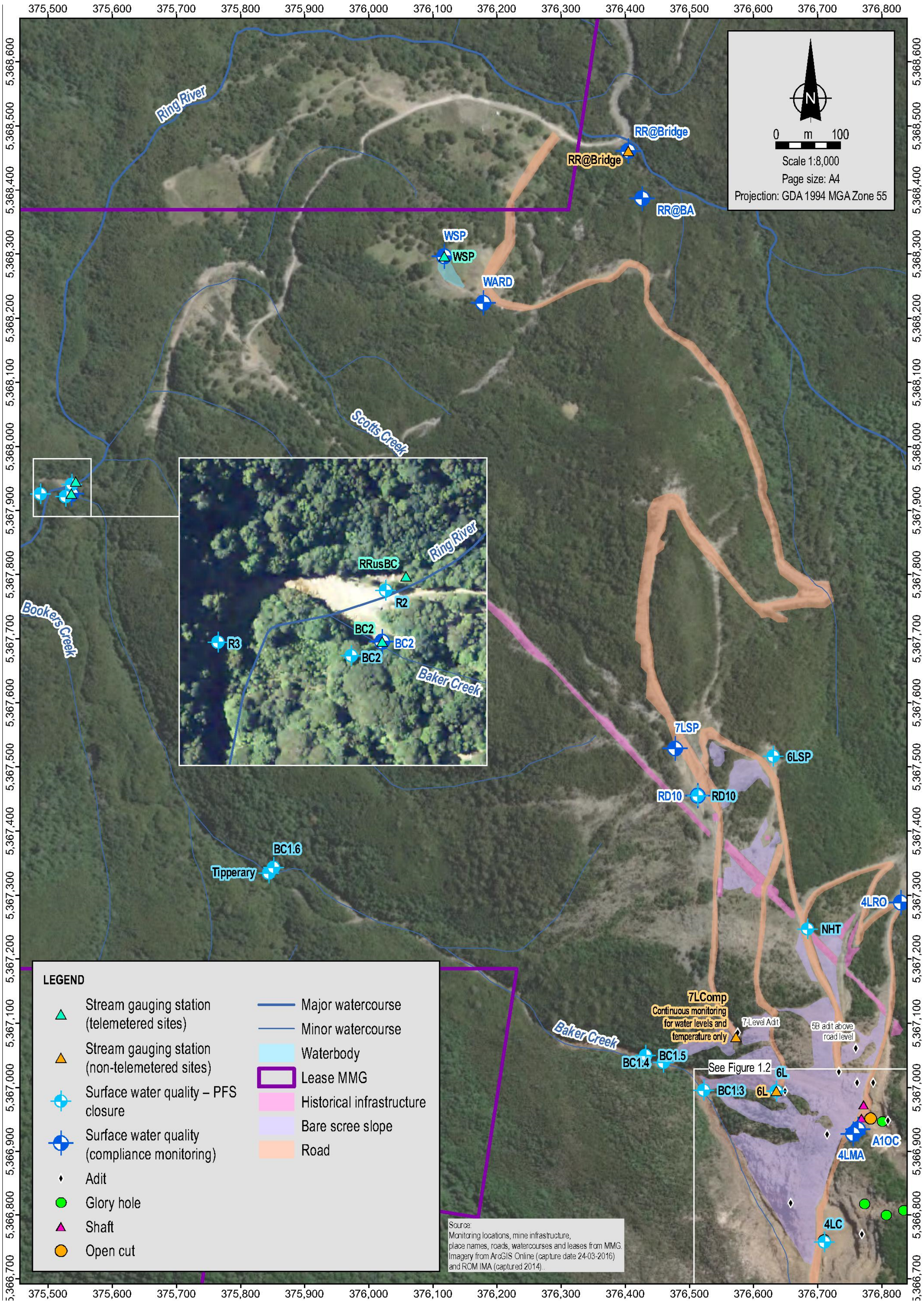


Figure 6 Hercules Mine northern portion

2.2 Metal loadings

Loads of selected metals (zinc, cadmium, copper, lead, manganese) and sulfate were calculated at the continuous monitoring sites, including adit sites (6 Level and 7 Level), Upper Baker Creek (BC1), Lower Baker Creek (BC2) and Ring River upstream of Baker Creek (RRusBC). Historical (pre-1991 to 1998) water quality and flow data for 5 Level were also used to infer loads that may be originating from this adit. MMG has since installed continuous monitoring equipment at 5 Level daylight adit and collected approximately 12 months of this data to refine the load calculations at Hercules.

