April 24, 2017

Mount Isa Mines Limited
Private Mail Bag 6
Mount Isa QLD 4825

Miss. Tamara Groves
ZOPS Environmental Advisor

Dear Miss. Groves:

Black Star Open Cut Waste Rock Dump Environmental Evaluation
Environmental Evaluation Report
Final

Klohn Crippen Berger (KCB) is pleased to provide this revised Environmental Evaluation report for the Black Star Open Cut Waste Rock Dump Environmental Evaluation.

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of *Mount Isa Mines Limited* (Client) for the specific application to the *Black Star Open Cut Waste Rock Dump Environmental Evaluation*. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. In this report, Klohn Crippen Berger has endeavoured to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Chris Strachotta
Project Manager

CK:CS:JT

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EXECUTIVE SUMMARY

The Department of Environment and Heritage Protection (DEHP) issued an Environmental Evaluation (EE) notice (Ref: 101/0008689) to Mount Isa Mines (MIM) to conduct an assessment of seepage from the Black Star Open Cut (BSOC) Waste Rock Dump (WRD). Key requirements of the EE are to:

- Identify the source, cause and extent of all seepage[1] being or likely to be released from the BSOC WRD to the receiving environment[2];
- Assess the impacts on the receiving environment and all identified environmental values (EVs) (surface water / groundwater quality, sediment quality, soils, flora and fauna);
- Determine potential options for prevention or reduction of further seepage from the BSOC WRD to the receiving environment; and,
- Identify a preferred option/s for both the remediation of identified impacts to the receiving environment and measures to prevent or limit future impacts.

Data Collation & Field Investigations

Previous investigations and historical monitoring data from the project site were reviewed, and a data gap assessment was conducted to identify additional data required to conduct the EE assessment. Based on the results of the data gap assessment, a phased field investigation program was developed and undertaken. Phase 1 comprised a site investigation program, including seepage mapping; seepage water and soil sampling; and, drill location selection for Phase 2. The Phase 2 field investigation program comprised the drilling and installation of 11 groundwater monitoring bores (5 alluvial aquifer monitoring bores and 6 bedrock aquifer monitoring bores); aquifer hydraulic testing using the installed monitoring bores and previously established bores; and, hydraulic testing of the BSOC WRD.

A concurrent assessment was undertaken to identify and/or design monitoring facilities at each of the seepage locations (BSOC WRD South Seepage, BSOC WRD North Seepage, TD3 Seepage) and within the Diversion Drain to monitor seepage from the BSOC WRD. These facilities comprised three weirs within the Diversion Drain (downstream of TD3 Seepage – Weir 1, downstream of BSOC WRD North Seepage – Weir 2 and upstream of BSOC WRD North Seepage – Weir 3); and, monitoring of pumped seepage from the BSOC WRD South Seepage trench.

Conceptualisation and Analysis

Data collected from the field investigation program was collated with the historical monitoring records and previous investigations to support the conceptualisation of the hydrogeological system across the project site (including the BSOC WRD landform) and the analysis of the seepage from the BSOC WRD.

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[1] The EE notice defines "seepage" as *any liquid originating from the Black Star Waste Rock Dump footprint regardless of its contaminant concentration that has the potential to enter the receiving environment.*
[2] The EE notice defines "receiving environment" as *all groundwater and surface water that are not in disturbed areas authorised by this environmental authority and excludes land within the surface water containment areas*.

- **Hydrogeological conceptualisation**

  Groundwater at the project site is generally hosted in two geological units – an overlying Quaternary alluvium and underlying bedrock geology. The unconsolidated alluvium occurs in and adjacent to surface water courses with a thickness that varies from 2 m to 10 m. Groundwater levels in the alluvium vary throughout the year with shallow groundwater levels observed during and immediately following the wet season and deeper groundwater levels, and possible dry conditions (i.e. no groundwater observed – BSOC_A4), during the dry season. Groundwater flow in the alluvium is a reflection of the surface topography of the alluvial extent, with the groundwater flow direction similar to the surface water flow direction.

  Beneath the unconsolidated alluvium groundwater is hosted in the bedrock geology. These geological units comprise the meta-sediment / meta-volcanic Bortala Formation (Judenan Beds), Eastern Creek Volcanics (ECVs) and Whitworth Quartzite, and occur as steeply-dipping, north-south striking beds. Limited primary porosity is observed in these meta-sediment / meta-volcanic units, resulting in groundwater being hosted in the secondary porosity, which comprise bedding planes (north-south orientated) and localised fracturing. Groundwater levels in the bedrock units range from 11 m to 23 m below the ground surface, with groundwater bearing units observed to a maximum depth of 60 m. The groundwater flow in the bedrock units is consistent with the regional groundwater flow direction across the MIM site, from south to north. Groundwater yield from the bedrock geology are expected to be low (i.e. <1 L/s), and as a result no water supply bores are located in the vicinity of the focus area.

- **BSOC WRD conceptualisation**

  Historical project site topography (pre-BSOC WRD landform); the final configuration of TSF3 and TSF5; and, the current BSOC WRD surface were used to develop a 3D BSOC WRD landform model and to select two-dimensional Seep/W model sections for seepage assessment. The BSOC WRD landform model identified that the upstream catchments for each of the seepage locations (i.e. seepage catchment underlying the WRD) comprised both historical tailings storage (TSF3 upstream of TD3 Seepage; and, TSF5 upstream of both BSOC WRD North and South Seepages) and waste rock; indicating a potential seepage source from both tailings and waste rock.

  Hydraulic testing (test pit soak-away tests) on the current BSOC WRD surface was unsuccessful, as water was not retained in the test pits. Anecdotal information from site personnel also indicated that limited ponding on the WRD surface is observed during and following rainfall events. As a result, the majority of rainfall on the WRD surface (not including the WRD slopes) is expected to infiltrate into the landform.

- **Seepage analysis**

  Conceptualisation of the hydrogeological system and the BSOC WRD landform provided the basis for the seepage analysis. The analysis was further supported by the assessment of the waste rock and tailings geochemistry, the seepage hydrochemistry and the downstream groundwater hydrochemistry. The combined results of these assessments provided an understanding of the seepage characteristics – the seepage extent, proportion of seepage source contribution, interpreted timeframe of seepage development and predicted timeframe for seepage migration to receptors.

Seepage Source, Cause and Extent

The three seepage points located around the BSOC WRD Landform are coincident with the natural drainage locations, which are now covered by the WRD. Upstream of these seepage locations (beneath the WRD) a spillway from historical tailings dams (TSF3 and TSF5) is present, buried beneath the WRD.

A review of waste rock and tailings geochemistry and kinetic testing was undertaken, in conjunction with a review of BSOC WRD seepage chemistry, as well as historical tailings chemistry data, to assess whether a definitive source (either tailings or waste rock) is providing the seepage now observed from BSOC WRD. The MIM landfill sludge pits were also considered as a potential source.

Based on the available chemistry data, the following is concluded:

- TD3 and BSOC WRD North Seepages have similar water qualities and both have similarities to waste rock seepage and tailings seepage characteristics.
- The MIM landfill sludge pits may also contribute, although it is difficult to determine the extent of this contribution quantitatively without further constraints on the internal geochemistry of TSF3 and the WRD.
- BSOC WRD South Seepage is broadly similar to TD3 Seepage and BSOC WRD North Seepage, but reports water quality that may have some of the characteristics similar to the TD5 pit sample.
- Based on the water qualities obtained from kinetic testing of both waste rock and tailings, as well as the measured seepage, it is interpreted that there is limited basis for clear differentiation between geochemical signatures of the waste rock and tailings in the seepage.

Previous geophysical surveys were completed to determine the cause of seepage migration from the BSOC WRD Landform, and to identify potential preferential pathways for seepage. The Phase 2 field investigation program was developed to target anomalies identified from the geophysical surveys to confirm the occurrence of seepage migration. The field investigation program did not identify zones of discrete preferential seepage pathways, as previously interpreted from the geophysical surveys, rather, diffuse seepage within the alluvium and bedrock units were identified.

A two dimensional modelling assessment was also undertaken to assist in determining the cause of seepage migration. This was completed using representative thicknesses of the site infrastructure as well as the underlying geology. Sensitivity analysis for the most uncertain parameters was also undertaken to assess the potential variability in the flux estimates and movement of water.

The cause of seepage has been interpreted as the following:

- Direct seepage movement within the alluvial alluvium, which originate under the BSOC WRD landform and are in connection with the alluvium beyond the extents of the landform.
- Seepage into the downstream alluvium beyond the constructed diversion drain.
- Bedrock seepage from the base of the TSFs as diffuse seepage with the bedrock units, likely to be along the bedrock bedding plane (south-north orientation).

The volume of seepage that is generated, and will continue to be generated, is a function of the net percolation into the WRD and the piezometric surface within the WRD. These parameters have been established based on limited testing of the WRD surface and previous site investigations.

BSOC WRD seepage migration has been identified in the alluvium downstream of TD3 Seepage, BSOC WRD North Seepage and BSOC WRD South Seepage.

- TD3 Seepage – Downstream of this location the extent of the BSOC WRD seepage migration is to the discharge location at the KSOC open pit. The alluvium downstream of this seepage location is fully saturated as a result of flow from TD3, BSOC WRD North and South Seepages discharging into the Diversion Drain.
- BSOC WRD North Seepage – The extent of seepage migration in the alluvium downstream of the BSOC WRD North Seepage (alluvial extent to the north, beyond the diversion drain) is interpreted to be limited to ~200 m to the north of the Diversion Drain. This interpretation is based on the groundwater quality results from monitoring bore BSOC_A3 (based on an interpreted seepage extent trigger of sulphate = 1,000 mg/L[3]).
- BSOC WRD South Seepage – The extent of the seepage migration in the alluvium downstream of the BSOC WRD South Seepage (alluvial extent to the west of the seepage) is interpreted to be limited to ~300 m to the west of the BSOC WRD South Seepage. Sulphate concentrations from alluvium monitoring bores located downstream of the BSOC WRD South Seepage (BSOC_A1 and BSOC_A2) indicate that the seepage has migrated beyond BSOC_A2 (~5,500 mg/L) but has not reached BSOC_A1 (~580 mg/L).

BSOC WRD seepage migration in the bedrock units was interpreted based on the groundwater quality results from monitoring bores installed in the weathered bedrock / bedrock, including bores installed as part of the field investigation program targeting discrete geological structures. As per the groundwater hosted in the alluvium, a sulphate concentration of 1,000 mg/L was adopted as the extent of the seepage front. Weathered bedrock / bedrock groundwater quality results indicate that the BSOC WRD seepage extent is generally localised to the BSOC WRD landform with two zones of seepage migration; to the north of TD3 Seepage, and to the west of BSOC WRD South Seepage. Bedrock aquifer seepage migration extent to the north of TD3 Seepage is limited to ~800 m and seepage migration to the west of the South Seepage is limited to ~350 m.

The analytical results were compared to the existing groundwater quality data. Analytical contaminant transport analyses were undertaken to assess the travel time of the seepage

[3] Sulphate has been selected as the water quality parameter to represent seepage migration from the BSOC WRD landform due to the conservative nature of the parameter (limited influence of sorption/attenuation mechanisms in the aquifer). Therefore, the interpreted extent of the seepage migration based on sulphate is considered conservative. A sulphate concentration limit of 1,000 mg/L has been applied to correspond with the ANZECC livestock watering quality guidelines.

migration front, and to predict the timing of further migration of the seepage. For conservatism sulphate was used as the contaminant parameter, while the extent of the focus area was used as the receptor for the simulation. However, Spear Creek, located approximately 5.4 km north of the BSOC WRD is considered to be the nearest downstream surface water receptor from this facility since it is the location of the nearest downstream surface water monitoring point. The analytical assessment is based on the assumption that seepage commenced during the development of the underlying TSFs (i.e. TSF3 for TD3 Seepage; and, TSF5 for BSOC WRD North and South Seepages). The analytical assessment results indicate that the seepage migration in the bedrock units to the north of TD3 Seepage has taken ~63 years to develop; and based on the current migration rate, the seepage front may reach Spear Creek in another 465 years.

Assessment of Impact on Receiving Environment

An assessment of impacts from the BSOC WRD seepage on the receiving environment was undertaken for surface water, groundwater, sediment / soil quality and flora / fauna based on the previously established environmental values (EVs). A summary of this assessment is outlined below:

- Surface water – seepage from the BSOC WRD occurs as surface water at each of the three seepage locations where the seepage discharges into the Diversion Drain, or seepage collection trench for BSOC WRD South Seepage. The occurrence of the seepage as surface water is managed by the Diversion Drain, which discharges the seepage water into KSOC pit, mitigating flow into the downstream water course (i.e. Leichhardt River, Hazeldene Creek). Therefore, potential impacts to the receiving environment surface water EVs from the BSOC WRD landform seepage is not anticipated.
- Groundwater – areas of potential impact to the alluvial and bedrock groundwater systems are defined by the interpreted plume extents. The groundwater levels in both systems are generally below the surface and inaccessible to fauna for consumption. During periods of high rainfall, groundwater may rise to the surface and flow as surface water within the water course, however, this water is likely to be diluted.

  Groundwater usage for industrial use, livestock watering and/or small scale irrigation (groundwater EVs) is not observed within the vicinity of the focus area. Additionally, discharge of groundwater to waterways supporting existing fauna and flora communities has not been identified within the vicinity of the focus area. Therefore, potential impacts on the groundwater EVs as a result of BSOC WRD landform seepage is not anticipated.
- Sediment / soil quality – specific EVs for sediment / soil quality have not been developed for ML8058, however, in this absence the established EVs for Land Use have been adopted. The extent of potential impact to sediment quality in the focus area as a result of BSOC WRD seepage is limited to the ~300 m downstream of BSOC WRD South Seepage and ~200 m downstream of BSOC WRD North Seepage within the alluvium extent of the downstream watercourse. No observable or interpreted impacts to the ecosystem biodiversity, health and significance (e.g. vegetation die-back); or, the integrity of the land surface for associated land use has been identified.
- Flora – groundwater levels in the alluvium fluctuate relative to seasonal variability, with higher groundwater levels anticipated during the wet season and lower groundwater levels during the dry season. It is anticipated that vegetation within the alluvial extent

downstream of the BSOC WRD North and South Seepages may source water from the alluvium. Therefore, potential impact to flora from the BSOC WRD seepage may occur, limited to the extent of the interpreted seepage within the alluvium. Current impacts to flora within the extent of the seepage plume have not been observed.

- Fauna – consumption of seepage influenced water by fauna is considered the pathway for the BSOC WRD seepage to impact fauna. Groundwater is considered inaccessible by fauna, therefore, consumption of seepage water is not anticipated outside of the Diversion Drain. Access to the Diversion Drain and seepage locations by livestock is currently managed by the mining lease boundary fence located along the western boundary of the focus area. Therefore, potential impacts to livestock from the BSOC WRD landform seepage is not anticipated.

Potential Options for Prevention or Reduction of Further Seepage

Three potential options have been identified to prevent or reduce further seepage into the alluvium. These conceptual options include a groundwater interception borefield, groundwater collection trench and an alluvial aquifer cut-off wall. A summary of these potential options are provided in the table below.

Mitigation Option	Summary Description	Cost Estimate	Implementation Timeframe
Interception Borefield	▪ Series of production bores installed along an alignment perpendicular to groundwater flow in the alluvium downstream of BSOC WRD South and North Seepages – located downstream of diversion drain ▪ Bores to be completed into bedrock, below the alluvium profile ▪ Collected water to be reticulated and discharged into diversion drain for management in KSOC pit ▪ Drilling and hydraulic testing required to confirm borefield configuration and operational requirements	$773,500	11 months
Groundwater Collection Trench	▪ Excavation of a trench aligned perpendicular to alluvial groundwater flow across the extent of the alluvium and to the base of the alluvial profile ▪ Due to the depth of excavation and the requirement to keep excavation open a “cut-back” on the trench slopes will be required ▪ Seepage water collected in the trench will be reticulated and discharged into the diversion drain for management in KSOC pit ▪ Testing of the alluvial material will be required to support the detailed design of the trench and operational requirements for the system.	$942,500	10 months

Mitigation Option	Summary Description	Cost Estimate	Implementation Timeframe
Cut-off Wall	▪ Location of the cut-off walls will be subject to site investigations to confirm extent of the alluvium and the depth to bedrock. ▪ Cut-off walls will be installed using low permeability cement / bentonite slurries, with installation conducted concurrently with excavation to the base of the alluvium and across the alluvium extent. ▪ Management of seepage water mounded upstream of the cut-off walls will be undertaken via surface drainage reconfiguration, or transfer pumping, into the diversion drain. This management option will be confirmed as part of the subsequent site investigation and detailed design.	$1,222,000	12 months

For the groundwater in the bedrock units, the prevention or reduction of further seepage during mine operations could be mitigated by the installation of a groundwater seepage interception borefield. A summary of this option is provided in the following table.

Mitigation Option	Summary Description	Cost Estimate	Implementation Timeframe
Interception Borefield	▪ Series of production bores installed along an alignment perpendicular to groundwater flow in the bedrock units downstream of TD3 Seepage ▪ Bores completed to below 60 meters below ground level (mbgl) (identified depth of seepage) ▪ Collected water to be reticulated and discharged into diversion drain for management in KSOC pit ▪ Drilling and hydraulic testing required to confirm borefield configuration and operational requirements	$988,000	12 months

Preferred Remediation Option/s and Measures to Prevent or Limit Future Impacts

Currently, no impacts to the receiving environment EVs for surface water, groundwater, sediment / soil quality and flora / fauna have been identified. There may be potential future impacts to these EVs, however, this could only be verified through ongoing monitoring, which has been captured as part of an adaptive management strategy. The adaptive management strategy comprises ongoing monitoring, impact assessment and, if required, implementation of a preferred mitigation option/s. Therefore, the immediate implementation of a preferred impact mitigation option/s is not considered necessary.

The ongoing monitoring program for the adaptive management strategy includes:

- Surface water monitoring in water courses downstream of the BSOC WRD North and South Seepages prior to the confluence with Hazeldene Creek – event based surface water quality (rising-stage samplers)
- Alluvium – groundwater levels, groundwater quality

- Bedrock units – groundwater levels, groundwater quality
- BSOC WRD Landform seepage – seepage flow rates, seepage water quality
- Flora –monitoring of vegetation condition was considered, it is considered that any mitigation measures proposed as a result of the water quality monitoring program would be appropriate.

At the completion of each monitoring round, and following the collation of the monitoring data, a review of the monitoring data set, including historical monitoring results, should be conducted. The objective of this review will be to identify potential changes to the BSOC WRD landform seepage characteristics; the seepage plume characteristics; and, potential impacts to the receiving environment (as a result of the surface water monitoring, groundwater monitoring and/or seepage plume characteristics). The review is expected to identify future impacts and, if required, recommend the implementation of seepage mitigation option/s.

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1 INTRODUCTION

Mount Isa Mines Limited (MIM) was issued with a *Notice to conduct an environmental evaluation* (EE Notice) investigation by the Department of Environment and Heritage Protection (EHP) in December 2014 (Reference No. 101/0008689). The grounds for issuing the EE Notice is in accordance with Section 326B (1)(b) of the *Environmental Protection Act 1994* whereby 'an activity or proposed activity is causing or likely to cause environmental harm' and states the following:

> *'Mount Isa Mines Limited (MIM) are likely to have caused or be causing environmental harm through a release of contaminated material via surface and predominantly sub-surface flow / seepage from the Black Star Open Cut Waste Rock Dump (BSOC WRD) in three locations known as the BSOC WRD North Seepage Point, BSOC WRD South Seepage Point and TD3 Seepage Point.'*

The EE Notice includes a summary of EHP's concerns and states that:

> *EHP has concerns on the volume, location and quality of seepage*[4] *that is occurring and the associated environmental harm that is likely to occur to environmental values.*

MIM's Environmental Authority EPML00977513 (the EA) authorises environmental harm to environmental values where mining activities are undertaken in accordance with the conditions of the EA. EA Condition A1 states:

> *This environmental authority authorises environmental harm caused by the carrying out of mining activities by the holder of this environmental authority. Where mining activities are undertaken in accordance with the conditions of this environmental authority, environmental harm caused in compliance with the conditions is taken to be authorised. Where there is no condition or this environmental authority is silent on a matter, the lack of a condition or silence shall not be construed as authorising environmental harm.*

This Environmental Evaluation (EE) Report provides the results of the investigation of the volume, location and quality of seepage[4] that is occurring and includes an assessment of environmental harm that is likely to occur to the receiving environment[5] and all identified environmental values.

The BSOC WRD contains waste rock material from the BSOC lead-zinc mining operations, both of which are located on ML8058. Construction of the WRD over the historical Tailings Storage Facility 3 (TSF3) commenced in 2004 and the WRD also now partially covers the northern extent of Tailings Storage Facility 5 (TSF5). Seepage from the WRD has been identified at three locations – TD3 Seepage, BSOC WRD North Seepage and BSOC WRD South Seepage.

MIM commissioned Klohn Crippen Berger Limited (KCB) to undertake the investigation in response to EHP's EE Notice. This EE Report serves as the final deliverable for the environmental evaluation.

[4] The EE Notice defines "seepage" as *any liquid originating from the Black Star Open Cut Waste Rock footprint regardless of its contaminant concentration that has the potential to enter the receiving environment.*
[5] The EE Notice defines "receiving environment" as *all groundwater and surface water that are not in disturbed areas authorised by this environmental authority and excludes land within the surface water containment areas*.

1.1 Environmental Evaluation Requirements

This EE report has been prepared in accordance with the EE Notice requirements, as detailed in Table 1-1. The table also provides details of the sections within this document where each of the items within the EE Notice have been addressed.

Table 1-1: Environmental Evaluation Notice Requirements

EE Notice Requirement	Section Addressed in this Document
1. *Identify the source, cause and extent of all seepages that are being, or are likely to be released from the Black Star Waste Rock Dump (BSOC WRD) to the receiving environment. This must include:*	Section 5
a. *the current preferential pathways/ mechanisms/ fault lines for release of seepage from the BSOC WRD to the receiving environment; and,*	Section 5.2
b. *the current and expected volume and rate of any seepage released from the BSOC WRD to the receiving environment; and,*	Section 5.3
c. *the current concentration of seepage released from the BSOC WRD to the receiving environment.*	Section 5.4
2. *The investigation required under item 1 must,*	
a. *be in accordance with ANZECC (2000) methodology; and,*	Section 2.3.2
b. *assess impacts on the receiving environment and all identified environmental values, the assessment must include consideration of:*	Section 6
i) *Water quality for surface and groundwater's (including any shallow ephemeral aquifers));*	Section 6
ii) *Sediment Quality;*	Section 6
iii) *Soils;*	Section 6
iv) *Flora and Fauna*	Section 6
3. *Determine all potential options for the prevention or reduction of any further release of seepage from the BSOC WRD to receiving environment; for all options, provide:*	Section 7
a. *A detailed description of each option; and,*	Sections 7.1 and 7.2
b. *Costs for implementation of each option; and*	Section 7.3
c. *A timeframe for implementation of each option.*	Section 7.4
4. *Identify a preferred option/s for both the remediation of identified impacts to the receiving environment, and measure to prevent or limit any future impacts. Provide justification for the nominated option/s, which includes assessment against best practice environmental management; and, identify a time-frame for implementation and completion of the nominated option/s.*	Section 8

1.1.1 EHP Information Request

EHP provided MIM with a *Notice requiring further information* (EPML00977513; STAT1033, 101/0008689) on August 15, 2016, regarding the BSOC WRD EE report completed by KCB and submitted on July 29, 2016. Based on the *Notice requiring further information* (EHP, 2016), MIM selected a number of requirements that could be addressed by KCB based on the analyses and results provided in the BSOC WRD EE report (current document). These selected requirements are provided in Table 1-2 and have been updated as part of this report. The associated report sections where the further information requirements have been addressed are also provided in Table 1-2.

Table 1-2 MIM Selected Further Information Requirements

Item Number	Information Request Requirement	Section Addressed in this Document
2.1	It is not clear that potential for other seepage points has been adequately assessed. Provide site observations and mapping referred to in section 2.2 of Appendix II (Site Investigation Report) and clarify whether field surveys were conducted, for example, around the periphery of infrastructure to determine potential for other seepage points. If these were undertaken prior to wet season, provide additional observations post-wet season when seepages are more likely to manifest.	Section 2.2 – Site Investigation Report
2.1.1	For example, is there potential for seepage, sourced from the focus area, to express in the watercourse which emerges south-west of the BSOC WRD, flowing to Hazeldene Creek?	Section 5.3.2 – BSOC WRD South Seepage Model Domain
2.1.2	Surface flows at weir 3 (p.72) in the absence of rainfall have been attributed to transfer from the BSOC WRD South seepage trench to the diversion drain. Were these transfers recorded events and do these flows indicate other seepage points?	Section 5.3.1
2.2	It is not clear how the extent of the alluvial horizon has been defined. Describe the alluvial mapping methodology referred to in section 2.2 of Appendix II (Site Investigation Report s.2.2).	Section 2.2 – Site Investigation Report
2.3	It seems that the inference can be made that the variability and non-uniformity of fractured rock aquifers and the relevance and effects of faulting in developing discrete hydrogeological structural units has been considered in the environmental report, however Section 3.6 does not clearly identify this. Expand Section 3.6 to clarify this information.	Section 3.6
2.4	In relation to Figure 5-20 (p.55) include the elevation of the seepage locations and surrounding surface water bodies, including the bed level of King Gully.	Section 5.2.2.2; Figure 5-20
2.5	Further information is required to characterise the seepage towards the west and east and substantiate the inferred boundaries in Figure 5-69	Section 5.5.3
2.6	Seepage rates into the alluvial aquifer are predicted to be low and absence of groundwater in BSOC_A4 is asserted to support this finding. This appears to be inconsistent with Table 5-1 which records a water level at 1.19mBGL. Provide clarification or further information to demonstrate the down-gradient constraint of alluvial seepage extents.	Section 5.2.2.1
2.8	Further information to clarify the seepage model boundary assumptions (s.5.3.2.3) is required as follows:	Section 5.3.2.3
2.8.1	Provide or clarify information to substantiate no flow conditions along the bottom of the seepage model.	Section 5.3.2.3
2.8.2	Rainfall recharge rates of 80% and 50% were adopted for 2-D seepage modelling however higher rates (86%-95%) were established in s.5.2.3 of the report. Provide information to demonstrate implications of applying higher recharge rates or to substantiate the rates adopted. Provide substantiation of the run-off values applied to WRD slopes.	Section 5.3.2.5
2.9	Further information is required to demonstrate that applicability of the one-dimensional analytical assessment, particularly the adoption of sulfate as a trace parameter.	Section 5.4.8

Item Number	Information Request Requirement	Section Addressed in this Document
2.9.1	The characterisation of sulfate as a conservative tracer is postulated in the report by apparently contradictory suppositions. Section 5.4.8 justifies its conservative nature by noting that it is prone to secondary reactions and attenuation / adsorption mechanisms along the flow path which appears counter-intuitive and in contradiction with s.6.2.2.1 wherein it is stated that sulfate is subject to limited influence of sorption/attenuation mechanisms in the aquifer. Provide further information to clarify the characterisation of sulfate as a conservative indicator.	Section 5.4.8
2.9.2	Provide values adopted for each of the variables used to model sulfate propagation in the Ogata-Banks calculations and an explanation of their derivation.	Section 5.4.8
7.1	The full reference should be provided so we can allow for information to be reviewed. For example MIM 2015a and MIM 2015b.	See References Section

1.2 Environmental Evaluation Approach

Upon commissioning KCB were requested to provide a conceptual environmental evaluation outline that summarised the approach to undertake the EE investigation. This outline was provided to MIM on July 20, 2015 and is provided in Appendix I. This approach to the Environmental Evaluation was presented to EHP at the Environmental Evaluation Outline Meeting on July 22, 2015.

A summary of the conceptual EE outline is provided in a flow chart presented in Figure 1-1.

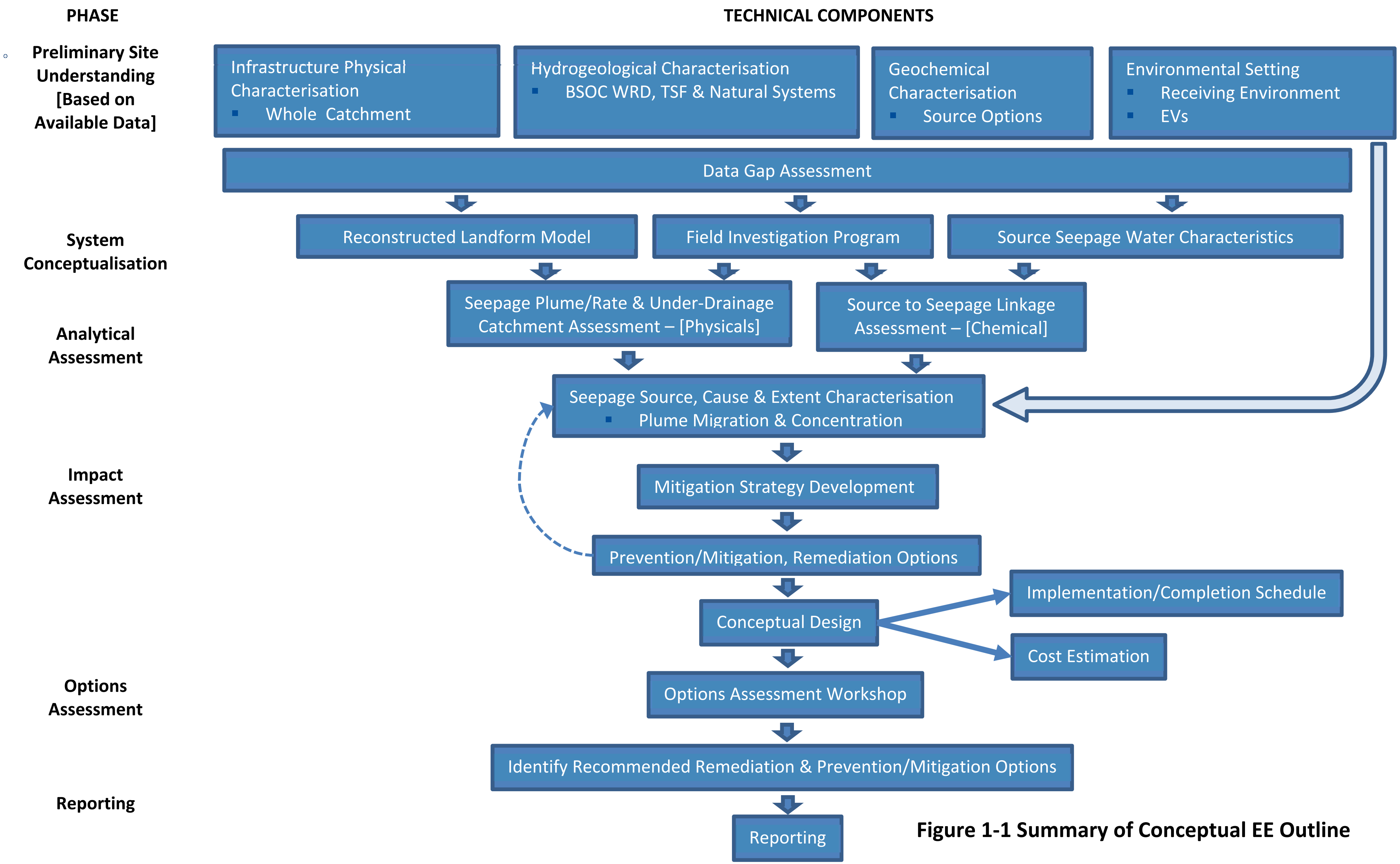

Figure 1-1 Summary of Conceptual EE Outline

1.3 EE Report Structure

This document comprises a main text component and supporting information / studies. An overview of the main text sections is presented below:

- Section 1 Introduction
- Section 2 Environmental Assessment Criteria
- Section 3 Environmental Setting
- Section 4 Site Infrastructure
- Section 5 BSOC WRD Source, Cause and Extent
- Section 6 Impact Assessment
- Section 7 BSOC WRD Seepage Prevention / Reduction
- Section 8 Preferred Impact Area Remediation Option/s
- Section 9 Conclusions and Recommendations
- Section 10 Closing

Appendices I to IV provide the supporting information / studies as follows:

- Appendix I Environmental Evaluation Outline Approach
- Appendix II Site Investigation Report
- Appendix III Seepage Weir Design Report
- Appendix IV Receiving Environment (Flora and Fauna) Assessment

2 ENVIRONMENTAL ASSESSMENT CRITERIA

2.1 Environmental Protection Act 1994

The *Environmental Protection Act 1994* (EP Act) was established with the objective to protect Queensland's environment while allowing for development that improves the quality of life, both now and in the future, in a way that maintains ecological processes on which life depends.

Sections 326B to 326DA of the EP Act outlines the process for when an environmental investigation is required to be undertaken to assess an activity / event causing, or likely to cause, environmental harm. Under the EP Act, if EHP is satisfied on reasonable grounds that an activity is causing or likely to cause environmental harm, or a proposed activity is likely to cause environmental harm, they may request that the proponent undertaking the activity conduct / commission an investigation (an environmental evaluation) about the activity / event and submit an environmental report about the investigation to EHP. A written notice from EHP (an investigation notice) will be issued informing the proponent of the requirement to undertake an environmental investigation.

2.2 Mount Isa Mines Environmental Management Requirements

2.2.1 Environmental Authority EMPL00977513

Mining activities conducted on ML8058 have been authorised by an Environmental Authority (EA) (EMPL00977513) issued under the Chapter 5 of the EP Act.

As stated in Section 1, the EA authorises environmental harm to environmental values where mining activities are undertaken in accordance with the conditions of the EA. EA Condition A1 states:

> *This environmental authority authorises environmental harm caused by the carrying out of mining activities by the holder of this environmental authority. Where mining activities are undertaken in accordance with the conditions of this environmental authority, environmental harm caused in compliance with the conditions is taken to be authorised. Where there is no condition or this environmental authority is silent on a matter, the lack of a condition or silence shall not be construed as authorising environmental harm.*

Other key sections of the EA relevant to this EE investigation include:

- Schedule C – Land and Rehabilitation;
- Schedule E – Mining, Mineral Processing and Smelting Waste; and,
- Schedule H – Water.

General conditions associated with Schedule C and Schedule E, relevant to this EE investigation, relate to the management of contaminants and/or surface seepage to prevent release to the receiving environment and to prevent environmental harm. Schedule H provides the monitoring, compliance and reporting requirements for surface water and groundwater systems across ML8058. These include the:

- surface water monitoring network (contaminant release points, downstream compliance points, reference sites and other monitoring locations – Schedule H – Table 1 and Table 8) and associated water quality release limits for controlled and uncontrolled releases (Schedule H Table 5 and Table 6, respectively); and,

- groundwater monitoring network and frequency (Schedule H – Table 10) and aquifer groundwater trigger levels and contaminant limits (Schedule H – Table 11a to 11d).

MIM are currently undertaking an investigation to establish the groundwater trigger levels and contaminant limits for or the groundwater aquifers across ML8058, and as a result trigger level and contaminant limit concentrations are not included in Schedule H – Table 11a to 11d.

2.2.2 Environmental Values

Of importance to this investigation are the established Environmental Values (EVs) for relevant receiving environment receptors, which are provided in the MIM Rehabilitation Plan (MIM, 2014), the EA EPML00977513 – Amendment Application Supporting Documentation version number 1.6 (MIM, 2015a) and EA EPML00977513 – Amendment Application Supporting Documentation version number 1.2 (MIM, 2015b). A summary of the EVs for surface water, groundwater, sediment / soil quality and flora / fauna are provided in Section 6.1.

2.2.3 Mount Isa Mines Rehabilitation Plan

The MIM Rehabilitation Plan (Revision number 1.1, 16 December 2014) has been established to provide an understanding of key components of rehabilitation requirements for disturbed land on ML8058. The key components of the Rehabilitation Plan include:

- Regulatory and policy framework;
- Rehabilitation goals, objectives, indicators and completion criteria;
- Geotechnical, geochemical and hydrological and hydrogeological studies;
- Conceptual final landform designs;
- Revegetation criteria and methods; and,
- Rehabilitation monitoring program.

Specific to the BSOC WRD, the Rehabilitation Plan provides the conceptual final landform design for the BSOC WRD, which includes the final landform surface contouring, drainage and erosion management strategy. Revegetation methods and criteria and the anticipated monitoring program for surface water, groundwater, erosion, cover system integrity / effectiveness and vegetation health/resilience are also provided in the Rehabilitation Plan.

2.3 Relevant Assessment Guidelines

2.3.1 Queensland Government Guidelines

Two guidelines released by EHP relevant to this EE investigation include:

- Guideline – Environmentally Relevant Activities Compliance and Enforcement (EHP, 2015b); and,
- Guideline – Notice to conduct or commission an environmental evaluation (EHP, 2015c).

The Guideline – Environmentally Relevant Activities Compliance and Enforcement (EHP, 2015b) was developed to assist Environmental Officers to act on Environmental reports under Section 326 of the EP Act. This guideline provides a summary of an EE including who can issue a notice to conduct or commission an EE, when EHP requires an EE, the environmental investigations associated with an EE and the requirements of an EE.

The Guideline – Notice to conduct or commission an environmental evaluation (EHP, 2015c) provides information to proponents who have been issued a notice to conduct or commission environmental evaluations under Section 321 to 329 of the EP Act. Specific to this EE investigation, this guideline provides:

- A summary of why a notice to conduct or commission an environmental investigation has been issued;
- Information that is provided in an investigation notice;
- Responsibilities upon receiving a notice to conduct or commission an EE;
- Penalties for failing to comply with a notice to conduct or commission an EE; and,
- The process EHP undertakes following receipt of the environmental report.

2.3.2 Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000)

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 developed by the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) provides guidance on the undertaking of environmental assessments relating to the measurement and evaluation of water quality. This document provides a framework for the monitoring and assessment of water quality, which comprises:

- Develop hypothesis – create a conceptual model of ecosystem processes and interactions, make assumptions against which monitoring results are tested;
- Study design – select water quality indicators relative to conceptual model, identify water quality objectives, determine sampling locations;
- Sampling – undertaking sampling program;
- Sample processing and analysis – analysis selection and documentation;
- Data analysis and interpretation – analytical assessment and interpretation of data;
- Evaluation and reporting; and,
- Management action.

This environmental evaluation investigation has been conducted in accordance with the ANZECC (2000) methodology to address item 2(a) of the EE Notice.

In the absence of groundwater trigger limits and contaminant values in the current MIM EA (EMPL00977513), the ANZECC water quality guidelines for livestock watering (ANZECC, 2000) has been adopted for comparison as part of this investigation. These guidelines have been selected as beef cattle are one of the main mammal groups present in this area.

Sediments / soil have been compared against the ANZECC (2000) provisional sediment quality low trigger and high guideline values. These guidelines were used to take into consideration the adsorption of soluble contaminants and deposition of particulate-bound contaminants leading to storage in alluvial sediments.

ANZECC (2000) guidelines were also used as part of the impact assessment (Section 6), where a screening-level risk assessment was undertaken. For both groundwater and sediment, the measured environmental filtered concentration for each contaminant was divided by the guideline values to calculate the Hazard Quotient (HQ). If the HQ was <1 that contaminant was considered to be of 'low risk' and was not considered further. If the HQ was >1, the contaminant was identified as a 'contaminant of potential ecological concern' (CPEC) (ANZECC 2000). ANZECC (2000) livestock (beef cattle) guidelines and ANZECC (2000) sediment quality guidelines were used for the calculation of the HQ for the measured water and sediment concentrations.

3 ENVIRONMENTAL SETTING

3.1 Site Investigation Location

ML8058 and the associated mine infrastructure is located immediately to the west of the Mount Isa township in northwest Queensland. The focus area of this investigation, shown in Figure 3-1, was presented to EHP at the Environmental Evaluation Outline Meeting on July 22, 2015, and was based on a geographic extent beyond the anticipated current BSOC WRD landform seepage impacts. It is acknowledged that downstream surface water receptors, Hazeldene Creek, Spear Creek, Leichhardt River and Lake Moondarra are located beyond the extent of the focus area, however these have been taken into account for the assessment of potential impacts.

3.2 Topography

The topography of the Mount Isa area is characterised by rolling hills with a series of prominent north-south ridges of moderate relief dissected by linear alluvial-filled valleys. These ridges are formed from outcrop of steeply dipping bedrock. The topography across ML8058 generally ranges in elevation between 300 and 450 mAHD.

3.3 Hydrology

The focus area is partially located within the sub-catchment of the Leichhardt River catchment. Major surface water drainages downstream of the focus area include:

- The Leichhardt River, which generally flows from south to north and is located approximately 2.5 km east of the BSOC WRD;
- Spear Creek, a tributary of the Leichhardt River, flows towards the east and is located ~5.3 km north of the BSOC WRD; and,
- Hazeldene Creek, which is a tributary of Spear Creek, flows south to north and is located approximately 1.5 km west of the BSOC WRD.

The location of these surface water drainage features are shown in Figure 3-1. Minor creeks / gullies are also located within the focus area. These watercourses are ephemeral, with the size and duration of flows dependent on the variable wet season.

The only permanent water bodies in the region exists in man-made structures such as large impoundments (Lake Moondarra, Lake Julius and Rifle Creek Dam), tailings dams, open pits and seepage collection ponds.

A key watercourse in the focus area is King Gully, which is located directly north of BSOC WRD and is now used as a diversion channel to manage runoff and seepage from the BSOC WRD. Further information about King Gully diversion is provided in Section 4.1.1.

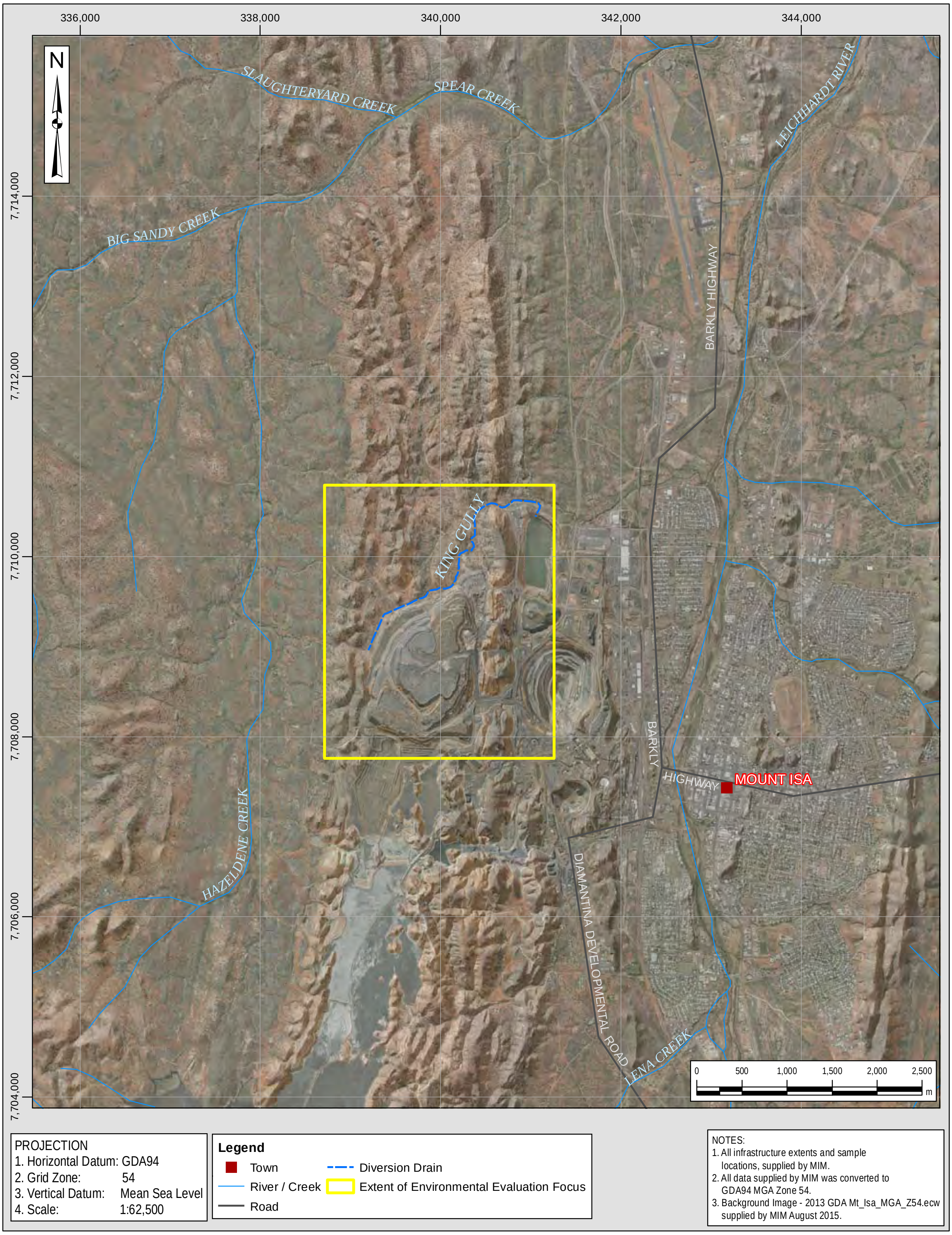

Figure 3-1: Regional setting and environmental evaluation focus area

3.4 Meteorological Conditions

The Mount Isa region is classified as being in the 'Grassland' climate group, based on the Köeppen classification system (Bureau of Meteorology, 2016), which consists of two distinct seasons: wet season from December to March; and the dry season from April to November. Table 3-1 presents monthly and annual climate statistics for rainfall, evaporation for the Mount Isa Mine (#029126) weather station and temperature for the Mount Isa Aero (#029127) weather station.

Table 3-1: Mount Isa climate statistics (Bureau of Meteorology, 2016)

Statistic	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean rainfall (1932 to 2015)	mm	97.3	91.5	60.4	15.7	15.9	10.9	6	3.1	6.7	18.7	31.4	63.7	424.3
Mean daily evaporation (1965 to 1992)	mm	10	9.3	9.1	8.1	6.1	5.1	5.3	6.6	8.5	10.2	11.2	11.3	8.4
Mean max temperature (1966 to 2015)	°C	36.4	35.4	34.3	31.9	27.9	24.9	24.8	27.3	31.3	34.8	36.5	37.1	31.9
Mean min temperature (1966 to 2015)	°C	23.7	23.3	21.8	18.5	13.8	10	8.7	10.2	14.2	18.5	21.5	23.1	17.3

In summary:

- Mean annual rainfall for records between 1932 and 2015 is 424.3mm, with around 74% of the mean annual rainfall occurring between December and March.
- During the wet season, monthly mean maximum temperature range between ~34°C and 37°C with monthly mean minimum temperatures ranging between ~21.8°C and 23.7°C.
- During the dry season, the monthly mean maximum temperature ranges between ~24.9°C and 36.5°C, with monthly mean minimum temperatures ranging between 10.0°C and 21.5°C.
- High evaporation rates are observed in the Mount Isa region throughout the year with distinct seasonal patterns and low variability. The average annual evaporation is 3,066 mm/year with a range in mean daily evaporation of between 5.1 and 11.3 mm/day, with highest evaporation occurring during the wet season months.

Figure 3-2 presents the daily rainfall for the weather station at MIM (#029126) and the associated rainfall excess / deficit trend between 1960 and 2016. Rainfall excess / deficit trends are used to depict long term rainfall trends, which can be difficult to interpret from raw rainfall totals alone. They are based on actual rainfall comparison to long term average conditions, and are used to show seasonality in data, as well as long term trends, which may in some cases persist for decades. This presentation of data can also be used for comparison against groundwater level hydrographs, discussed further in Section 5.2.2.2 The graph shows the annual seasonality of the rainfall, as well as long periods of decline, where rainfall is lower than the long-term average and periods of recovery, for example between 1997 and 2012.

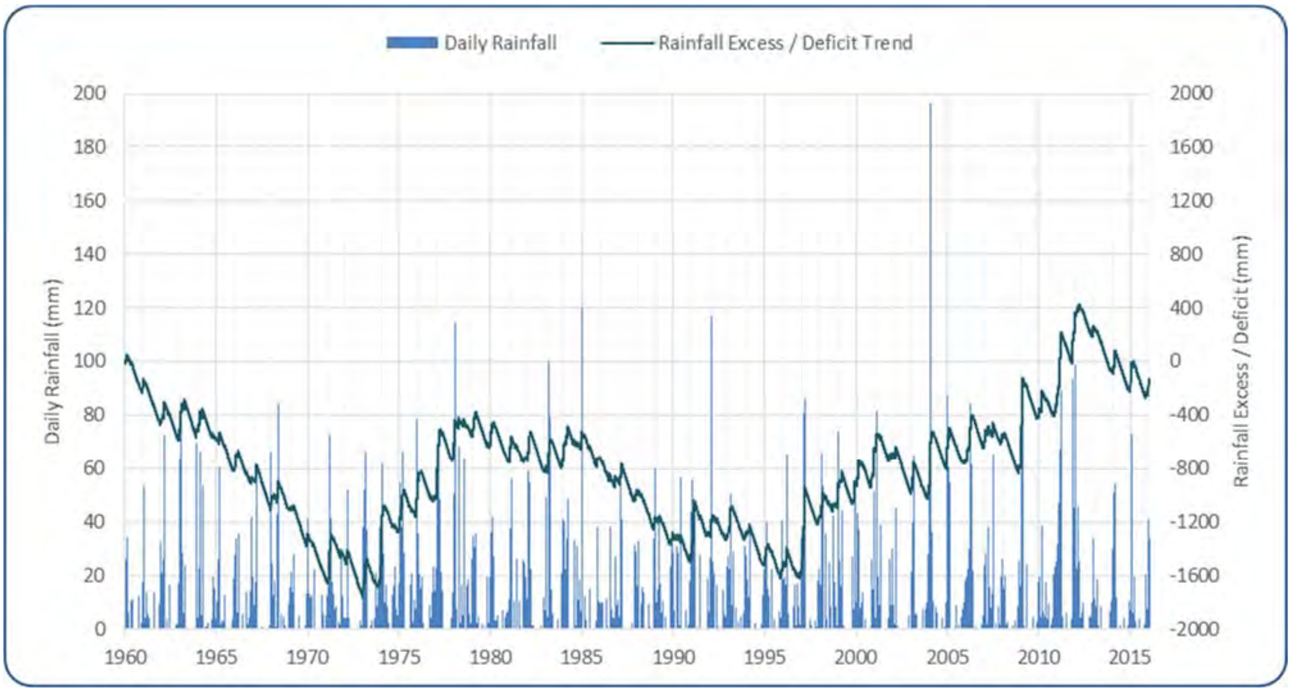

Figure 3-2: Daily rainfall and excess / deficit trend (Mount Isa Mine #029126)

3.5 Geological Setting

3.5.1 Regional Geology

Regionally, the Mount Isa Inlier encompasses the majority of the Mount Isa region. The Inlier comprises Early to Middle Proterozoic rocks and covers an area of approximately 50,000 km^2. Geological units of the Inlier have been subdivided into three broad north-south trending Provinces, namely:

- The Western Fold Belt Province;
- The Kalkadoon-Ewen Province; and,
- The Eastern Fold Belt.

The EE focus area is located on the western portion of the Inlier within a sedimentary sequence regionally referred to as the Leichhardt River Fault Trough of the Western Fold Belt complex. The Mount Isa Group and Haslingden Group (Myally Subgroup) of geological units are present within the EE focus area.

The sequence of rocks are interpreted to have been deposited in a rift-basin setting and comprises a series of upward fining and increasing carbonate sedimentary sequences. The Mount Isa Group comprises several formations in 5 km thick sequences of weakly metamorphosed mid-Proterozoic carbonate siltstones, mudstones and shales with basal sandstone and conglomerate units zone (Forrestal, 1990).

Regional deformation has tilted this sequence producing uniform westerly dipping (approx. 65°) bedding throughout the area. This pattern is modified at the site by parasitic folding. Asymmetrical folding on all scales occurs, the largest in the area being the Mount Isa Fold, with the majority of ore resources on the western limb of this fold system. Urquhart shears are axial planar to the Mount Isa Fold, and form the eastern limits of the ore zone (Forrestal, 1990). The western extent of the ore zone is defined by the north-south striking Mount Isa Fault; a major structural lineament, steeply dipping towards the east.

The hydrostratigraphy of the localised geological units underlying and within the vicinity of the EE focus area are outlined in Table 3-2, with the regional geological map shown in Figure 3-3. Geological formations located within the immediate EE focus area are highlighted in bold text. Nomenclature presented in the table has been updated based on the Geology of Queensland (Jell, 2012).

3.5.2 Weathering

Weathering across the Mount Isa region is variable and influenced by the presence of sulphide minerals within geological structures. The weathering profile is divided into two distinct horizons classified based on the degree of oxidation and leaching. These horizons are separated by distinct boundaries, and include:

- The base of complete oxidation (BOCO) – which is represented by a level where all the sulphide minerals are completely oxidised, and the lithologies have been leached of readily soluble minerals; and,
- The base of moderate leaching (BOML) – is defined by the appearance of ore minerals and below which comprises of a zone where the lithologies are variably leached resulting in secondary porosity.

Beyond the mine area, these surfaces are not as easily distinguished and occur at approximately 15m below ground surface (KCB, 2013b).

3.5.3 Alluvium

Quaternary alluvial deposits are generally associated with drainage features across the Mount Isa area. These deposits typically comprise silts, coarse sand and gravel deposits derived from the surrounding rock ridges, and are associated with streambed and active channel margins. These sediments are typically shallow and range from less than 3 m thick in smaller water courses to up to 15 m thick in larger drainage systems (e.g. Leichhardt River).

Table 3-2: Summary of the regional geology

Location	Parent Group	Unit Name	Unit Thickness (m)	Lithology Summary	Dominate Rock Types	Hydrostratigraphy
East of Mount Isa Fault	Mount Isa Group	Magazine Shale	unknown	Thin bedded calcareous sericitic shale, minor greenstone	Shale to siltstone, carbonaceous calcareous to dolomitic	Aquitard – generally forms ridges, only minor oxidation and leaching, minor storage potential in greenstone
		Kennedy Siltstone	300	Coarse bedded sequence of dolomitic and siliceous siltstone; sedimentary structure – cross-bedding, flute and load cast, slumping	Carbonaceous dolomitic and siliceous siltstone	Aquitard – generally siliceous, relatively unleached and unoxidised, strongly jointed and fractured
		Spear Siltstone	170	Thin (laminated) to medium bedded siltstone and shale	Carbonaceous calcareous to dolomitic siltstone	Aquitard – generally siliceous, relatively unleached and unoxidised, strongly jointed and fractured
		Urquhart Shale	920	Thin to coarse bedded, typically laminated, dolomitic and carbonaceous shale and siltstone with pyritic bands, deeply weathered and iron stained.	Carbonaceous dolomite shale and siltstone	Aquifer – oxidation and leaching enhance secondary porosity creating zones of high water storage, faulting also provides increased water storage conduits for groundwater movement and further leaching and oxidation
		Native Bee Siltstone	780	Bedded and laminated dolomitic, siliceous siltstone with interbeds of shale	Carbonaceous calcareous to dolomitic siltstone	Aquifer – faulting and weathering increases potential water storage and provide conduits for groundwater movement
		Breakaway Shale	600 – 1000	Laminated to thinly bedded pyritic to micaceous shale with minor siltstone	Carbonaceous and siliceous shale or siltstone	Aquitard – siliceous shales and slate, unleached and unoxidised.
		Moondarra Siltstone	1200	Medium to coarse bedded siltstone, dolomite minor shale with pyrite	Carbonaceous calcareous to dolomitic siltstone	Aquitard – siliceous minor leaching and oxidation
West of Mount Isa Fault	**Haslingden Group (Myally Subgroup)**	**Whitworth Quartzite**	**unknown**	**Massive medium to coarse feldspathic to quartzose sandstone, fine purple sandstone and mudflake conglomerate**	**Sandstone, conglomerate**	**Aquifer – faulting and weathering increases potential water storage, with some primary porosity**
		Bortala Formation (Judenan Beds)	**unknown**	**Flaggy, fine feldspathic sandstone, siltstone, micaceous siltstone, dolomitic sandstone, tuffaceous siltstone, grey-green chert**	**Conglomerate, sandstone, siltstone**	**Aquitard – occasionally quartzose shale may be locally permeable but is virtually unleached and unoxidised**
	Haslingden Group	**Eastern Creek Volcanics**	**>1000**	**Metamorphosed basalt, intercalated with silty and sandy sediments, quartzite tuff, pelitic schist, which is only minimally leached and oxidised**	**Metamorphosed basalt, silty and sandy sediments**	**Within the ECV, the Lena Quartzite forms an impervious groundwater barrier where relatively unsheared.**

*Blue fill indicates geological units which are within the immediate focus area, underlying the BSOC WRD and TSF's.

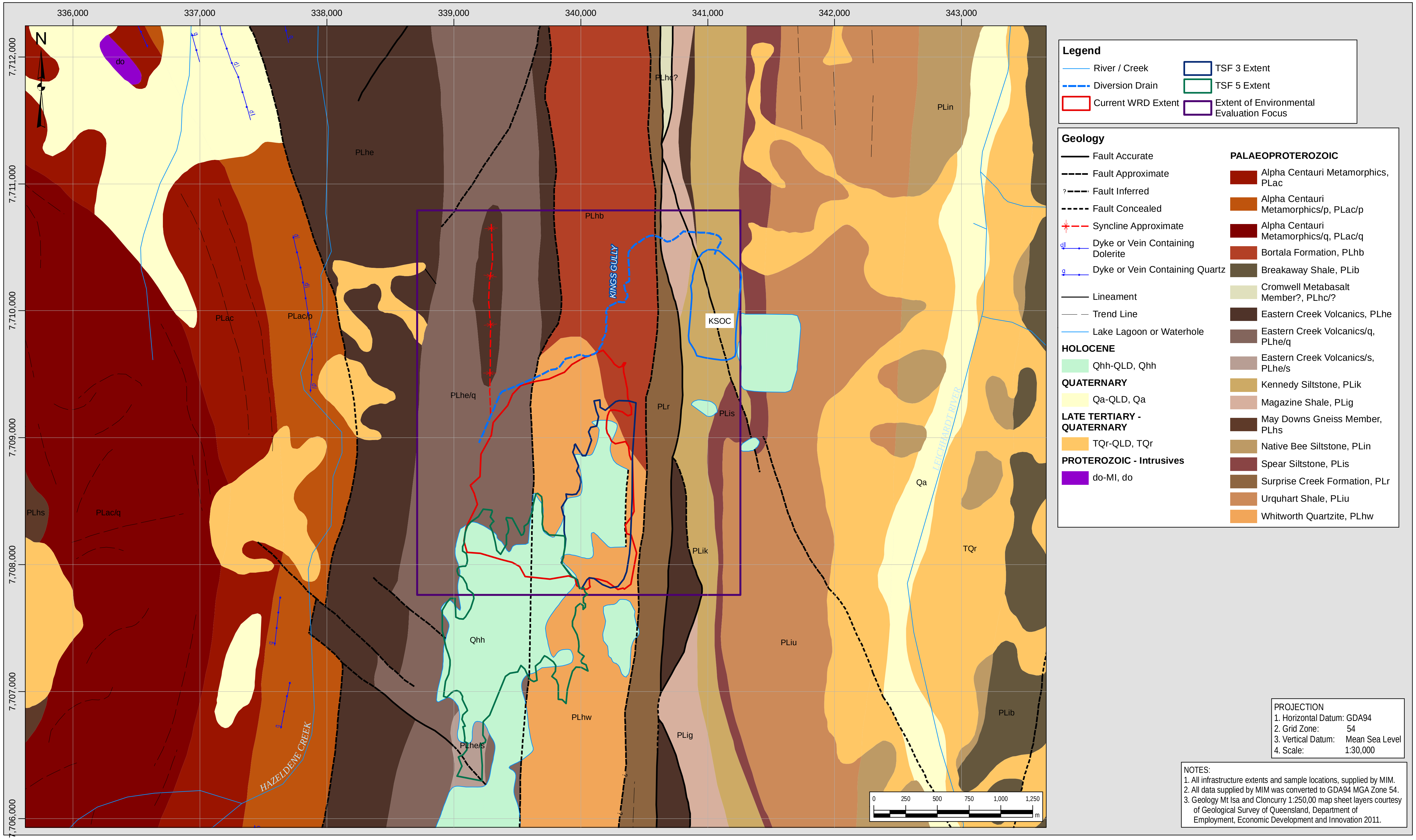

Figure 3-3: Regional geology map

3.6 Hydrogeological Setting

In general, groundwater is hosted in two geological units in the Mount Isa area, in the overlying unconsolidated Quaternary alluvium and the underlying bedrock geology. Further information regarding these units are provided in the following sections.

3.6.1 Alluvium

3.6.1.1 Extent

Quaternary alluvium within the EE focus area is limited to the watercourse downstream of the BSOC WRD. These watercourses represent the western tributaries of the Leichhardt River. The watercourses downstream of the BSOC WRD South and North Seepages flow into Hazeldene Creek towards the west, which flows into Spear Creek and ultimately the Leichhardt River. The watercourse downstream of the TD3 Seepage (King Gully) originally flowed towards the east into the Leichhardt River (Figure 3-1).

Alluvium thickness within the Mount Isa area is variable and is generally relative to the size of the watercourse; with larger thicknesses observed associated with the Leichhardt River (~15 m). Within the vicinity of the EE focus area the alluvium thickness varies from 2 m to 10 m.

For the purposes of this assessment, the alluvium has been conceptualised as a homogenous unconsolidated sandy unit that allows uniform saturation through the alluvium profile. This represents a conservative approach to the assessment of potential impacts, as the unsaturated zone and potential variability in the alluvium lithology (e.g. silt and clay lenses) may restrict seepage migration.

3.6.1.2 Hydraulic Parameters

Hydraulic testing of the Quaternary alluvium has not be conducted at the Mount Isa area. The alluvial deposits observed across the site comprises predominantly sand with some silt and minor gravels. Referenced hydraulic conductivity values for these unconsolidated materials typically range from 0.1 m/d to 10 m/d (Freeze and Cherry, 1979).

3.6.1.3 Potentiometric Surface, Recharge, Flow and Discharge

Recharge of the alluvial groundwater system occurs via a combination of direct rainfall infiltration and creek / river leakage. Due to the relatively high porosity of the unconsolidated alluvial sediments, the recharge rate would be relatively high. The recharge rate would decrease as the alluvial aquifer saturates and reaches storage capacity, which would occur during and immediately following prolonged periods of rainfall. Once the alluvium is fully saturated, direct rainfall would result in surface water runoff.

Groundwater levels in the Quaternary alluvium within the EE focus area are anticipated to vary throughout the year with shallow groundwater levels anticipated to occur during, and immediately following, the wet season (December to March) and deeper water levels, with possible dry conditions (i.e. no groundwater observed in the bore) occurring during the dry season (May to October). The Phase 2 field investigation program which occurred during the wet season groundwater levels were monitored to be between 0.43 mbGL and 1.97 mbGL. Groundwater flow in the alluvium is a reflection of the surface topography with the flow direction down-gradient along the water course flow path. Groundwater flows and discharges for each of the watercourse alluvium systems are:

- BSOC WRD South Seepage – groundwater flow is towards the west, parallel with the surface watercourse and discharging into Hazeldene Creek;
- BSOC WRD North Seepage – groundwater flow is towards the northwest, parallel with the surface watercourse and discharging into Hazeldene Creek; and,
- TD3 Seepage – groundwater flow in King Gully alluvium is towards the east and should be diverted at the King Gully Dam to KSOC pit.

A comparison of groundwater levels in the alluvium with levels in the bedrock EE focus area indicate a vertical hydraulic gradient from the alluvium to the bedrock. Therefore, infiltration of groundwater from the alluvium to the underlying bedrock may occur, however, this will likely to be governed by zones of higher hydraulic conductivity that will permit the infiltration. Based on the site investigations completed to date, evidence of alluvium groundwater infiltrating into the underlying bedrock has not be observed in the EE focus area.

3.6.1.4 Yield and Use

Groundwater yield from the alluvium are typically low (less than 1 L/s). As mentioned in Section 3.6.1.3, groundwater occurrence is variable throughout the year, therefore the alluvium is not considered to be a sustainably yielding aquifer.

No water supply bores are located in the alluvium within the vicinity of the EE focus area.

3.6.2 Bedrock Geology

3.6.2.1 Extent

Groundwater in the bedrock geology within the vicinity of the EE focus area is hosted in the meta-sediment / meta-volcanic Bortala Formation (Judenan Beds), Eastern Creek Volcanics (ECVs) and Whitworth Quartzite. These geological units occur as north-south striking beds that are steeply dipping towards the west (approx. 65^{o}). Regional geological mapping (1:250,000 Mount Isa and Cloncurry Geology sheets) indicates that the Whitworth Quartzite predominantly occurs to the south of the EE focus area and underlies the BSOC WRD, while the Judenan Beds predominantly occurs to the north of the BSOC WRD pinching out approximately 3 km to the north of the focus area due to faulting. The ECVs, located under the western extent, and to the west, of the BSOC WRD extends to the north and south of the focus area.

The bedrock geology bedding planes represent secondary porosity within these geological units, which potentially allow groundwater storage and flow. These bedding planes are orientated along a north-south axis, indicating the preferential flowpaths for groundwater in the bedrock. Perpendicular to the north-south bedding plane the groundwater flow is anticipated to be limited as the bedrock predominantly comprise silicified meta-sediments / meta-volcanics with very low porosity and limited groundwater storage and flow potential. The Mount Isa Fault is located approximately 300 m to the east of the BSOC WRD and has been previously interpreted as a low hydraulic conductivity structure that is a barrier to groundwater flow from west to east (KCB, 2011b). This fault is interpreted to be the eastern extent of the bedrock geology groundwater system.

Hydrogeological drilling of the bedrock geology encountered groundwater predominantly between 11 mbGL and 23 mbGL (Appendix 2). Below these depths the groundwater yield recorded during drilling remained relatively constant, indicating that additional groundwater inflow zones were not encountered at depth. Previous monitoring bore installations in the bedrock, within the vicinity of the EE focus area, comprised screened intervals up to a maximum depth of 55 mbGL, indicating groundwater occurrence predominantly limited to a depth of 60 mbGL. This groundwater occurrence is also consistent with the interpretation that the bedrock geology becomes more competent with depth, decreasing the potential for groundwater storage / flow.

3.6.2.2 Hydraulic Parameters

Hydraulic testing of the bedrock geology groundwater system completed as part of the Phase 2 field investigation program (Section 5.2.2.3) identified a range of hydraulic conductivities for the weathered bedrock and bedrock, which included:

- Weathered bedrock – 0.04 to 2.0 m/d (average = 0.58 m/d, median = 0.20 m/d); and,
- Bedrock – 0.0006 to 2.4 m/d (average = 0.40 m/d, median = 0.03 m/d).

Bedrock hydraulic conductivity results indicate a relatively large variation of up to four orders of magnitude. This variability is not identified to be related to specific bedrock geological units (i.e. Judenan Beds, ECVs, Whitworth Quartzite) as the testing was completed across all bedrock units within the EE focus area. Available geological information at each of the hydraulic testing locations indicate that the variation in the hydraulic conductivity may be associated with localised variability in the geology (e.g. increased matrix porosity, fracturing).

Two monitoring bores (BSOC_B4 and BSOC_B6) completed during the Phase 2 field investigation program (Appendix II) targeted geological structure (interpreted faults) to the north of the BSOC WRD. Limited groundwater yields were encountered during the drilling of these holes, and hydraulic testing of BSOC_B4 identified a hydraulic conductivity of 0.13 m/d. This indicates limited groundwater flow and storage potential within the encountered fault structures.

3.6.2.3 Potentiometric Surface, Recharge, Flow and Discharge

Generally, recharge to the bedrock units is from direct rainfall infiltration. Recharge rates will be influenced by geological structures and the degree of weathering, with higher recharge rates anticipated to occur in zones with increased porosity (higher weathering) and surface exposure of geological structures. Where more competent or unfractured rocks occur at the surface, limited recharge is anticipated. Localised recharge to the bedrock may also occur from infiltration from stream bed leakage of surface water features where watercourses and associated alluvial deposits overlie fractured bedrock units. However, since the local creeks flow intermittently and areas of streambed are frequently dry, the potential for connectivity between surface and groundwater is limited, with the exception of larger watercourses which comprise saturated / partially saturated alluvial profiles (e.g. Leichhardt River).

The regional potentiometric surface of the bedrock groundwater system across the Mount Isa area represents a groundwater flow direction from south to north. Previous studies have identified a regional hydraulic gradient of 0.00025 (KCB, 2013b). Locally, the potentiometric surface across the EE focus area also displays a south to north groundwater flow direction, however, localised bedrock groundwater flow to the west of the BSOC WRD is from southeast to northwest (Figure 5-20). The estimated localised hydraulic gradient within the EE focus area is 0.022 to 0.024.

Discharge of groundwater from the bedrock units have not been identified, however, based on the interpreted groundwater flow direction, discharge may potentially occur to the north of the EE focus area in areas where the groundwater level rises above the surface topography.

3.6.2.4 Yield and Use

Sustainable groundwater yields from the bedrock geology are expected to be low (less than 1 L/s), and as a result this unit is not considered to be a sustainably yielding aquifer. No water supply bores are located in the bedrock geology in the vicinity of the EE focus area.

3.7 Ecological Setting

The Mount Isa Mine is located in the Northwest Highlands bioregion. The highly seasonal nature of the environment affects biodiversity and environmental cues within ML8058, particularly post-wet season when rainfall results in higher botanical recruitment and increased fauna species and populations recorded during biodiversity surveys (Amec Foster Wheeler, 2015).

ML8058 is characterised by rugged, rocky hills and poor shallow soils. The vegetation reflects the complex geology, infertile soil and semi-arid climate. Low open woodland with Eucalyptus, Corymbia and Acacia species predominates, with a ground layer of Triodia species (spinifex). ML8058 is surrounded by (and overlays) neighbouring pastoral leases, which are used for rangeland grazing. Conditions are unsuitable for improved pasture so clearing of native vegetation has generally been limited to areas required for mining and supporting infrastructure.

MIM has commissioned various biodiversity studies and surveys across ML8058 over the past few years, and this has included the mapping and ground-truthing of regional ecosystems (Amec Foster Wheeler, 2015). These investigations identified that overall native vegetation communities across ML8058 are in moderate to good condition, meeting remnant status and close to benchmark values.

A more detailed summary of the terrestrial flora and fauna, and the aquatic flora and fauna, within the EE investigation area is provided in Sections 2.2, 2.3 and 2.4 of the BSOC Environmental Evaluation Receiving Environment (Flora and Fauna) Assessment report (Amec Foster Wheeler, 2016), which is provided in Appendix IV.

4 SITE INFRASTRUCTURE

MIM currently operates two separate mining and processing operations for copper and lead-zinc on ML8058 and includes crushing plants, mills, two concentrators, and lead and copper smelters. The main infrastructure relevant to this study include:

- BSOC WRD – construction commenced in 2004 and stores waste rock from the BSOC Pit.
- Tailing Storage Facilities (TSF): TSF3 and TSF5, commissioned and operated between 1946 and 1955 (TSF3) and 1958 and 1964 (TSF5) (Forsyth, 2014).
- The MIM landfill, which has been in operation for more than 30 years and is located to the east of the BSOC WRD.

The following sections 4.1 to 4.3 provide further details on these facilities, respectively, with the location of these facilities presented in Figure 4-1.

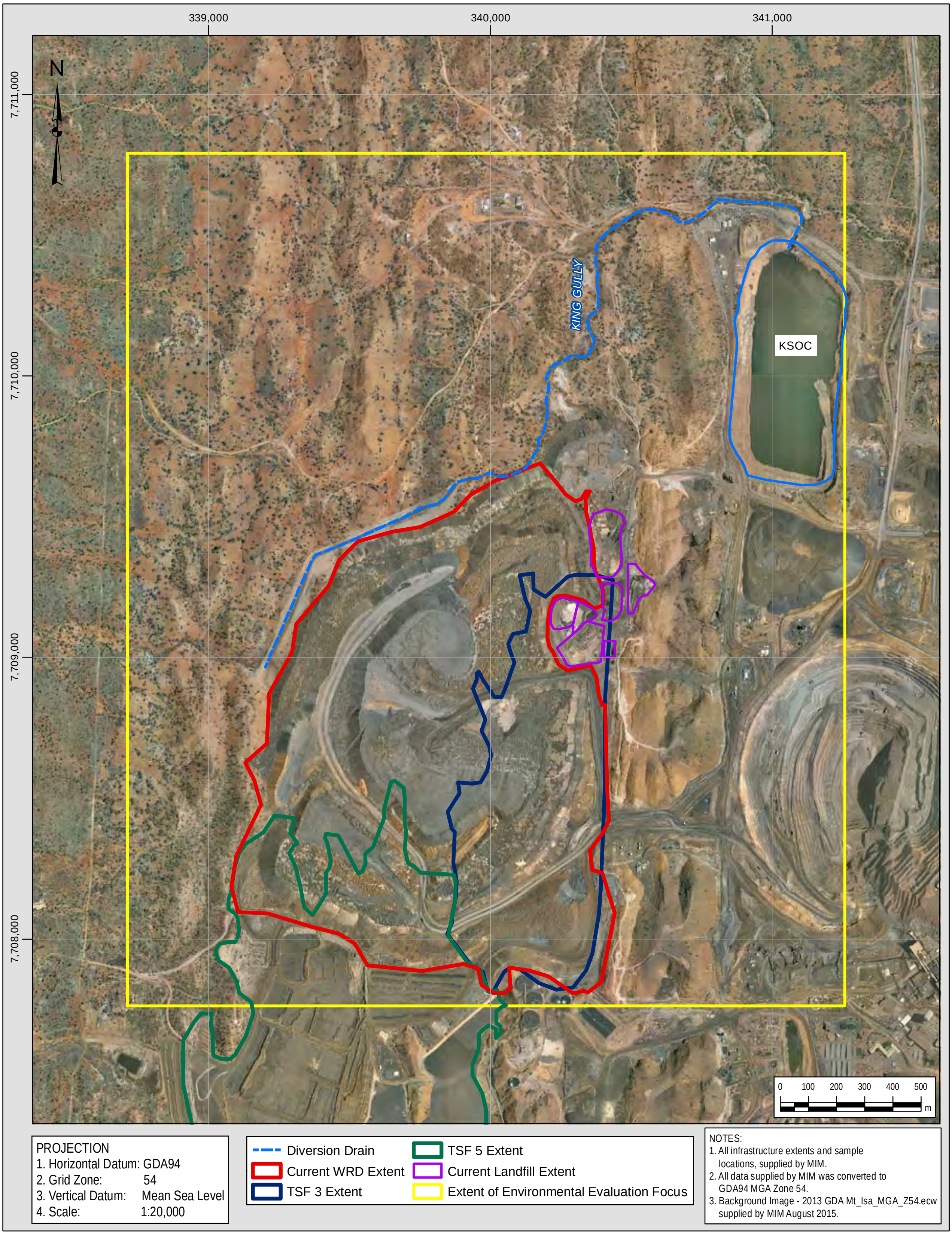

Figure 4-1: Location of BSOC WRD (current extent), TSF3, TSF5 and Landfill extent (current)

4.1 Black Star Open Cut (BSOC) Waste Rock Dump (WRD)

4.1.1 Physical Characteristics

The BSOC WRD is a valley-fill waste rock storage facility and has been in construction since 2004 containing material from the BSOC pit zinc-lead mining operations. The WRD was constructed entirely over the existing TSF3 and partially over the northern extent of TSF5. Figure 4-2 shows a photograph of the current construction of BSOC WRD (August, 2015), facing to the north.

Figure 4-2: BSOC WRD, facing north (August, 2015)

The WRD design was based on the principal of progressive encapsulation of Potentially Acid Forming (PAF) waste rock material by Non Acid Forming (NAF) waste material, resulting in PAF cells. A basal layer of NAF, of 10 m thickness, was placed on top of TSF3 to form the base of the PAF cell, while a 20 m buffer of NAF was placed onto the natural topography along the WRD base prior to the placement of PAF material. The 20 m NAF buffer was retained along the sides of the WRD adjacent to the natural topography. The design capacity of the BSOC WRD is 147 Mt, which equates to a height of 87 m above the original surface level. Currently, the WRD is scheduled to be placed in care-and-maintenance in H2 2016 (MIM, 2014).

In 2011, a Diversion Drain was constructed along the western and northern margin of the BSOC WRD. The intent of the Diversion Drain was to manage runoff and seepage water discharging from the BSOC WRD to the Kennedy Siltstone Open Cut (KSOC) process water pit via King Gully and the King Gully "first-flush" diversion weir. The Diversion Drain is referred to within the EA as the 'BSOC WRD West Diversion Drain' and is listed as a 'Regulated Dam' in the Mount Isa East Containment Area (EA, *Appendix 1, Table 1*). The Diversion Drain and transfer of seepage water is therefore included as an 'Authorised Mining Activity' under the EA.

In 2014, the King Gully Dam and associated infrastructure were installed within King Gully to collect the seepage water and pipe it to KSOC Pit as part of the clean and dirty water separation project, as shown in Figure 4-3.

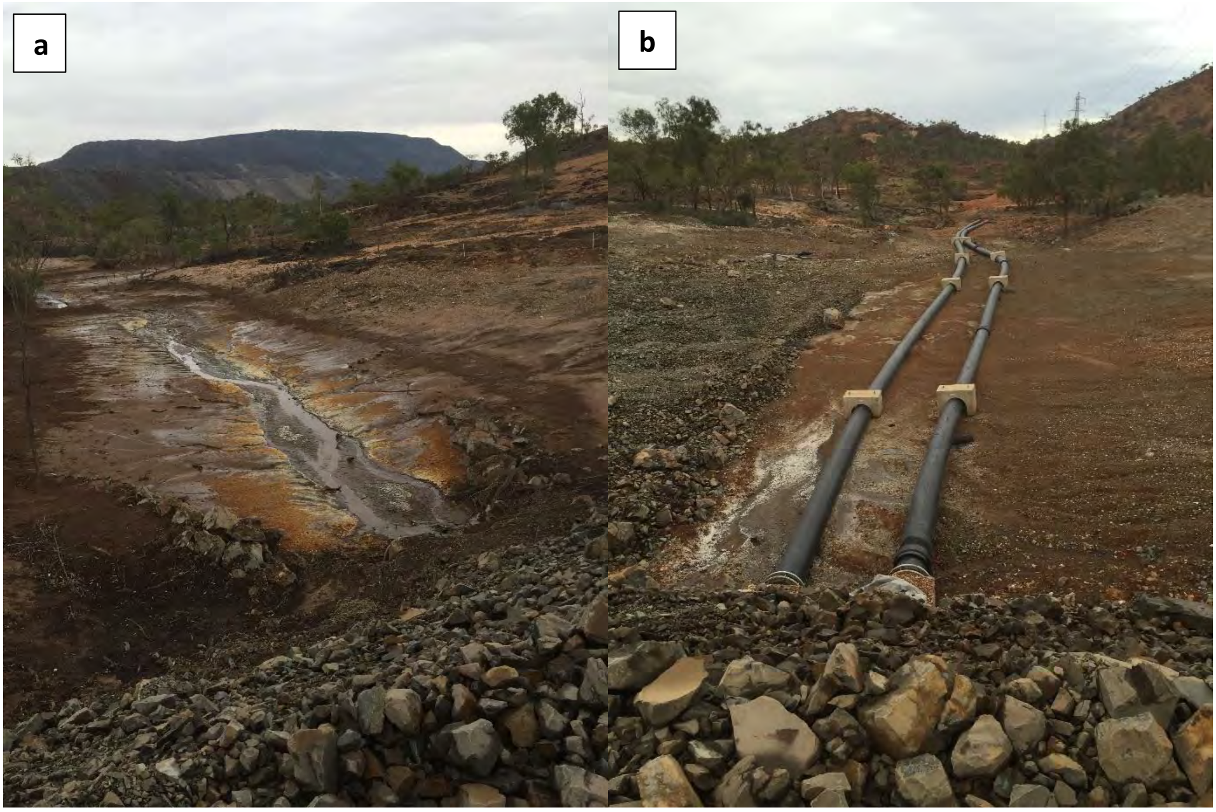

Figure 4-3: King Gully Dam. a) upstream facing south, with BSOC WRD in the background, b) downstream, facing north, where seepage is piped to KSOC (August, 2015)

4.1.2 Geochemical Characteristics

Waste rock from the BSOC pit placed within the WRD includes Urquhart Shale, Kennedy Siltstone, Spear Siltstone and Eastern Creek Volcanics. The acid-base characteristics of the waste rock in the BSOC WRD have been described extensively in a number of reports and research work (e.g. KCB 2011, 2012, 2013, 2014; Forsyth 2014, unpublished thesis) and are summarised in Table 4-1 which includes ore samples for comparison. These samples were chosen based on previous studies, which have identified (from a large dataset) these samples to be representatives of the waste rock (and ore) and are therefore considered appropriate to this study. A number of the samples have high sulphur concentrations and are considered as PAF.

Table 4-1: Acid-base accounting summary statistics for representative BSOC waste rock samples

Lithology	Statistics	Total S %	ANC (kg H_2SO_4/t)	MPA (kg H_2SO_4/t)	NAPP (kg H_2SO_4/t)	NPR
Eastern Creek Volcanics (ECV)	*Mean*	0.0026	60.96	0.08	-60.88	789.02
	Median	0.0025	54	0.08	-53.92	705.88
	Maximum	0.006	310	0.18	-2.42	4052.29
	Minimum	0.0025	2.5	0.08	-309.92	32.68
	Standard Deviation	0.0006	58.56	0.02	58.56	770.3
	Count	51	51	51	51	51
Kennedy - Spears	*Mean*	0.35	133.51	10.69	-122.83	1114.74
	Median	0.0025	110	0.08	-99.92	124.43
	Maximum	8	900	244.8	134.8	11764.71
	Minimum	0.0025	0.5	0.0765	-899.92	0.05
	Standard Deviation	1.19	143.16	36.27	150	1921.3
	Count	153	153	153	153	153
Urquhart	*Mean*	3.22	111.2	98.55	-12.65	315.3
	Median	0.21	9.5	6.43	-0.82	1.48
	Maximum	22	520	673.2	472	6274.51
	Minimum	0.0025	0.25	0.0765	-489.76	0.001
	Standard Deviation	5.54	160.14	169.4	210.1	1209.45
	Count	212	212	212	212	212

ANC – Acid Neutralisation Capacity
MPA – Maximum Potential Acidity
NAPP – Net Acid Producing Potential
NPR – Neutralisation Potential Ratio
Mean NPR – Calculated from individual samples.

Comparison of whole-sample concentration has been undertaken for the main waste rock types in BSOC WRD using data from previous studies. Whole-sample refers to analysing the entire sample of a particular waste rock or tailings material. For solid samples, this is achieved by either dissolving the entire sample with acid and analysing the composition using mass spectrometry, or fusing a portion of the sample into a 'glass' disk and analysing using X-ray fluorescence (XRF) spectroscopy. The comparisons are shown in Figure 4-4 and Figure 4-5. The following observations are made:

- In general, Urquhart Shale waste rock samples have the highest zinc, iron and lead, as would be expected in material that contains the majority of the ore bodies.
- The Kennedy-Spears waste rock samples have higher zinc and iron concentrations than the Eastern Creek Volcanic (ECV) samples.
- Kennedy-Spears waste rock samples also have greater concentrations of lead compared to the ECV samples (at least one order of magnitude greater in most cases.
- Manganese and cadmium concentrations are comparable between the waste rock types, although some Urquhart Shale samples exhibit increased cadmium (Figure 4-5).
- Kennedy-Spears and Urquhart Shale samples have comparable sulphur concentrations but Urquhart Shale waste rock samples generally have far higher iron concentrations (Figure 4-5).

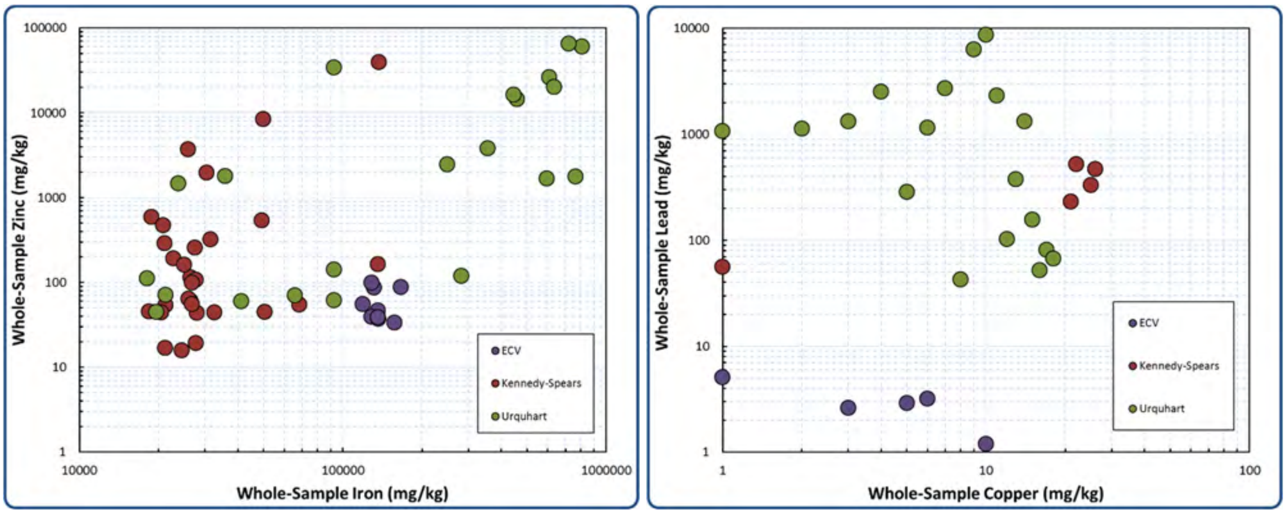

Figure 4-4: Whole-sample concentrations of the main waste rock samples a) iron and zinc concentrations, b) copper and lead concentrations

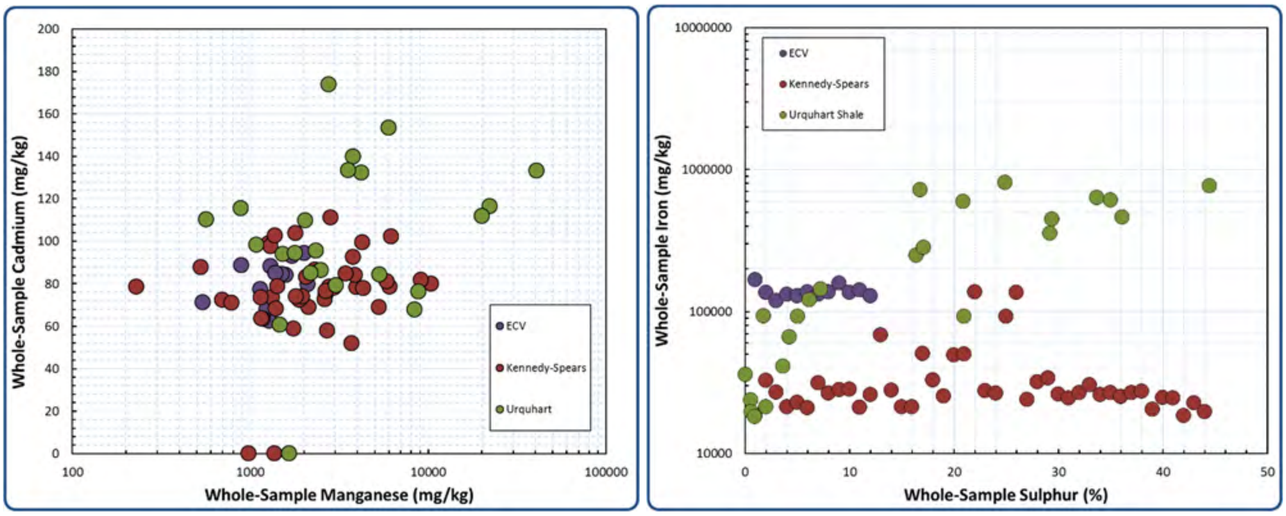

Figure 4-5: Whole-sample concentrations of the main waste rock samples a) manganese and cadmium concentrations, b) sulphur and iron concentrations

4.2 Tailings Storage Facilities

4.2.1 Physical Characteristics

Tailings Storage Facilities (TSF) 3 and 5 cover an area of approximately 182 Ha and 189 Ha, respectively. These TSFs are unlined valley-fill facilities and have been inactive for many years; TSF3 was in operation between 1946 and 1955, and TSF5 was in operation between 1958 and 1964 (Forsyth, 2014).

From the 1970s, a portion of the northern end of TSF3 was partially buried by the MIM landfill, as shown in Figure 4-1. Historical photographs provided by MIM, dated 1997 (Figure 4-6) show that the southern end of TSF3 was rehabilitated (revegetated).

Figure 4-6: TSF3 historical photograph from 1997 facing north and shows the partially rehabilitated TSF3 and MIM landfill to the east

Construction of the BSOC WRD, which began in 2004, resulted in the progressive burial of the remainder of TSF3 and a northern portion of TSF5. During construction of the WRD, a 3 m gravel cap was placed on three-quarters of the TSF3 surface. At the commencement of the WRD construction tailings in TSF3 was estimated to have been up to 25 m thick.

Figure 4-7 shows a photograph of BSOC WRD and TSF5 where it is not covered by the WRD, facing south. Mining of tailings materials from TSF5 has been undertaken since 2011 to be used as paste fill underground at the George Fisher Mine. Mining of these tailings has resulted in the exposure of the base of TSF5 and ponding of tailings water, resulting from the desaturation of the adjacent tailings profile. This occurs within the northern area of TSF5, adjacent to the southern extent of BSOC WRD. The ponded tailings water is managed via a sump and pump-back system, with ponded water pumped back to the KSOC Pit.

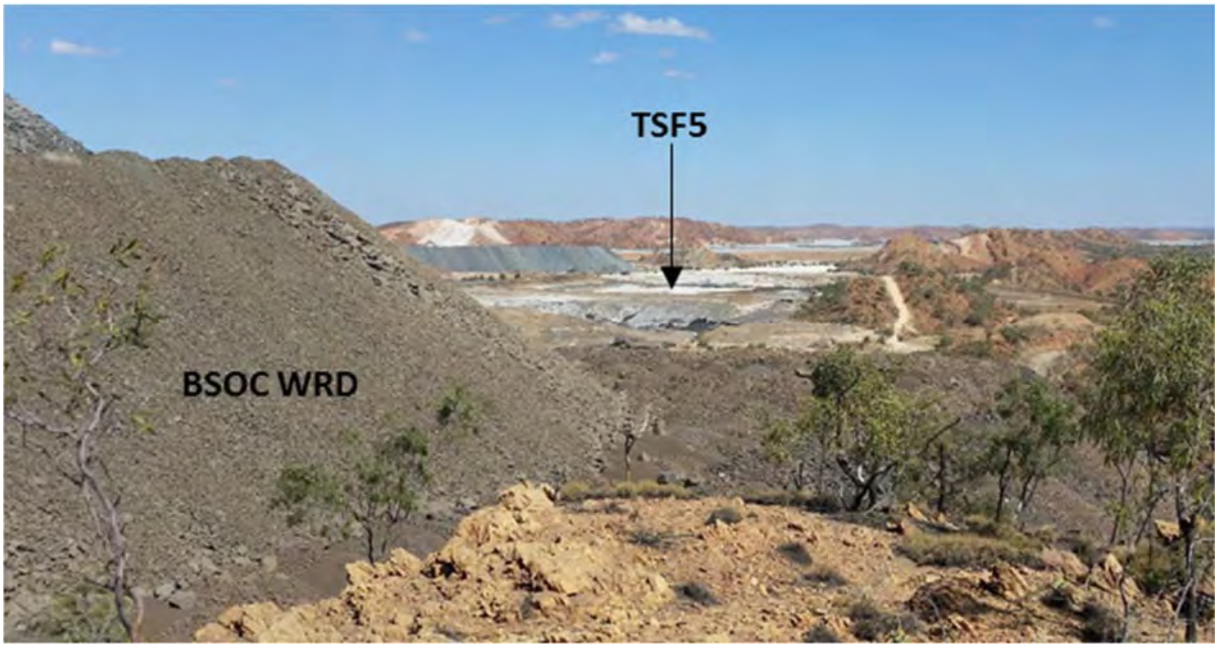

Figure 4-7: Photograph facing south showing BSOC WRD and TSF5 where it is not covered by BSOC WRD (August, 2015)

4.2.2 Geochemical Characteristics

The acid-base characteristics of the tailings have been described in a number of reports and research work (e.g. KCB 2011, 2012, 2013, 2014; Forsyth 2014, unpublished thesis) and are summarised in Table 4-2. Subsequent descriptions in this section make use of the 'historic' data found in these reports. The copper, lead-zinc-silver and mixed copper and lead-zinc samples have high sulphur concentrations and are described as PAF.