A three-step process was used to calculate loads, as described below:

1. It was determined if there was a statistically significant numerical relationship between EC and the concentrations of metals measured in the grab samples collected through time from each site. The coefficient of determination (R2) of the line of best fit between concentration and EC was calculated and used to determine whether the relationship was reliable (strong) enough to be used for load calculations. An R2 value above 0.9 was deemed to be very reliable, an R2 value between 0.5 and 0.9 was considered to be acceptable, and an R2 value below 0.5 was considered unacceptable. When the R2 value was below 0.5, a constant concentration (80 percentile of the measured data) was applied across the full range of flows.
2. For each timestep in the continuous monitoring record, the measured EC was transformed into equivalent metal concentration (mg/L) using the correlation equations (or 80-percentile values) produced in the first step. The continuous flow data were then converted to litres per hour (L/h) or litres per 15 minutes (L/15 min), depending on how the continuous monitoring data was recorded, and the load for each timestep calculated by multiplying the metal concentration values (mg/L) by the flow for the relevant time period (L/hour or L/15 min).
3. The total load (expressed in kg) over the period of interest was calculated by summing the load calculated for each timestep comprising that period.

The assessment of continuous monitoring data indicated that flows from the adits are likely the most substantial sources of metals and acidity in the Baker Creek catchment. This conclusion casts doubt on the conclusions made in some previous studies (ETS 2002; Smith 1998), which suggested that the majority of the contaminant load was from the Baker Creek waste rock dump. Further work is underway to develop a final contaminant load balance, as described in Section 4.

However, based on detailed analysis of the continuous monitoring data, it was found that the sum of upstream loads was unable to be reconciled with the total load calculated at BC2 downstream. This was due to a number of identified data gaps, including unknown characteristics of flows from 5 Level daylight adit, primarily due to accessibility issues, as well as issues with the calibration of flows at the gauging station at the downstream end of Baker Creek (BC2) upstream of its junction with the Ring River (Figure 5). The problems at this location appeared to be the result of the almost constant infill of the gauge weir pool with rocks being conveyed down Baker Creek at times of high flow. To address these issues, a program of works to improve the quality and reliability of data, including installation of additional continuous monitoring stations, was implemented.

An additional 12 months of continuous monitoring data has now been collected, along with field surveys that were conducted at base flow with the aim of identifying entry points and better estimating loads and flows from each of the adits (and other potential distributed sources) into Baker Creek. Interrogation of this data is currently in progress.

To provide context for magnitude of water quality challenges at the site, 80-percentile concentrations for flows from the main adits and receiving waters based on historical data are provided in Table Table 1 with water quality guidelines.

Table 1 Summary of 80-percentile flow and selected water quality parameters at key sites at the Hercules Mine[1]

Site	Flow (L/s)	pH	EC (µS/cm)	Acidity (mg/L $CaCO_3$)	Total Cd (mg/L)	Total Cu (mg/L)	Total Pb (mg/L)	Total Mn (mg/L)	Total Zn (mg/L)	Sulfate (mg/L)
5 Level daylight adit	2.73	3.1	3,141	1,962	1.38	12.62	1.50	59.14	671	2,400
6 Level	5.95	3.04	3,088	1,640	1.21	6.89	0.75	60.50	587	2,078
7 Level (at Williamsford settling pond)	5.77	4.3	1,361	668	0.25	1.69	1.17	31.00	144	618
Ring River downstream of Baker Creek (R3B)	870	4.54	271	60	0.04	0.23	0.40	4.50	22.30	90
ANZG (2018)[2]	–	6.5 to 7.5[3]	30–350[3]	–	0.0002	0.0014	0.0034	1.9	0.008	–

[1] Based on data collected in 2021 and 2022.

[2] Australian and New Zealand guidelines for fresh and marine water quality (2018).

[3] For Upland Rivers in Tasmania (DPIPWE 2021).

3 Conceptual groundwater study

A preliminary groundwater investigation was undertaken simultaneously with the contaminant source study described above to develop a conceptual model of the study area for the purposes of identifying potential AMD groundwater transport pathways resulting from mining activities and in turn potential risks to receptors.

Two groundwater processes with a **moderate** AMD groundwater risk potential were identified, where moderate risk is defined as potential AMD groundwater flux received by the receptor that is likely to be moderate relative to AMD fluxes received via surface water pathways:

- Groundwater discharging as baseflow or seeps to Baker Creek interacting with the waste rock dump in the creek.
- Groundwater intercepting the adits and underground workings and interacting with exposed potential acid forming (PAF) material, contributing to the mine effluent load ultimately discharging either directly to Baker Creek or indirectly to the Ring River.

No AMD sources were identified with a **high** AMD groundwater risk potential, where high risk is defined as potential AMD groundwater flux received by the receptor that is likely to be high relative to AMD fluxes received via surface water pathways.

A number of data gaps were identified associated with the two moderate risk processes:

- The presence and magnitude of seeps with the potential to interact with PAF material in waste rock on the scree slopes and the waste rock dump.
- The spatial and temporal nature of groundwater–surface water interaction along the mid and lower reaches of Baker Creek and the waste rock dump.
- The extent to which groundwater interacts with adits and underground workings, so that the potential effectiveness of closure options such as plugging of adits and flooding of underground workings can be assessed.

The preliminary groundwater investigation included recommendations to address these data gaps, which formed the basis of the Phase 2 groundwater study currently in progress.

4 Phase 2 studies

Based on the recommendations to address the information gaps identified in the studies described above, as well as consideration of regulator and independent peer-reviewer recommendations, an integrated program of work for surface water and groundwater was developed. The key components of these studies included:

Surface water: Longitudinal surveys of Baker Creek involving collection of water quality and flow information at low flow or baseflow conditions to identify points of entry of acidity and metals from inflows from the 5 Level, 6 Level and 7 Level adits and other currently unknown distributed sources. In addition, these surveys will help to identify and quantify significant gaining and/or losing sections of Baker Creek in the context of interactions of the creek with groundwater. The contaminant loads derived in Phase 1 will be recalculated using the data from an enhanced program of continuous monitoring and water quality grab sampling.

Groundwater: Development of a more targeted groundwater monitoring well network to assess interaction between groundwater and surface water in Baker Creek at selected locations, and whether such processes present significant AMD pathways.

Radon-222, which can be used as a natural tracer for both surface water and groundwater samples, was included in the most recent water quality suite to investigate the potential for using radon concentrations to identify water sources and assess the extent to which groundwater interacts with the adits, underground working and surface water. When scoping the assessment, the use of stable isotopes was considered; however, Radon-222 was selected as the most appropriate tracer as the residence time of recharge to groundwater prior to discharging to surface water was suspected be quite short (weeks to months) due to potentially significant recharge via the glory holes, in addition to some flow-through historical underground workings. Given the time to secular equilibrium, where the rate of Radon-222 production is balanced by the rate of decay, is reported to be in the order of 20 days (Cook 2020), and the primary objective of the testing was to identify where there was interaction between groundwater and surface water, not groundwater mixing or residence time, the use of a radiogenic tracer was preferred.

Surface water and groundwater monitoring locations for Phase 2 studies are shown in Figure 7.