Table 4-2: Summary of MIM Tailings Characteristics

Sample	pH	EC	MPA	ANC kg H_2SO_4	NPR (ANC/MPA)	NAPP (MPA-ANC)	Total sulphur %	Oxidisable sulphur	NAG pH
84 Copper (401)	6.8	2000	94.95	90	0.95	4.95	3.1	3	7.3
86 Copper (413)	7.5	2400	116.39	100	0.86	16.39	3.8	3.7	6.9
85 Copper (407)	7.8	2600	119.46	100	0.84	19.46	3.9	3.8	7.6
84 Mixed (403)	7.2	2100	248.10	100	0.40	148.10	8.1	7.4	7.6
85 Mixed (409)	7.5	2500	336.93	110	0.33	226.93	11	10	7.7
86 Mixed (415)	7.8	2600	266.48	110	0.41	156.48	8.7	8.2	7.8
84 Lead-Zinc (405)	7.5	2300	398.19	230	0.58	168.19	13	10	7.9
85 Lead-Zinc (411)	7.7	2500	367.56	220	0.60	147.56	12	8.9	7.8
86 Lead-Zinc (417)	7.9	2700	398.19	230	0.58	168.19	13	10	7.9
Minimum	**6.8**	**2000**	**94.95**	**90**	**0.33**	**4.95**	**3.1**	**3**	**6.9**
Maximum	**7.9**	**2700**	**398.19**	**230**	**0.95**	**226.93**	**13**	**10**	**7.9**
Median	**7.5**	**2500**	**266.48**	**110**	**0.58**	**148.10**	**8.7**	**8.2**	**7.7**

ANC – Acid Neutralisation Capacity
MPA – Maximum Potential Acidity
NAPP – Net Acid Producing Potential
NPR – Neutralisation Potential Ratio
NAG – Net Acid Generation

Figure 4-8 and Figure 4-9 compare the whole-sample sulphur and iron concentrations of copper tailings, lead-zinc-silver tailings, mixed tailings and samples from TSF3 and TSF5, which were analysed prior to construction of BSOC WRD over the TSF's (URS, 2004). Also shown are concentrations from the Urquhart Shale (waste rock), which contains the majority of the zinc-ore bodies.

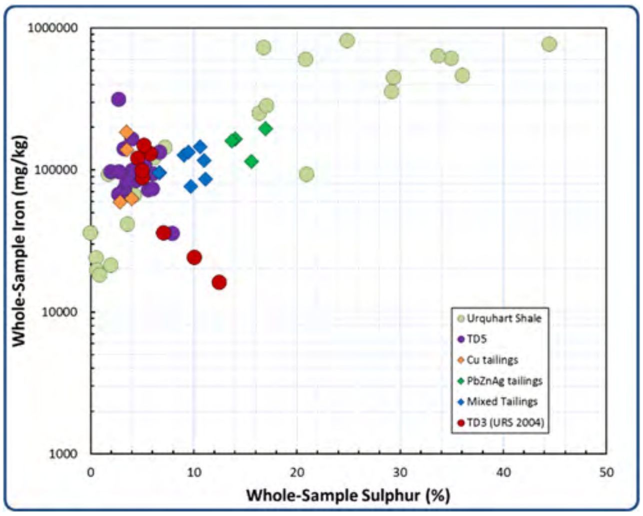

Figure 4-8: Whole-sample sulphur and iron concentrations of the copper, lead-zinc-silver and mixed tailings, compared to concentrations taken from TSF3 and TSF5.

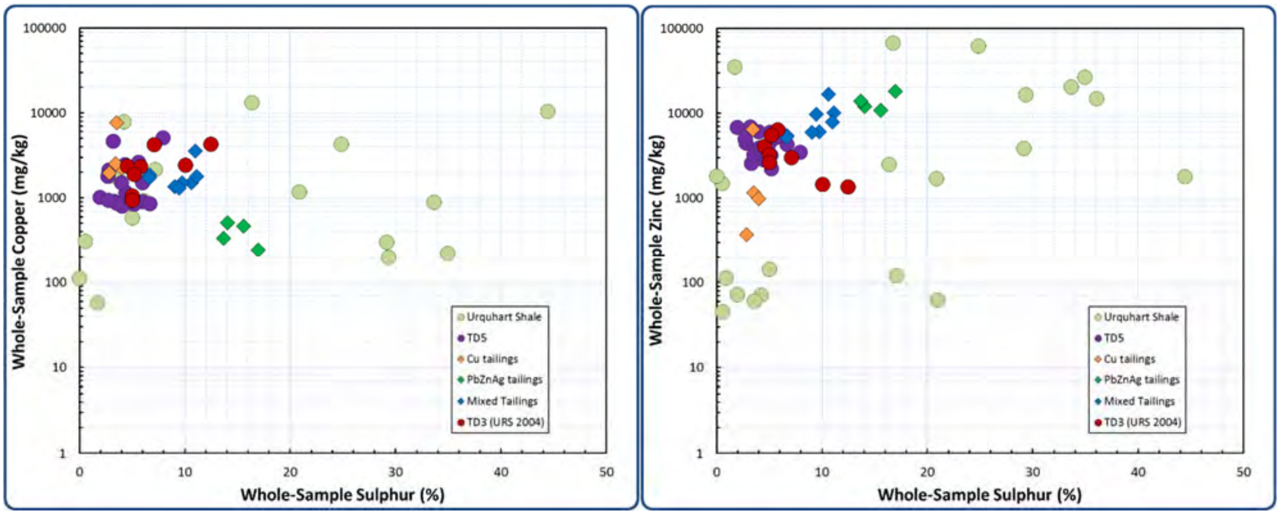

Figure 4-9: Whole-sample concentrations of the copper, copper-zinc and mixed tailings, compared to concentrations taken from TSF3 and TSF5, a) sulphur and copper concentrations, b) sulphur and zinc concentrations

As may be expected, all tailings samples have similar iron concentrations; the lead-zinc-silver and mixed tailings have higher sulphur concentrations. Whole-sample copper and zinc concentrations follow the tailings type; TSF3 and TSF5 have similar copper and zinc contents.

4.3 Mount Isa Mines Landfill Facility

The MIM landfill has been in operation for more than 30 years and was partially constructed over the existing TSF3. The site is located to the east of the BSOC WRD, as shown in Figure 4-1.

Waste disposal within this facility is authorised by the EA, which provides criteria for waste disposal and acceptance and states that the waste disposal must not extend beyond the boundary of the Mount Isa Mines Landfill.

The MIM landfill is authorised by the EA to accept the following waste types:

- Domestic waste;
- Commercial waste;
- Industrial waste;
- Regulated waste (subject to hazardous characteristics,Table 4-3);
- Construction and demolition waste; and
- Liquid waste and wastes yielding free liquid must only be disposed of in a dedicated cell (sludge pit).

Table 4-3: Waste Hazard Characteristics (Schedule F – Table 1)

Hazard Characteristic	Description of the Hazard Characteristic
Ignitability	Regulated wastes that are capable of causing a fire when ignited through friction, absorption of moisture, or spontaneous chemical changes under standard temperature and pressure
Corrosivity	Regulated wastes which on dissolution exhibit a pH of 2 or less or 12.5 or greater
Reactivity	Regulated wastes that have any of the following properties: ▪ React violently with water; and/or, ▪ Form potentially explosive mixtures with water and other substances likely to be disposed of in the landfill facility; and/or, ▪ Generate toxic gases, vapours, or fumes dangerous to human health or the environment when mixed with water and other substances likely to be disposed of in the landfill facility; and/or, ▪ Contain substances which generate toxic gases, vapours or fumes when exposed to pH conditions between 2 and 12.5; and/or, ▪ Are capable of detonation or explosive reaction when subjected to a strong initiating sources or if heated under confinement; and/or, ▪ Are readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

The location of each of the EA authorised waste types are shown on Figure 4-10, with the outline of the landfill area. The figure also shows BSOC WRD to the west of the landfill area. The waste cells directly overlying TSF3 are the general waste, tyre cell and contaminated cells, as well as the sludge pits. Regulated wastes which exhibit the hazard characteristics outlined in Table 4-3 can only be disposed of in the sludge pit or contaminated cells at the MIM Landfill, as shown on Figure 4-10.

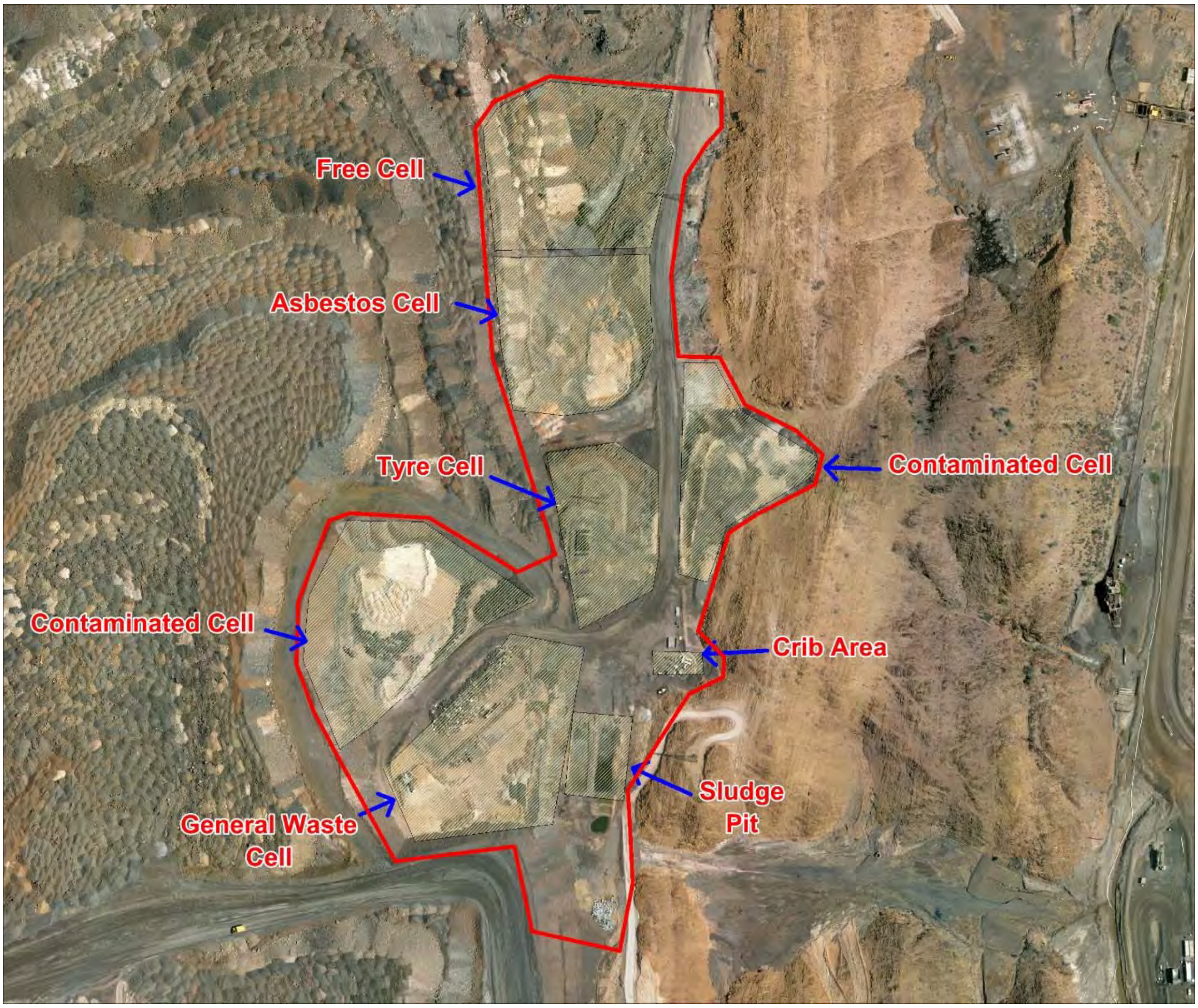

Figure 4-10: Outline of Mount Isa Landfill and associated authorised waste cells from the EA Schedule K (Figure 11)

The two sludge pits, shown in Figure 4-11, are unlined and used to dispose of liquid wastes from the MIM site and some external facilities. A landfill register of liquid waste placed in the sludge pits has been maintained since September 2009. This register indicates approximately 3.4 ML of liquid waste is placed in the sludge pits each year.

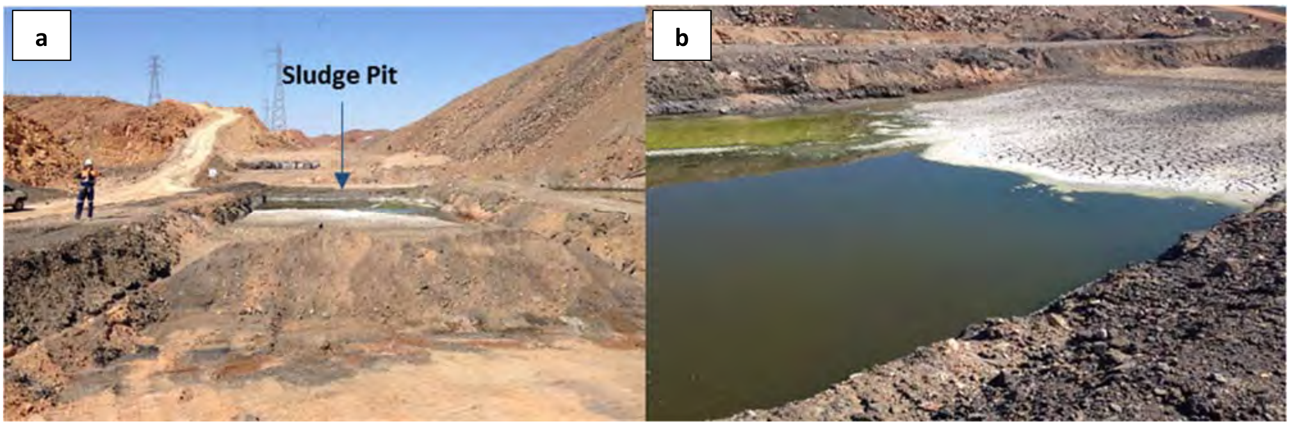

Figure 4-11: Sludge Pits. a) Sludge pit facing south, b) Sludge pit east wall facing west (August, 2015)

5 BSOC WRD SEEPAGE SOURCE, CAUSE AND EXTENT

This section of the report provides information on the source, cause and extent of the seepage associated with the BSOC WRD and addresses item 1 (a, b, c) of the EE Notice.

An overview of each of the seepage locations identified in the EE Notice is also provided in this section (section 5.1) of the report.

To provide additional understanding of the seepage associated with BSOC WRD and the underlying site infrastructure, site investigations were undertaken in August and December, 2015 by KCB personnel (Appendix II). These site investigations also aimed to address data gaps identified as part of the preliminary site understanding and data gap assessment (KCB, 2016). Two phases of site investigation were undertaken:

- Phase 1: Site inspection and field mapping, undertaken in August, 2015 by KCB Hydrogeologists.
- Phase 2: Drilling, testing and sampling, undertaken in December, 2015 by KCB Hydrogeologists and January, 2016 by MIM personnel.

The methods and results of these site investigations are further outlined below.

It should be noted that the following terminology is used in the following sections:

> ***BSOC WRD Landform:*** *Refers to all infrastructure within the footprint of BSOC WRD, including BSOC WRD, MIM Landfill, TSF3 and part of TSF5.*

5.1 BSOC WRD Landform Seepage

Seepage associated with the BSOC WRD landform generally occurs at three locations around the landform, as shown in Figure 5-1. The seepage locations were identified within the EE Notice and referred to as:

- BSOC WRD South Seepage;
- BSOC WRD North Seepage; and
- TD3 Seepage.

A description of each of the seepage points is provided in the following section.

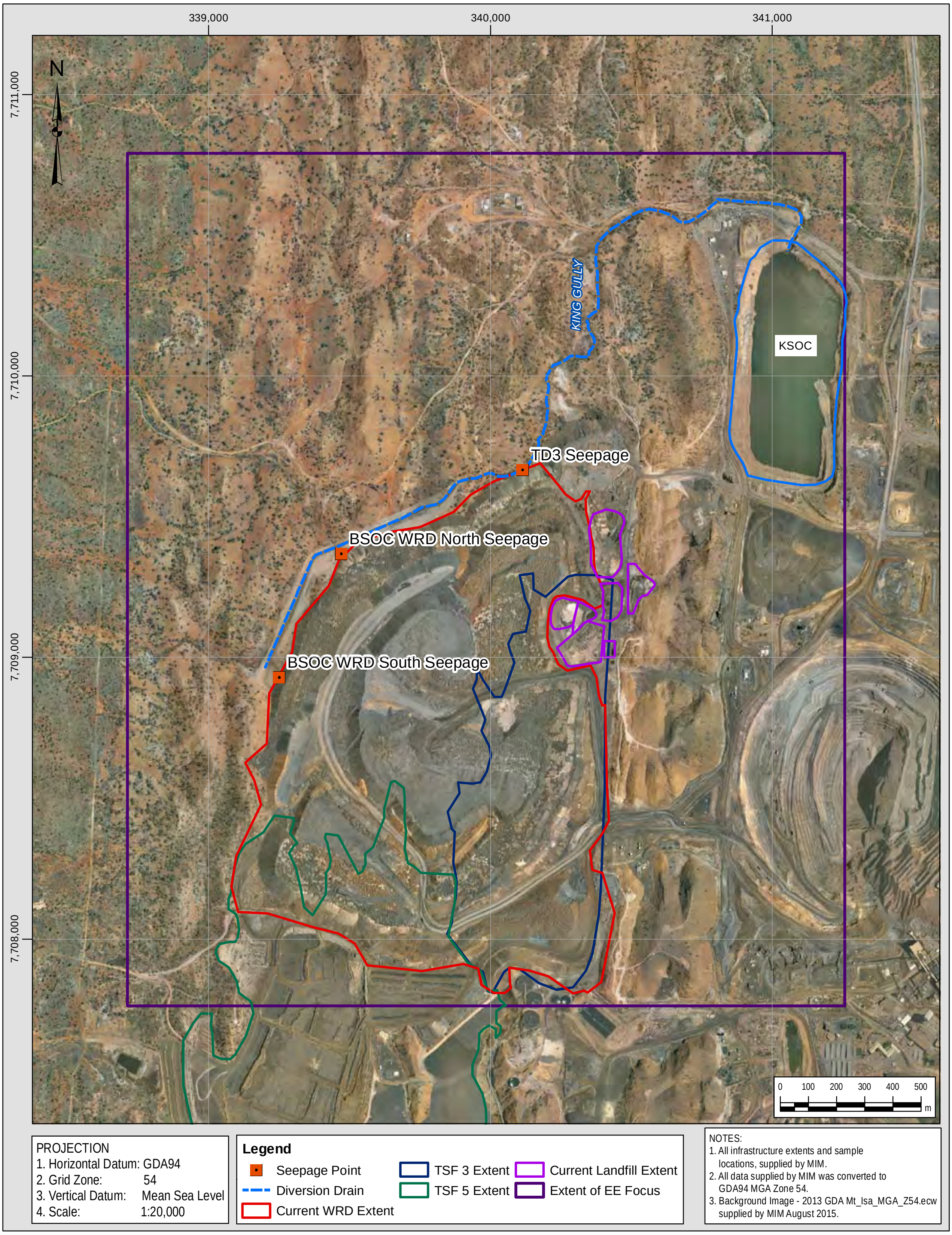

Figure 5-1: Location of Seepage associated with BSOC WRD Landform

5.1.1 BSOC WRD South Seepage

BSOC WRD South Seepage has been monitored by MIM since 2011. The location of the south seepage aligns with a natural drainage line now covered by the WRD. Prior to construction of the WRD, a dam wall / spillway for TSF5 was installed at the headwaters of this watercourse and historical aerial photographs indicate the presence of salt precipitation, which may suggest that seepage occurred downstream from the TSF5 spillway (Figure 5-2). However, natural occurrence of mineral precipitation on the ground surface has been identified during previous investigations undertaken at the MIM site (CMLR, 2009; AGE, 2002).

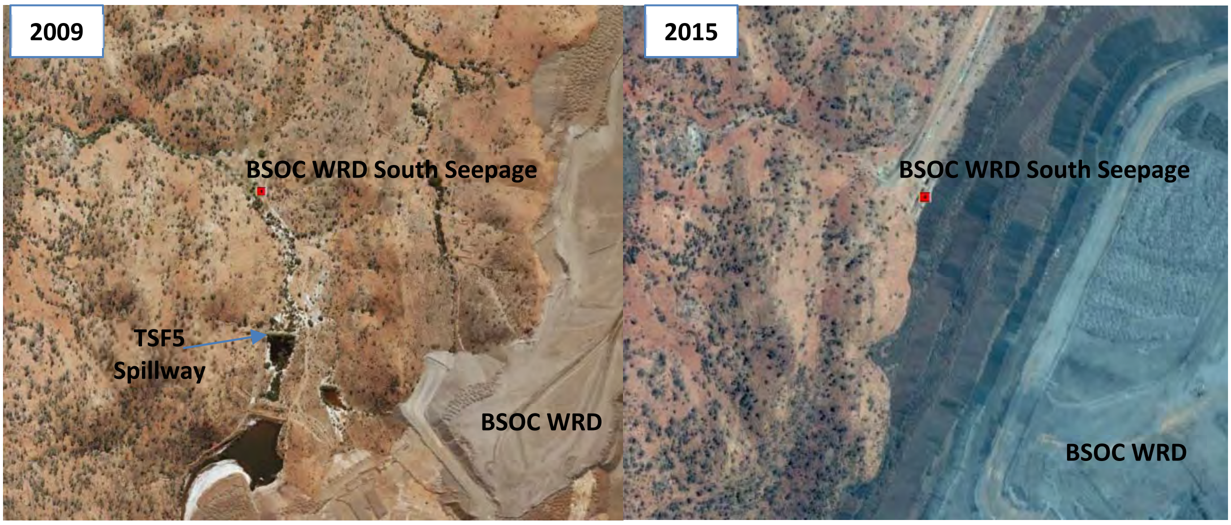

Figure 5-2: Aerial photographs of BSOC WRD South Seepage point in 2009 prior to WRD construction (left) and after WRD construction (right) in that area

Prior to the installation of the Diversion Drain, surface water flow at the BSOC WRD South Seepage location was towards the west, with the original watercourse being a tributary of Hazeldene Creek.

Multiple seepage points are observed at the BSOC WRD South Seepage, and as a result MIM have excavated a trench to allow the collection of seepage from each of these sources (Figure 5-3 and Figure 5-4). The collected seepage is mechanically transferred into the Diversion Drain, also shown in Figure 5-3, via a transfer pump, which is manually operated when the water level in the collection trench rises.

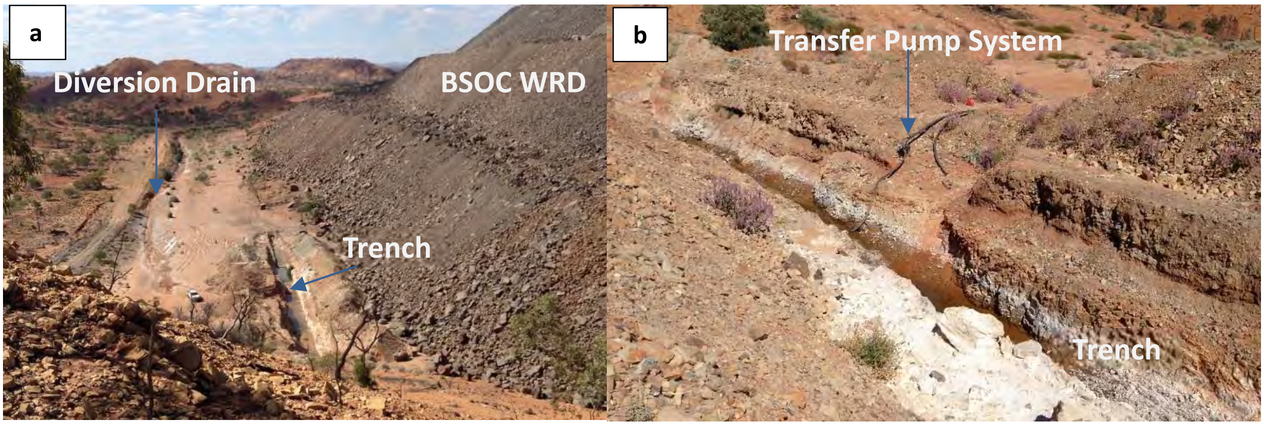

Figure 5-3: BSOC WRD South Seepage. a) Facing north, with the Diversion Drain, WRD and trench shown, b) Trench and transfer pump system (August, 2015)

Figure 5-4: BSOC WRD South Seepage. a) Facing north, toe seepage behind the trench, b) Collection of seepage within the trench (facing south) (August, 2015)

Seepage at the BSOC WRD South Seepage point occurs throughout the year, however, visual inspections indicate some seasonality influence in the flow rates (increased rates during the wet season). Monitoring of seepage rates / volumes had not been undertaken prior to this investigation, however, flow monitoring facilities have been installed in the Diversion Drain as part of this investigation to allow future monitoring (discussed further in Section 5.3.1).

5.1.2 BSOC WRD North Seepage

BSOC WRD North Seepage has also been monitored by MIM since 2011. The location of the north seepage aligns with a natural drainage line, which is now covered by BSOC WRD. Surface water flow from this watercourse, prior to the installation of the diversion, was towards the north, before flowing towards the north-west and joining Hazeldene Creek. Historical aerial photographs (Figure 5-5) before the construction of the WRD provide an indication of salt precipitation along this watercourse, which could be associated with seepage from TSF5; however as discussed previously, natural occurrence of mineral precipitation on the ground surface in this area has been identified during previous investigations (CMLR, 2009; AGE, 2002).

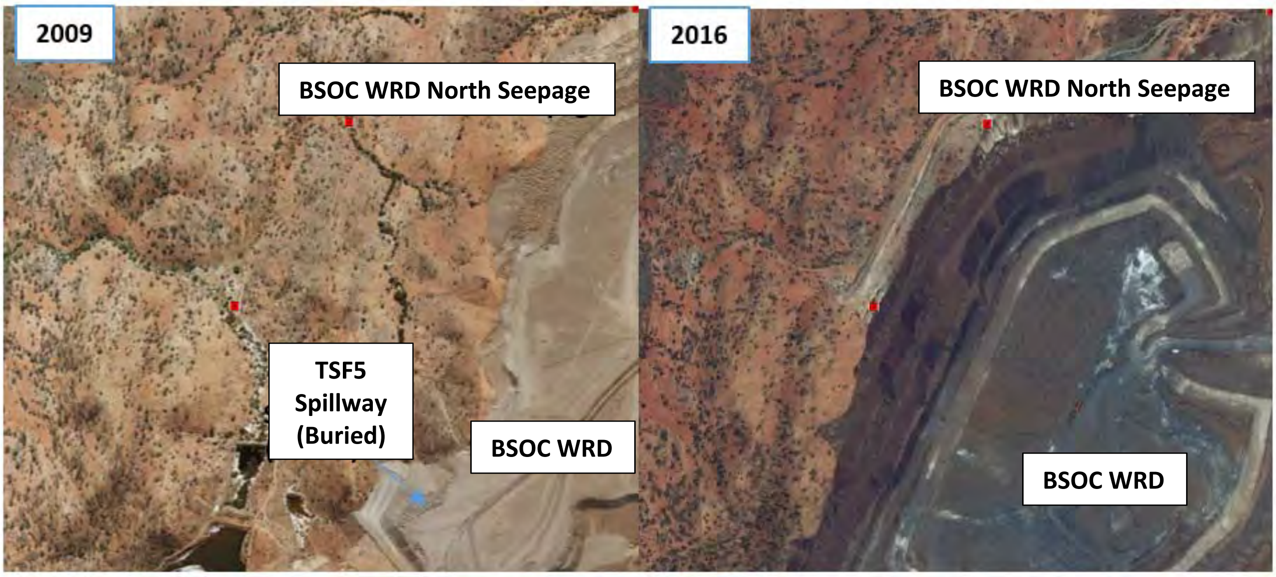

Figure 5-5: Aerial photographs of BSOC WRD North Seepage. 2009 – Prior to WRD construction, 2016 – after WRD construction

Historical monitoring of seepage at the BSOC WRD North Seepage indicates that the seepage is ephemeral, with seepage occurring during the wet season and the early dry season. Recent visual inspection of the Diversion Drain within the vicinity of this location (Phase 1 site investigation; August, 2015 (dry season)) has identified minor seepages downstream of the main seepage location, as shown in Figure 5-6. Monitoring of seepage rates / volumes had not been undertaken prior to this investigation, however, flow monitoring facilities have been installed in the Diversion Drain as part of this investigation to allow future monitoring (discussed further in Section 5.3.1).

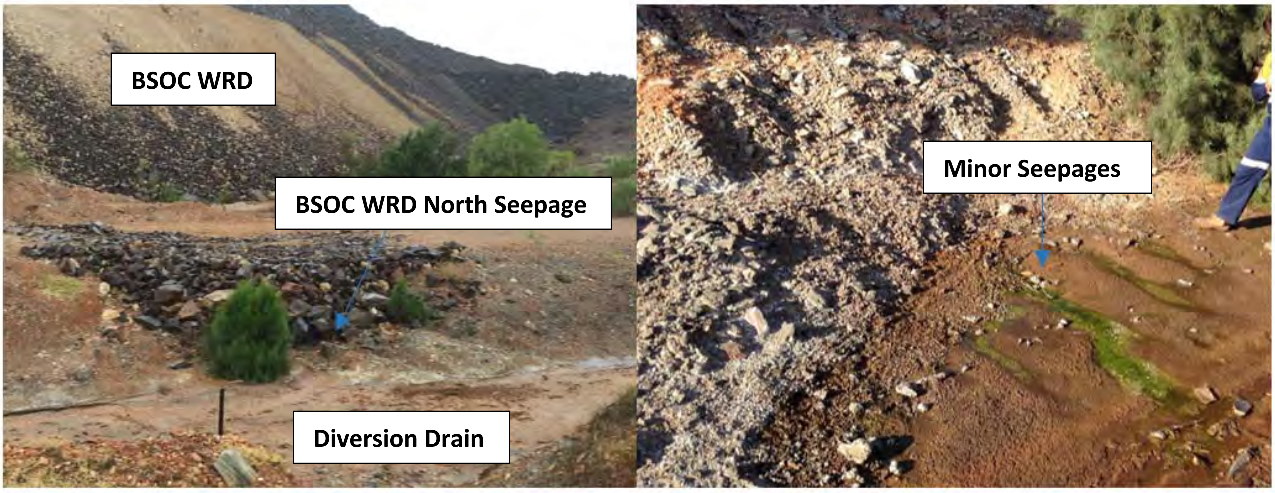

Figure 5-6: BSOC WRD North Seepage. a) Facing south, with BSOC WRD and the Diversion Drain shown, b) Minor seepages identified downstream of the main BSOC WRD North Seepage location (August, 2015)

5.1.3 TD3 Seepage

TD3 Seepage is located along the northern edge of the BSOC WRD and was identified in September 2014. The seepage location aligns with a natural drainage line underlying the WRD, which can be traced upstream to the TSF3 spillway / dam, as shown in Figure 5-7. Prior to installation of the WRD, surface water flow along this drainage line was from south to north prior to the drainage joining King Gully.

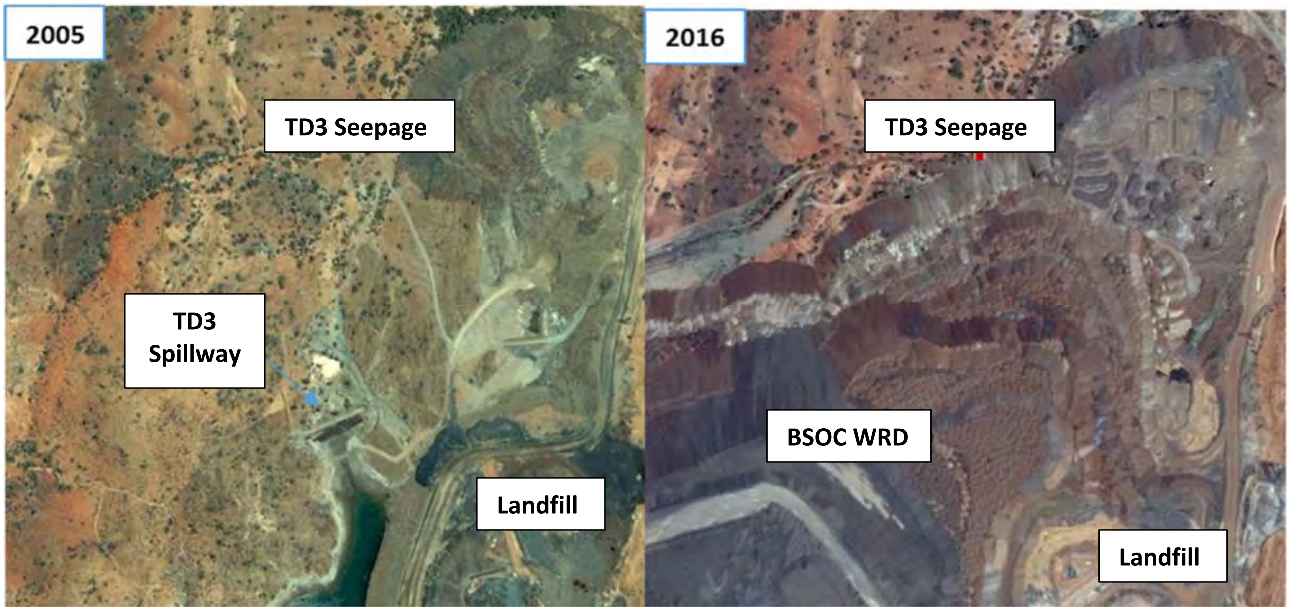

Figure 5-7: Aerial photographs of TD3 Seepage. 2005 – Prior to WRD construction, 2016 – after WRD construction

TD3 Seepage is a perennial seepage from the BSOC WRD landform, and comprises the highest seepage rate of the three seepages. The seepage discharges directly into the Diversion Drain at the BSOC WRD toe, which flows into King Gully to the King Gully Dam and eventually discharges into KSOC Pit (Figure 5-8). Monitoring of seepage rates / volumes had not been undertaken prior to this investigation, however, flow monitoring facilities have been installed in the Diversion Drain as part of this investigation to allow future monitoring (discussed further in Section 5.3.1).

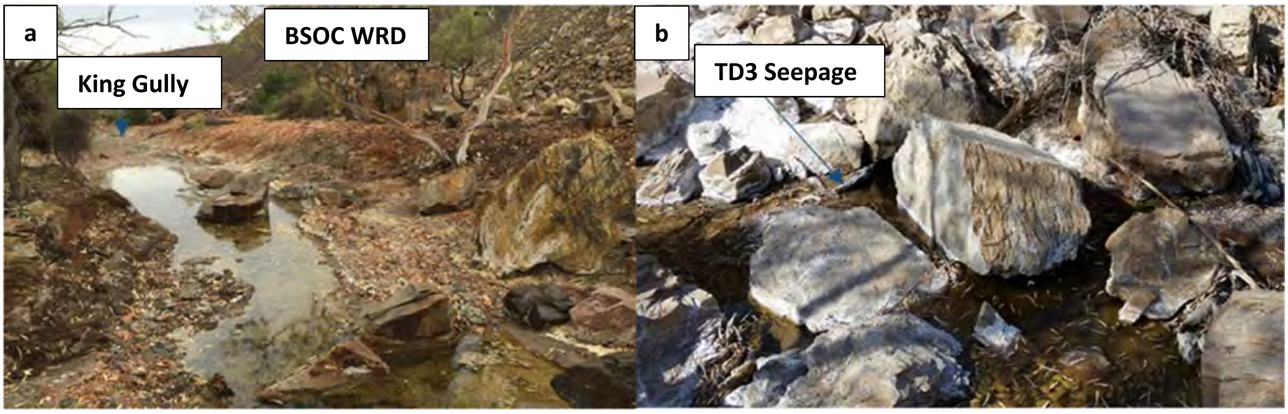

Figure 5-8: TD3 Seepage. a) Facing east at TD3 Seepage, with BSOC WRD and King Gully / Diversion Drain shown, b) Main TD3 Seepage point (August, 2015)

5.2 Current Preferential Pathways / Mechanisms / Fault Lines for Seepage

In order to determine the current preferential pathways / mechanisms / fault lines for the release of seepage from the BSOC WRD to the receiving environment (1 (a) of the EE Notice), the following tasks were undertaken:

- Development of a Reconstructed Landform Model:
  - Sub-catchment mapping of original topography underlying the BSOC WRD, prior to WRD and TSF construction.
- Development of a Conceptual Hydrogeological Model:
  - Identifying the aquifer systems associated with the BSOC WRD;
  - Drilling of 11 new investigation bores into both alluvium and bedrock;
  - Determining groundwater levels and movement;
  - Hydraulic conductivity testing of newly installed bores and existing bores;
  - Determining the hydraulic properties of waste materials, including infiltration testing on the BSOC WRD; and
  - Collection of surface water, groundwater, seepage and soil samples.

The methods and results of these investigations are presented in the following sections.

5.2.1 Reconstructed Landform Model

As part of system conceptualisation, a Reconstructed Landform Model has been generated for the area surrounding and including the BSOC WRD landform; this included the following surfaces:

- Original topographic surface before construction of TSF's and the WRD, which was interpreted based on historical topographic maps.
- Topographic surface of the TSF's, prior to construction of the WRD, provided by MIM, however the date of this is surface is unknown.
- Current topography, which was provided by MIM for Q2, 2015.

The three surfaces are presented in Figure 5-9 and also show the location of current seepage (BSOC WRD South, BSOC WRD North and TD3 Seepages), as well as an interpretation of the original drainage lines and sub-catchments.

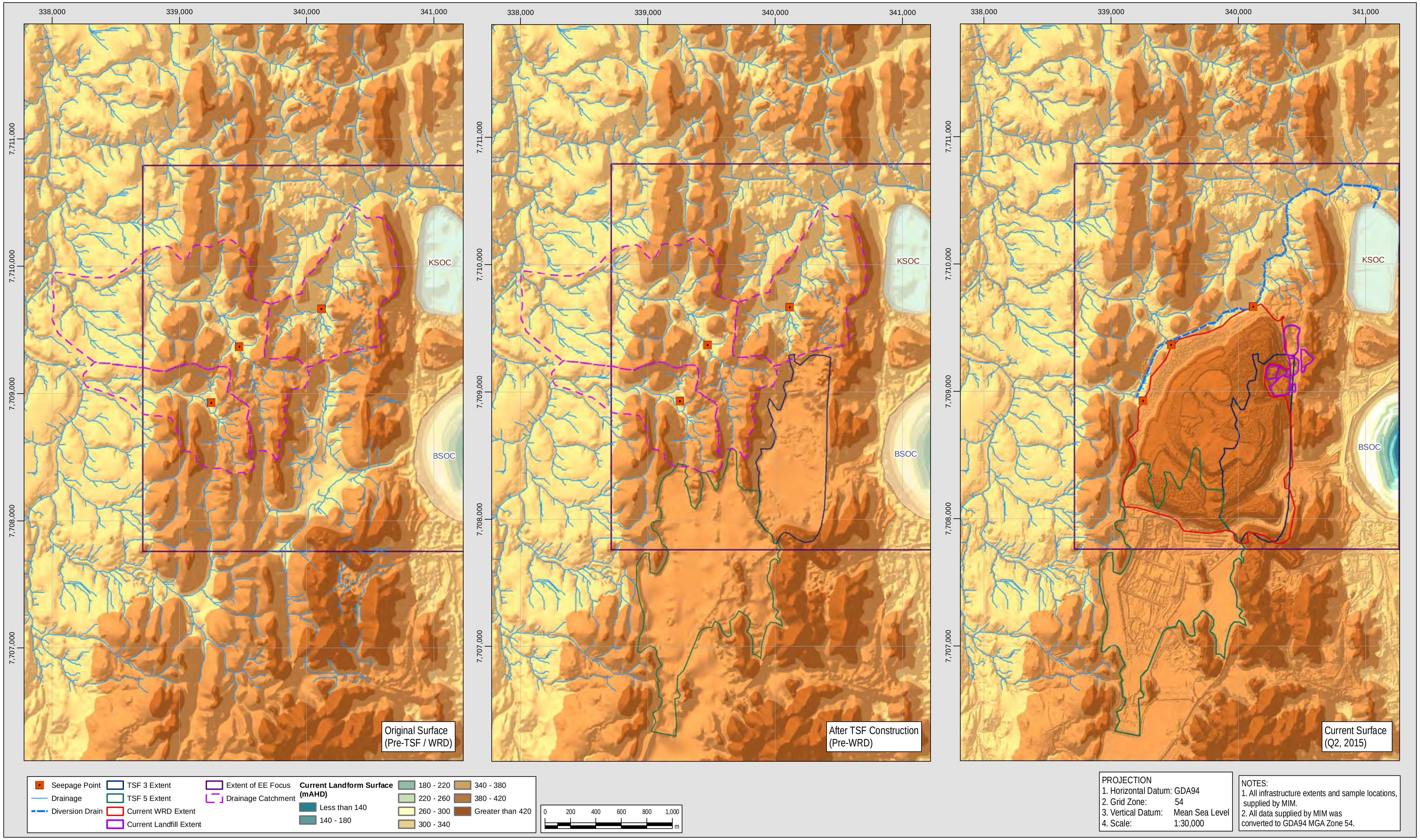

Figure 5-9: Reconstructed landform surfaces and current seepage locations. a) Original drainage / catchments – prior to TSF construction, b) After TSF construction, c) Current surface (Q2, 2015)

5.2.2 Hydrogeological Conceptualisation

This section provides the hydrogeological understanding of the groundwater system in the EE focus area. The hydrogeological conceptual model has been developed from existing background information and studies as well as the data / information obtained during the site investigations. The conceptualised hydrogeological system forms the basis for the assessment of hydraulic connection between the BSOC WRD landform and underlying groundwater system; and, the assessment of potential seepage in the groundwater system.

5.2.2.1 Aquifer Systems

Two aquifer systems are identified in the investigation area: alluvial aquifer and bedrock aquifer.

Alluvial Aquifers

The alluvial aquifer is identified as an unconfined system associated with unconsolidated alluvial sequences adjacent to watercourses across the project site. These aquifers are shallow and develop as a result of rainfall recharge and / or stream / river leakage. The alluvial aquifers within these areas have limited effective storage, due to the presence of the lower permeability clays and silts and the lack of coarse grain material. As a result this reduces the potential for these aquifers to provide baseflow during the dry season (AGE, 2002; URS, 2011).

Mapping of the alluvial aquifer system within the focus area was undertaken in the Phase 1 site investigation. The location of the mapped alluvium is presented in Figure 5-10. Also shown is the inferred location of the alluvium underlying the WRD which has been inferred based on the reconstructed landform model, as discussed in Section 5.2.1 (Figure 5-9).