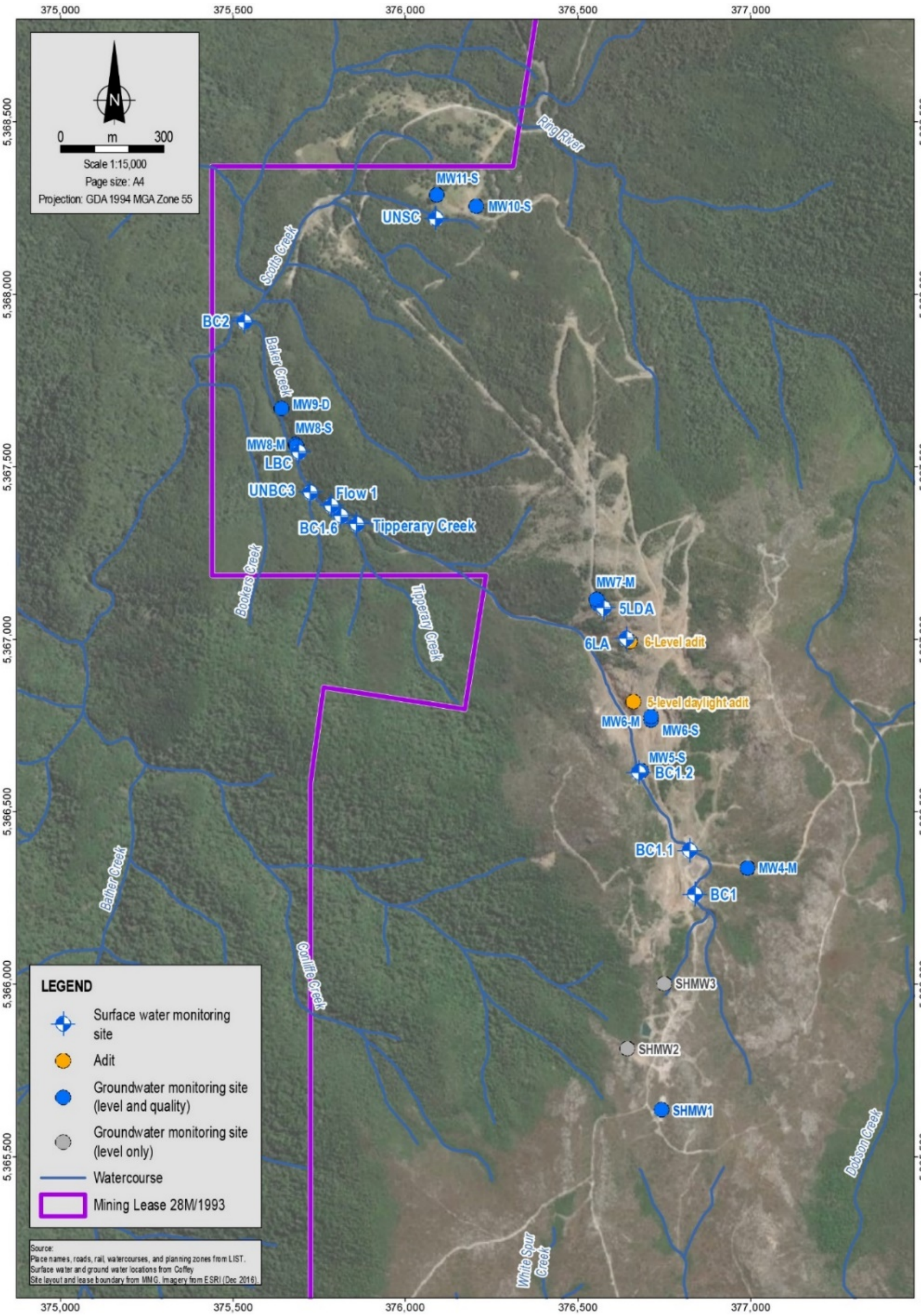


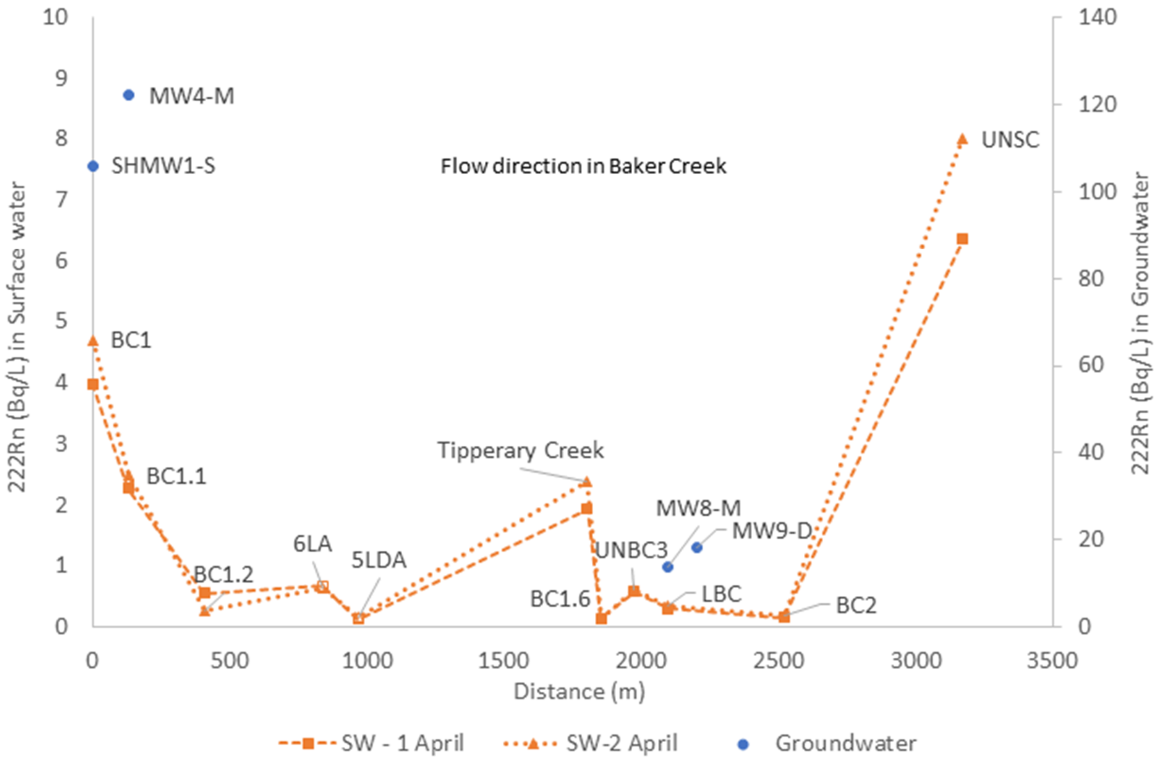
Figure 7 Baker Creek groundwater and longitudinal survey monitoring sites

4.1 Preliminary Phase 2 study results

A network of 10 groundwater monitoring wells, including two locations with paired shallow- and medium-depth wells, was installed at key locations across the site (Figure 7). All newly installed wells were tested to assess hydraulic conductivity and pressure transducers installed to monitor groundwater-level changes over time and in response to rainfall. EC was also logged in selected monitoring wells and at two locations in Baker Creek adjacent to shallow monitoring wells. Pressure transducers were placed in one existing well upgradient of the mine, and in Baker Creek where EC was logged.

The groundwater monitoring network, adjacent locations in Baker Creek and adit flows were sampled following a dry period at the end of summer when conditions in Baker Creek were expected to represent baseflow. Water samples were analysed for total and filtered metals, cations and anions, general water quality parameters (field and laboratory) and Radon-222. Radon-222 in groundwater is typically much higher than in surface water, with the analysis intended to be used in conjunction with the geochemical data to identify where groundwater discharge is occurring to Baker Creek.

The Radon-222 (measured in becquerels/litre, Bq/L) results from the first two surveys along Baker Creek and the first round of groundwater sampling at the end of summer are shown in Figure 8. The data indicate that groundwater contributes more to Baker Creek upstream of the waste rock dump, in the vicinity of BC1 and BC1.1, and downstream in tributaries to Baker Creek, Tipperary Creek and the unnamed tributary of Scotts Creek (UNSC) (Figure 7). The results from the two surveys of surface water samples are very similar, indicating that the results are reproducible.



Note: Hollow symbols represent samples from adits, and groundwater axis is an order of magnitude greater than surface water

Figure 8 Radon-222 levels in surface water and groundwater along Baker Creek

Groundwater level and EC data are being evaluated and will be used in conjunction with the geochemical data and Radon-222 results (Figure 8) to confirm where groundwater is discharging to Baker Creek and whether it is AMD affected prior to discharge. Groundwater sampling in spring is also proposed to understand the seasonal influences on groundwater discharge and quality.

5 Conclusion

Potential closure mitigation options for the adits and waste rock have been identified for Hercules, including the option to treat AMD being discharged from the site and the possibility for source reduction. To inform the closure options assessment, a study has commenced to investigate options for the treatment of mine-impacted waters from the Hercules Mine. This study will proceed in two phases. The first phase will involve identification of the most appropriate candidate treatment technologies. Phase 2 will comprise a laboratory water treatment test work and technology evaluation followed by trial test work of the final shortlisted option. The results will be compared to a 'do nothing' option, to evaluate the predicted change in impact at downstream receptors.

The studies that have been completed or are in progress described herein have informed/will inform the closure completion criteria development and potential options for remediation, rehabilitation and closure of the Hercules Mine site.

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