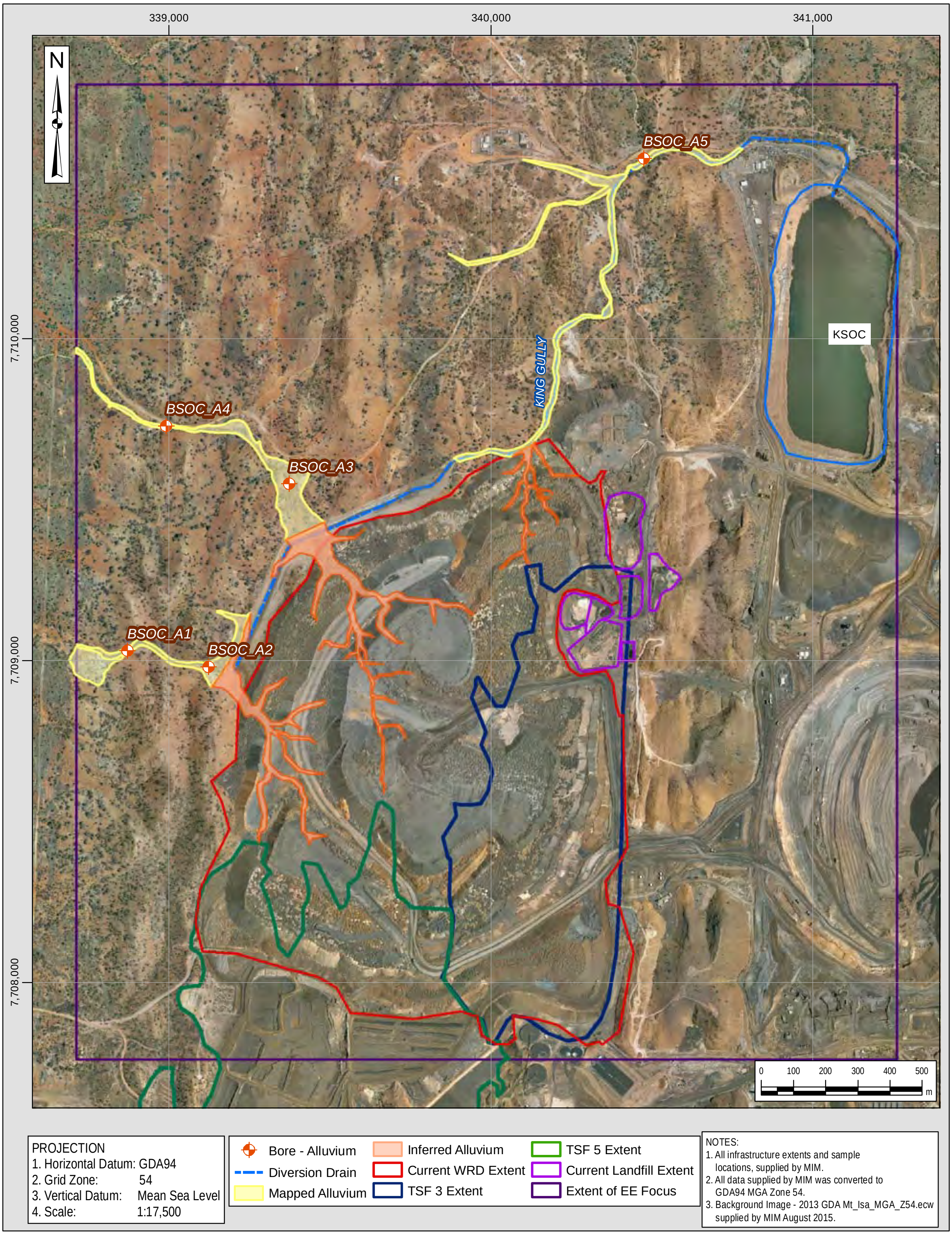

Figure 5-10: Location of mapped alluvium, inferred alluvium and alluvial monitoring bores

During the alluvium mapping exercise, a pathway for seepage was identified within the Diversion Drain, where the drain has been constructed across the alluvium. Figure 5-11 shows a conceptual schematic of the Diversion Drain from its origin close to BSOC WRD South Seepage to downstream of King Gully Dam. An inset focusing on BSOC WRD North Seepage shows the seepage water flowing down the Diversion Drain and when the seepage reaches where the drain is constructed over the alluvium, seepage water infiltrates into the alluvium, which will then flow downgradient towards the west.

Based on the Phase 1 site investigation findings, drilling and construction of five alluvial bores was undertaken during the Phase 2 site investigation. Location and Completion details for these bores are provided in Table 5-1, with the location of the bores shown in Figure 5-10. Further information on these bores is provided in Appendix II.

All bores were constructed in accordance with the *'Minimum Construction Requirements for Water Bores in Australia'* (NUDLC, 2012), under the supervision of a KCB Hydrogeologist. Airlift development of the installed bores was completed by licenced water bore drillers (Tulla Drilling), under the supervision of MIM personnel.

Table 5-1: Location and Completion Details for Alluvial Monitoring Bores

Target Aquifer	Bore ID	GDA94 MGA Zone 54 (m)		Ground Elevation (mAHD)	Stick up (m)	Drilled Depth (mbGL)	Screened Interval (mbGL)	Screened Geology	Water Level (mbGL)
		Easting	Northing						
Alluvium	BSOC_A1	338873	7709022	368	0.94	4.0	1.3 to 2.8	Alluvium, clayey gravel	0.61
	BSOC_A2	339122	7708981	375	0.70	10.0	3.6 to 9.6	Alluvium, silty gravel	1.97
	BSOC_A3	339373	7709550	378	0.94	5.5	0.8 to 2.8	Alluvium, clayey gravel	0.80
	BSOC_A4	338990	7709729	366	0.84	5.0	0.7 to 1.7	Alluvium, gravel and sand	1.19
	BSOC_A5	340475	7710561	362	0.85	5.0	0.5 to 1.5	Alluvium, gravel and sand	0.43

Bores surveyed using MIM handheld GPS
Water level measured on 21st December prior to development

The alluvium encountered was generally no deeper than 3 mbGL, with the exception of BSOC_A2, where alluvium was intersected to a depth of 9 mbGL and corresponds with the location of the confluence of two watercourses, and where the alluvium is approximately 100 m wide (perpendicular to watercourse drainage line). The alluvium generally comprised silty, sandy gravel, with angular grains. No groundwater was intersected during the drilling, however shortly after bore construction groundwater was observed in all bores. At BSOC_A3 in the period between drilling and construction, groundwater was observed flowing into the bore, which may be a result of the dewatering of a perched layer (groundwater on a low permeability layer within the alluvium profile), indicating the presence of groundwater in the alluvium. It should also be noted that groundwater in BSOC_A4 was removed during bore development in January, 2016 and did not recover for a period of up to 7 months (based on time between monitoring rounds where groundwater was encountered), indicating a dry alluvial system. However, subsequent monitoring of BSOC_A4 has recorded a groundwater level of 1.76 mbGL, indicating a recovery in groundwater levels in the alluvium.

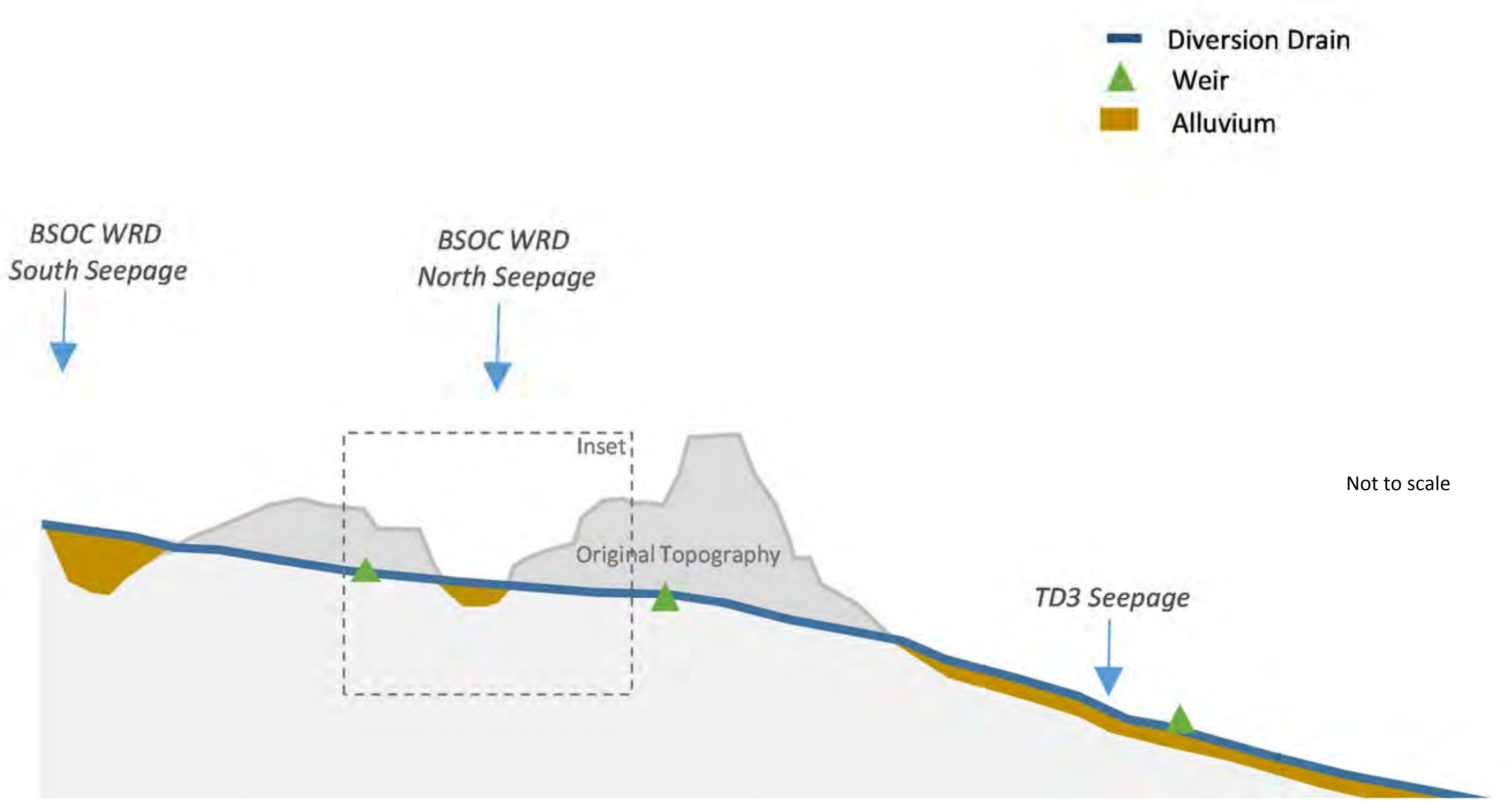

Figure 5-11: Conceptual schematic of the Diversion Drain and alluvium (as marked on Figure 5-10)

Bedrock Aquifers

Within the vicinity of the BSOC WRD landform, the bedrock aquifer is hosted in meta-sediment / meta-volcanics, comprising the Bortala Formation (Judenan Beds) and Eastern Creek Volcanics (ECVs). These formations are considered to be 'fractured rock' aquifers. Groundwater storage in this aquifer is generally limited to secondary porosity associated with the formation bedding planes. Limited weathering / leaching and faulting / fracturing are observed within these stratigraphic units, and hence primary porosity is low. Differential weathering in stratigraphic units of this aquifer is observed to be between 7 and 13 mbGL.

Previous investigations indicate that mine dewatering has a limited impact on groundwater flow in the bedrock aquifer EE focus area due to the limited hydraulic connectivity across the low permeability Mount Isa Fault, which is located to the east of the BSOC WRD Landform.

Figure 5-12 presents the location of geological structures (Stoker geology) in relation to the BSOC WRD Landform. Also shown are the interpreted conductive zones (electrical) from a Hummingbird Electromagnetic Survey (HEM), which was undertaken in 2002 by AGE Consultants and Fugro Airborne Surveys. The HEM system is designed to provide information on the spatial conductivity (electrical) variations. Over a survey region, these changes may be related to lithology, porosity, or surficial fluids. This survey was conducted with the aim of mapping the location of potential conductive trends, which may be indicative of contaminant migration.

From the figure, the following observations are made:

- Three north-south faults are located within the EE focus area:
  - The Mount Isa Fault, located east of the BSOC WRD landform;
  - On the western boundary of the focus area; and
  - Underlying TSF5, which corresponds to the geological change from the ECV to the Bortala Formation / Whitworth Quartzite.
- Zones of conductance, associated with the underlying TSF3, have been interpreted as being located from the TSF3 dam wall towards the north, which appears to discontinue at the intersection with a southeast-northwest trending structure. These were previously interpreted as being significant seepage, which is occurring at the northern end of TSF3. The report stated that this was evident by a moderate to high conductivity zone extending approximately 700 m to the north of the TSF3.
- A zone of conductance was identified from the TSF5 north dam wall towards the north. The original survey (2002) indicated that it was not clear whether this conductive trend was all the result of fluid migration, or whether the northern end of the trend is responding to a lithological cause.
- Faults within the focus area have also been considered in the context of providing a pathway or barrier for seepage. The majority of these faults are north-south trending. Of significance is the fault which is underlying TSF5 and also corresponds with the change in geology to the ECVs in the west.

This information and field observations were used to determine bore locations to target and investigate further groundwater flows in the bedrock within the focus area.

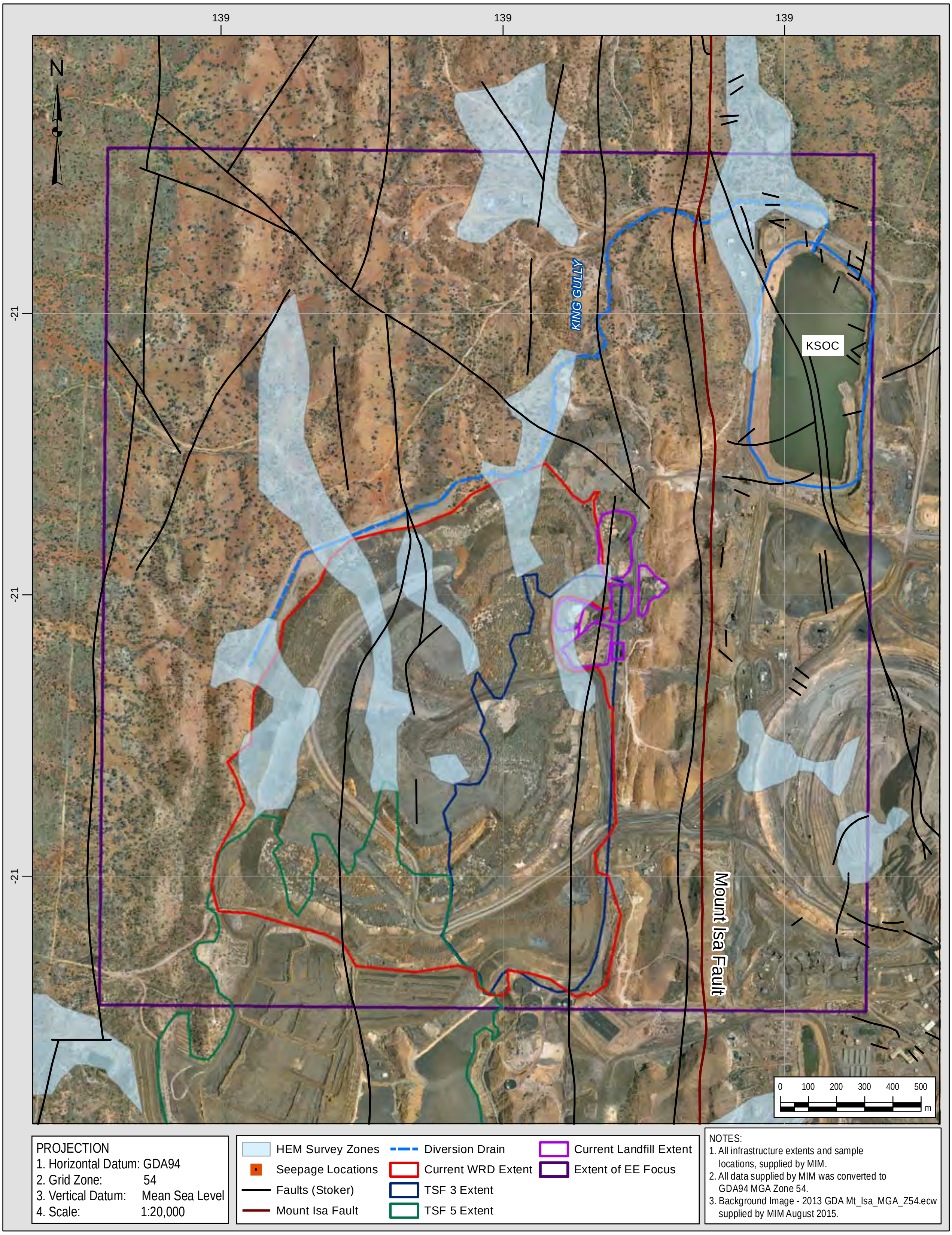

Figure 5-12: Location of faults / structures and inferred conductive zones

Drilling and construction of six bedrock bores was undertaken during the Phase 2 site investigation. Location and completion details for these bores are provided in Table 5-2, with the location of the bores shown in Figure 5-13. Further information on these bores is provided in Appendix II.

As with the alluvial bores, all bedrock bores were constructed in accordance with the *'Minimum Construction Requirements for Water Bores in Australia'* (NUDLC, 2012), under the supervision of a KCB Hydrogeologist. Airlift development of the installed bores was completed by licenced water bore drillers (Tulla Drilling), under the supervision of MIM personnel.

Table 5-2: Location and Completion Details for Bedrock Bores

Target Aquifer	Bore ID	GDA94 MGA Zone 54*(m)		Ground Elevation* (mAHD)	Stick up (m)	Drilled Depth (mbGL)	Water Strike (mbGL)	Screened Interval (mbGL)	Screened Geology
		Easting	Northing						
Bedrock	BSOC_B1	339153	7708920	384	0.75	29.2	9	11.0 to 29.0	Meta-sediments, fresh
	BSOC_B2	339177	7709783	388	1.06	26.2	9	7.8 to 25.8	Meta-sediments, fresh
	BSOC_B3	339446	7709681	381	0.29	35.3	20	17.2 to 35.2	Meta-sediments, fresh
	BSOC_B4	339676	7709695	386	1.11	36.3	20	18.3 to 36.3	Meta-sediments, fresh
	BSOC_B5	340255	7710381	367	1.07	35.0	14	14.3 to 32.3	Meta-sediments, fresh
	BSOC_B6	340189	7710685	369	0.75	72.0	42	37.0 to 55.0	Meta-sediments, fresh

* Bores surveyed using MIM handheld GPS

Some observations made during the drilling of the bedrock bores are provided in the following:

- Meta-sediments were encountered within all drill holes, generally comprising of siltstones and sandstones with varying degrees of metamorphism. Schist was common throughout, as was significant chlorite alteration in some locations.
- The base of the weathered profile was encountered at depths between 7 and 13 m.
- BSOC_B2 was drilled at a location of high conductance identified during the HEM in 2002 (as reported in URS, 2011). Some primary porosity within a meta-sandstone was observed in the drill cuttings from BSOC_B2, which may reflect a zone of increased groundwater flow. Based on the lithology and groundwater encountered during drilling, this conductive zone can be interpreted as a geological anomaly rather than an area impacted by seepage.
- Evidence of oxidation / leaching (possible fracturing) was observed in all drill holes, and generally decreased with depth.
- Groundwater was generally intersected at transition between the weathered zone and fresh bedrock, at depths of between 6 and 12 mbGL.
- Airlift yields ranged between 0.1 and 1.6 L/s, with the highest yield observed in BSOC_B2, where both matrix porosity and increased oxidation / leaching was evident.

Figure 5-13: Location of new monitoring bores

5.2.2.2 Groundwater Levels and Flow

Groundwater movement in the bedrock aquifers predominantly occurs along structural defects (faults, fractures, joint, bedding and foliation) with the rate of flow governed primarily by defect characteristics (frequency, length, aperture and orientation). Generally, these discrete structural features across the MIM site are orientated along a south to north strike. Therefore, regional groundwater movement in the bedrock aquifer is likely to be from south to north, with previous studies estimating the regional hydraulic gradient as 0.00025 (KCB, 2013b).

Limited historical data exists for groundwater levels within the alluvial aquifer within the vicinity of the BSOC WRD landform, however, groundwater level measurements from the new alluvial bores (BSOC_A1 to BSOC_A5) indicate that groundwater movement in the alluvial aquifer is a general reflection of the surface water flow regime, with movement within these unconsolidated sediments occurring as a function of gravity drainage within intergranular pore spaces.

Within the vicinity of the BSOC WRD Landform, MIM have a number of monitoring bore facilities installed within the bedrock aquifer. These have been used to assess the current and historical groundwater conditions. Some of these facilities are monitored as part of the EA (Schedule H – Table 10). Other facilities installed as part of previous (unrelated) investigations have been considered where data is available. Data from the bores drilled as part of this investigation are also included.

The location of bores discussed in the following sections are presented in Figure 5-14.

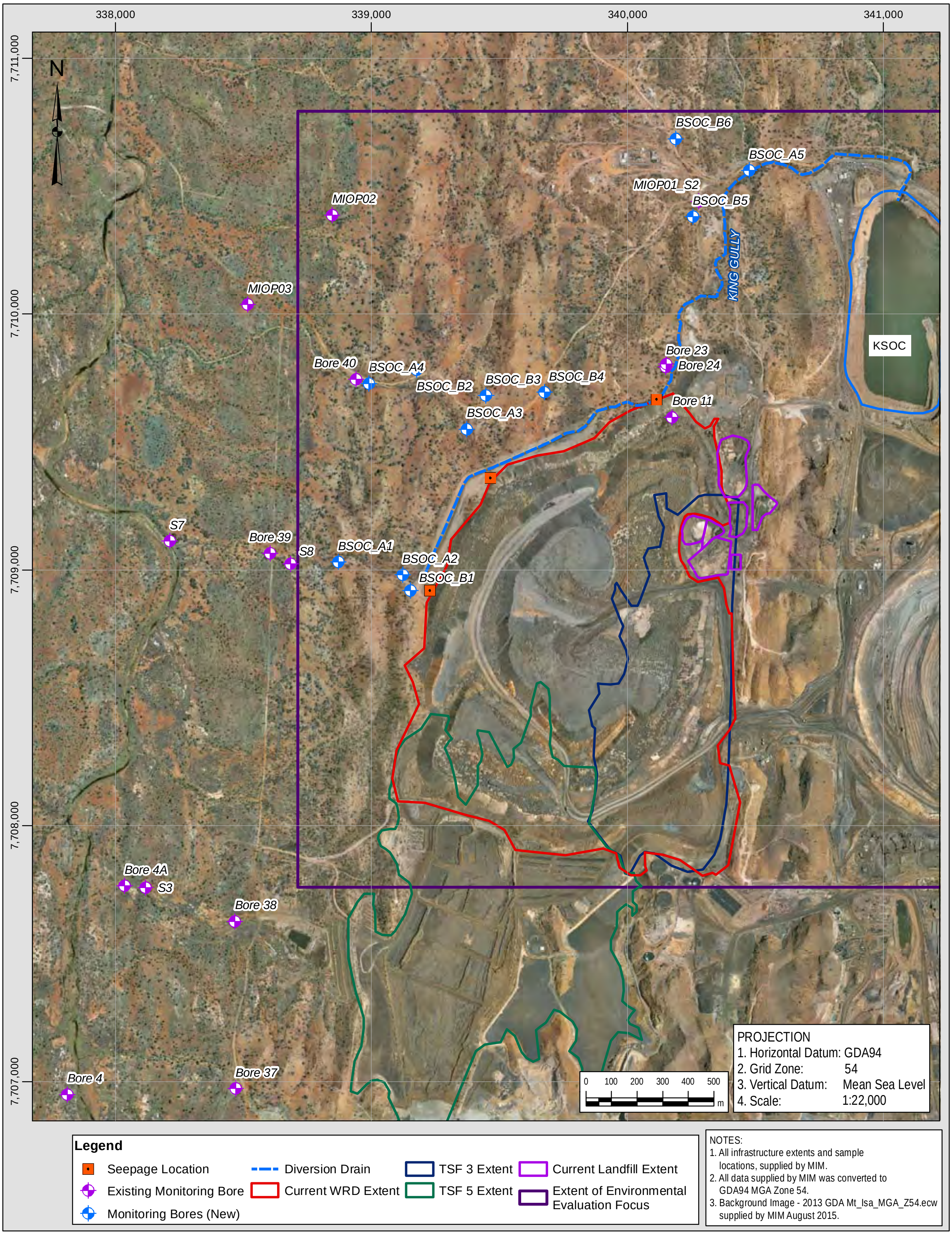

Figure 5-14: Location of bores with groundwater level records

Groundwater hydrographs are presented and discussed in the following sections, including historical data and recent data-logger data collected during this investigation (August, 2015 and February, 2016). All bore hydrographs in the following section are compared to the regional rainfall trends at the MIM site using the rainfall excess / deficit trend over the period 1995 to 2016 (Figure 3-2).

Historical groundwater level data for bores in the vicinity of BSOC WRD are presented in Figure 5-15 to Figure 5-19 based on their spatial location.

Hydrographs for bores located north of BSOC WRD and the TD3 Seepage location are shown in Figure 5-15, including Bore 23, Bore 24, MIOP01/S2 and Bore 11, which is now decommissioned and covered by BSOC WRD. Measurements taken from the new bores BSOC_B5 and BSOC_B6 are also included, however there is only one measurement.

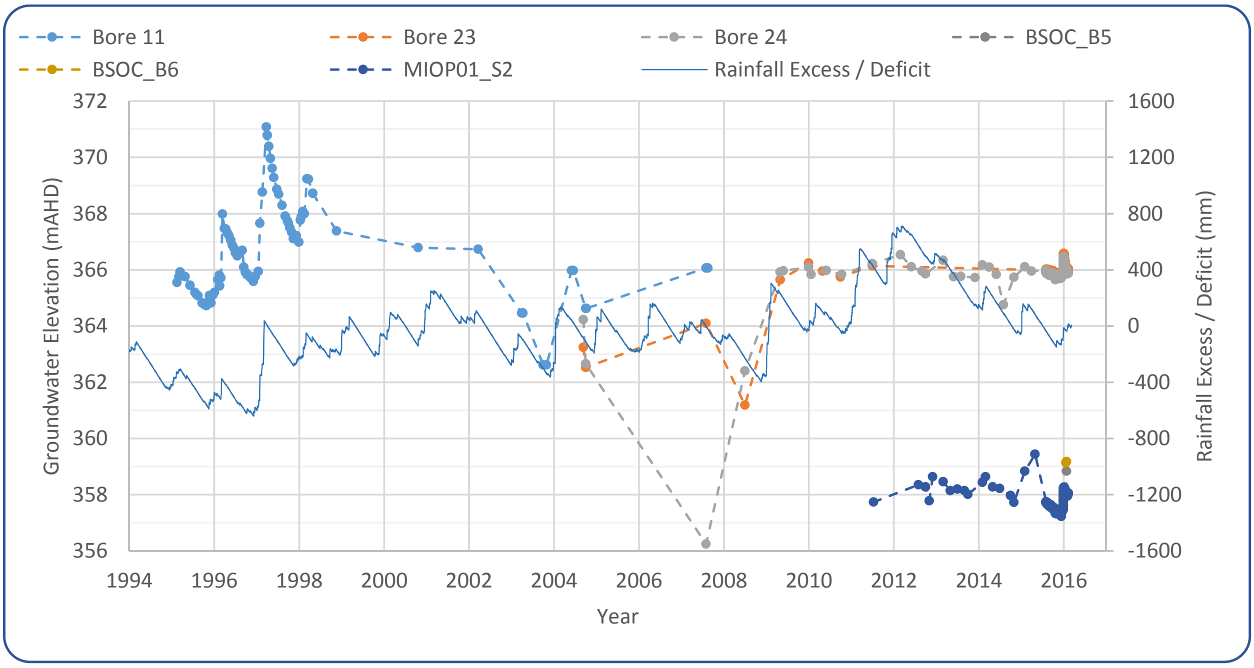

Figure 5-15: Groundwater hydrograph – bores located north of BSOC WRD and TD3 Seepage

Bore 11 has the oldest monitoring record, commencing in 1995, and ending in 2007 when it was covered by BSOC WRD. Prior to 1999, frequent measurements were collected at this location. Groundwater levels are seasonal in their response, comparable to the rainfall excess / deficit trend. After 1999 it is difficult to comment on the water level trend due to the decreased frequency of measurements.

Of the other bedrock aquifer bore monitoring records, there are limited and infrequent measurements prior to 2015 to provide a detailed interpretation of the long term groundwater trend, however some comments are made in the following:

- MIOP01/S2 is located north of BSOC WRD and screened to a depth of 5.5 mbGL. The water level hydrograph shows a very good correlation with the rainfall excess / deficit trend. Increases in the groundwater level occur as a result of large rainfall events, which suggests that recharge at this location is almost instantaneous and that groundwater levels are controlled by the rainfall conditions.

- Bore 23 and Bore 24 can be considered as a nested monitoring site, with screens located within the weathered bedrock and fresh bedrock respectively. These sites are located the closest to the BSOC WRD and show a similar water level response to each other, indicating connection between the weathered and fresh bedrock at this location and a downward gradient (discussed further later in this section).

Based on the available historical data for Bore 23 and Bore 24, groundwater levels do not correlate with the long term excess / deficit trend, showing a relatively stable groundwater levels observed when compared against the decline in the rainfall trend. This is highlighted further in Figure 5-16, which shows the difference in the change in water level for Bore 24 relative to two other sites, Bore 39 and Bore 40, which correlate with the overall rainfall trend. The graph shows that since 2011, although there have been seasonal responses, these are of a lower magnitude than observed in the other monitoring sites. The overall change (for the period presented) has been a decline of ~0.5 m for Bore 24, whereas the decline is ~6 m in Bore 40 and ~4.5 m in Bore 39. This response differs to those observed at other sites and potentially indicates a secondary source of recharge (BSOC WRD Landform) at Bore 23 / Bore 24.

The recent data-logger data for Bore 23 and Bore 24 also supports this in the response to the wet season rainfall. Following the large rainfall event in December 2015 / January 2016, groundwater levels increase by ~0.7 m and decline to close to pre-event levels by February 2016. The other bores water levels do not respond in the same way to Bore 23 and Bore 24 and are still at their peak at the time of data-logger removal.

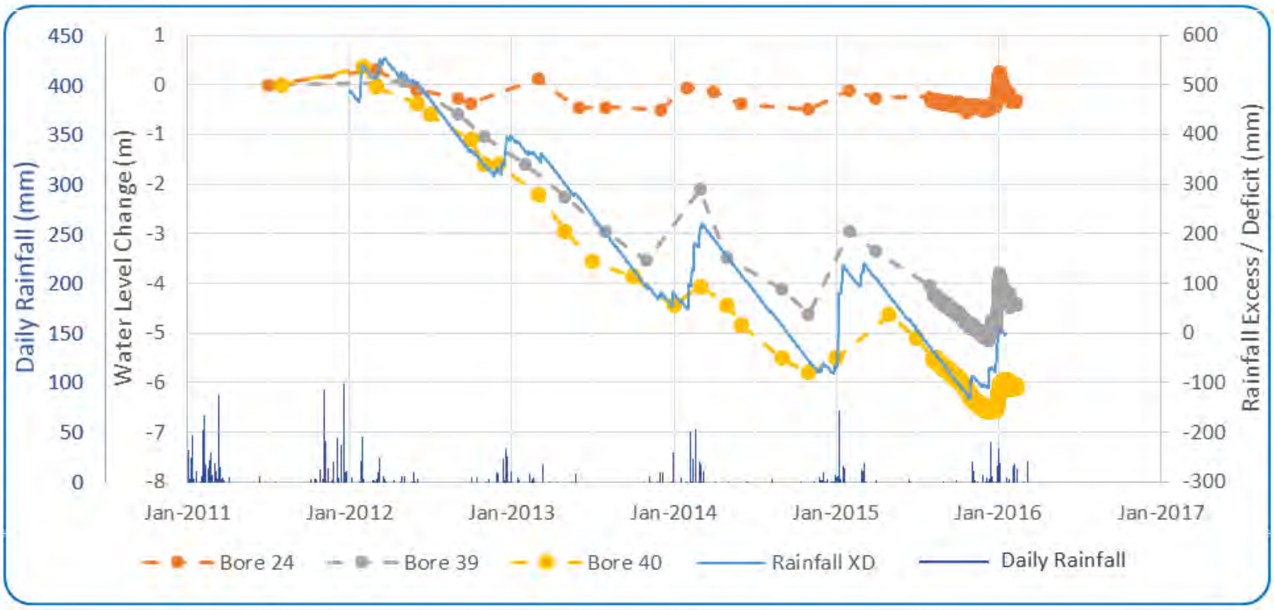

Figure 5-16: Change in groundwater level at Bore 24, Bore 39 and Bore 40 from July, 2011 to February, 2016, with rainfall excess / deficit trend and daily rainfall

Hydrographs for bores located along the creek line west of the BSOC WRD (and BSOC WRD South Seepage) are presented in for Figure 5-17, including Bores 39, S7 and S8. New bore BSOC_B1 is also included, however, there is only one measurement.

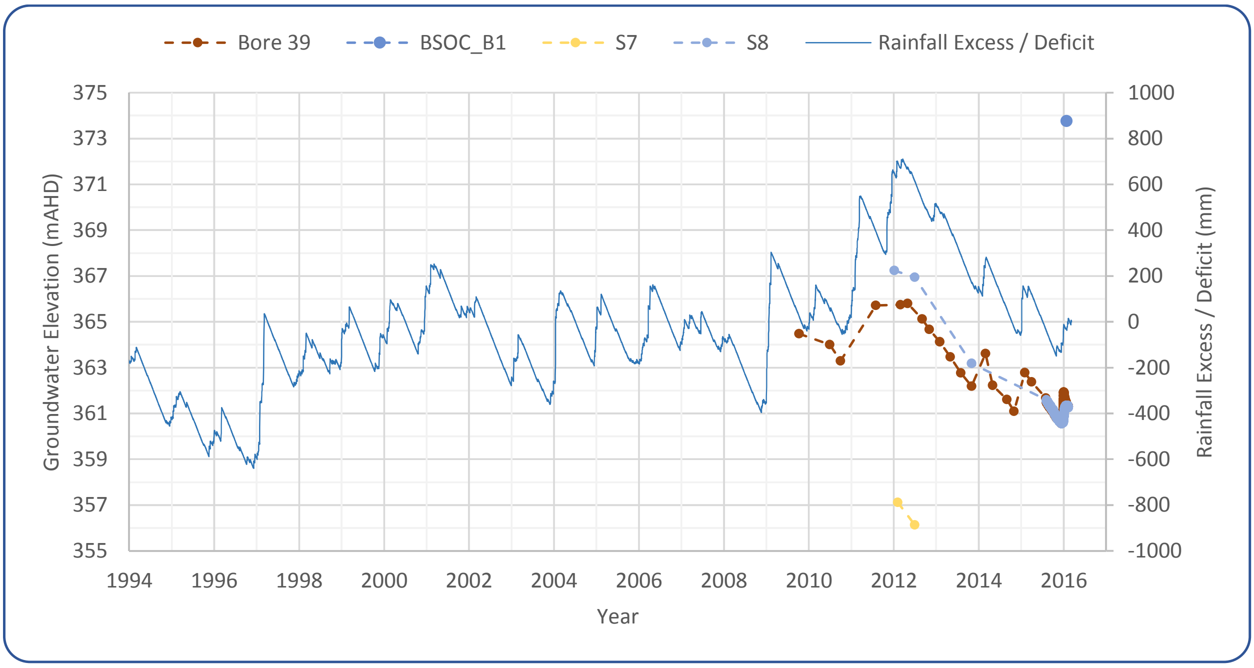

Figure 5-17: Groundwater Hydrograph – Bores located west of BSOC WRD South Seepage

The groundwater level monitoring record commences after 2009 for these monitoring sites. Generally it can be observed that the water levels in these locations are seasonal in their response and the decline in groundwater levels between 2012 and 2016, which correlates with the rainfall excess / deficit trend during the same period. Bore specific observations from the recent data-logger data include:

- Bore 39 and S8 are located to the west of BSOC WRD and the BSOC WRD South Seepage. The two bores are located ~80 m apart and based on available geology information the bores are screened within different formations. Although relatively close together these sites are also located on opposite sides of a north-south trending fault. The hydrograph also shows that the water levels observed in the bores are considerably different.
  - Bore 39 correlates well with the rainfall excess / deficit trend, with rises in groundwater level observed following rainfall events. The large rainfall event in December 2015 / January 2016 results in an increase of over 1 m in Bore 39, with a steady decline in the following month.
  - Water levels from S8 show a much more subtle response to rainfall events, with a lag time of 20 days before groundwater levels peak following the December 2015 / January 2016 event.

Hydrographs for bores located north and northwest of BSOC WRD North Seepage are shown in Figure 5-18, including Bore 40, MIOP02 and MIOP03. Measurements taken from the new bores BSOC_B2, BSOC_B3 and BSOC_B4 are also included, however, there is only one measurement.

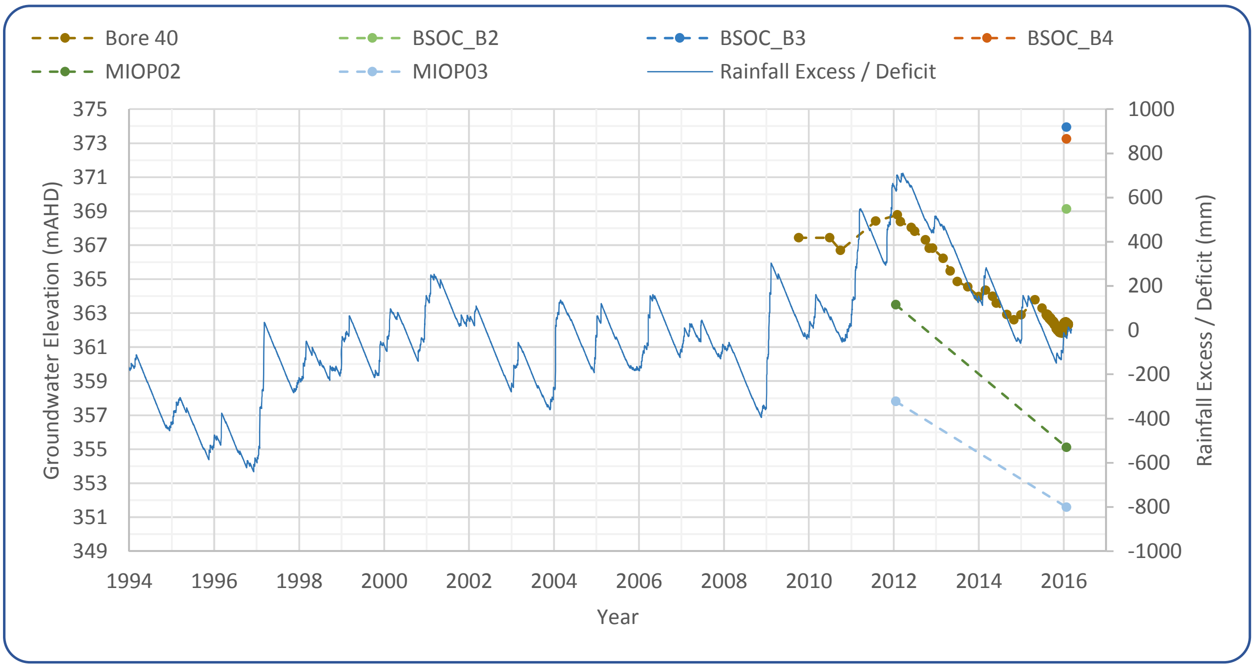

Figure 5-18: Groundwater Hydrograph – Bores located north and northwest of BSOC WRD North Seepage

Limited data exists at these bores, as they were drilled for investigative purposes rather than monitoring, with the exception of Bore 40, which is monitored as part of the EA, with records commencing in 2009. The hydrograph for Bore 40 shows an overall declining trend between 2009 and 2016, which corresponds with the trend observed in the rainfall / excess deficit plot. The water levels are similar to that of S8, located to the south of Bore 40, however there is less of a lag in response to the rainfall event. Based on the two points available for MIOP02 and MIOP03, both these sites have also experienced a decline in groundwater level, however no further comment can be made due to the limited data.

Hydrographs for bores located to the southwest of BSOC WRD are shown in Figure 5-19, including Bore 37, 38, 4, 4A and S3.

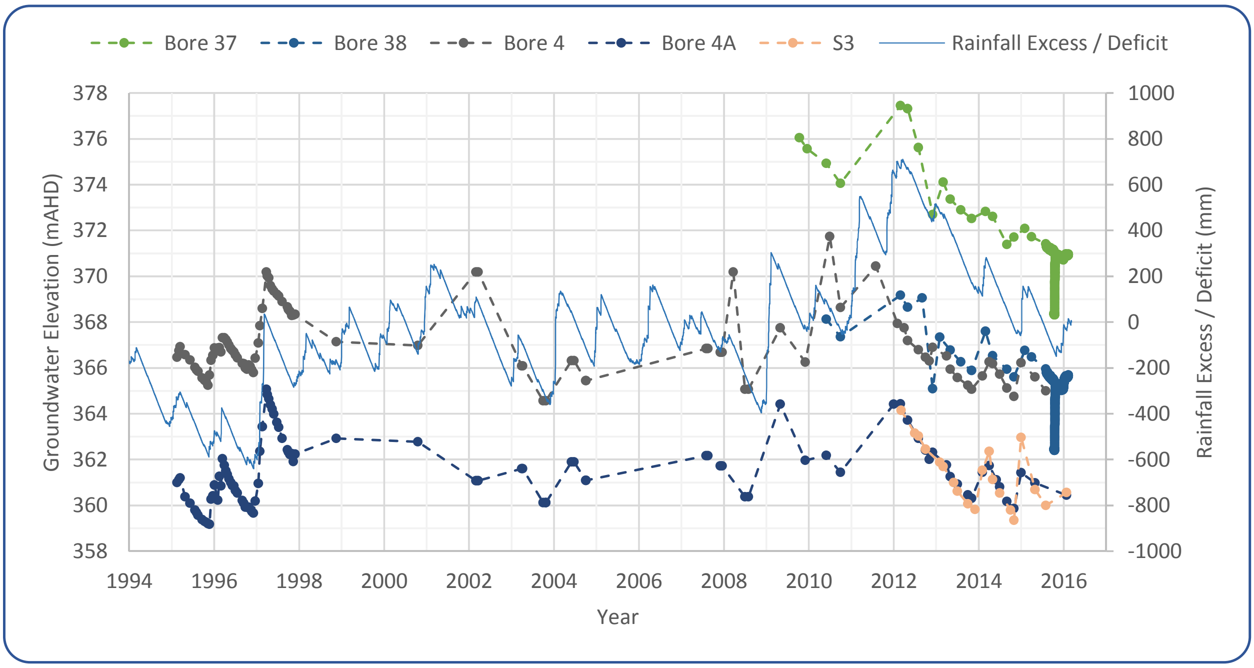

Figure 5-19: Groundwater Hydrograph – Bores located south-west of BSOC WRD and west of TD5

The records for two sites (Bore 4 and Bore 4A) have a good frequency of data between 1995 and 1998 and the water levels between this period show a good correlation with the rainfall excess / deficit trend. A rise of ~4 m in the groundwater level at both sites is observed following large rainfall events during the 1996 / 1997 wet season. Between 1998 and 2012, the available groundwater data is infrequent and therefore no comment is able to be made in reference to trends during this period.

From 2012 groundwater levels across all monitoring sites show a general decline, which correlates to the decline observed in the rainfall excess / deficit trend. Bore 4A and S3 appear to have greater fluctuations associated with the wet / dry seasons, while bores such as Bore 37 have a more tempered response. It should also be noted that the water level records for Bore 37 and Bore 38 show a drawdown response in late 2015, which may relate to pumping associated with quarterly groundwater sampling of these bores required by the EA *Schedule H (Table 10)*.

Groundwater Level Summary

Based on the available groundwater level data presented and discussed in the previous sections, the following comments are made relating to the groundwater system:

- Across most sites, there is a good correlation with the rainfall excess / deficit trend, particularly post 2012, where the majority of data exists.
- Wet / dry season fluctuations are also observed, varying in the magnitude of response across the monitoring sites, likely to be a function of variable hydraulic conductivities in the bedrock aquifer (driven by variable lithologies).
- The groundwater level response to large rainfall events is often almost instantaneous, indicating that there is direct infiltration from rainfall.

- Hydrographs for Bore 23 and Bore 24 indicate a secondary recharge mechanism for the bedrock aquifer at this location, and is likely to be the BSOC WRD Landform, given their proximity to the landform.

Groundwater Flow Contours

Previous studies have interpreted the regional groundwater flow direction within the Myally Sub-group and Eastern Creek Volcanics as being in a north to north-westerly direction (CMLR, 2010), based on topography.

Groundwater level contours have been produced to provide an understanding of the groundwater flow regime within the immediate vicinity of the BSOC WRD Landform and provide an indication of the direction of groundwater flow. The contours have been generated for the bores screened within the weathered and fresh bedrock for the wet season in January 2016; insufficient data was available to produce contours for the dry season.

Figure 5-20 shows the inferred groundwater level contours, which indicate a general radial pattern around the BSOC WRD, with groundwater flowing away from the BSOC WRD Landform towards the west and north. This radial groundwater flow adjacent to the BSOC WRD Landform is indicative of a higher hydraulic head within the BSOC WRD Landform, which is in hydraulic connection / influencing the underlying bedrock piezometric surface. It should be noted that at the groundwater levels were collected on January 26, 2016 and if a comparison is made for that period between the inferred contour pattern to the response presented in the hydrographs; the contrasting response after the rainfall event, which is seen in Bore 23 and Bore 24, is also observed in the contours.

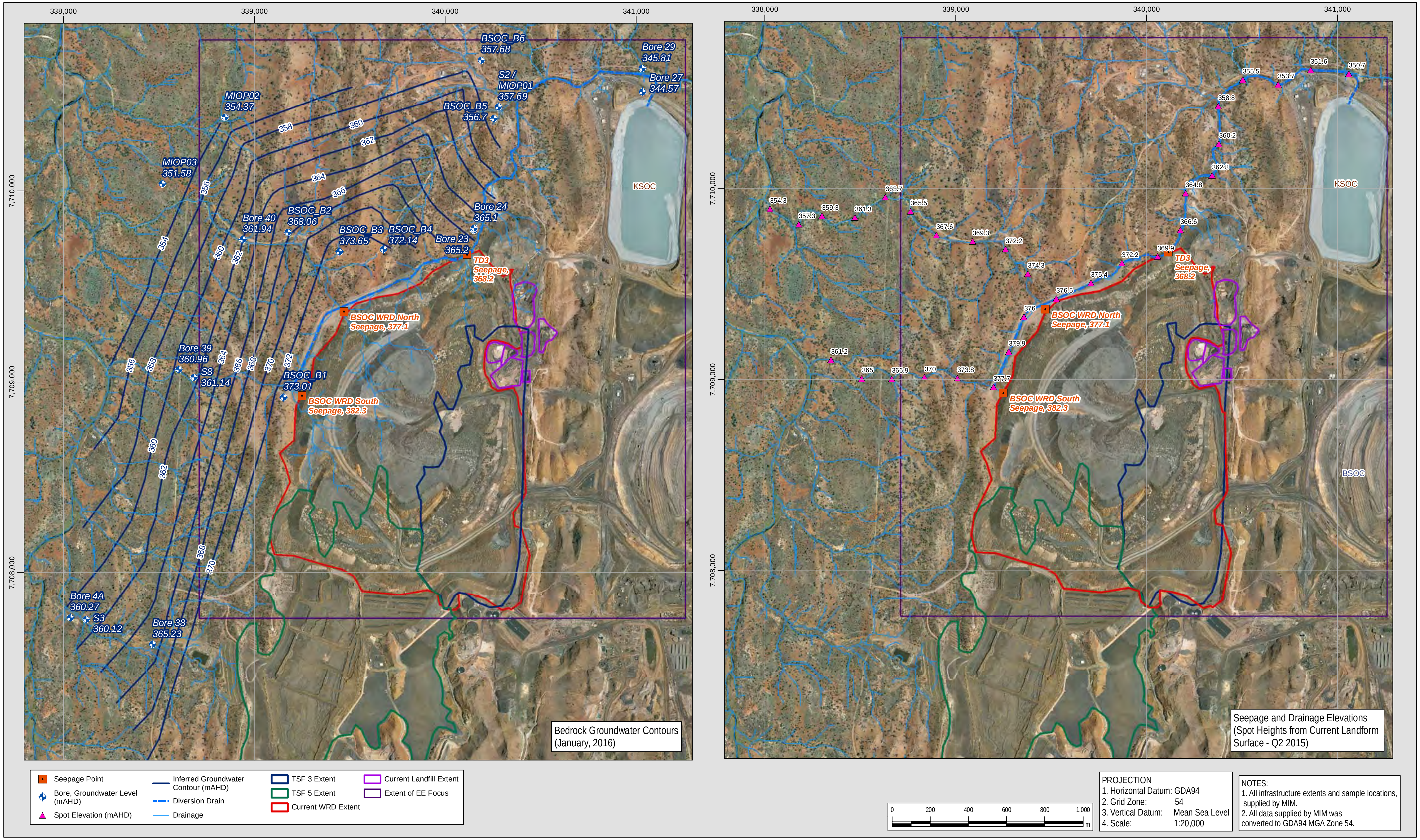

Figure 5-20: Bedrock groundwater level contours (January, 2016), seepage elevations and drainage spot elevations

Groundwater Flow Gradients

Based on the groundwater level contours presented in Figure 5-20 and groundwater level measurements for the alluvial aquifers, groundwater flow gradients (horizontal) have been estimated. Gradients are estimated based on the change in hydraulic head over a distance. These are presented in Table 5-3.

Table 5-3: Groundwater Flow Gradients

Flow Path	Estimated Hydraulic Gradient
Alluvial aquifer underlying the drainage associated with BSOC WRD South Seepage to the west	0.015
Alluvial aquifer underlying the drainage associated with BSOC WRD North Seepage to the west	0.013
Bedrock / weathered bedrock to the west	0.022
Bedrock / weathered bedrock to the north	0.024

Previous studies have indicated the regional groundwater flow gradient as being north-south, and estimated the flow gradient as 0.00025 (KCB, 2013b). A steeper hydraulic gradient is observed in the bedrock aquifer adjacent to the BSOC WRD in comparison to the regional groundwater flow gradient.

Vertical Groundwater Gradients

Vertical groundwater gradients between the alluvial and bedrock aquifers were not able to be assessed as limited bore pairs are installed within the focus area.

While the direct assessment of the hydraulic connectivity between the waste materials, alluvium and basement rocks is not possible, conceptually it can be inferred that vertical leakage from the overlying waste rock / tailings to the alluvium would occur. Additional, vertical leakage from the overlying waste rock / tailings and alluvium to the underlying bedrock may also occur (provided the water level in the bedrock is lower than the water level in the overlying alluvium / waste material), however, this infiltration is rate limited by the low permeability of the underlying bedrock units.

In contrast, upward seepage from the bedrock aquifer into the alluvial aquifer along drainage depression may occur. This can occur where upward hydraulic gradients due to confining conditions associated with structural features are present, however, due to limited nested groundwater monitoring facilities this could not be confirmed.

The vertical gradient between the weathered zone and bedrock aquifer is able to be assessed using the groundwater levels from Bore 23 and Bore 24. Based on the data-logger data collected between August, 2015 and February, 2016, water levels in the weathered zone are higher than the bedrock, indicating a downwards vertical gradient at all times (during the record). The downwards vertical gradient at this location has been calculated as 0.002. This indicates that groundwater within the weathered zone is in hydraulic connection with groundwater in the bedrock aquifer as the groundwater levels from these aquifers are relatively similar.

5.2.2.3 Hydraulic Conductivity

Literature values for a range of hydraulic conductivity for different geology are provided in Driscoll (1986). The following are relevant to this study for comparison against site testing values:

- Unfractured igneous and metamorphic rocks – 1 x 10^{-5} to 1 x 10^{-9} m/d
- Fractured igneous and metamorphic rocks – 100 to 0.001 m/d

Hydraulic testing to obtain site specific estimates of hydraulic conductivity was completed during the Phase 2 site investigation on new and selected existing monitoring bores. Testing was undertaken through packer testing and slug testing techniques, and is discussed in the following sections. The purpose of the testing was to provide additional understanding of the ability of the groundwater / seepage to move within the aquifers across the focus area.

Packer Testing on New Bedrock Bores

Packer testing was completed in the bedrock drill holes prior to bore construction. Borehole inflatable packers are designed to enable permeability (hydraulic conductivity) testing in open holes and/or discrete test sections, with the packers used to seal off (isolate) the desired section of the hole prior to testing. To carry out the test, drill rods with the packer assembly attached were inserted to the selected test interval depth, where the packers were inflated using nitrogen gas. Following the packers inflation, hydraulic testing of the sealed interval was undertaken by injecting water into the formation under constant pressure, with a measurement of the average stabilised flow rate (or water consumption) at the test pressure. This was repeated at a number of different pressure steps to measure the formation response at different pressures (Lugeon Tests). The resulting data was used to calculate a transmissivity of the test interval and consequently the hydraulic conductivity of the formation, which will provide an indication of the ease of which fluid can move through rock media.

Testing was undertaken on five of bedrock drill holes, with between two to three tests carried out per hole. Testing was not completed on BSOC_B6 due to problems with the packer equipment. The test intervals were selected based on the encountered drill cuttings and airlift yields or water inflow zones identified during drilling. The tests were analysed using solutions by Houslby (1976) and Thiem (1906). Details of the packer testing results can be found in Appendix II. A summary of the packer testing intervals and estimates of hydraulic conductivity are presented in Table 5-4.

Table 5-4: Summary of Packer Testing Intervals and Average Hydraulic Conductivity

Bore ID	Test Interval Depth (mbGL)	Inferred Geology	Interval Description	Average Hydraulic Conductivity (m/d)
BSOC B1	12.9 to 14.9	Weathered Bedrock	Water inflow zone, with yield increase observed during drilling at ~14m	0.29
	22.9 to 24.9	Bedrock	Fresh bedrock, with little or no fracture evidence	0.006
BSOC B2	7.9 to 9.9	Weathered Bedrock	First water strike, less than 0.2 L/s. Meta-sediments, moderately weathered, strong evidence of water contact	1.41
	13.9 to 15.9	Bedrock	Increase in yield observed at this depth and continuous flow from airlift sustained	1.16

Bore ID	Test Interval Depth (mbGL)	Inferred Geology	Interval Description	Average Hydraulic Conductivity (m/d)
	20.9 to 22.9	Bedrock	Quartzite with potential matrix flow and an increase in yield to 1.6 L/s observed during airlifting.	0.04
BSOC B3	19.9 to 21.9	Bedrock	First water strike interval	0.08
	24.4 to 26.4	Bedrock	Fresh bedrock with limited fracturing	0.003
BSOC B4	18.9 to 20.9	Bedrock	First water strike interval	0.37
	27.2 to 29.2	Bedrock	Fresh bedrock with no evidence of fracturing	0.001
	32.2 to 34.2	Bedrock	Fresh bedrock, with schist (very weak) layers. No evidence of fracturing or matrix flow	0.004
BSOC B5	12.8 to 14.8	Weathered Bedrock	First water strike interval	0.1
	18.9 to 20.9	Bedrock	Fresh rock with no evidence of fracturing	0.004
	28.7 to 30.7	Bedrock	Significant water inflow zone identified during drilling at ~30m.	0.61

The following observations on the packer testing program / results are made:

- Testing of the fresh bedrock, where there was little or no evidence of fracturing was conducted in four of the five holes. The average hydraulic conductivity across all the tests in this horizon is ~0.003 m/d.
- Testing horizons within the weathered bedrock were completed across three of the bores, with a range of hydraulic conductivity of 0.1 to 1.4 m/d.
- Values estimated within BSOC_B2 are generally higher than other bores which is a reflection of the geology encountered at this location, with some matrix porosity observed in the drill cuttings.
- The deepest zone tested in BSOC_B5 (28.7 to 30.7 mbGL) has an estimated hydraulic conductivity of 0.6 m/d, which is higher than observed at similar depths in other holes and was tested as an inflow zone, which was identified during drilling.

In-situ Hydraulic Testing of Existing Monitoring Bores

Hydraulic (slug) testing was completed on selected existing monitoring bores by MIM personnel between 2 February and 25 February, 2016, to provide estimates of hydraulic conductivity. The location of the bores tested are presented in Figure 5-21.

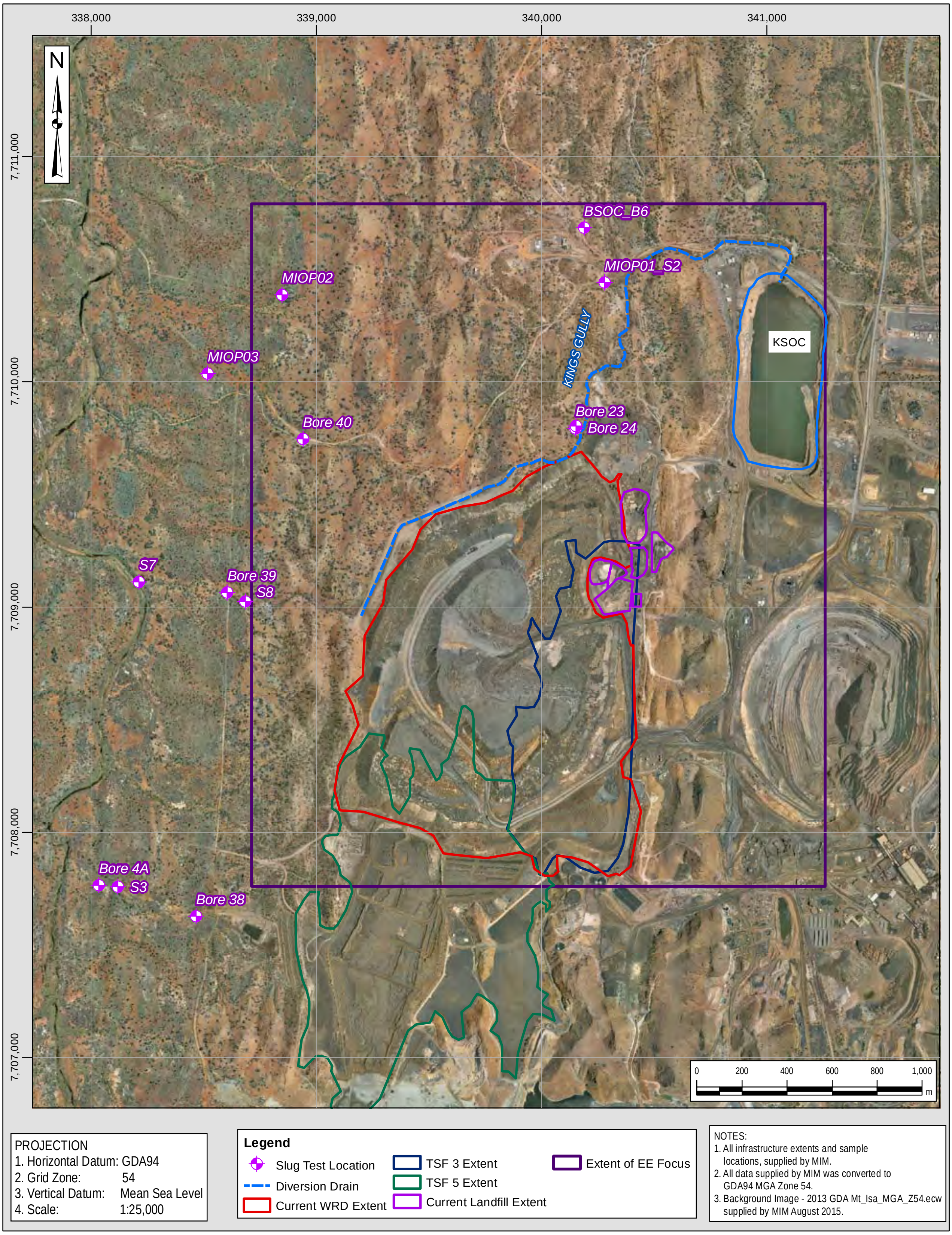

Figure 5-21: Location of Hydraulic Testing on existing bores

Data from the slug tests were reviewed and hydraulic conductivity values calculated using AQTESOLV Pro v4.5 software. Analytical solutions were selected based on underlying analytical assumptions, specific well conditions, and aquifer responses (Butler, 1998). The majority of tests were analysed using the Bouwer and Rice (1976), KGS Model (Hyder et al., 1994) methods and Hvorslev (1951). If bores are screened across the water table these required additional compensation to account for the effective screened interval using Bouwer and Rice (1976) as described in Butler (1998). Table 5-5 presents the estimates of hydraulic conductivity at each of the bores, with the full results provided in Appendix II.

Table 5-5: Estimates of Hydraulic Conductivity from In-situ Permeability Tests

Bore ID	Screened Interval (mbGL)	Assumed Geology	Aquifer Model	Analysis Method	Average Hydraulic Conductivity (m/day)
BSOC_B6	37.0 to 55.0	Bedrock	Confined	KGS Model	0.0006
Bore 23	4.0 to 8.0	Weathered Bedrock	Unconfined	KGS Model	2.0
Bore 24	40.0 to 58.0	Bedrock	Confined	Hvorslev	0.07
Bore 38	29.0 to 37.0	Bedrock	Confined	Hvorslev	0.0006
Bore 39	18.5 to 24.5	Bedrock	Confined	KGS Model	2.4
Bore 40	19.0 to 25.0	Bedrock	Confined	KGS Model	2.0
Bore 4A	10.0 to 47.5	Bedrock	Confined	KGS Model	0.03
MIOP01/S2	2.5 to 5.5	Weathered Bedrock	Unconfined	Bouwer and Rice, corrected	0.04
MIOP02	10.0 to 15.0	Weathered Bedrock	Unconfined	Bouwer and Rice, corrected	0.1
S3	11.0 to 14.0	Weathered Bedrock	Confined	KGS Model	0.1
S7	8.0 to 13.0	Weathered Bedrock	Confined	Hvorslev	0.6
S8	11.0 to 14.0	Bedrock	Confined	KGS Model	0.003

The following observations on the in-situ permeability test program / results are made:

- Estimates of hydraulic conductivity ranged between 0.0006 m/d and 2.4 m/d.
- Higher values were observed in Bore 23, Bore 39 and Bore 40:
  - Bore 23 is likely to be screened within the weathered zone, which is considered to have a higher hydraulic conductivity than the fresh bedrock due to the weathered geology at this location.
  - Bore 39 is likely to be screened below the weathered zone, with the geological log indicating the screen is located within meta-basalt (Eastern Creek Volcanics), with the potential that there is some primary porosity remaining as well as a degree of fracturing. The water level hydrograph for this bore also shows a rapid response to and following the large rainfall event which is likely a result of this higher hydraulic conductivity.
  - Bore 40 is also described as being screened within meta-basalt (Judenan Beds) and is screened below the weathered zone. The closest bore to Bore 40 is BSOC_B2, which also has some higher hydraulic conductivity values due to potential matrix porosity

(observed during drilling), which could also be present at Bore 40, however detailed geological descriptions from the time of drilling Bore 40 are not available to confirm.

- The lowest values of hydraulic conductivity were estimated from the tests were observed at BSOC_B6[6], Bore 38 and S8.
    - BSOC_B6 is a relatively deep bore, with limited oxidation / fracturing and primary porosity observed during drilling, therefore a value of 0.0006 m/d is representative of the conditions observed.

Hydraulic Conductivity versus Depth

A comparison of the hydraulic conductivity values and the testing depth (screen mid-point) is presented in Figure 5-22 for values obtained during the packer testing and in-situ permeability testing. The figure shows there is a general decrease in hydraulic conductivity with depth, which is to be expected for this geological environment, where secondary porosity (structural deformation and weathering) is more prevalent at shallow depths. With the exception of three results, all other results are indicative of fractured igneous and metamorphic rocks as reported in literature.

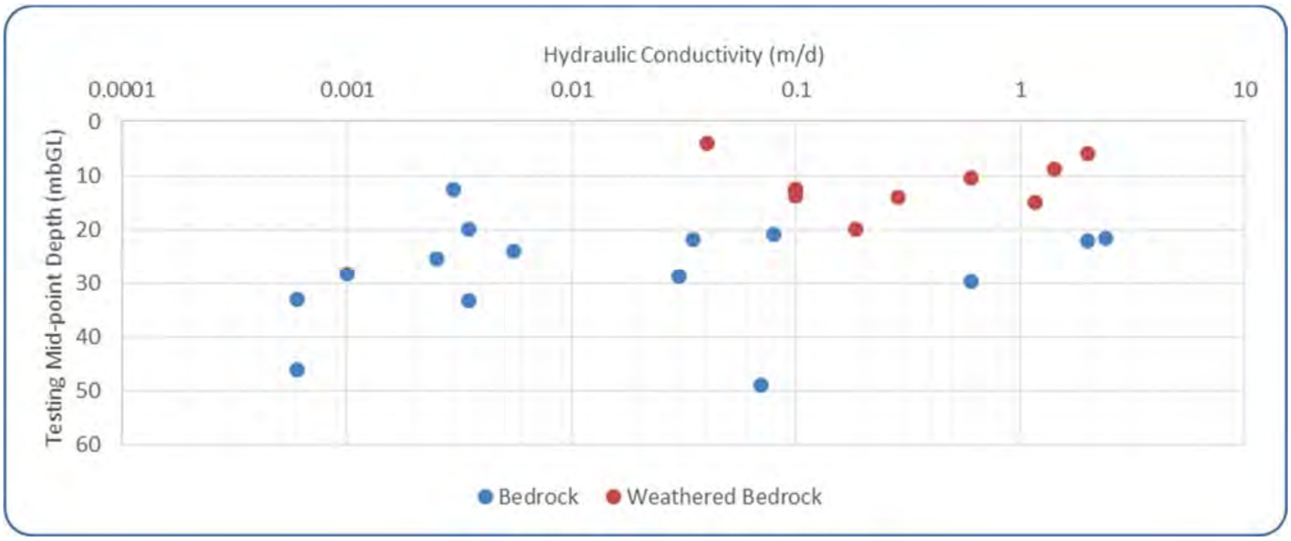

Figure 5-22: Weathered Bedrock and Bedrock Hydraulic Conductivity versus Depth

5.2.3 Hydrogeology of the BSOC WRD Landform

Limited hydraulic testing of waste rock and tailings has been undertaken across the MIM site. A summary of hydraulic parameters for waste rock and tailings, obtained from available background information, is provided Table 5-6.

Table 5-6: Waste Material Hydraulic Parameters from Previous Studies

Waste Material Description	Compaction	Hydraulic Conductivity (m/d)	Source
BSOC waste rock – oxide waste rock	Compacted	0.05	O'Kane (2007)
	Relatively unconsolidated (one compaction cycle)	2.3	O'Kane (2007)

[6] Packer testing was planned at this location, however due to issues with the packer testing equipment, in-situ testing was completed instead.

Waste Material Description	Compaction	Hydraulic Conductivity (m/d)	Source
BSOC waste rock – primary material	Compacted	0.07	O'Kane (2007)
BSOC waste rock – primary material (Modelled)	Non-compacted	86.4	O'Kane (2007)
BSOC waste rock – cover surface material	Unknown	0.0004	O'Kane (2011)
BSOC waste rock (trafficked)	Compacted	0.07 to 0.45	Schneider (2012)
BSOC waste rock – cover trial material	Compacted	0.36 to 0.47	Schneider (2012)
BSOC waste rock – cover trial material	Non-compacted	0.21 to 0.73	Schneider (2012)
Tailings	n/a	0.0001 – 0.18	Forsyth (2014)

Estimation of the saturated hydraulic conductivity of the tailings material was completed by Forsyth (2014) as part of a column leaching test program. Relevant to this assessment is the testing completed for TSF5, with TSF3 already covered by the WRD at the time of testing. Four tailings samples were tested for TSF5, with the range of results provided in Table 5-6. A mean hydraulic conductivity value of 0.027 m/d was calculated from these results.

Field saturated hydraulic conductivity testing was completed by O'Kane Consultants in 2007, reporting that values were obtained for compacted waste rock surface and primary waste rock. Testing was reported to be unsuccessful on the compacted coarse-grained material and therefore the study states that these values (presented in Table 5-6) represent the lower range of values expected. O'Kane (2007) also undertook in-situ consolidation hydraulic conductivity tests where they reported a value for a relatively unconsolidated oxide waste rock, which had undergone one compaction cycle. Modelling within the same study for development of a cover design system used a value of 86.4 m/d for the saturated hydraulic conductivity of the WRD primary waste rock and a porosity of 0.32.

Particle size distribution (PSD) was also undertaken by O'Kane (2007) and they report that the PSD of the BSOC materials are approximately 60% gravel, 25% sand and 15% silt and clay sized particles according to the Unified Soil Classification System.

A cover trial program at MIM was completed between 2008 and 2011 as part of a PhD thesis and reported in Schneider (2012). During the cover trial program measurements of hydraulic conductivity were obtained for waste rock, both compacted and uncompacted, through infiltration tests using disc and hood infiltrometers. The values obtained from the testing are provided in Table 5-6. The thesis also details limitations and issues encountered during the infiltration testing, which indicate that the values presented represent lower end (minimum) hydraulic conductivity values. This is as a result of unsuccessful testing of the coarser material as the rate of infiltration was too high. Also due to limitations with the instruments used, testing was only able to be undertaken on even surfaces where smaller sized rocks were present, excluding areas of protruding stones / boulders. The thesis also concludes that when comparing the hydraulic conductivity values obtained with the results from the cover trials, the hydraulic conductivity is likely to be higher than values obtained from the infiltration testing.

As part of the Phase 2 field program, infiltration testing was planned to be carried out on the current WRD surface using a ‘soakaway’ style test to estimate the hydraulic conductivity of the WRD. A test was attempted in the centre of the WRD (Figure 5-23), however, the rate of infiltration was greater than the rate of filling from the water truck (approximately 150 L/min) and the test was abandoned. The size range of waste rock at this location was highly variable, with the observed rocks on the surface greater than 10 cm in diameter.

Figure 5-23: WRD Infiltration ‘Soakaway’ Testing. a) water infiltrating test pit, b) Typical WRD surface material (December, 2015)

As a result, observational evidence was collected across the WRD surface, which included observing the rate of infiltration on a heavily compacted / trafficked area of the WRD (Figure 5-24). Water was observed to pool on the surface and run off. Generally the size of the rocks in this area is no greater than 2 cm diameter and are compacted.

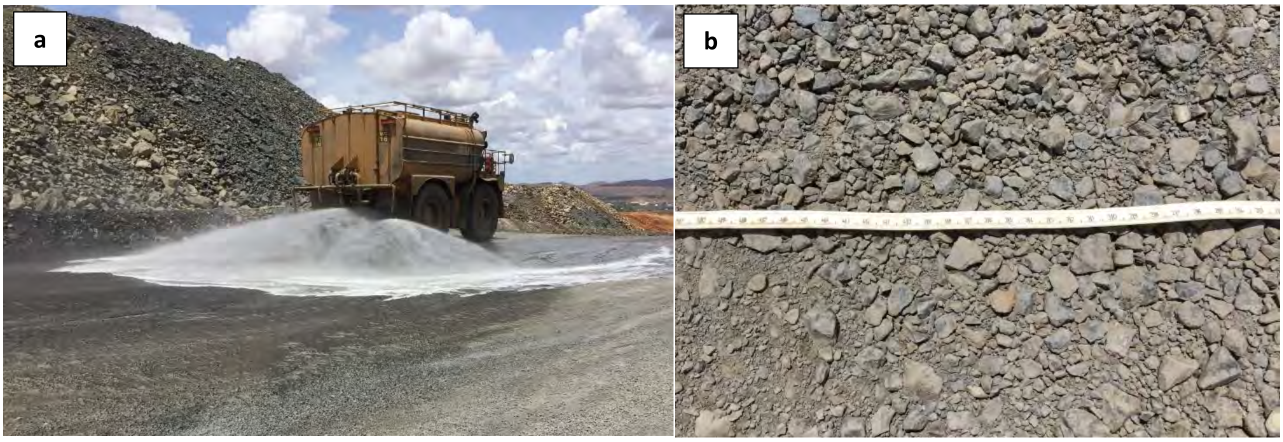

Figure 5-24: Infiltration observations on highly trafficked / compacted area. a) water infiltration test, b) compacted waste rock surface (December, 2015)

Additional observational evidence was collected across the WRD surface to assess potential areas where the rate of infiltration may vary and run-off may occur. Further details are provided in Appendix II, with some commentary provided below:

- Heavy metals rejects (HMR) are also deposited on the waste rock dump surface for use in traffic areas. The rock size in this area is relatively uniform and no greater than 3 cm diameter, with little or no compaction observed.

- Within a highly compacted area of the BSOC WRD, located at a trafficked section, the size of waste rock ranges between 1 cm and 5 cm and shows evidence of salt precipitation. Silt-sized particles were also present as a result of erosion and compaction of the rock.
- Anecdotal information from site personnel also indicate that during / after rain events, ponding of water is not observed on the flat surface of the WRD.

Based on site observations and the infiltration test which was attempted in the centre of the BSOC WRD on the recently placed primary waste rock (non-compacted), the maximum hydraulic conductivity of the surface material is approximated to be ~100 m/d[7]. This approximation indicates that the non-compacted surface material is highly permeable, which has allowed maximum infiltration at surface to occur in the non-compacted areas of the WRD following rainfall events. However, it is anticipated that the hydraulic conductivity approximation would not be uniform across the whole WRD surface due to compaction (trafficked areas) and also within the internal structure of WRD, where potential traffic compaction may have also occurred.

As well as rainfall infiltration, the water balance of the WRD will also include evaporation and run-off. As previously discussed, there was little impediment on the typical WRD surface to rainfall infiltration (based on the testing) and no ponding of water observed after rainfall events. Evaporation is high in the Mount Isa region, exceeding rainfall in every month of the year, however there is no testing to confirm the impact evaporation would have on infiltration (or net percolation) into the WRD.

Schneider (2012) also provides a site specific estimate of ‘net percolation’ into the WRD material following three wet seasons. These rates are measured as seepage from the base of 2 m thick cover materials trial plot (comprising both compacted and non-compacted waste rock), across six plots. Issues were encountered with the measurement equipment, however the most complete trial indicated that up to 95% of the rainfall over the three wet seasons percolated into the WRD. It was also concluded from the trials that runoff from the trial plots does not occur and that all incident rainfall percolated into the WRD material.

Based on the results from Schneider (2012) and the observations made during the Phase 2 field investigation, the net percolation into BSOC WRD is likely to be high, although it is not possible to estimate an exact value. Literature values have been reviewed for a number of mines within Australia and rates are reported as high as 86% of rainfall (Harries, 1990; Rodhe & Williams, 2009) for the net percolation into WRDs.

Water levels, and the associated interpreted piezometric surface, within the BSOC WRD is unknown due to the lack of groundwater monitoring facilities within the WRD. However, due to the interpreted radial groundwater contours adjacent to the BSOC WRD landform it is interpreted that a saturated head is present within the WRD and underlying TSFs which is in hydraulic connection / influencing the underlying bedrock piezometric surface.

5.2.4 Summary of Current Preferential Pathways / Mechanisms / Fault Lines for Seepage

The above investigations concluded that the potential pathways for seepage from the BSOC WRD landform include:

[7] Calculation based on flow rate entering test pit, divided by approximate area where the water was placed during the test

- Groundwater flow through alluvial aquifers;
- Surface water flow along the Diversion Drain infiltrating into the higher permeability alluvial aquifer; and,
- Groundwater flow within bedrock aquifers, either through primary matrix, fractures / faults / structural defects / structural anomalies.

Alluvial Aquifer

Movement through the alluvium is dependent on the hydraulic properties of the aquifer and groundwater flow gradients. Based on the evidence collected during the Phase 2 site investigation and reported in the preceding sections, the following interpretations are made relating to seepage pathways within the alluvial aquifers:

- Mapping on the alluvium during the Phase 1 site investigation and the inferred location of the alluvium underlying BSOC WRD, developed using the reconstructed landform models and historical aerial photographs, indicates that a connection exists between the alluvium underlying the WRD and the alluvium beyond the dump toe. Seepage may directly enter groundwater within the alluvial aquifer underlying the WRD and flow downgradient.
- Historical aerial images indicate the presence of salt precipitation prior to construction of the WRD which may have originated from dams / spillways associated with TSF3 and TSF5, which when correlated with the HEM survey, indicates zones of conductance along the creek lines.
- Groundwater flow gradients indicate groundwater moves towards the west within the alluvium associated with BSOC WRD North and BSOC WRD South seepages.
- Observational evidence from the Phase 1 site investigation also confirmed that seepages occur within the Diversion Drain where the alluvium is exposed at surface due to the construction of the drain.
- As the seepage within the Diversion Drain flows towards King Gully and passes over the alluvium (e.g. at BSOC WRD North Seepage), it was observed that seepage on the surface infiltrated into the alluvium at these locations. This seepage then joins the groundwater system within the alluvium and flows towards the north-west, away from the drainage alignment.

Bedrock Aquifer

Groundwater movement through the bedrock is more complex. Based on the site investigation results, primary matrix flow is limited and therefore seepage movement of this nature is limited, with long term migration rates. Evidence of oxidation and potential fracturing and bedding planes, indicating presence of water within the bedrock aquifer, was encountered within the majority of the drill holes and there is potential for seepage through the bedrock, should extensive connectivity exist. As well as within fractures, groundwater flow within the area may also occur within faults and structural lineaments.

Zones of conductance (seepage plumes) identified from previous HEM survey investigations have been disproved and inferred as a geological anomaly rather than seepage plumes.

5.3 Current and Expected Volume and Rate of Seepage

In order to determine the current and expected volume and rate of seepage from the BSOC WRD to the receiving environment (1 (b) of the EE Notice), the following tasks were undertaken:

- Design and installation of flow monitoring weirs within the Diversion Drain; and
- Completion of a two-dimensional seepage modelling assessment.

5.3.1 Seepage Weir Design and Installation

5.3.1.1 Overview and Design Basis

A site visit was carried out as part of this assessment by a KCB Senior Civil Engineer to inspect the seepage points and provide feedback on recommended flow measurement methods. A concept design and construction requirements for flow gauging weirs and pump flow meters to estimate seepage volumes from BSOC WRD was then undertaken. This component of the investigation also included recommendations for the installation of flow gauges to develop an understanding of the emergent seepage volumes and flow patterns. The design basis for the seepage monitoring weirs is outlined in Table 5-7. The full seepage design report is provided in Appendix III, with a summary provided in the following sections.

Table 5-7 Seepage Monitoring Weirs Design Basis

Item	Design Criteria	Reference
Design Intent	To estimate the seepage volumes and flow rates, from the BSOC WRD at each of three discharge points.	(KCB, 2015)
Design Life	Intended as semi-permanent structures, to gauge flows for a duration of 5 – 10 years with ongoing maintenance during this time	
Hydrology		
Rainfall	IFD for the Mount Isa Region	BOM, 1987 ARR based IFD generated at www.bom.gov.au
Runoff estimation method	Rational method Bransby-Williams Time of concentration	(Pilgram, 1987; TMR, 2010)
Runoff Coefficient estimate	Table 5.9.1 – Runoff coefficient estimation in rural areas	(TMR, 2010)
Weir		
Flow Gauging Range	Able to monitor low flows (seepage) and higher, wet season flows. *Assume: maximum gauging of 5 year ARI (Average Recurrence Interval) flows*	KCB Assumption
Location	Defined channel with sufficient longitudinal grade in the channel to provide some vertical drop between the weir and the downstream channel section. Bedrock channel base, avoid alluvium materials.	
Construction Materials	Concrete and steel plate	

5.3.1.2 Flow Monitoring Design and Construction

Three flow monitoring weirs were proposed as part of the EE investigation, and were constructed in December 2015. The location of the weirs is shown in Figure 5-25.

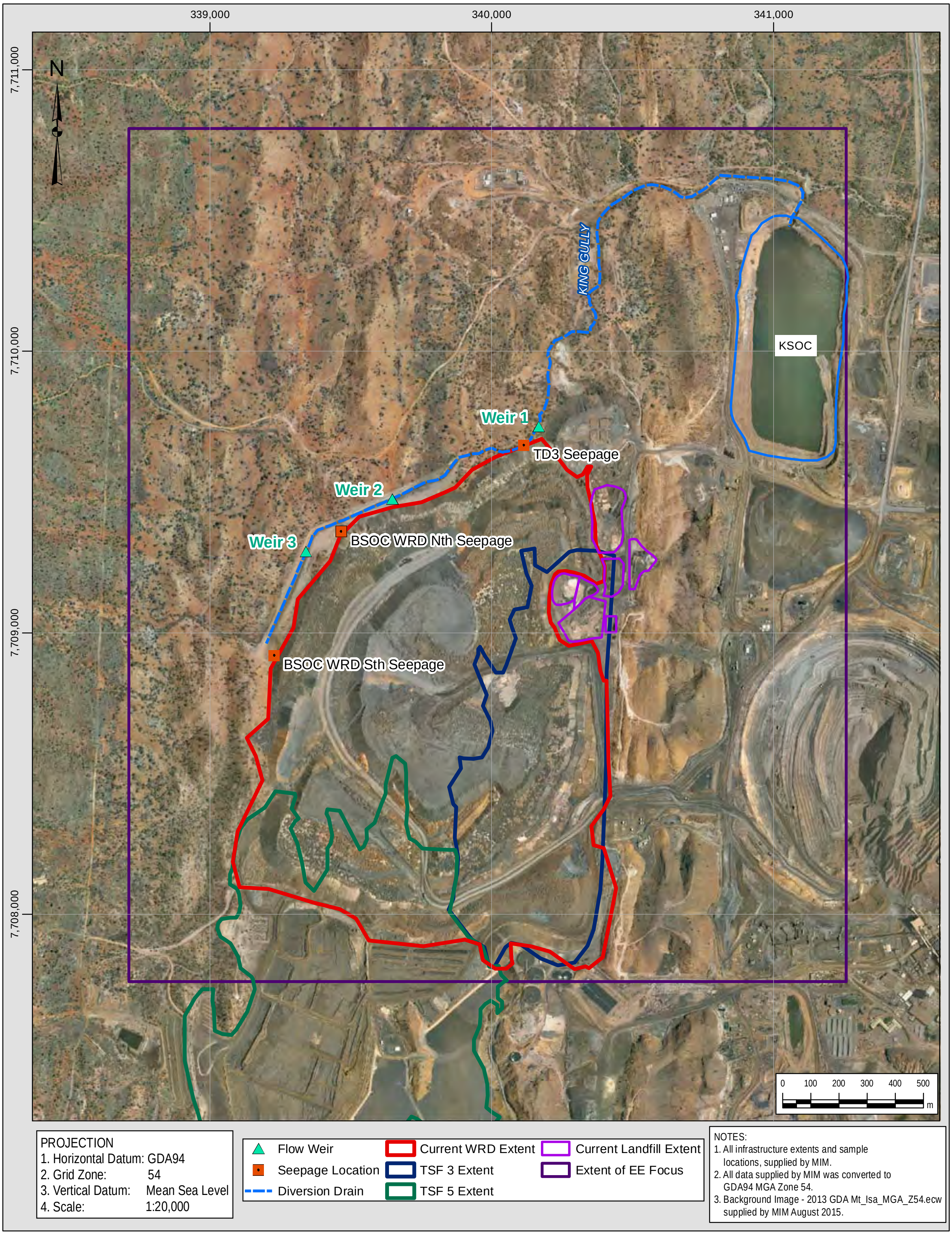

Figure 5-25: Location of flow monitoring weirs

The weirs were proposed at locations along the Diversion Drain where the depth to bedrock was relatively shallow (to allow the weir structure to be "keyed" into the bedrock), and between seepage points along the Diversion Drain. The weirs were constructed as concrete structures with a v-notch steel weir plate to measure the low flows, primarily from seepage, with the higher flows estimated based on the channel cross section. A summary of the weirs is provided below.

BSOC WRD Weir 1 (Figure 5-26) is located immediately downstream of the TD3 Seepage and was installed to estimate total seepage from the BSOC WRD captured by the diversion drain, and provide inputs to calculate the seepage at the TD3 Seepage.

Figure 5-26: BSOC WRD Weir 1 after construction (January, 2016)

BSOC WRD Weir 2 (Figure 5-27) is located downstream of the BSOC WRD North Seepage, and was installed to provide inputs to calculate the seepage at the BSOC WRD North Seepage captured by the diversion drain.

Figure 5-27: BSOC WRD Weir 2 after construction (January, 2016)

BSOC WRD Weir 3 (Figure 5-28) is located upstream of the BSOC WRD North Seepage and was installed to estimate the flow in the diversion drain prior to the BSOC WRD North Seepage. Flows monitored at BSOC WRD Weir 3 will include surface water runoff from the catchment as well as seepage from BSOC WRD South Seepage. BSOC WRD South Seepage is captured by the seepage collection trench located adjacent to, and downstream of, the seepage location. Collected seepage in the trench is manually transferred to the diversion drain via a transfer pump which is manually operated on an “as needed” basis (to prevent seepage water from spilling from the collection trench).

Figure 5-28: BSOC WRD Weir 3 after construction (January, 2016)

Recommendations were also made for water level loggers, which were installed adjacent to the Weirs 1 and 3 in March, 2016. Installation of a water level logger at Weir 2 is yet to be completed, due to issues with the automated flow monitoring equipment. Information from MIM site personnel is that since construction there has been no water flowing over Weir 2, however pools of water have been observed upstream of the weir.

Automated flow monitoring equipment has been installed (June, 2016) on the transfer pump at the BSOC WRD South Seepage trench (Figure 5-29) to record the timing and volume of seepage water being transferred to the diversion drain. Since installation the cumulative volume of water transferred from the BSOC WRD South Seepage trench to the diversion drain is 1,180,260 L (average transfer rate of 0.11 L/s – from June 14, 2016 to October 10, 2016). The data-logging capabilities of the flow monitoring equipment has not been functioning since installation and is in the process of being repaired. Therefore, only the average transfer rate based on the cumulative volume of water transferred can be calculated from the monitoring records.

Figure 5-29: BSOC WRD South Seepage transfer pump flow monitoring equipment (June, 2016)

5.3.1.3 Diversion Drain Flow Monitoring

Flow data was recorded for Weirs 1 and 3 between March and May 2016 following installation of the water level loggers.

The hydrograph for Weir 1 is shown in Figure 5-30 and Weir 3 is shown in Figure 5-31. Rainfall recorded during the same period was sourced from the Bureau of Meteorology for the rain gauge at Mount Isa Mine (#029126) and is included for comparison against the Weir 1 hydrograph.

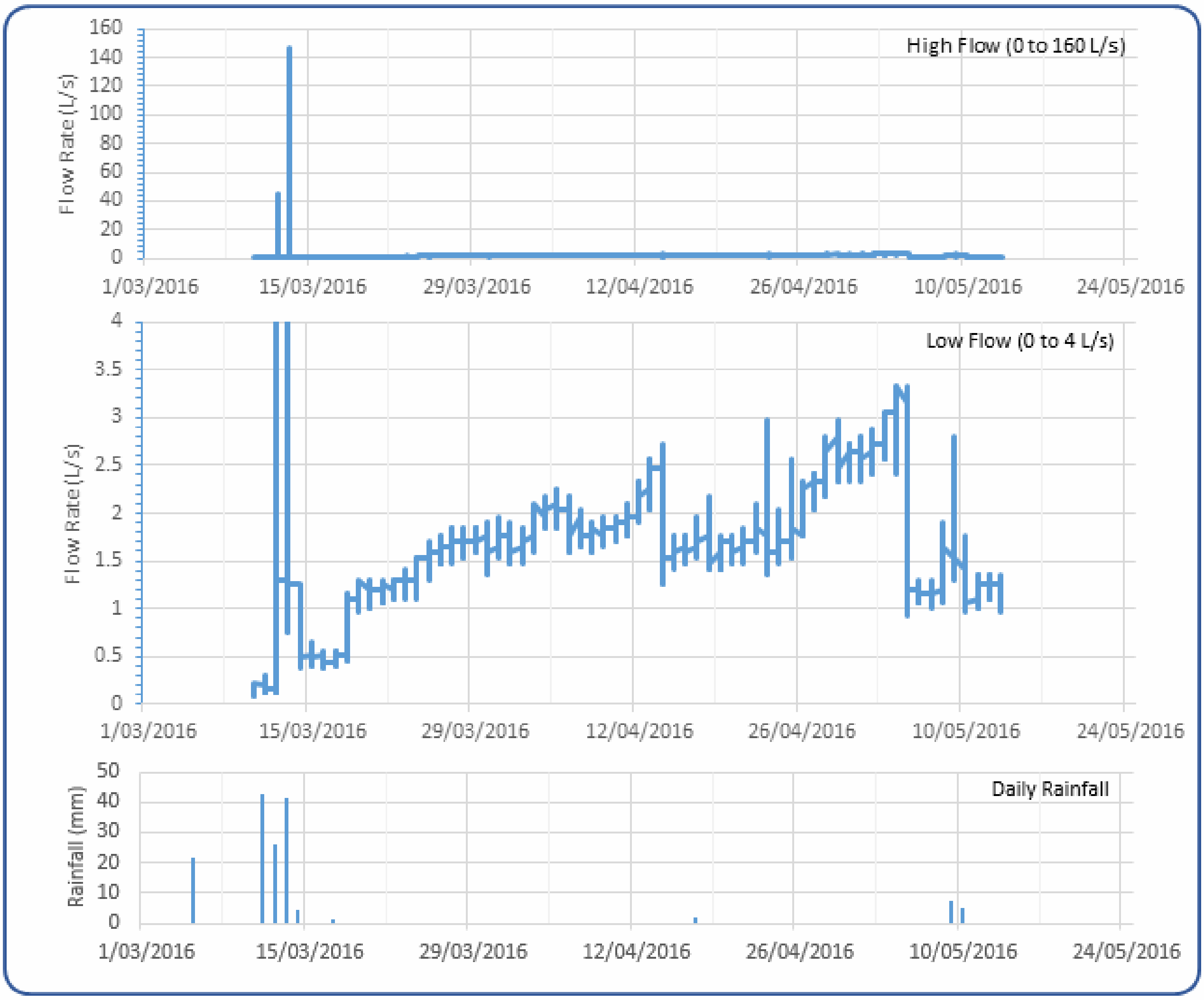

Figure 5-30: Weir 1 hydrographs from March to May 2016, shown as high flow graph, low flow graph and rainfall

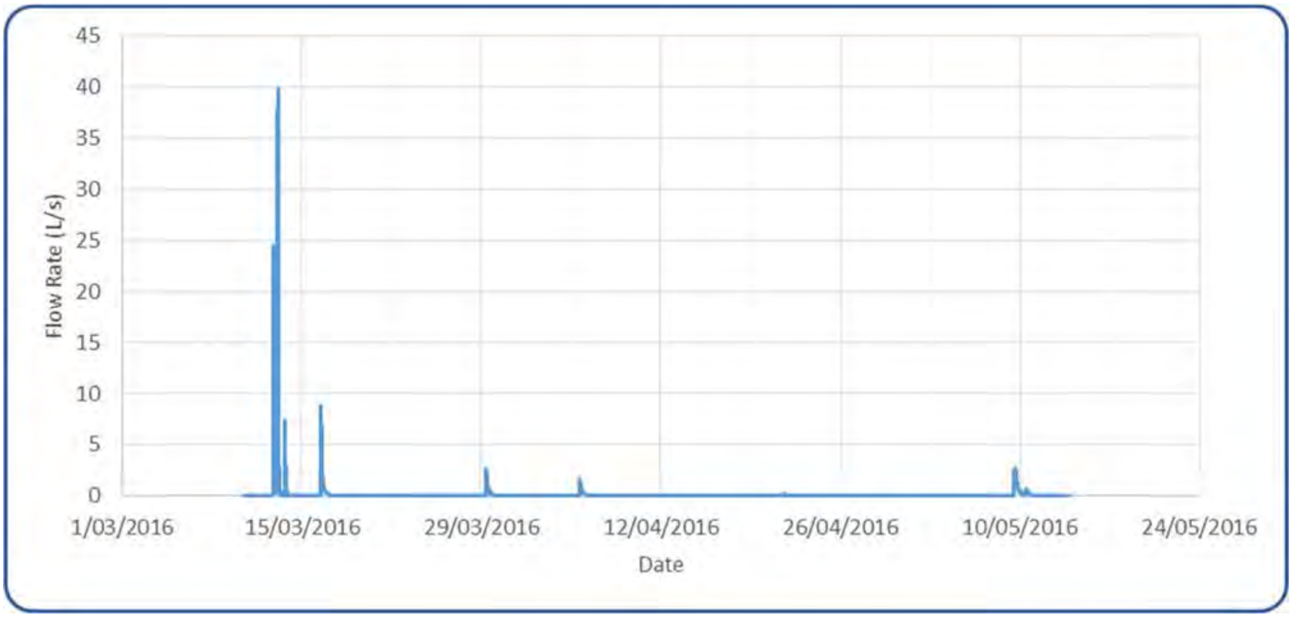

Figure 5-31: Weir 3 hydrograph – March to May 2016

Based on the short period of record available, the following observations are made:

- Weir 1, located downstream of TD3 Seepage, has recorded a flow for the full period of record:
  - Higher flow rates were recorded in March in response to rainfall events, with 115mm of rain falling between March, 11 and March, 17 (BOM, 2016). Two smaller rainfall events occurred on April, 17 (1.6mm) and May 9/10 (12.2mm).
  - The average flow rate over the period of record at Weir 1 is 1.83 L/s.
  - The hydrograph shows an increasing trend following the rainfall event at the beginning of the record, which may be indicative of an increase in seepage at TD3 in response to the large rainfall event.
- Weir 3, located downstream of BSOC WRD South Seepage, has recorded limited flow across the period of record.
  - Based on the above rainfall, flow at this weir correlates with the rainfall events, with the exception of the three smaller flows within the middle period of the record (March, 29 and April 5, 25).
  - In the absence of rainfall in these periods, these smaller flows are likely to have occurred as a result of the transfer of water from the BSOC WRD South Seepage collection trench into the Diversion Drain. The maximum flow for these events was ~2.7 L/s (March, 29).

    Results of the field mapping and site reconnaissance completed as part of the Phase 1 Site Investigation program (Appendix II) confirmed that additional BSOC WRD seepages (beyond the three existing seepage locations) do not occur between the BSOC WRD South Seepage and Weir 3. Therefore, the flow monitoring records from Weir 3 represent the intermittent transfer of seepage water from the BSOC WRD South Seepage and rainfall runoff within the Weir 3 catchment.

5.3.2 Two-Dimensional Seepage Modelling

5.3.2.1 Overview

Two-dimensional seepage modelling was undertaken as part of this assessment using the modelling platform Seep/W (Geo-Slope International; September, 2013 release). Seep/W allows the numerical representation of two-dimensional flow, representing variability in material hydraulic properties and the capacity to model a wetting front through unsaturated materials. The seepage modelling comprised the following:

- Construction of three 2D models through each of the seepage locations (TD3, BSOC WRD North Seepage and BSOC WRD South Seepage), which included representative thicknesses of the BSOC WRD, TSFs and underlying geology (alluvium, weathered bedrock and bedrock);
- Assignment of material properties, based on both literature values and analysed field testing values (where available);
- Assessment of the wet / dry season flux variation using average monthly rainfall;
- Estimation of unit seepage volumes at each of the seepage locations;
- Estimation of the water flux between site infrastructure (WRD, TSF) and the underlying geology;
- Estimation of groundwater flux through the alluvium, weathered bedrock and bedrock;
- Model scenarios to assess the sensitivity of the model to parameters of uncertainty; and,
- Conversion of fluxes / seepage rates from two-dimensions to three-dimensions to be representative of the focus area.

5.3.2.2 Model Domain and Layers

Three representative 2D cross sections through the BSOC WRD landform were selected for the seepage modelling, with their locations shown in Figure 5-32. These sections are located through each of the seepage points and the upstream and downstream interpreted catchments. Alluvial material was included in each of the sections, as well as a representative thickness of weathered zone and bedrock material.

A summary of each of the seepage model domains is provided in the following sections.

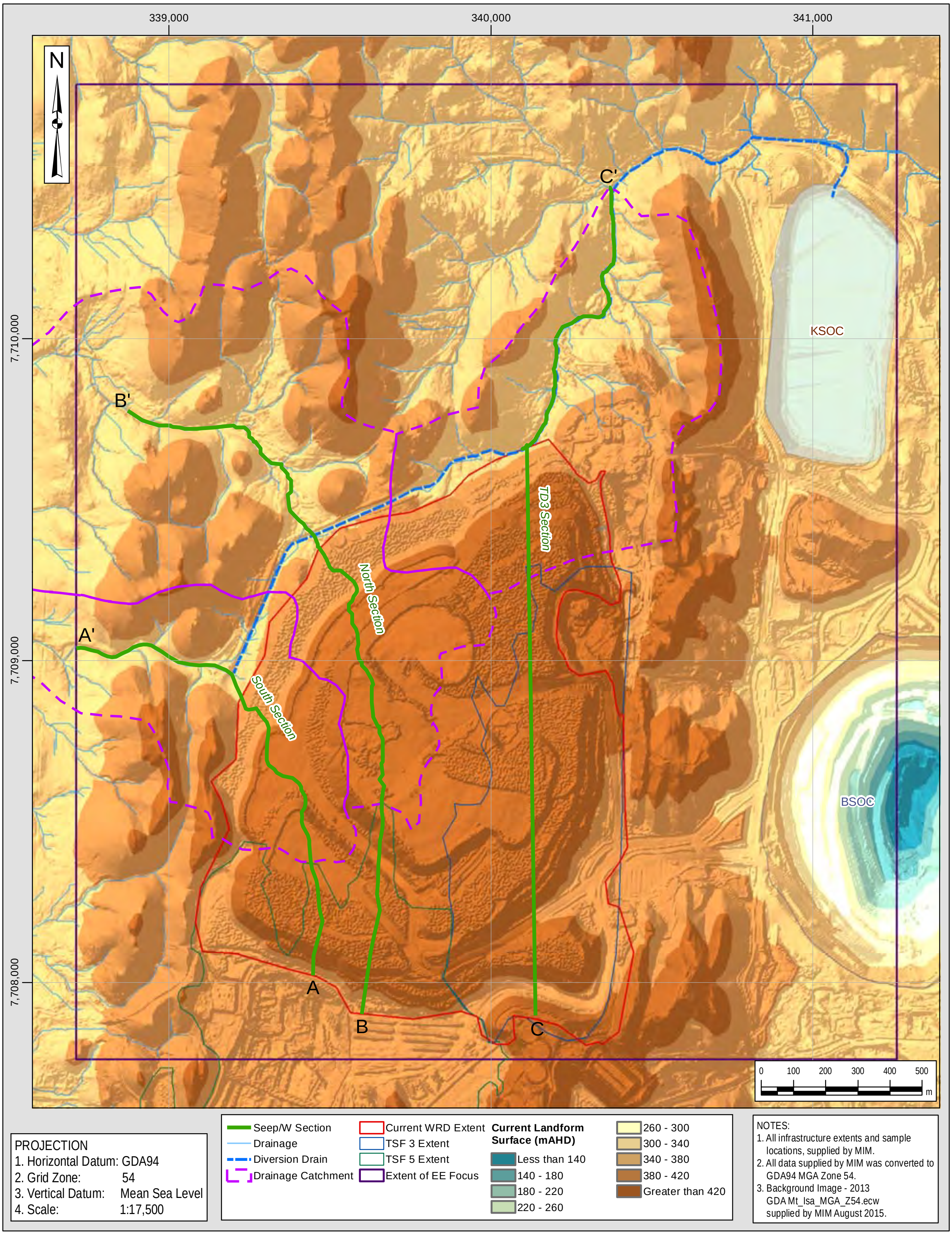

Figure 5-32: 2D Model Locations

TD3 Seepage Model Domain

The TD3 Seepage 2D model domain, as shown in Figure 5-33 is orientated in a general south to north direction and includes the full length of TSF3, which is approximately 1,100 m in length. BSOC WRD overlies TSF3 and ranges in width from ~1,600 m where the WRD overlies TSF3 and underlying geology; and, ~1,000 m at the top of the dump.

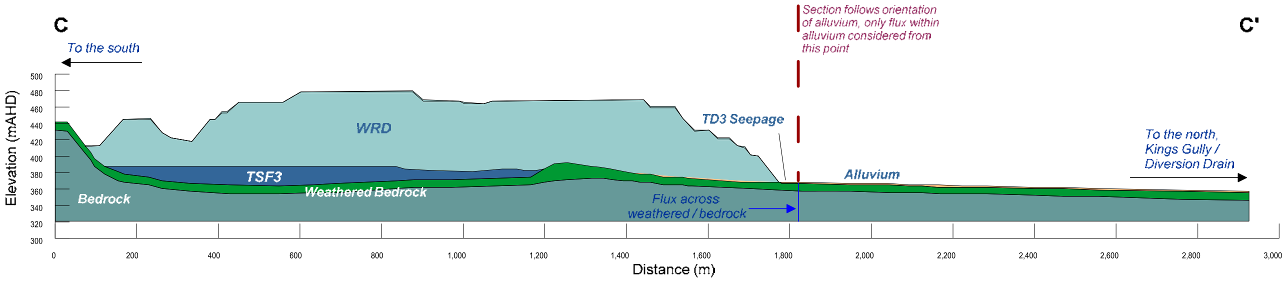

Figure 5-33: TD3 Seepage slice model section

At the TD3 seepage point, the section is orientated to follow the creek towards King Gully Dam. Alluvium is included underlying the BSOC WRD to the north of TSF3. Seepage nodes are placed at the toe of the WRD and within the Diversion Drain (constructed within the alluvial system), before flowing into King Gully downstream. Seepage nodes represent zones where groundwater flow can leave the model (i.e. discharge as surface water flow)

Conceptually, this two-dimensional section has been scaled to represent seepage from TD3 and any discharge to groundwater within the bedrock or alluvium flowing towards the north.

BSOC WRD North Seepage Model Domain

The BSOC WRD North Seepage 2D model domain is shown in Figure 5-34 and includes the footprint of TSF5 covered by the WRD, which is approximately 700 m in length. BSOC WRD overlies TSF5 and is ~1,500 m wide at the base and ~1,000 m at the top of the section.

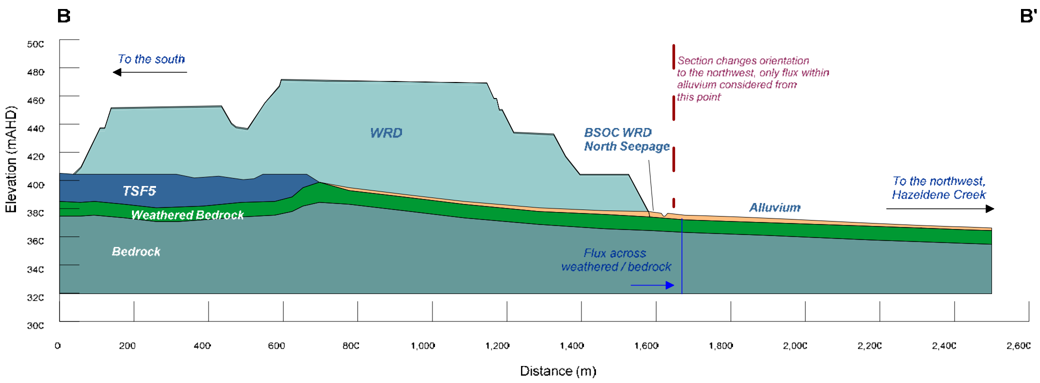

Figure 5-34: BSOC WRD North Seepage 2D Model Section

The 2D section is orientated in a general south to north direction, up to the North Seepage point, at which point the section follows the alignment of the creek to capture potential seepage through the alluvium.

Seepage nodes are placed at the toe of the WRD and within the Diversion Drain which has been constructed within the alluvial layer.

Conceptually, this section can be scaled to represent the catchment underlying the dump associated with north seepage and any discharge flowing west towards the focus area boundary. Within the bedrock, regionally groundwater is flowing from south to north and therefore any fluxes estimate from the model will be estimated from directly underlying the BSOC WRD North seepage point.

BSOC WRD South Seepage Model Domain

The BSOC WRD South Seepage model domain is presented in Figure 5-35 and includes the western dam of TSF5, which is covered by the WRD. TSF5 is approximately 400 m in length within the model domain. The WRD is ~850 m in length along the base of the model domain and ~540 m across the top.

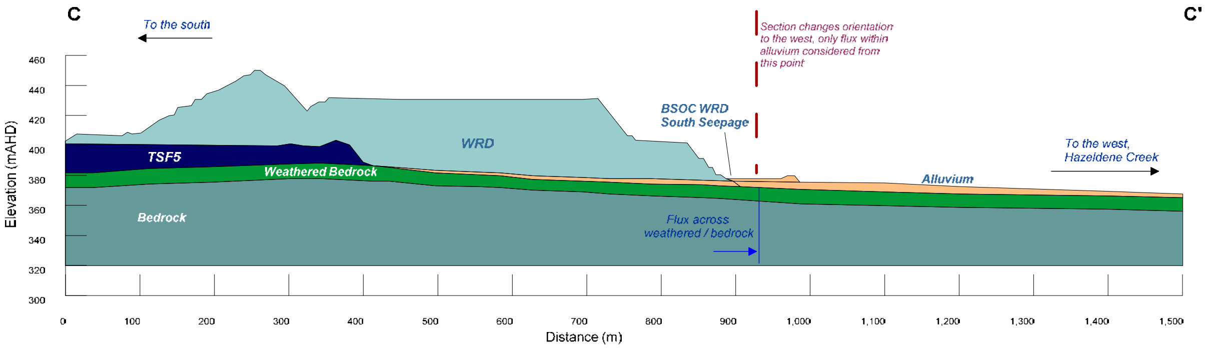

Figure 5-35: BSOC WRD South Seepage 2D model section

The 2D model section is orientated south to north from the southern extent of the WRD to the BSOC WRD South Seepage point, at which point the section follows the alignment of the creek to capture potential seepage through the alluvium.

Adjacent to the BSOC WRD South Seepage point is the start of the Diversion Drain. To encourage surface water flow in the northerly direction into the Diversion Drain, this area was built up to provide the surface gradient required for the flow. A trench was also excavated into the bedrock at this location, however this has not been included in the model as the extent of the underlying alluvium is beyond the length of the trench and migration of seepage in the alluvial aquifer can bypass the collection trench. All seepage exiting the WRD within this section is captured at the WRD toe through the placement of seepage nodes.

Conceptually, this section can be scaled to represent the catchment underlying the dump associated with BSOC WRD South Seepage and any discharge entering the groundwater system flowing towards the west for the alluvial aquifer and a flux line to represent flow towards the north (measured directly underneath the dump) in the bedrock aquifer.

5.3.2.3 Model Boundary Conditions and Material Properties

Boundary Conditions and Assumptions

The following boundary conditions were established in the SEEP/W models. Assumptions and limitations of the modelling are also included in this section.

- No flow boundary conditions were established along the bottom of the model (no flow bedrock conditions), a minimum of 60 m below the natural ground surface. This no flow boundary condition was based on the interpreted extent (depth) of groundwater inflows in the bedrock units (Section 3.6.2.1).
- Rainfall recharge was applied across the top surface of the WRD at a rate equivalent to 80% of average monthly precipitation (Model A). Rates equivalent to 50% (Model B) and 95% (Model C) of average monthly precipitation were also simulated. Model B is included as a lower bound and is based on incident rainfall losses due to evaporation and runoff from heavily trafficked areas. Model C was included as a higher bound model, based on net percolation rates estimated in Schnieder (2012).
  - The 80% rate was selected based on values presented in Schneider (2012), literature values (Section 5.2.3) and observational evidence collected during the Phase 2 site investigation, whereby site personnel indicated little or no ponding of water on the dump surface during and following rainfall events.
  - The 50% rate was utilised to assess variability in the model should significant evaporation occur as a result of water storage within the upper near-surface layers of the WRD.
- A 30% rainfall infiltration rate was adopted for the WRD slopes as this was considered to be a conservative (i.e. higher than anticipated infiltration rate) estimate of infiltration. Referenced runoff coefficients from similar lower angled waste rock dump batter slopes (Evans K.G. et al., 2000) and other lower angled mine waste material (Warner R.C. et al., 2010) support the conservative nature of the adopted WRD slope infiltration rate.
- A seepage face (represented by seepage nodes) was applied to the toe of the WRD and within the Diversion Drain (if applicable).
- Flux boundaries were established to assess the transfer of water within areas of the model, e.g. the volume of water leaving the base of TSF3 or TSF5, and the flux of water flowing within the alluvium aquifer.
- The through-flow of water down-gradient was specified using a constant head boundary at the model edges. The values chosen where taken from the groundwater contours interpreted from January 2016 groundwater levels.
- The WRD has been modelled as a single unit, however it is acknowledged that there would be variability within the WRD due to compaction / trafficked areas during various stages of its construction. Sensitivity of the WRD hydraulic conductivity has been included to address this.
- The models do not take into consideration any flow of water which enters the alluvium as a result of flow along the Diversion Drain where the drain crosses the alluvium.
- Measured and calibrated flow data from Weir 1 (downstream of TD3 seepage), which is indicative of seepage volumes, is available for period between March and May 2016. This data was used to compare against predicted results from the TD3 Seepage Model (Section 5.3.2.5).
- Each model is simulated within the Seep/W transient platform based on daily time steps for a period of 20 years to allow the model to establish static conditions. This option was

selected as the dump is simulated as the current landform and does not allow for the construction of the dump over time. On reaching static conditions, a second model run was simulated for 365 days to assess total flux during a 1 year period.

Material Properties

Each hydrostratigraphic unit in the models has a unique hydraulic function of conductivity (m/d) versus pore-water pressure and volumetric water content versus pore-water pressure (soil-water characteristic curve or SWCC). Table 5-8 summarises the various materials used in the modelling and lists the adopted material properties, used for the 'base case' scenario. In the absence of site-specific SWCC functions, default sample functions were used (from SEEP/W) for each typical material.

Table 5-8: Range of Hydraulic Conductivity Values (m/d)

Slice Model	Material	Saturated Hydraulic Conductivity (m/d)	Source
All	Waste Rock	10	Observational Evidence
	Tailings	0.027	Forsyth (2014) – TSF5
	Alluvium	1	Literature
TD3	Weathered Zone	0.28	Phase 2 Testing
North		0.16	Phase 2 Testing
South		0.28	Phase 2 Testing
TD3	Bedrock	0.008	Phase 2 Testing
North		0.015	Phase 2 Testing
South		0.01	Phase 2 Testing

5.3.2.4 Model Scenarios

For each model section a base case scenario has been modelled with some additional model runs to assess the sensitivity of certain model parameters. For each model section the following scenarios have been modelling:

- ***Base Case:*** using model input parameters as discussed in the previous sections.
- ***Sensitivity 1:*** A decrease of half an order of magnitude in the saturated hydraulic conductivity of the alluvium (0.5 m/d).
- ***Sensitivity 2:*** An increase of half an order of magnitude in the saturated hydraulic conductivity of the alluvium (5 m/d).
- ***Sensitivity 3:*** A decrease of half an order of magnitude in the saturated hydraulic conductivity of the WRD (2 m/d).
- ***Sensitivity 4:*** An increase of half an order of magnitude in the saturated hydraulic conductivity of the WRD (50 m/d).
- ***Sensitivity 5:*** An increase in the saturated hydraulic conductivity of the WRD (50 m/d) and a decrease in the saturated hydraulic conductivity of the alluvium (0.5 m/d).

All of the above scenarios were run using the 80% (Model A), 50% (Model B) and 95% (Model C) infiltration rates.

5.3.2.5 Modelling Results

Results of each scenario from the three models are presented in the following sections. The two-dimensional flux lines / nodes have been 'scaled up' to represent water flow / seepage across those locations in three-dimensions (i.e. incorporating the lateral extent of the WRD landform). This area, representing the 'scale up' is also provided. The results are presented as a rate of m^3/d, which has been extracted from the 1 year static condition model for the 50%, 80% and 95% infiltration scenarios. Discussion of the results for each seepage model is provided in the following sections, with some discussion common to the three models provided below.

Across the three 2D seepage models, varying the infiltration rate within the models (50%, 80% and 95% of average monthly rainfall) resulted in similar flux volume transfers, which is a result of simulating seepage under static conditions. Generally slightly lower volumes are observed in the 50% model, which is to be expected as there is less water available within the model. This also impacted the rates of seepage, which were lower in the 50% model than the 80% and 95% infiltration scenarios.

The sensitivity of the alluvial K_{sat} was significant, with the higher value (5 m/d) resulting in the smallest seepage volumes across all of the models and in most cases this resulted in no seepage at all. The lower K_{sat} of the alluvium (0.5 m/d) increased the rate of seepage, which was as a result of limiting this pathway for seepage.

Modifying the K_{sat} of the BSOC WRD also resulted in variation across the flux and seepage estimates. A lower K_{sat} of the WRD increased the amount of water within the WRD and subsequently modelled a larger head of water overlying the TSF's. The higher K_{sat} scenario generally resulted in higher seepage rates which is as a result of water being able to move more quickly through the WRD following infiltration.

Seasonality in the seepage rates was also predicted across the three 2D models, with peak seepage generally occurring after 60 to 90 days, equivalent to a time period at the end of February / March (end of wet season); and, the minimum seepage after ~240 days, equivalent to a time period at the end of July (dry season).

TD3 Seepage Model

Results for the TD3 seepage model are provided in Table 5-9 for the 80%, 50% and 95% rainfall recharge rate models for all sensitivity scenarios.

Table 5-9: TD3 Seepage 2D Model – Seepage Modelling Results (m^3/d)

Model	Flow Path	Flux Type	Representative Flux (Q) Area (m^2)	Model Scenario (m^3/d)					
				Base Case	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4	Sensitivity 5
Model A (80% Infiltration)	TSF3 to Weathered Bedrock	Horizontal Flux	701,220	13.0	13.0	13.0	33.9	3.6	3.6
	Bedrock to North	Vertical Flux	23,200	5.4	5.5	5.1	13.8	4.3	4.2
	Weathered Bedrock to North	Vertical Flux	5,800	15.2	15.2	15.1	15.2	15.1	15.2
	Alluvium to North	Vertical Flux	46	0.4	0.2	2.4	0.4	0.4	0.2
	TD3 Seepage	Flux Node	580	307.2	427.7	-	143.2	358.3	479.6
	Seepage into Diversion Drain / Alluvium Daylighting	Flux Node	23	15.6	11.0	25.8	17.0	13.6	9.0
Model B (50% Infiltration)	TSF3 to Weathered Bedrock	Horizontal Flux	701,220	9.4	9.4	9.4	30.5	2.1	9.4
	Bedrock to North	Vertical Flux	23,200	4.5	4.4	5.4	11.3	3.1	4.4
	Weathered Bedrock to North	Vertical Flux	5,800	15.2	15.2	15.1	15.2	15.1	15.2
	Alluvium to North	Vertical Flux	46	0.4	0.2	2.4	0.4	0.4	0.2
	TD3 Seepage	Flux Node	580	112.3	227.2	-	38.1	195.5	228.8
	Seepage into Diversion Drain / Alluvium Daylighting	Flux Node	23	14.4	10.1	17.0	15.6	11.1	12.0
Model C (95% Infiltration)	TSF3 to Weathered Bedrock	Horizontal Flux	701,220	14.7	14.7	14.7	37.8	4.0	4.0
	Bedrock to North	Vertical Flux	23,200	6.1	6.2	5.6	14.2	4.2	4.1
	Weathered Bedrock to North	Vertical Flux	5,800	21.5	18.3	46.8	21.5	21.4	18.3
	Alluvium to North	Vertical Flux	46	0.4	0.2	2.4	0.4	0.4	0.2
	TD3 Seepage	Flux Node	580	411.3	534.2	-	223.3	466.9	589.2
	Seepage into Diversion Drain / Alluvium Daylighting	Flux Node	23	15.9	11.4	30.3	17.8	13.8	9.2

Model refers to the infiltration rate used
Flow path refers to the flux section or node
Flux type provides a description of the orientation of the flux or if it's a node
Representative flux (Q) area is the cross sectional area which has been used to 'scaled up' from two-dimensions to three-dimensions

Results from the TD3 seepage model estimates that the volume of seepage at this location is between 143 and 480 m^3/d (1.6 and 5.5 L/s) for the 80% model; between 38 and 229 m^3/d for the 50% model (0.4 and 2.7 L/s); and, between 223 and 589 m^3/d (2.6 and 6.8 L/s) for the 95% model. These estimates are deemed appropriate based on the observed flow within the Diversion Drain / King Gully and the data obtained from Weir 1 downstream of this seepage location.

A summary of the fluxes from the TD3 Seepage model is provided as follows:

- TD3 Seepage:
  - 1.6 to 5.5 L/s (Model A – 80%), 0.4 to 2.7 L/s (Model B – 50%) and 2.6 to 6.8 L/s (Model C – 95%)

    91.4% (Model A), 82.3% (Model B) and 94.3% (Model C) of total flux from BSOC WRD landform at TD3 Seepage point for Base Case simulation.
- Seepage to alluvium:
  - 0.002 to 0.03 L/s (Model A, B and C)

    0.1% (Model A), 0.3% (Model B) and 0.1% (Model C) of total flux from BSOC WRD landform at TD3 Seepage point for Base Case simulation.
- Diversion Drain (daylighting) seepage:
  - 0.05 to 0.4 L/s (Model A - 80%), 0.12 to 0.2 L/s (Model B - 50%) and 0.1 to 0.35 L/s (Model C – 95%)

    4.6% (Model A), 10.5% (Model B) and 3.2% (Model C) of total flux from BSOC WRD landform at TD3 Seepage point for Base Case simulation
- Seepage into bedrock from BSOC WRD Landform (BSOC WRD and TSF3):
  - 0.05 to 0.16 L/s (Model A - 80%) and 0.02 to 0.35 L/s (Model B - 50%) and 0.05 to 0.44 L/s (Model C - 95%)

    3.9% (Model A), 6.9% (Model B) and 9.1% (Model C) of total flux from BSOC WRD landform at TD3 Seepage point for Base Case simulation

Potential Sludge Pond Contribution to TD3 Seepage

Infiltration from the landfill sludge ponds to the BSOC WRD landform has been hypothesised as a contribution flux to the TD3 Seepage. The potential contribution of the sludge ponds can be conservatively estimated based on a flux balance of the sludge ponds, which comprises:

- Direct waste water placement in the sludge ponds – 3.4 ML/year;
- Evaporation from the sludge ponds
  - Average evaporation rate = 3,066 mm/year
  - Pond size = 10 m x 25 m (2 ponds); and
- Conservative infiltration rate into the underlying formation – difference between the direct waste water placement rate and evaporation rate.

Based on the above fluxes, a conservative infiltration rate into the underlying formation is 0.06 L/s. Assuming all of the sludge pond infiltration contributes to the total flux in the TD3 Seepage catchment, the proportion of the sludge pond flux is conservatively estimated at 1% to 3% of the total flux in the catchment. Based on this proportion of sludge pond flux contribution, it is interpreted that the water quality signature of the sludge pond would be “over-printed” by, and would be negligible compared to, the BSOC WRD landform seepage water quality signature.

BSOC WRD North Seepage Model

Results for the BSOC WRD North seepage model are provided in Table 5-10 for the 80%, 50% and 95% infiltration rate models for all sensitivity scenarios.

Table 5-10: BSOC WRD North Seepage 2D Model - Seepage Modelling Results (m^3/d)

Model	Flow Path	Flux Type	Representative Flux (Q) Area (m^2)	Model Scenario (m^3/d)					
				Base Case	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4	Sensitivity 5
Model A (80% Infiltration)	TSF5 to Weathered Bedrock	Horizontal Flux	168,300	22.4	19.8	22.1	12.3	20.1	20.0
	Bedrock to North-West	Vertical Flux	11,825	2.9	3.0	2.7	3.0	2.9	3.0
	Weathered Bedrock to North-West	Vertical Flux	2,750	3.6	3.6	3.6	3.6	3.6	3.7
	Alluvium to North-West	Vertical Flux	50	0.7	0.4	3.5	0.7	0.7	0.4
	North Seepage	Flux Node	275	123.2	152.7	-	111.5	131.1	160.9
	Seepage into Diversion Drain / Alluvium Daylighting	Flux Node	25	8.9	6.0	19.6	9.2	8.6	5.7
Model B (50% Infiltration)	TSF5 to Weathered Bedrock	Horizontal Flux	168,300	23.0	20.2	26.0	18.5	20.7	20.7
	Bedrock to North-West	Vertical Flux	11,825	3.0	2.9	2.7	3.0	2.7	2.9
	Weathered Bedrock to North-West	Vertical Flux	2,750	3.6	3.6	3.5	3.5	3.6	3.7
	Alluvium to North-West	Vertical Flux	50	0.7	0.4	3.6	0.7	0.7	0.4
	North Seepage	Flux Node	275	57.3	87.0	-	52.3	63.6	93.3
	Seepage into Diversion Drain / Alluvium Daylighting	Flux Node	25	8.6	5.8	12.5	8.8	8.4	5.6
Model C (95% Infiltration)	TSF5 to Weathered Bedrock	Horizontal Flux	168,300	40.7	40.5	44.7	13.9	40.0	39.8
	Bedrock to North-West	Vertical Flux	11,825	2.5	2.6	2.3	2.5	2.5	2.6
	Weathered Bedrock to North-West	Vertical Flux	2,750	3.7	4.0	3.3	3.7	3.7	4.0
	Alluvium to North-West	Vertical Flux	50	0.8	0.4	3.6	0.8	0.8	0.4
	North Seepage	Flux Node	275	156.0	185.6	-	148.6	164.3	194.1
	Seepage into Diversion Drain / Alluvium Daylighting	Flux Node	25	8.9	6.0	23.1	9.4	8.6	5.7

Model refers to the infiltration rate used
Flow path refers to the flux section or node
Flux type provides a description of the orientation of the flux or if it's a node
Representative flux (Q) area is the cross sectional area which has been used to 'scaled up' from two-dimensions to three-dimensions

Similarly to the TD3 seepage model, models with variable infiltration (50%, 80% and 95%) resulted in similar flux rates of seepage, with the main difference in the two models being the volume of seepage.

The results from the BSOC WRD North Seepage model indicates that the volume of seepage from the WRD toe ranges between ~52 and ~194 m^3/d (0.6 to 2.2 L/s) across the model scenarios. Actual seepage rates were not available to compare against model results, however based on observational evidence from site personnel, seepage at the BSOC WRD North Seepage does not flow all year round and therefore the lower estimates obtained with the higher k_{sat} alluvium scenario would seem most appropriate for this model.

A summary of the fluxes from the BSOC WRD North Seepage model is provided as follows:

- BSOC WRD North Seepage:
  - 1.3 to 1.9 L/s (Model A – 80%), 0.6 to 1.1 L/s (Model B – 50%), 1.7 to 2.2 L/s (Model C – 95%)

    79.4% (Model A), 42% (Model B) and 75.8% (Model C) of total flux from BSOC WRD landform at BSOC WRD North Seepage point for Base Case simulation
- Seepage to alluvium:
  - 0.005 to 0.04 L/s (All Models)

    0.5% (Model A, B and C) of total flux from BSOC WRD landform at BSOC WRD North Seepage point for Base Case simulation
- Diversion Drain (daylighting) seepage:
  - 0.07 to 0.2 L/s (Model A – 80%), 0.07 to 0.01 L/s (Model B – 50%) and 0.07 to 0.17 L/s (Model C – 95%)

    5.7% (Model A), 6.3% (Model B) and 4.6% (Model C) of total flux from BSOC WRD landform at BSOC WRD North Seepage point for Base Case simulation
- Seepage into bedrock from BSOC WRD Landform (BSOC WRD and TSF5):
  - 0.1 to 0.3 L/s (Model A – 80%), 0.2 to 0.3 L/s (Model B – 50%) and 0.2 to 0.5 L/s (Model C – 95%)

    14.4% (Model A), 25.7% (Model B) and 19.1% (Model C) of total flux from BSOC WRD landform at BSOC WRD North Seepage point for Base Case simulation

BSOC WRD South Seepage Model

Results for the BSOC WRD South seepage model are provided in Table 5-11 for the 80%, 50% and 95% infiltration rate models for all sensitivity scenarios.

Table 5-11: BSOC WRD South Seepage 2D Model - Seepage Modelling Results (m^3/d)

Model	Flow Path	Flux Type	Representative Flux (Q) Area (m^2)	Model Scenario (m^3/d)					
				Base Case	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4	Sensitivity 5
Model A (80% Infiltration)	TSF5 to Weathered Bedrock	Horizontal Flux	89,010	35.8	35.6	38.8	27.1	46.5	48.6
	Bedrock to North-West	Vertical Flux	16,500	4.7	4.8	4.3	8.1	3.1	3.1
	Weathered Bedrock to North-West	Vertical Flux	3,375	17.2	18.0	15.8	17.2	17.2	18.0
	Alluvium to West	Vertical Flux	300	4.9	2.6	22.5	4.9	4.9	2.6
	South Seepage	Flux Node	375	152.5	173.0	0.9	136.8	179.1	200.3

Model	Flow Path	Flux Type	Representative Flux (Q) Area (m^2)	Model Scenario (m^3/d)					
				Base Case	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4	Sensitivity 5
Model B (50% Infiltration)	TSF5 to Weathered Bedrock	Horizontal Flux	89,010	32.1	31.9	35.9	27.5	44.7	44.7
	Bedrock to North-West	Vertical Flux	16,500	4.2	4.2	4.2	7.0	2.9	2.9
	Weathered Bedrock to North-West	Vertical Flux	3,375	18.0	18.0	15.4	18.0	18.0	19.5
	Alluvium to West	Vertical Flux	300	4.9	2.6	21.2	4.9	4.9	2.3
	South Seepage	Flux Node	375	103.8	123.7	0	95.5	130.5	152.1
Model C (95% Infiltration	TSF5 to Weathered Bedrock	Horizontal Flux	89,010	41.9	41.8	43.9	31.7	56.7	56.6
	Bedrock to North-West	Vertical Flux	16,500	5.1	5.1	4.6	8.2	3.3	3.3
	Weathered Bedrock to North-West	Vertical Flux	3,375	38.5	40.2	34.8	38.6	38.6	40.2
	Alluvium to West	Vertical Flux	300	5.2	2.7	27.3	5.2	5.2	2.7
	South Seepage	Flux Node	375	190.9	211.0	39.8	160.8	219.2	240.9

Model refers to the infiltration rate used
Flow path refers to the flux section or node
Flux type provides a description of the orientation of the flux or if it's a node
Representative flux (Q) area is the cross sectional area which has been used to 'scaled up' from two-dimensions to three-dimensions

A summary of the fluxes from the BSOC WRD South Seepage model is provided as follows:

- BSOC WRD South Seepage:
  - 0.01 to 2.3 L/s (Model A – 80%), 0 to 1.1 L/s (Model B – 50%) and 0.5 to 2.8 L/s (Model C – 95%)

    78.2% (Model A), 72.8% (Model B) and 64.6% (Model C) of total flux from BSOC WRD landform at BSOC WRD South Seepage point for Base Case simulation
- Seepage to alluvium:
  - 0.03 to 0.26 L/s (Model A – 80%), 0.03 to 0.25 L/s (Model B – 50%) and 0.03 to 0.3 L/s (Model C – 95%)

    2.6% (Model A), 3.4% (Model B) and 2.9% (Model C) of total flux from BSOC WRD landform at BSOC WRD South Seepage point for Base Case simulation
- Seepage into bedrock from BSOC WRD Landform (BSOC WRD and TSF5):
  - 0.3 to 0.6 L/s (Model A – 80%), 0.3 to 0.5 L/s (Model B – 50%) and 0.4 to 0.7 L/s (Model C – 95%)

    18.3% (Model A), 22.5% (Model B) and 32.4% (Model C) of total flux from BSOC WRD landform at BSOC WRD South Seepage point for Base Case simulation

Model Results Discussion

The model results provided in the above three sections are based on analytical assessments using field tested, and assumed (in the absence of field testing), hydraulic parameters; and, the conceptualised flow systems for the underlying groundwater regime and the BSOC WRD landform. These results comprise a summary of predicted fluxes leaving the BSOC WRD landform via toe seepage, seepage into the Diversion Drain, infiltration into the alluvial aquifer and infiltration into the bedrock aquifer, for each of the model sections. Verification of these predicted fluxes have been undertaken based on results of the field investigation program, historical monitoring results and operational anecdotal observations. A summary of these verifications include:

- Seepage monitoring facilities (v-notch weirs installed in the Diversion Drains) were established as part of this investigation. Monitoring records were collected between March and May 2016, and these records were used to compare against the predicted model results.
  - TD3 Seepage is a perennial seepage discharging directly into the Diversion Drain. Observational estimates of the seepage rate from TD3 Seepage, during the Phase 1 field investigation program (middle of the dry season) was ~1.5 to 2 L/s. Limited monitoring of flow at Weir 1 between March to May 2016 identified an average flow rate of 1.8 L/s.
  - Historically BSOC WRD North Seepage was observed as an ephemeral seepage that flows following the commencement of the wet season and ceases to flow during the dry season. During the Phase 1 field investigation program (dry season) minor seepages at BSOC WRD North Seepage were observed in the Diversion Drain.
  - Two points of seepage are observed at BSOC WRD South Seepage, within the excavated seepage collection trench and at the toe of the WRD. Seepage in the seepage collection trench occurs throughout the year with lower seepage rates are observed during the dry season. Seepage at the WRD toe is ephemeral with seepage flow occurring during the wet season and ceasing during the dry season.
  - These seepage observations are comparable with the results from the 2D modelling.
- Seepage from the BSOC WRD landform into the alluvial aquifer is predicted in each model. This prediction is supported by the results of the Phase 2 field investigation program (alluvial aquifer monitoring bore installation), with groundwater observed in the alluvial aquifer downstream of each seepage location. Field investigations were limited to the extent of the EE focus area, therefore, although BSOC WRD landform infiltration was observed in the alluvium downstream of the WRD it is uncertain if the landform infiltration has migrated to the downstream water course (e.g. Hazeldene Creek).
- The predicted seepage rates into the alluvial aquifer are also supported by the field investigation results. Monitoring bores installed in the alluvial aquifer downstream of the BSOC WRD North Seepage indicate that the alluvial aquifer has a limited saturated thickness (i.e. low groundwater level relative to the alluvium thickness). Limited groundwater in the alluvial aquifer downstream of the BSOC WRD North Seepage is supported by the predicted low seepage rates from the BSOC WRD landform to the alluvial aquifer.
- Seepage into the bedrock aquifer is predicted for each of the model slices. However, results from the field investigation program indicate that the downstream migration of BSOC WRD landform seepage in the bedrock aquifer is limited, with the exception of TD3 Seepage. Groundwater quality results from monitoring bores installed in the bedrock

aquifer downstream of BSOC WRD North and South Seepages do not indicate the presence of BSOC WRD Landform seepage in the groundwater (BSOC_B2, B3 and B4). Therefore, although modelling has indicated seepage into the bedrock aquifer at the BSOC WRD North and South Seepages, targeted field investigations have indicated that evidence of seepage is not present in the bedrock aquifer at the downstream bore locations, which is likely a function of groundwater flow velocities, and is considered further as part of the one-dimensional analytical assessment, discussed in Section 5.4.8.

- Seepage contribution from the landfill sludge ponds to the TD3 Seepage catchment has been conservatively assessed to contribute 1% to 3% of the total flux from the TD3 Seepage catchment. Based on the estimated proportion of sludge pond flux contribution to TD3 Seepage, this contribution would be negligible compared to the seepage contribution from the BSOC WRD landform.

5.4 Current Concentration and Extent of Seepage

In order to determine the current concentration of seepage released from the BSOC WRD to the receiving environment (1 (c) of the EE Notice), the following tasks were undertaken:

- Analysis of recent and historical WRD seepage water quality chemistry,
- Analysis of recent and historical tailings seepage water quality chemistry,
- Analysis of sludge pit water quality chemistry from the MIM Landfill Facility,
- Analysis of groundwater quality chemistry from newly installed investigation bores,
- Analysis of surface water quality chemistry,
- Analysis of isotope samples from groundwater and seepage water,
- Analysis of mineral precipitation observed downstream of the WRD,
- A one-dimensional analytical contaminant transport assessment (Ogata-Banks).

The information compiled from these investigations was then used to interpret the extent of seepage water to the receiving environment.

The approach adopted in the geochemistry investigation was as follows:

- Section 5.4.1: Describe the observed seepage water chemistry. This section describes and compares the major and trace-element seepage chemistry of BSOC WRD South seepage, BSOC WRD North seepage and TD3 seepage;
- Section 5.4.1: Compare the observed seepage water chemistry at TD3 to historical and recent seepage associated with TSF5. This section describes the historical and more recently observed seepage water quality associated with TSF5 to provide a useful comparison with the seepage observed at TD3, BSOC WRD South and BSOC WRD North. Time-series diagrams show the variations in water quality over the sampling periods;
- Section 5.4.1.1: Describe the leachate chemistry from waste rock and tailings humidity cells. Kinetic testing (humidity cell testing) is currently being undertaken for a range of waste rock and tailings samples. Humidity cell tests are conducted under controlled laboratory conditions and as a result are not strictly representative of the seepage

chemistry observed in the field. However, they do provide an indication of which chemical species *may* be mobilised and appear in seepage water. This section compares the results of the kinetic tests to the BSOC WRD seepage chemistry;

- Section 5.4.2: Describe the observed seepage chemistry of the landfill/sludge pit. This section describes the water chemistry from the sludge pit seepage and compares the results to the seepage chemistry observed at TD3, BSOC WRD South and BSOC WRD North;
- Section 5.4.3: Describe the observed groundwater chemistry. This section provides descriptions of water from monitoring bores in the alluvial aquifer and bedrock aquifer and compares the results to the seepage locations TD3, BSOC WRD South and BSOC WRD North. Together with time-series diagrams, these results should provide an indication of which monitoring bores are likely to be impacted by the seepage(s);
- Section 5.4.4: Describe the isotope chemistry of seepage and groundwater samples. Stable isotopes of hydrogen, oxygen and sulphur may provide some additional insight into potential seepage sources. This section describes the results from the analysis of a number of water samples that were selected to undergo stable isotope investigation and compares these to the previous isotope investigation (Forsyth, 2014);
- Section 5.4.5: Describe the observed surface water chemistry. This section provides descriptions of the King Gully surface water quality and compares the results to TD3 seepage;
- Section 5.4.6: Describe mineral precipitation calculations. This section describes the results of hydrogeochemical modelling the observed seepage water quality. The Geochemist's Workbench and PHREEQC were used to determine the minerals that are likely to be in equilibrium with the seepage water and to then simulate precipitation of these minerals from the seepage water. This was then compared to mineral precipitates observed downstream from the seepage points (see KCB site investigation report) to provide an indication of whether the downstream sites may have experienced influx from seepage water; and,
- Section 5.4.7: Provide a summary of the water chemistry.

The geochemical dataset consists of the following main types of recent and historical information that have been used to assess the nature of the seepage water and the potentially impacted sites:

- Major element parameters (major anions, major cations, EC, pH). These have been used to provide the main characteristics of the water samples;
- Trace elements have allowed further insight into the water types, where appropriate; and
- Isotopes have been used to provide additional information on possible source(s).

5.4.1 Seepage Water Chemistry

Seepage concentrations are presented below for the three BSOC WRD landform seepage locations. The location of the seepage, along with historical seepage locations, groundwater samples and the TD5 pit water sample (collected in February, 2016) are shown in Figure 5-36.

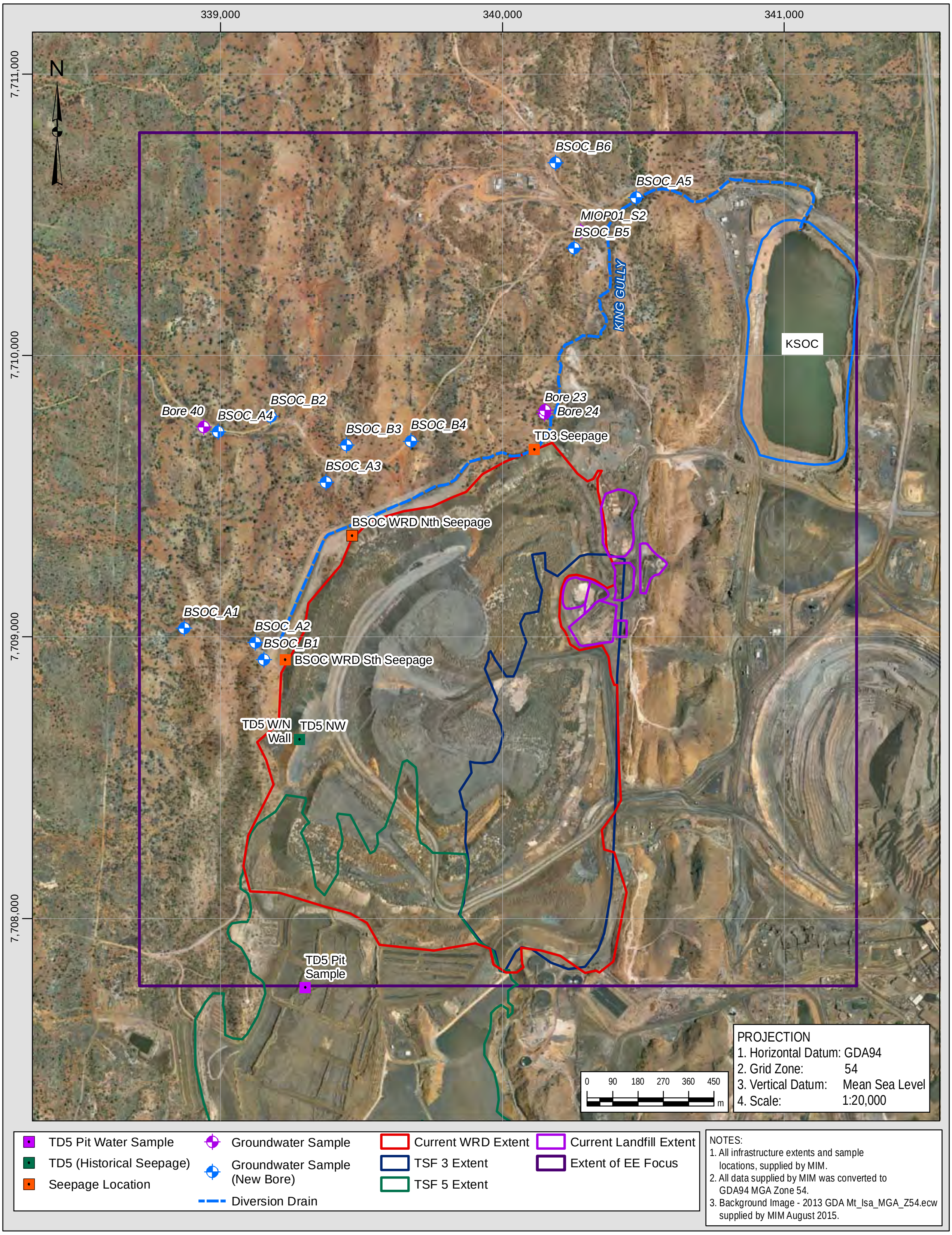

Figure 5-36: Location of water chemistry samples including seepage, groundwater and TD5 pit water sample

BSOC WRD South Seepage

Figure 5-37 presents a multi-element diagram (also known as a Schoeller plot) showing the concentration of a number of trace elements and dissolved metals for the BSOC WRD South Seepage. The purpose of this diagram is to provide an overview of the potential dissolved trace element 'signatures' that may be characteristic of the seepage point and may allow the identification of potential source(s) characteristics. BSOC WRD South Seepage has relatively low concentrations of zinc (~0.001 – 0.1 mg/L), cadmium (~0.0001 – 0.01 mg/L), manganese (~1 mg/L) and nickel (~0.01 mg/L; Figure 5-37). BSOC WRD South Seepage concentrations are superficially similar to those for BSOC WRD North seepage and TD3 (cf. Figure 5-37, Figure 5-38 and Figure 5-39). However, BSOC WRD South Seepage is generally lower in zinc and manganese; and, contains cadmium and nickel around two orders of magnitude lower in concentration.

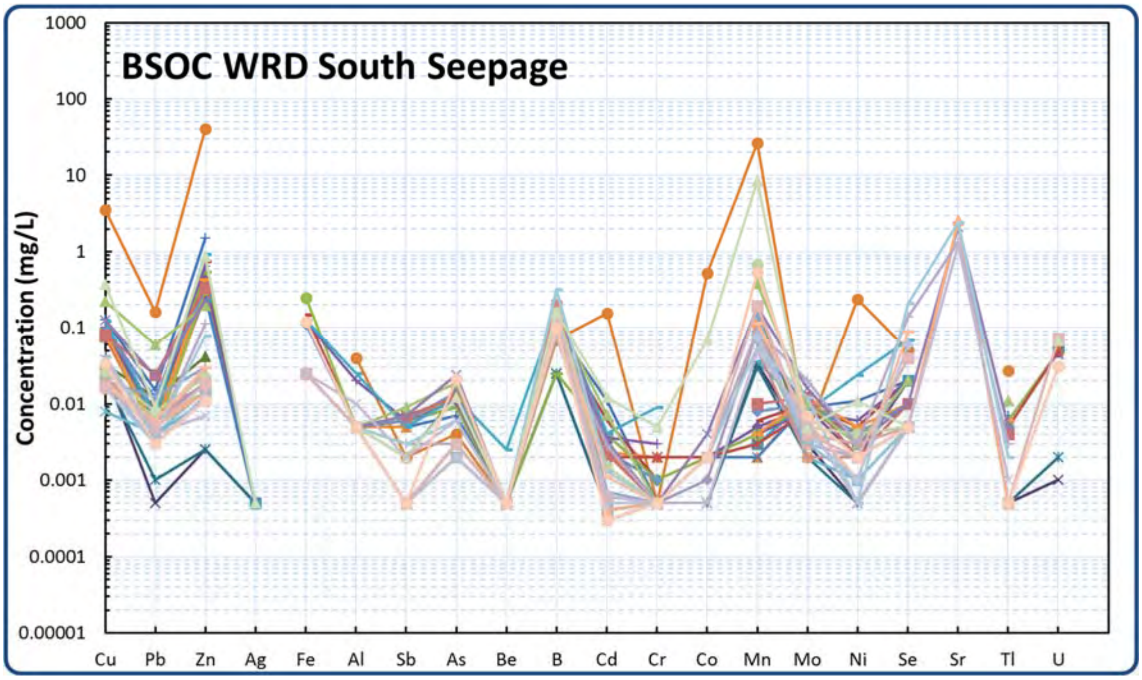

Figure 5-37: Multi-element plot showing BSOC WRD South Seepage trace element concentrations

BSOC WRD North Seepage

BSOC WRD North seepage (Figure 5-38) has a similar trace element 'signature' to TD3 seepage (Figure 5-39), with relatively high zinc and manganese concentrations and moderate cadmium, cobalt and nickel concentrations.

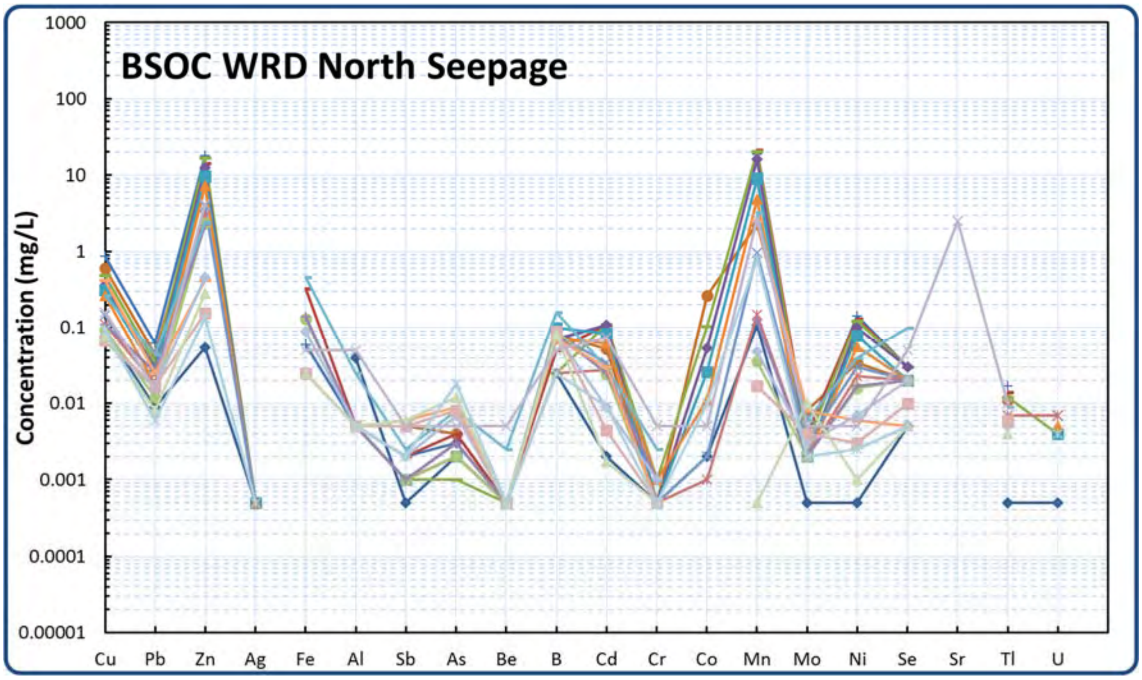

Figure 5-38: Multi-element plot showing BSOC WRD North Seepage trace element concentrations

TD3 Seepage

Figure 5-39 shows the dissolved trace element pattern for TD3 seepage. The diagram shows that the seepage contains relatively high zinc and manganese concentrations (~10 mg/L) and moderate cadmium, cobalt and nickel concentrations (~0.1 mg/L). TD3 seepage contains roughly one order of magnitude more copper than lead.

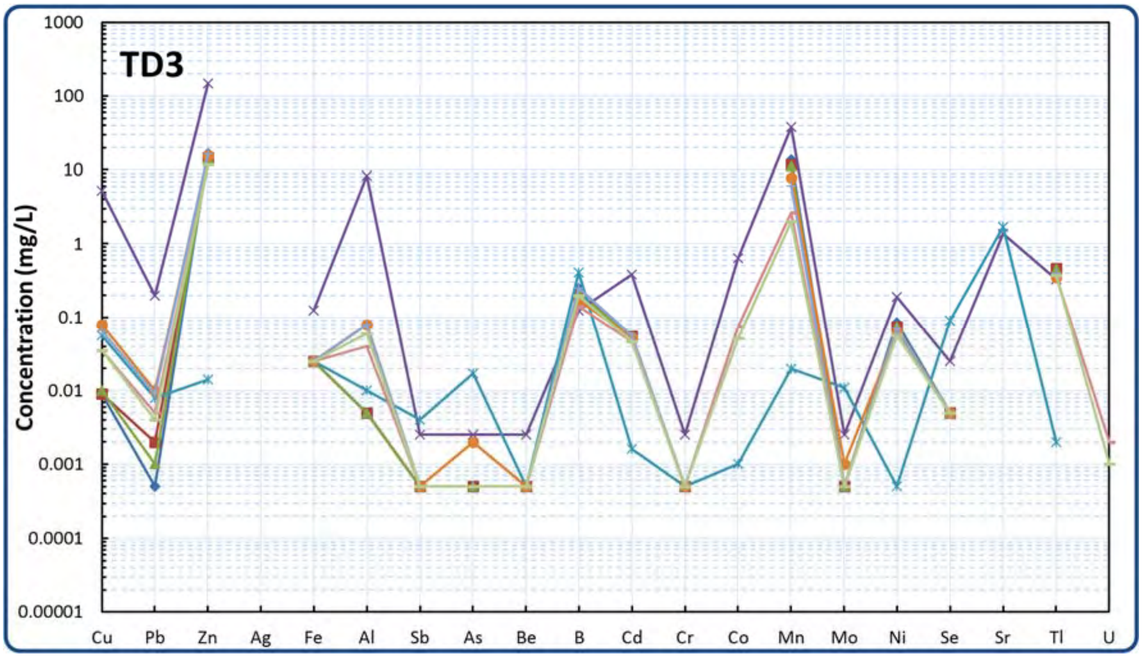

Figure 5-39: Multi-Element Plot Showing TD3 Seepage Trace Element Concentrations

Major Parameter Seepage Characteristics

Major element characteristics of the BSOC WRD landform seepage water samples are shown in Figure 5-40. BSOC WRD North Seepage has slightly higher calcium and similar sulphate concentrations compared to seepage from BSOC WRD South Seepage, which tends to be slightly richer in sodium, potassium and chloride, which may reflect differences in the waste material deposited. TD3 Seepage generally falls within the field of BSOC WRD North Seepage samples. Seepage water from all sources displays a wide range of electrical conductivities (EC), but a generally narrow range of pH.

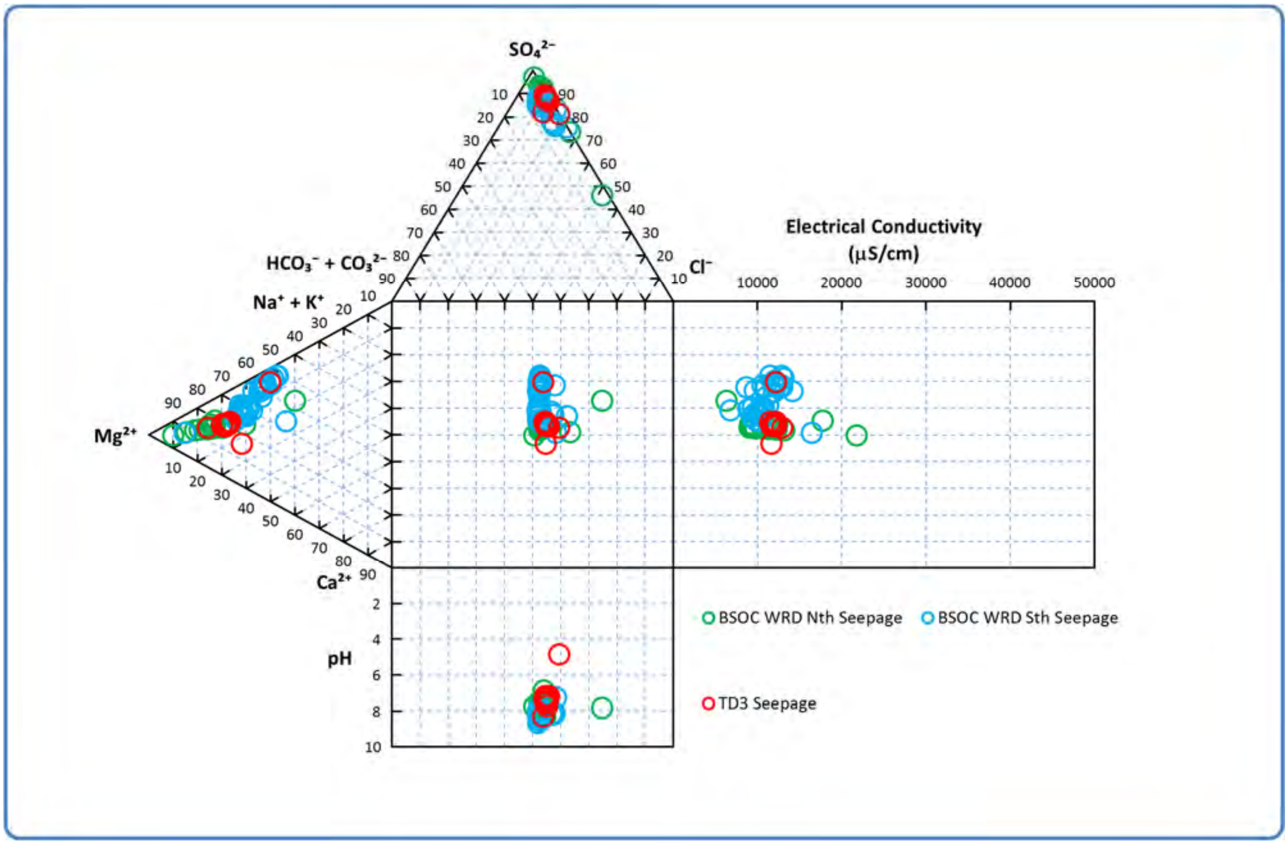

Figure 5-40: Durov diagram showing the dissolved major element contents, pH and electrical conductivity of seepage from BSOC WRD North, BSOC WRD South and TD3.

BSOC WRD landform seepage water chemistry is likely to be influenced by gypsum solubility, with most of the TD3 Seepage samples and BSOC WRD North and South Seepage samples saturated in gypsum (Figure 5-41). Despite some high salinity reported in some of the seepages, they are likely to remain under-saturated in halite (Figure 5-42).

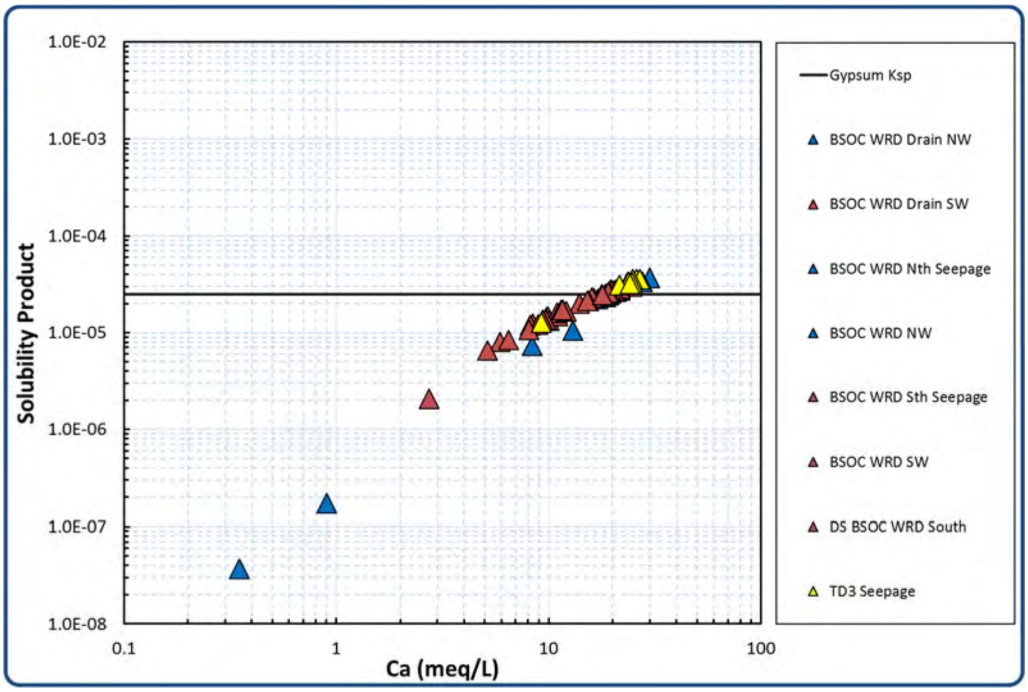

Figure 5-41: Calculated gypsum ($CaSO_4$) solubility product for BSOC samples plotted against calcium concentration (meq/L)

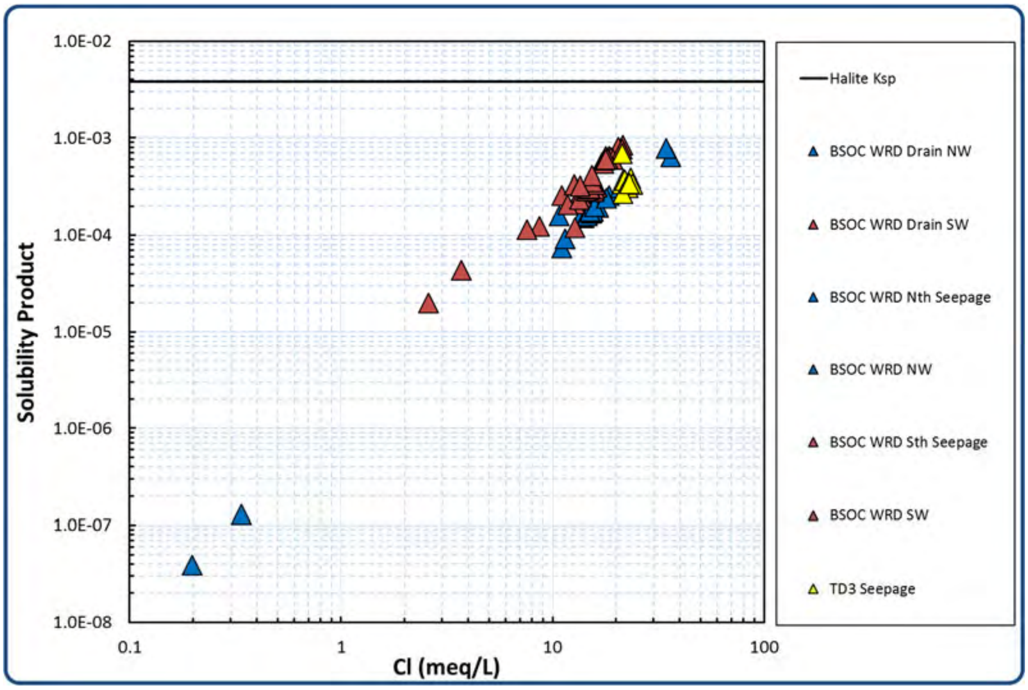

Figure 5-42: Calculated halite (NaCl) solubility product for BSOC samples plotted against chloride concentration (meq/L)

Comparison of Current BSOC WRD Landform Seepage to Historical Tailings Seepage Water Chemistry

Previous investigations of TSF3 and TSF5 indicate that the tailings materials are generally alkaline and contain high salinity water with elevated concentration of some metals. Historical sampling of TSF3 seepage at the East Wall from January 2001 to February 2004 (Forsyth & Edraki, 2010) indicates slightly alkaline pH, elevated EC and elevated concentration of total cadmium, total copper, fluorine, total lead, total zinc and sulphate.

Time series graphs for selected parameters were used to see the variation in these parameters over the sampling periods. The plots may be useful to observe long-term trends, or potential seasonal responses in the geochemistry. Figure 5-43 shows the variation of sulphate, alkalinity, pH and zinc over time[8], for recent quality monitoring of TD3 Seepage, BSOC WRD North Seepage and BSOC WRD South Seepage. A water sample was collected from within TSF5, where mining of the tailings is occurring, as part of this investigation (February, 2016; Figure 5-36) to provide additional context against current and historical seepage concentrations. This is also included within the following graphs.

Also shown, as a useful comparison of changes over time, are time series parameters from the TD5W seepage collection point as presented in Forsyth (2014).

[8] These parameters were chosen because sulphate, pH and alkalinity represent major characteristics of the seepage water, whereas zinc concentrations may be indicative of the zinc source, since mixed and lead-zinc tailings are present.

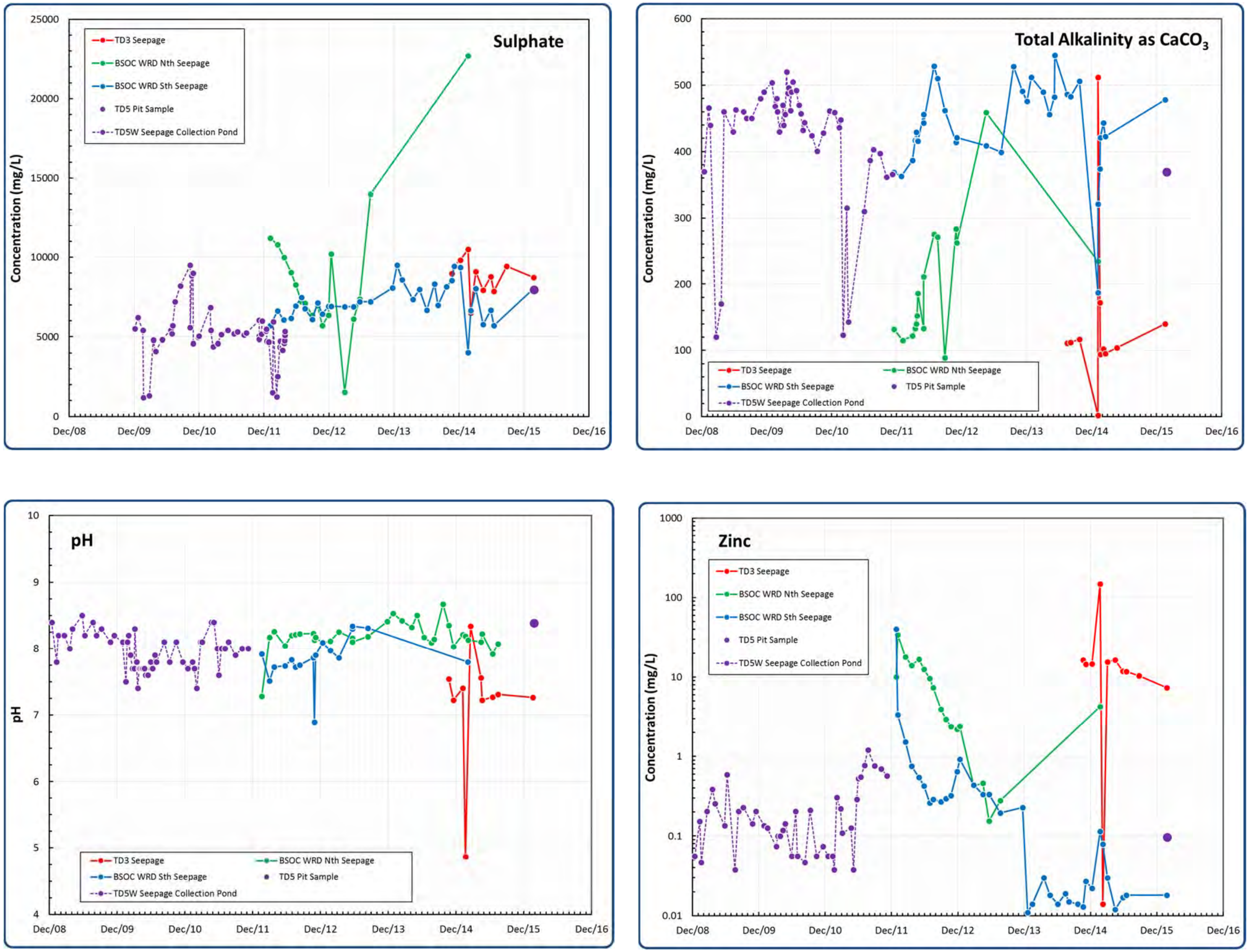

Figure 5-43: Time series for selected seepage locations a) sulphate, b) alkalinity, c) pH, d) zinc

TSF5 Seepage (Historical)

TSF5 seepage water quality has remained relatively constant throughout the years it has been monitored: the recent TSF5 pit sample (location shown on Figure 5-36) collected in 2016 has similar concentrations to the data monitored prior to 2012. Sulphate concentrations might be showing a slight increase and alkalinity may be showing a slight decrease, but the pH values reported for the TSF5 pit sample are ~8, suggesting that the water quality is not experiencing a drop in pH. Multi-element plots of TSF5 seepage samples give a reasonably tightly defined locus of concentrations. The trace element 'fingerprint' of TSF5 appears to be similar to that for BSOC WRD South Seepage (cf. Figure 5-37 and Figure 5-44). Parameter values are generally consistent with 'historical' values (e.g. sulphate ~5000 mg/L and pH ~ 8 (Forsyth & Edraki, 2010).

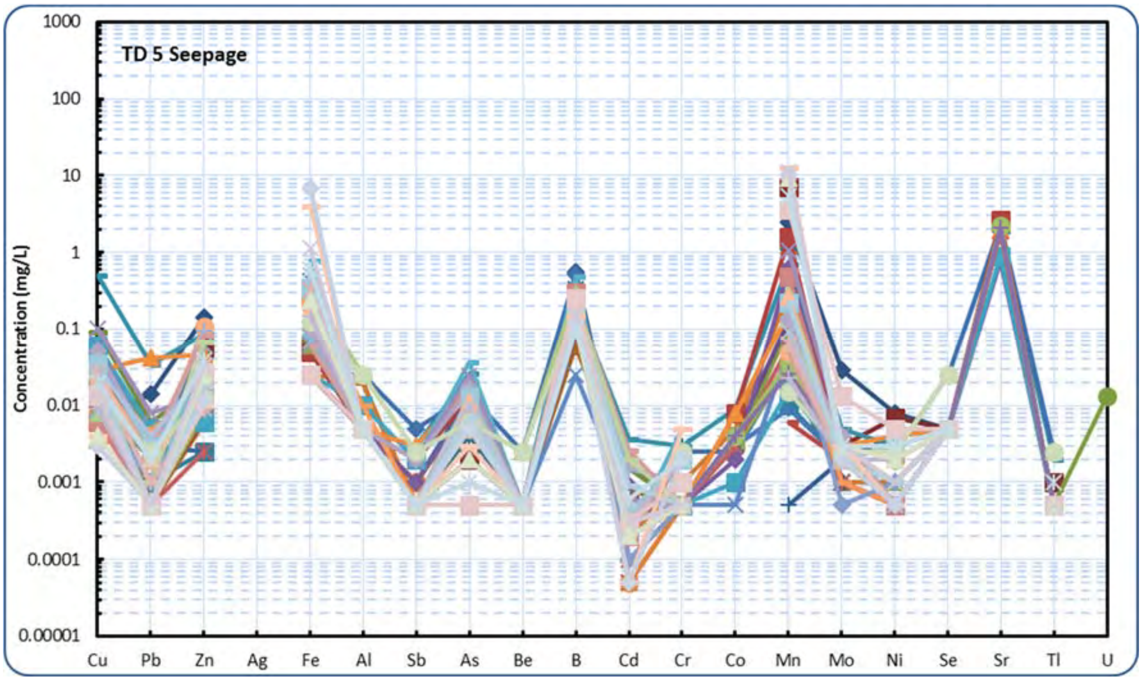

Figure 5-44: Multi-Element Plot Showing TSF5 Seepage Trace Element Concentrations

TSF3 Seepage (Historical)

TSF3 seepage water quality differs from the other seepage water qualities and exhibits higher concentrations of sulphate and zinc and lower pH, which may be due to contributions of historical disposal of acidic wastes (MIM Waste Management Register). TD3 seepage is similar to those from BSOC WRD North Seepage and broadly similar to BSOC WRD South Seepage and TSF5 (cf. Figure 5-38, Figure 5-39, Figure 5-44). Although TD3 seepage water quality has exhibited spikes in concentrations over time (e.g., sulphate), these are potentially isolated events and may represent outliers. A pH value of ~7, is similar to that reported prior to 2009 (Forsyth and Edraki, 2010).

The trace element 'signature' of TSF3 samples is shown in Figure 5-45. Relatively high zinc and manganese concentrations are similar to those seen in the tailings humidity cell leachate (cf. Figure 5-50, Figure 5-51 and Figure 5-52 with Figure 5-45), which would be expected for seepage that may have some influence from tailings chemistry.

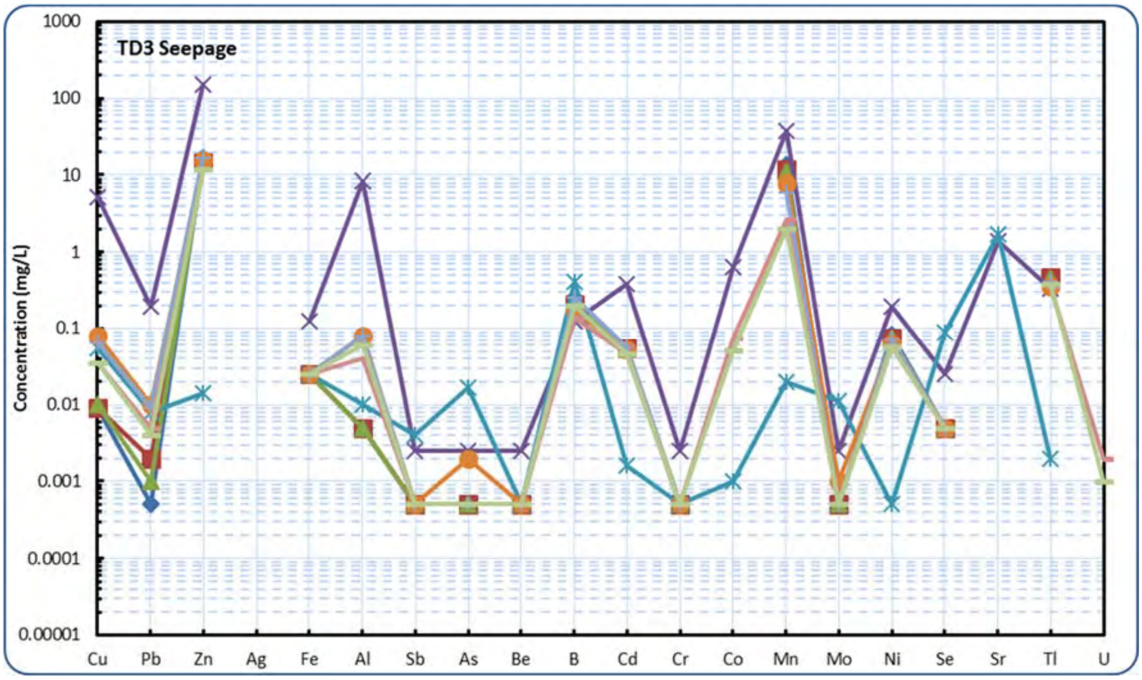

Figure 5-45 Multi-element plot showing TD3 seepage trace element concentrations

Major water quality parameters show the similarities between the seepage locations, although when compared with the TD5 pit sample (collected 2016), the TD5 pit sample is higher in sodium and slightly higher in chloride.

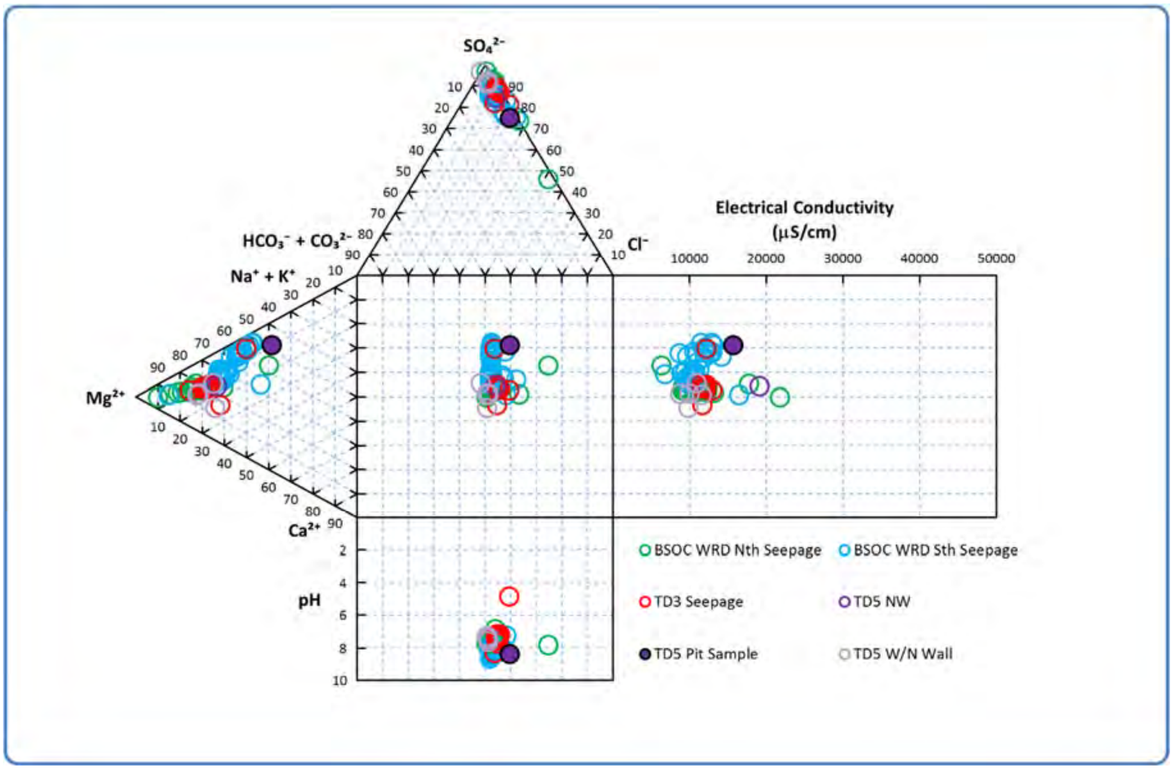

Figure 5-46: Durov diagram showing the dissolved major element contents of seepage from BSOC WRD North, BSOC WRD South,TD3, TD5 Pit Sample, TD5 NW and TD5 W/N Wall. Also shown are seepage pH and EC

5.4.1.1 Kinetic Testing Leachate Chemistry

Humidity cell testing provides an indication of which parameters of a particular waste material are likely to be mobilised under aerobic conditions. Humidity cells are designed to simulate weathering of the waste material under carefully controlled laboratory conditions and leachate chemistry is therefore not intended to provide the absolute concentrations of solutes when scaled to the waste rock or TSF. The tests do, however, provide an indication of the relative reactivity and mobility of elements of concern and are useful to assess the expected proportions of these parameters from waste material subjected to weathering.

BSOC waste rock and tailings (see below) are currently undergoing an extensive kinetic testing program (humidity cell testing) to assess their weathering characteristics (see KCB, 2014). Detailed information on sample selection, humidity cell testing and results can be found in KCB (2014) BSOC Humidity Cell Testing Interim MEMO. The sample tests consist of ECV, Kennedy-Spears and Urquhart Shale waste rock types and Copper, Copper-Lead-Zinc mixed and Lead-Zinc tailings (see below for tailings). Three waste rock types and all three tailings samples are classified as potentially acid forming and should give some indication on the mobilisation and nature of metals due to weathering.

Waste Rock Humidity Cell Leachate Chemistry

Dissolved trace elements in leachate from the humidity cell tests on the waste rock types are shown in Figure 5-47, Figure 5-48 and Figure 5-49. Leachate concentrations for both the ECV and the Kennedy-Spears samples are generally low (≤ ~0.1 mg/L) for most trace element parameters. Urquhart Shale leachate from humidity cell tests reports higher concentrations of zinc and manganese (~1 mg/L) and low copper/zinc ratios.

With the caveat above in mind, the humidity cell leachate chemistry of the Urquhart Shale waste rock does somewhat resemble the leachate chemistry observed at BSOC WRD North, which may be expected since the BSOC WRD North leachate should be influenced by the waste deposited at the waste rock dump. Humidity cell Urquhart Shale leachate also bears some similarities to TD3 seepage (cf. Figure 5-39 and Figure 5-48).

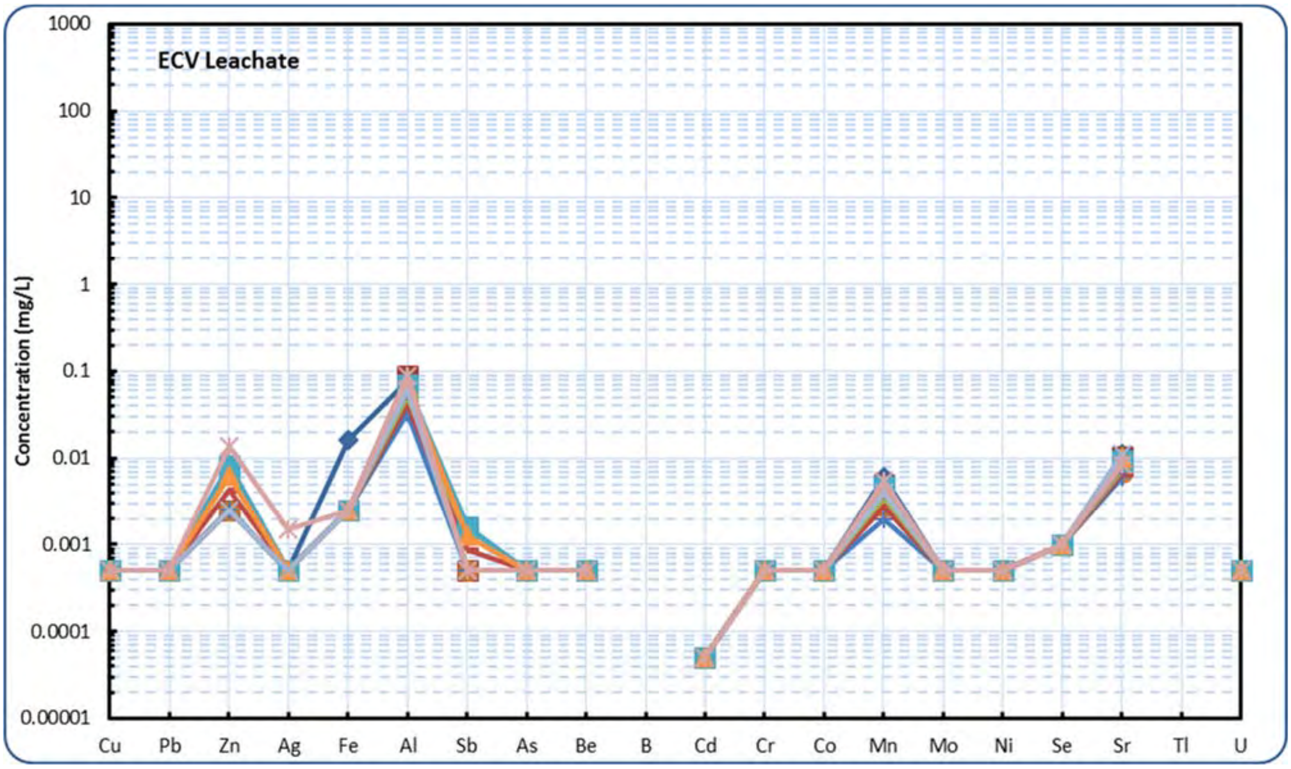

Figure 5-47: Multi-element leachate concentrations from ECV samples subjected to humidity cell testing

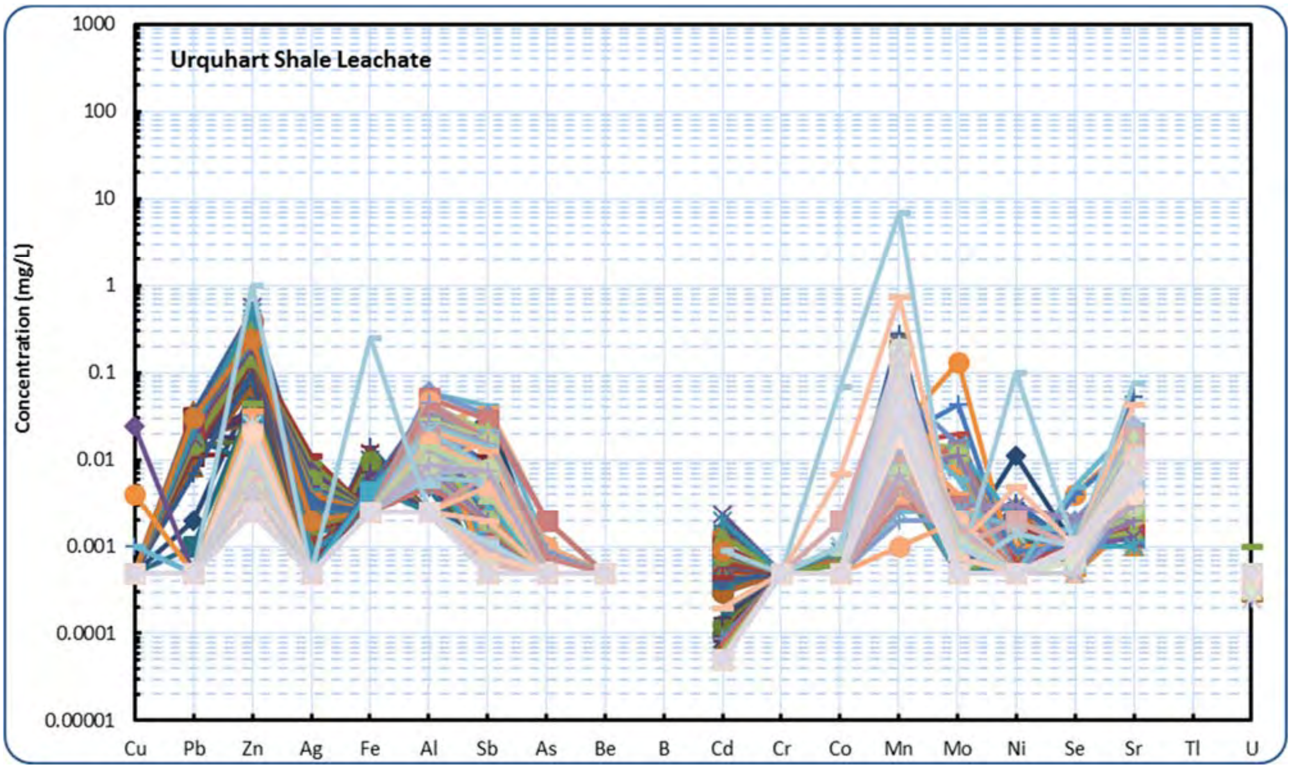

Figure 5-48: Multi-element leachate concentrations from Urquhart Shale samples subjected to humidity cell testing

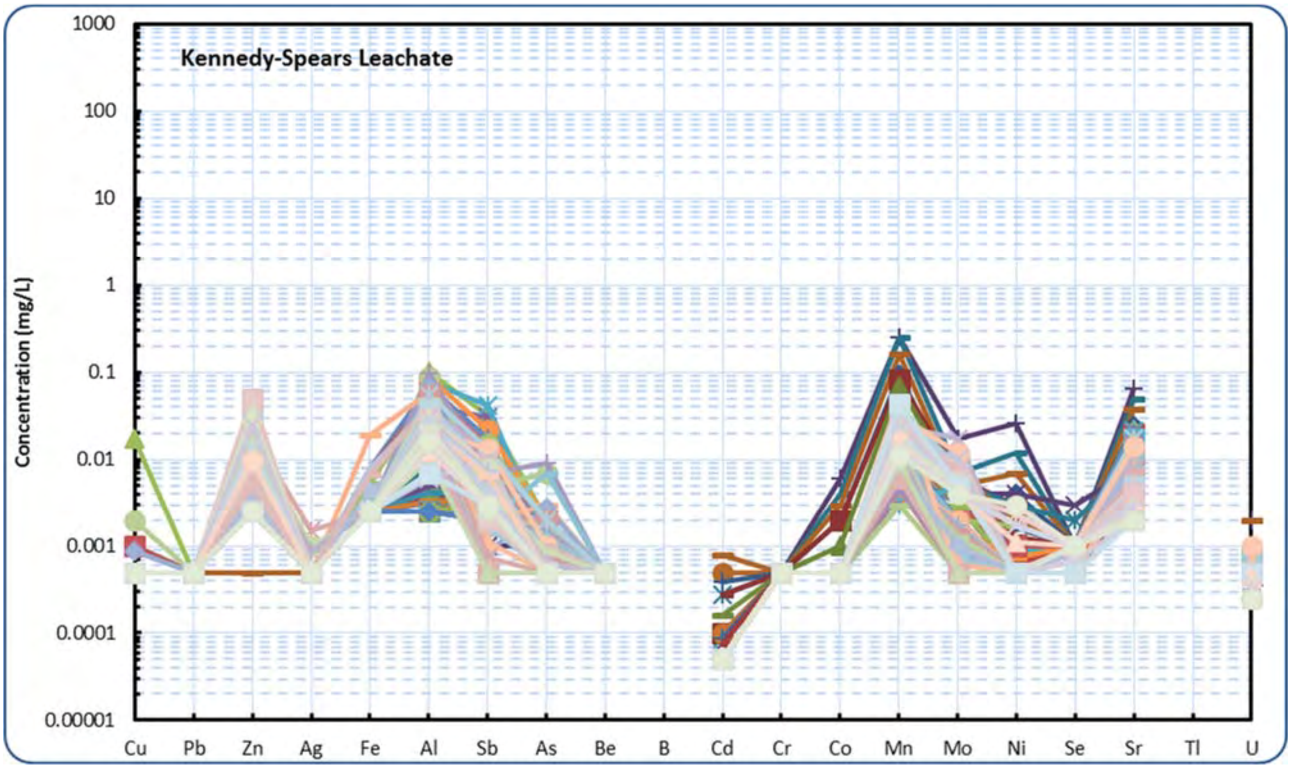

Figure 5-49: Multi-element leachate concentrations from Kennedy-Spears samples subjected to humidity cell testing

Tailings Humidity Cell Leachate Chemistry

As stated above, humidity cell tests *may* provide a useful indication of which parameters are likely to leach from, in this case, the tailings samples. Leachate concentrations from humidity cell tests on copper tailings (Figure 5-50), mixed copper and lead-zinc tailings (Figure 5-51) and lead-zinc tailings (Figure 5-52) have greater concentrations of most trace elements, as would be expected, when compared to those from similar tests on waste rock (see Section 0). In particular, manganese and cadmium concentrations are relatively high in leachate from the mixed and lead-zinc tailings. Also, and as expected, the copper tailings reports leachate with high copper-zinc ratios, whereas the mixed and lead-zinc tailings have low copper-zinc ratios. The copper tailings (and some of the leachate samples from the mixed tailings) have relatively high cobalt concentrations, such that the manganese-cobalt ratio is close to ~1, whereas the manganese-cobalt ratio for the lead-zinc tailings is below ~1. All tailings leachates have nickel concentrations at or below 0.01 mg/L.

As for the waste rock humidity cells (see above), comparison of the tailings humidity cell leachate with BSOC WRD North and TD3 seepage suggests some similarities (cf. Figure 5-50, Figure 5-51, Figure 5-52, Figure 5-38, Figure 5-39).

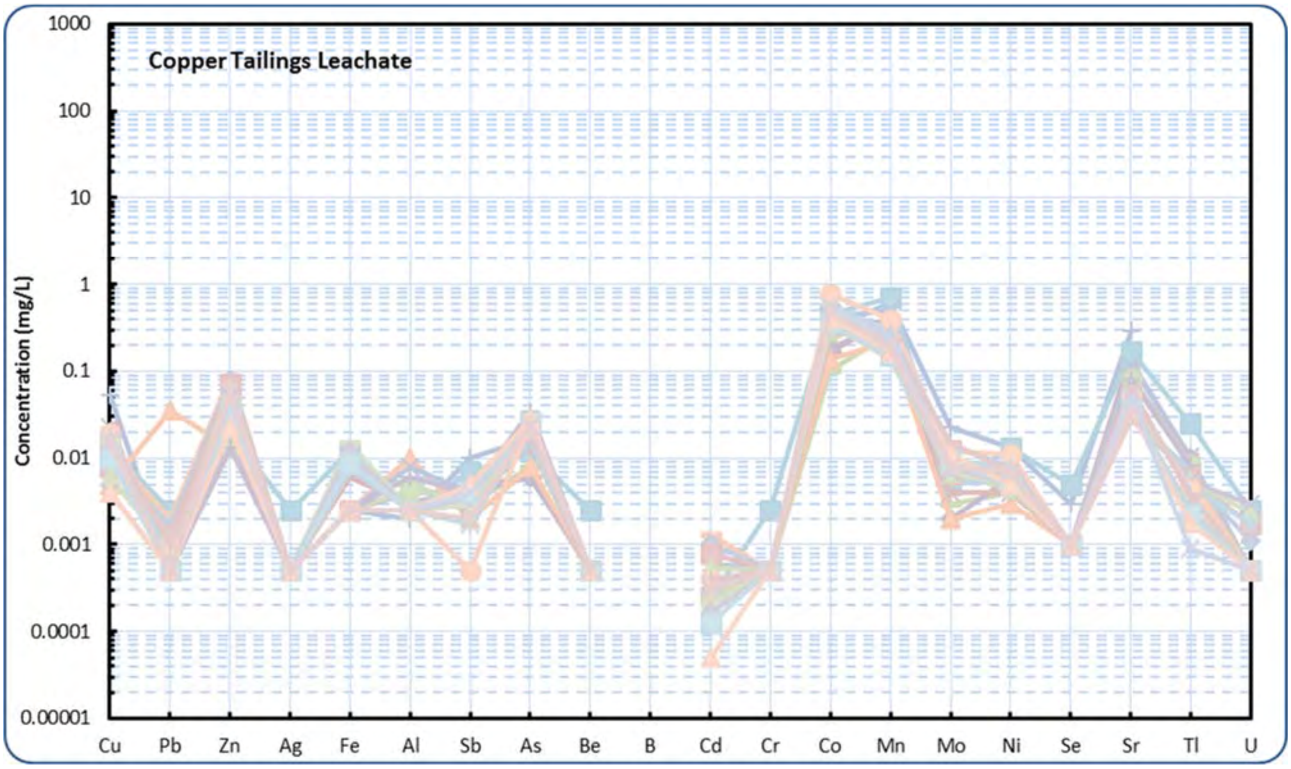

Figure 5-50: Multi-element leachate concentrations from Copper Tailings samples subjected to humidity cell testing

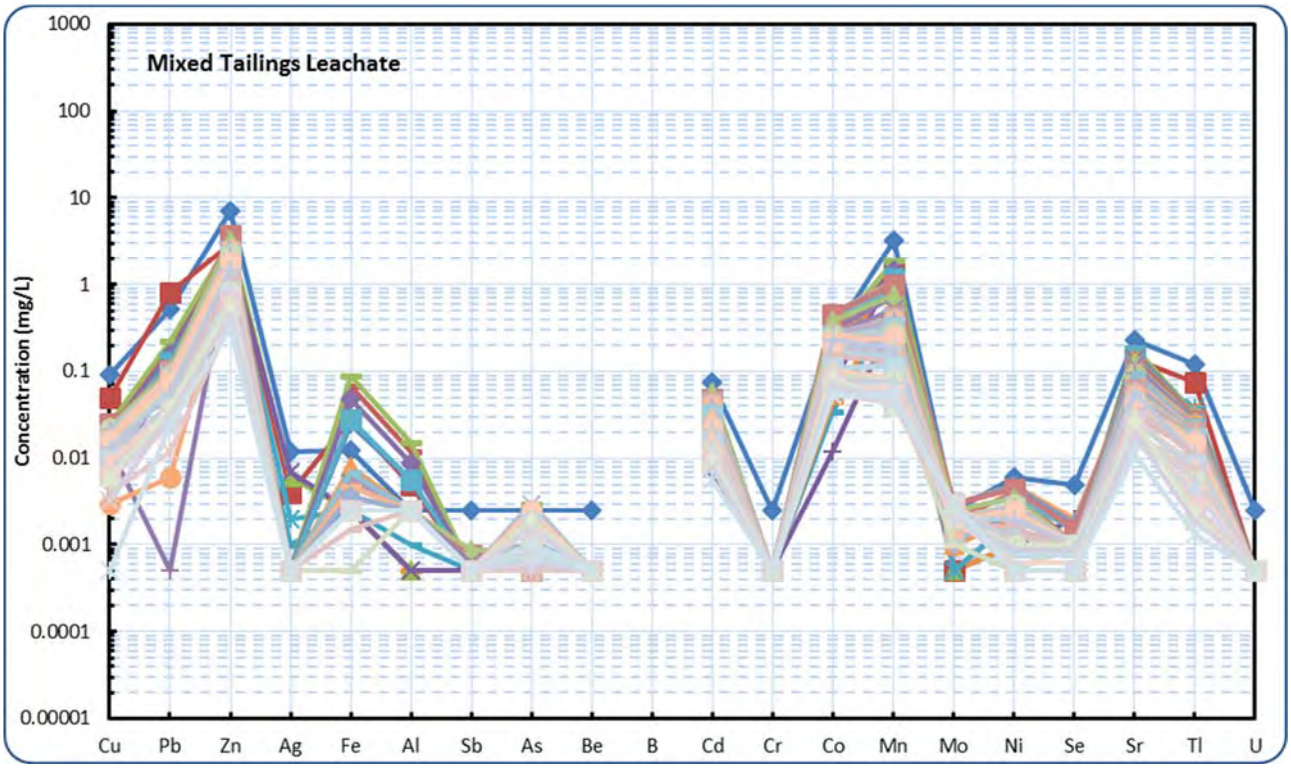

Figure 5-51: Multi-element leachate concentrations from Mixed Tailings samples subjected to humidity cell testing

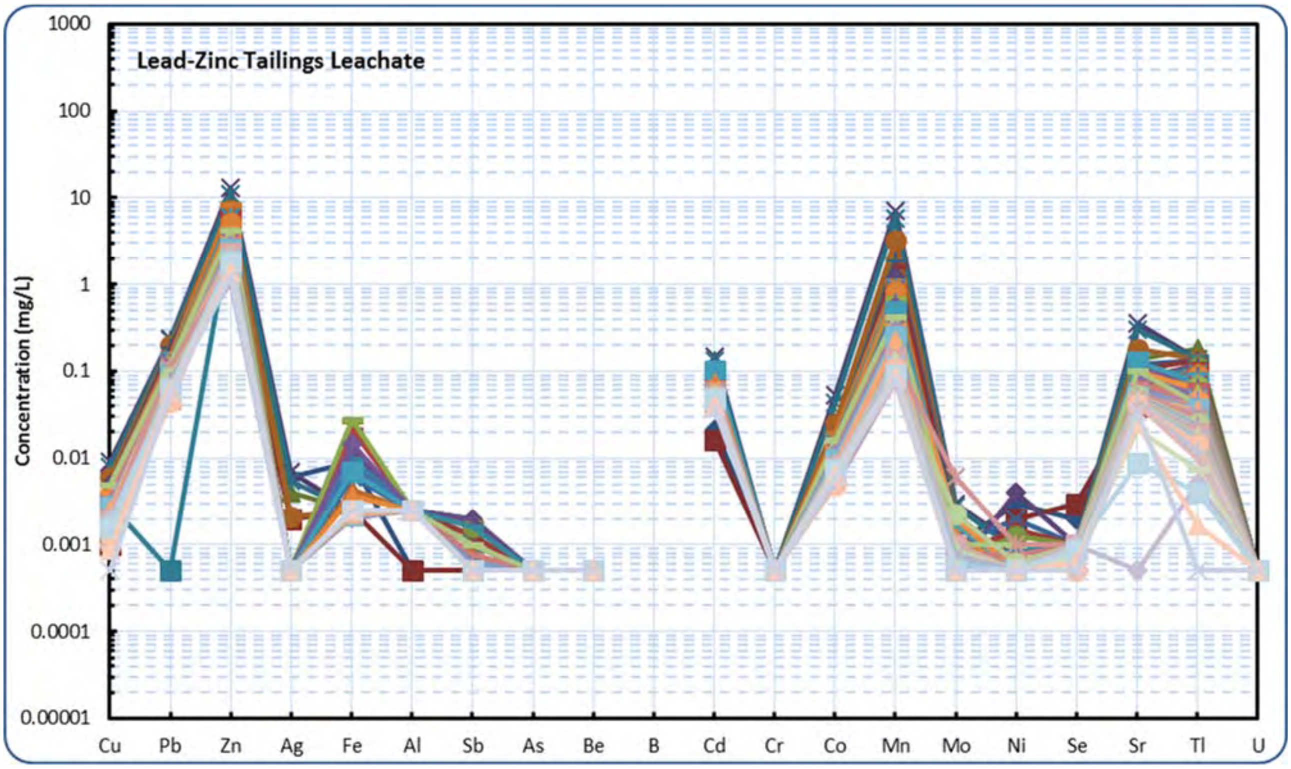

Figure 5-52: Multi-element leachate concentrations from Lead-Zinc Tailings samples subjected to humidity cell testing

5.4.2 Landfill / Sludge Pit Water Chemistry

Limited historical chemical data exists for the sludge pits, with one historical sample available.

The landfill and sludge pits were visited on August 25, 2015 as part of the Phase 1 site investigation and a water sample was collected from both sludge pits. Figure 5-53 shows the location of the landfill, sludge pits and samples.

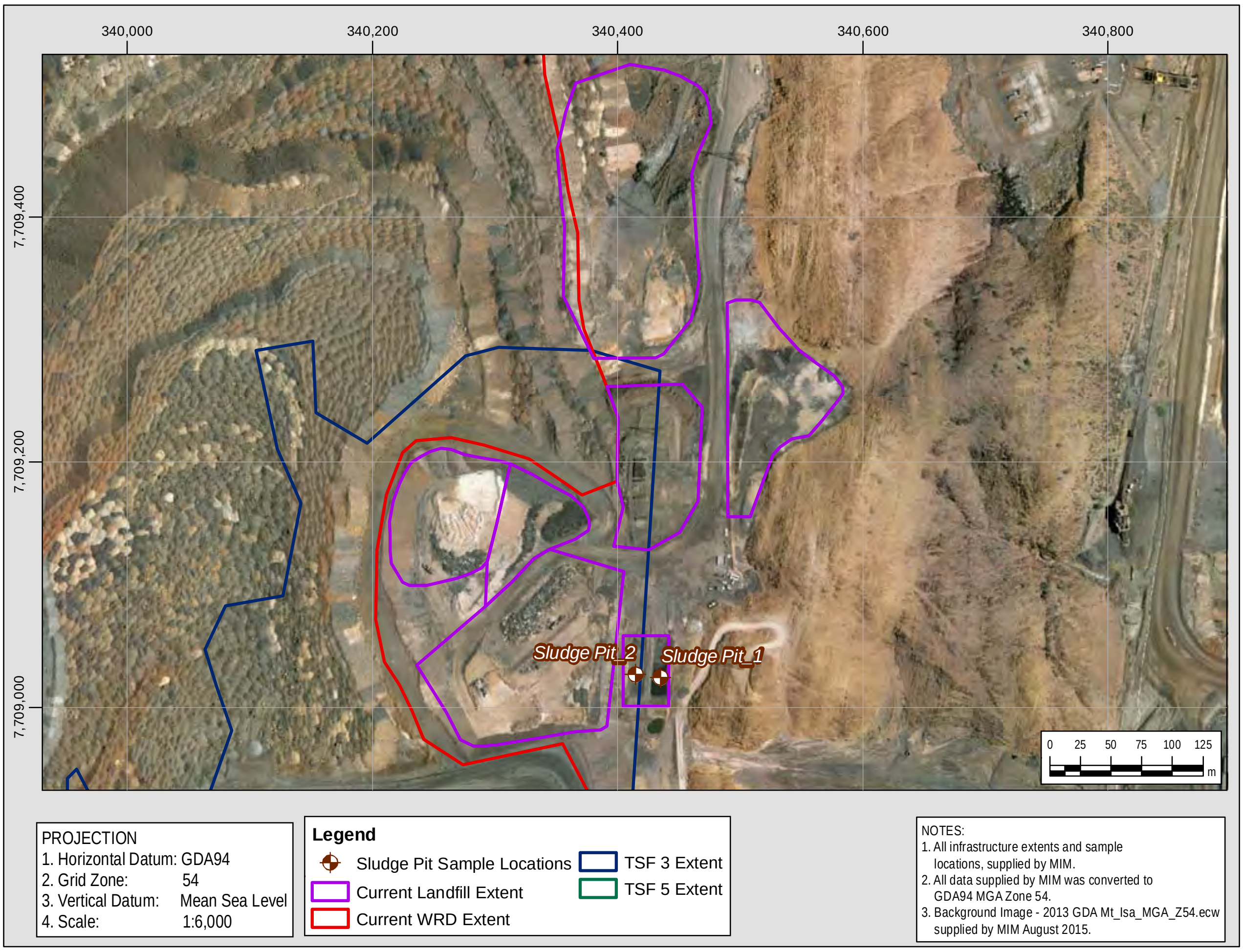

Figure 5-53: MIM Landfill General Waste Cell and Sludge Pits and Location of Sample Collection

Table 5-12 presents a summary of the water sample results from the sludge pits. Certificate of analysis for these samples are presented in Appendix II.

Table 5-12: Summary of Sludge Pit Sample Results

Parameter	Unit	SludgePit_1	SludgePit_2
		Date Sampled	
		25/08/2015	25/08/2015
Laboratory pH	pH_Units	9.03	5.43
Electrical conductivity	µS/cm	28700	4650
Total Dissolved Solids	mg/L	34500	3870
Magnesium	mg/L	1240	222
Calcium	mg/L	70	406
Alkalinity (Bicarbonate as $CaCO_3$)	mg/L	5340	4
Alkalinity (Carbonate as $CaCO_3$)	mg/L	1990	1
Alkalinity (total) as $CaCO_3$	mg/L	7340	4
Sodium	mg/L	7090	301
Potassium	mg/L	501	56
Sulphate	mg/L	13400	2540
Chloride	mg/L	3080	399
Fluoride	mg/L	3.3	6.3
Ammonia as N	µg/L	120	27700
Nitrate (as N)	mg/L	0.01	0.01
Nitrite (as N)	mg/L	0.01	0.01
Total Organic Carbon	mg/L	2	11.3
Phosphorus	mg/L	7.5	0.83
Aluminium	mg/L	0.11	2.59
Antimony	mg/L	0.023	0.017
Arsenic	mg/L	1.45	0.858
Barium	mg/L	0.163	0.016
Beryllium	mg/L	0.005	0.001
Bismuth	mg/L	0.005	0.008
Boron	mg/L	1.85	0.27
Cadmium	mg/L	0.15	2.66
Chromium (III+VI)	mg/L	0.004	0.002
Cobalt	mg/L	0.027	0.568
Copper	mg/L	0.187	44.2
Iron	mg/L	0.94	8.62
Lead	mg/L	1.12	3.51
Manganese	mg/L	0.511	4.05
Mercury	mg/L	0.0001	0.0001
Molybdenum	mg/L	0.081	0.001
Nickel	mg/L	0.124	0.446
Selenium	mg/L	0.05	0.04
Silver	mg/L	0.005	0.001
Strontium	mg/L	0.591	0.588
Thallium	mg/L	0.05	1.5
Thorium	µg/L	5	1
Titanium	mg/L	0.05	0.01
Uranium	µg/L	16	1
Vanadium	mg/L	0.05	0.01
Zinc	mg/L	0.607	15.3

Metals as filtered
EC and pH – lab values

Figure 5-54 presents the multi-element diagram for sludge pit water concentrations, for the samples collected during the Phase 1 site investigation and a historical sample from 2011.

Based on these samples, TD3 seepage may also contain a minor component of sludge pit water (cf. Figure 5-54 and Figure 5-45); cadmium and manganese concentrations show some similarities between the samples shown here, however this is inconclusive as it is based on comparison of two sample events only.

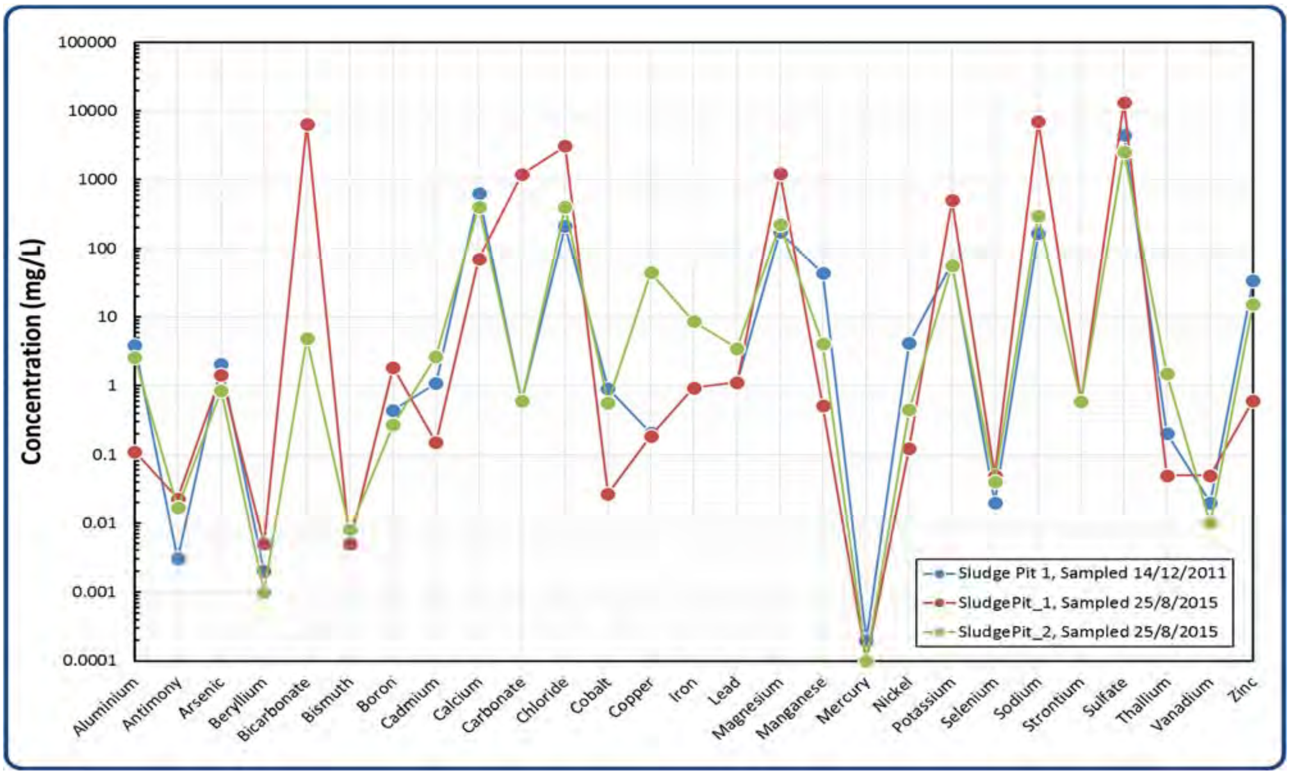

Figure 5-54: Multi-element diagram showing concentrations in sludge pit water

5.4.3 Groundwater Chemistry

Historical groundwater chemistry data is available for a number of existing MIM bores which are monitored as part of the EA *Schedule H*.

As part of this investigation, groundwater samples were collected by MIM personnel from the new monitoring bores, following completion of airlift development and dispatched under chain of custody protocol to ALS for analysis. It should be noted that BSOC_A4 was dry at the time of sample collection and therefore a sample was not collected.

A summary of the field water quality parameters and results of the water quality analysis are presented in Table 5-13, with the complete water quality analysis results presented in Appendix II. Samples were also collected from BSOC WRD South Seepage and TD3 Seepage. BSOC WRD North Seepage was not flowing at the time of sample collection.

Table 5-13: Summary of Phase 2 groundwater and seepage sample results

Sample Type	Sample ID	Date Sampled	Field Parameters*			Laboratory Results									
			Temp	pH	EC	SO_4	F	Al	As	Cd	Co	Cu	Pb	Ni	Zn
	Unit			-	*µS/cm*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Groundwater	BSOC_A1	19/1/16	32.9	8.66	3,933	576	2.3	0.9	0.003	<0.0001	<0.001	0.005	<0.001	<0.001	<0.005
	BSOC_A2	19/1/16	29.4	7.18	12,753	5,580	6.4	2.20	0.002	<0.0001	<0.001	0.005	0.002	0.002	0.006
	BSOC_A3	21/1/16	33.7	8.23	5,830	727	3.4	25.8	0.007	<0.0001	<0.001	0.049	0.002	<0.001	<0.005
	BSOC_A4	Dry	-	-	-	-	-	-	-	-	-	-	-	-	-
	BSOC_A5	19/1/16	34.8	7.39	16,048	4,870	5.1	18.5	0.014	0.0001	0.004	0.002	0.002	0.003	0.015
	BSOC_B1	20/1/15	30.7	7.28	5,372	1,760	5.3	1.51	<0.001	<0.0001	<0.001	0.001	<0.001	<0.001	0.007
	BSOC_B2	20/1/15	30.1	6.93	1,346	152	1.8	0.35	<0.001	<0.0001	<0.001	<0.001	<0.001	<0.001	0.006
	BSOC_B3	20/1/15	30.0	7.13	3,926	182	5.3	0.39	<0.001	<0.0001	<0.001	0.005	0.004	<0.001	0.022
	BSOC_B4	21/1/16	36.7	8.33	3,699	320	4.1	0.68	0.010	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.005
	BSOC_B5	20/1/16	30.6	7.13	6,364	1,410	6.1	0.35	0.011	<0.0001	<0.001	<0.001	<0.001	<0.001	0.006
	BSOC_B6	21/1/16	35.0	8.79	6,224	413	4.7	4.15	0.012	<0.0001	<0.001	0.038	0.004	0.001	0.005
Seepage	BSOC WRD South Sump	25/1/16	32.2	8.57	18,600	11,900	3.9	0.1	0.092	<0.0001	0.002	0.067	0.004	0.002	0.008
	BSOC WRD South Seepage	25/1/16	30.8	8.31	12,000	8,030	4.6	0.12	0.005	0.0011	0.002	0.051	0.019	0.002	0.036
	TD3 Seepage	25/1/16	28.3	7.76	11,900	8,720	1.4	0.03	0.002	0.0344	0.002	0.026	0.009	0.036	7.59
	TD5 Pit	29/1/16	-	8.38	15,700	7,920	5.3	0.07	0.02	0.0011	0.046	0.034	0.039	0.013	0.126

*Seepage Samples – EC / pH laboratory values
Metal as total

Alluvial Aquifer

Limited historical data exists for the groundwater quality within the alluvial aquifer, with this interpretation relying solely on the groundwater samples collected as part of this investigation.

Figure 5-55 shows the average major water quality parameters for alluvial aquifer groundwater. Also shown, for comparison, are the seepage water qualities, including those from the TSF5 pit water sample.

Water quality from the alluvial monitoring bores is generally more sodium and potassium rich than seepage water. Of the alluvial monitoring bores in Figure 5-55, BSOC_A2 and BSOC_A5 have higher sulphate concentrations and higher ECs than BSOC_A3 and BSOC_A1. BSOC_A2, located closest to the BSOC WRD South Seepage, reports water that has similar major parameter characteristics to the seepage samples, although all alluvial bores have lower magnesium concentrations than the BSOC WRD seepages. BSOC_A1 and BSOC_A3 appear to be only slightly similar to the seepage water from any of the sources. Values of pH remain slightly to mildly alkaline at ~7 – 8.

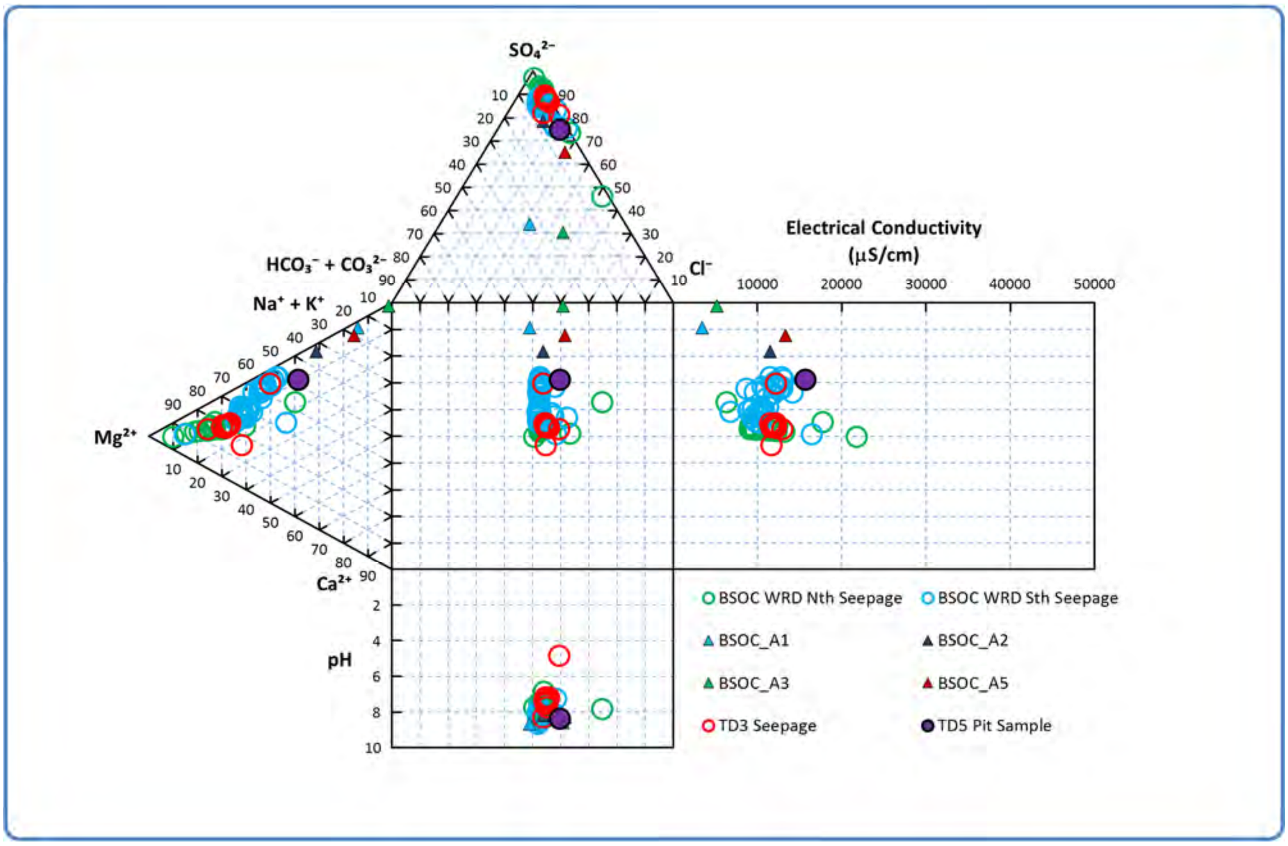

Figure 5-55: Major water quality parameters for alluvial groundwater. Also shown are seepage water qualities from BSOC WRD North, BSOC WRD South and TD3 and parameter values from the TD5 seepage pit

Bedrock Aquifer

Figure 5-56 shows the average major water quality parameters for bedrock groundwater, including the recently installed bores and the longer-term monitoring bores (Bores 23, 24, 39 and

40). Also shown, for comparison, are the seepage water qualities, including those from the TD5 pit sample.

With the exception of Bores 23 and 24, all monitoring bores in Figure 5-56 have lower sulphate concentrations, higher sodium and potassium concentrations and lower EC values. Bores 23 and 24 are close to the TD3 seepage point and may be exhibiting some influence from this water.

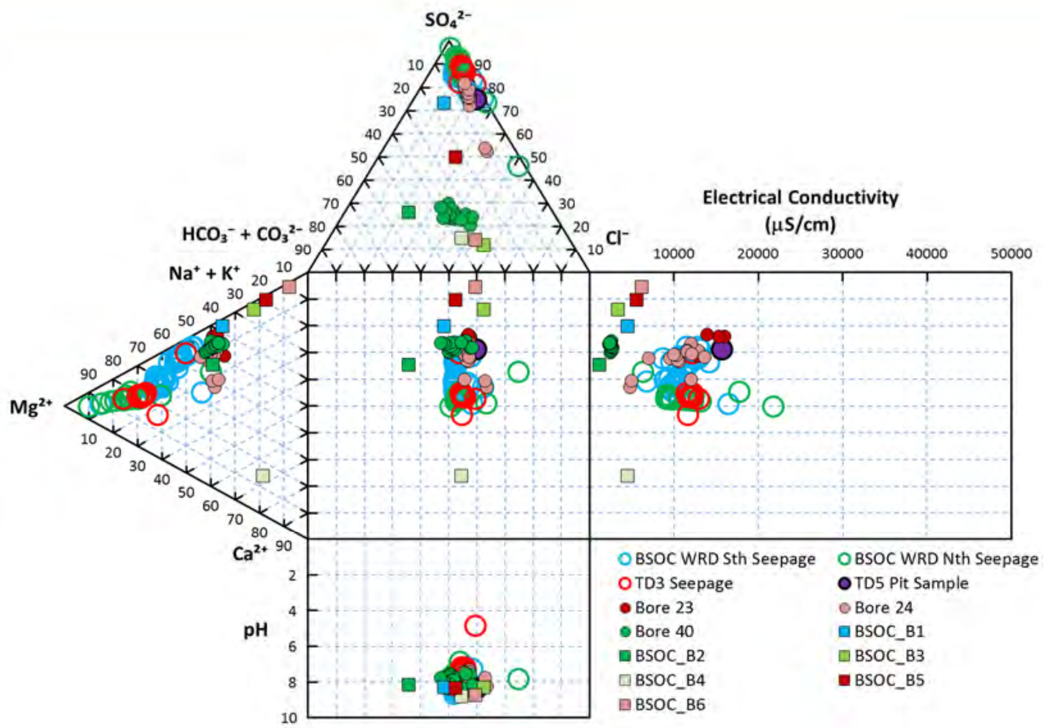

Figure 5-56: Major water quality parameters for bedrock groundwater, including the long-term groundwater monitoring bores 23, 24, 39 and 40. Also shown are seepage water qualities from BSOC WRD North, BSOC WRD South and TD3 seepage and parameter values from the TD5 seepage pit

Time-Series Diagrams

Figure 5-57 shows the variation over time of sulphate, chloride, pH, alkalinity, zinc and copper, respectively, in alluvial and bedrock aquifers[9]. Also shown in these figures are values collected for Bore 40 from the study of Forsyth (2014), to provide a comparison of the variations over a longer timescale.

Concentrations for a given sample have remained relatively consistent over the monitoring periods. For sulphate, the highest concentrations over time are found in Bore 24, which is the closest bore downgradient of TD3 Seepage. For a given area (e.g., in the vicinity of TD3 seepage), the alluvial monitoring bores report higher concentrations than the bedrock bores. In the vicinity of BSOC WRD North Seepage (green symbols), Bore 40 has reported sulphate consistently ~ 300

[9] Colours represent 'areas' of bores: red symbols are in the vicinity of TD3 Seepage, green symbols are in the vicinity of BSOC WRD North Seepage and blue symbols are in the vicinity of BSOC WRD South Seepage

mg/L, which is comparable to the nearby bores BSOC_B2, BSOC_B3 and BSOC_B4, which were drilled as part of this investigation.

Chloride concentrations show the same relatively consistent trends over time, with bores in the vicinity of TD3 Seepage reporting the highest concentrations. Values of pH have remained relatively consistent at ~ 7 to ~ 9, whereas alkalinity for all bores varies by ~ 1500 mg $CaCO_3$/L. Zinc and copper concentrations have remained below ~ 0.1 mg/L throughout the monitoring period.

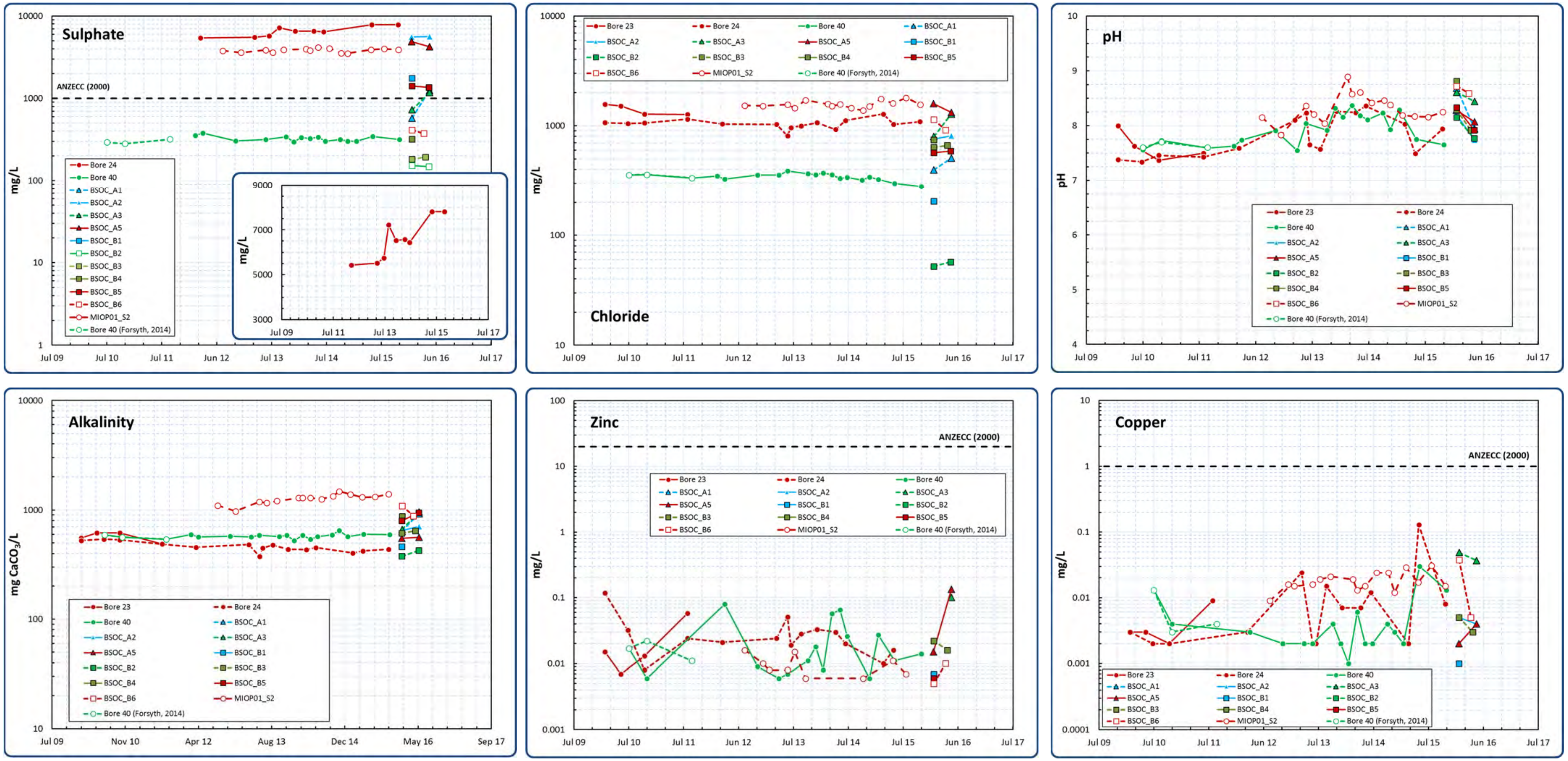

Figure 5-57: Time-series concentrations for alluvial and bedrock bores, a) Sulphate, b) Chloride, c) pH, d) Alkalinity, e) Zinc, f) Copper

5.4.4 Isotope Samples

Water samples from the seepage locations and groundwater samples were collected from a selection of existing monitoring bores and the monitoring bores installed during the Phase 2 field investigation program were analysed for hydrogen, oxygen and sulphur stable isotopes. The analysis was performed at the University of Queensland, using the methods described in Forsyth (2014).

Oxygen and hydrogen isotopes were chosen because they are the constituents of H2O (i.e., water); sulphur stable isotopes were chosen because sulphide / sulphate is ubiquitous throughout the mine site. In addition, these isotopes were investigated by Forsyth (2014) and it is useful to compare the previous results with information gleaned in this study. Subtle changes in the ratios of O18 and O16 and H1 and H2 (Deuterium, D) may reflect differences in water source(s) or the conditions the water samples may have been subjected to. Differences in S32 and S34 stable isotopes may reflect redox conditions.

Results from sulphate δS^{34}, referenced to Canyon Diablo troilite, show that TD5 pit seepage is almost 4 ‰ enriched in S^{34} compared to TD3 seepage (Figure 5-58). Enrichment of sulphate S^{34} may be caused by reduction of sulphate to sulphide (bacterial), or by oxidation of sulphide to sulphate. This may also be consistent with the fact that TSF3 tailings has been buried for a longer duration than TSF5 as less sulphide oxidation is a mechanism for lower sulphate S^{34}. The results show that BSOC_A5 and BSOC_A2 may have been influenced by components of TSF3 and TSF5, respectively.

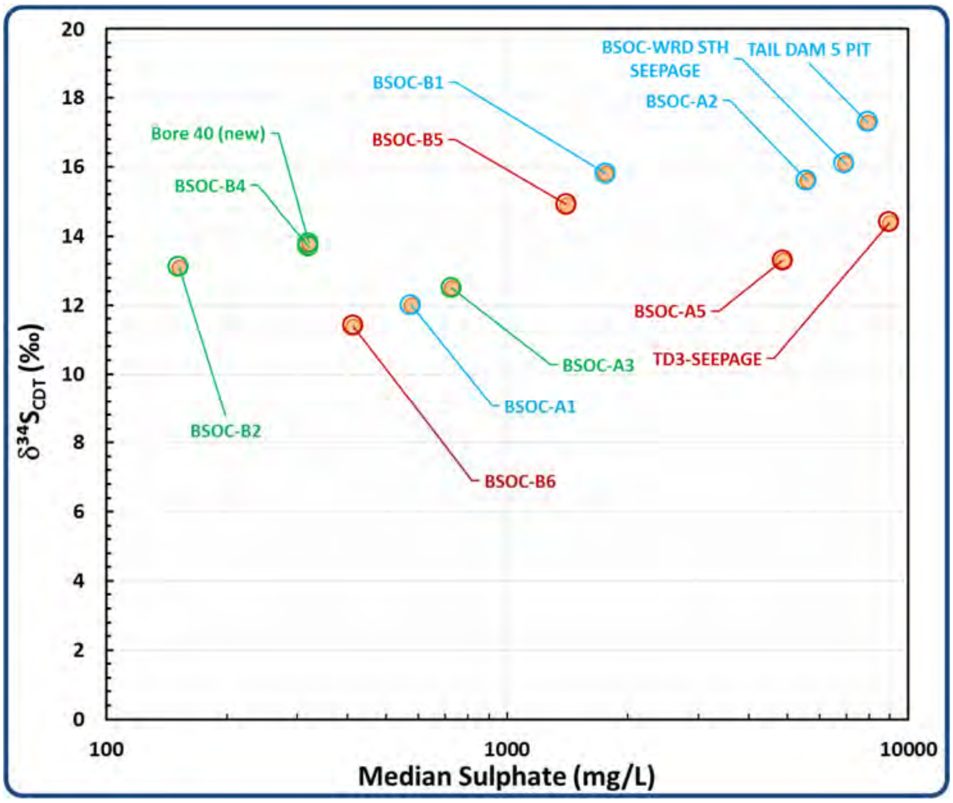

Figure 5-58: $\delta^{34}S$, referenced to Canyon Diablo troilite, against median sulphate for alluvial and bedrock groundwater bores, TD3 Seepage, TD5 pit sample and BSOC WRD South Seepage

Figure 5-59 shows the variation in stable isotopes of oxygen and hydrogen (Deuterium, D), referenced to Vienna Standard Mean Ocean Water (VSMOW). Figure 5-59 shows the global meteoric water line (GMWL) and a local meteoric water line (LMWL), calculated by regression of rainfall values δ18O and δD at Mount Isa collated by CSIRO between 2008 and 2010 (Crosbie et al., 2012). The slope of the LMWL is ~ 5 and is comparable to that calculated by Forsyth (2014). Compositions plotting to the right of the LMWL are likely, at Mount Isa, to have experienced evaporative events, which favour loss of the lighter isotopes of oxygen (O16) and hydrogen (H1) resulting in the enrichment of the residual water in O18 and H2(D).

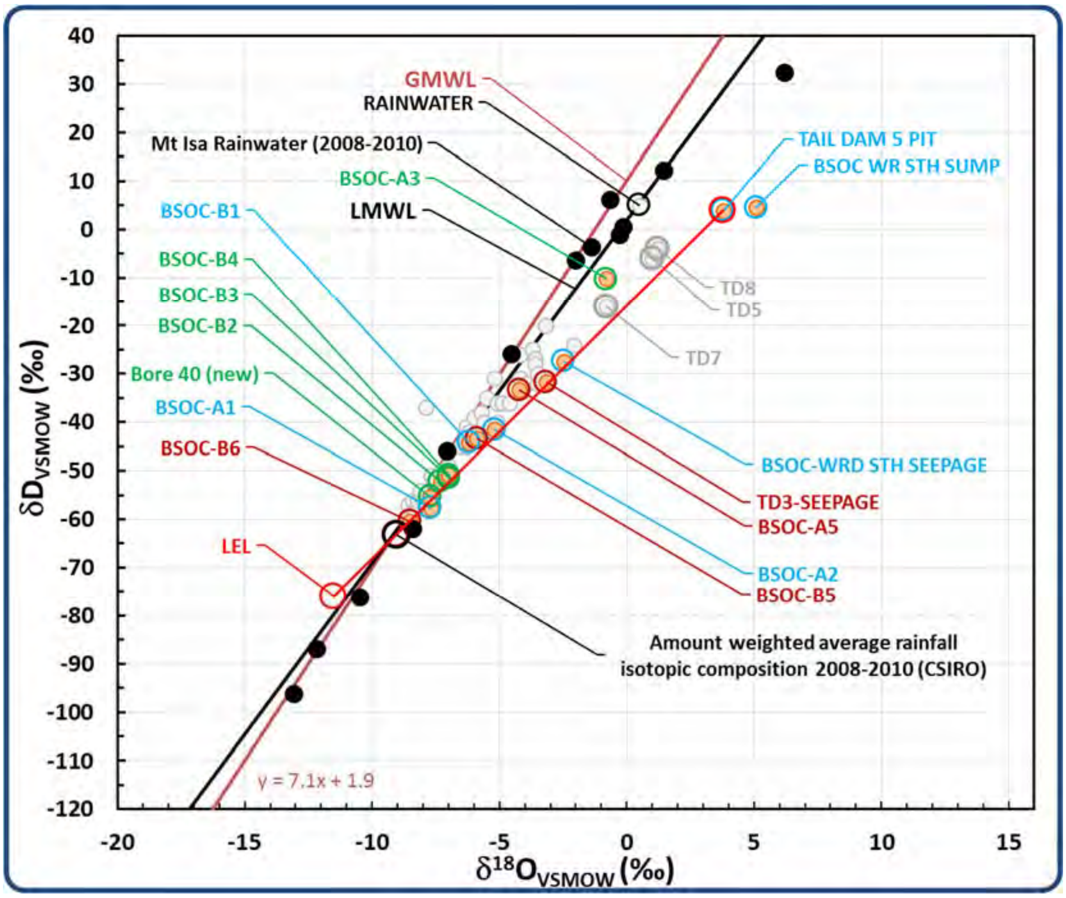

Figure 5-59: δ^{18}O and δD, referenced to Vienna Standard Mean Oceanic Water (VSMOW), for alluvial and bedrock groundwater bores and seepage water

A Local Evaporation Line (LEL) is thus calculated between the isotopically 'heavy' TD5 pit water and an average weighted rainfall value (CSIRO). The TD5 pit sample water is perhaps expected to have among the heaviest isotopic signature since it is exposed to the air and may experience extensive evaporation. Other seepage compositions generally fit on the similar trends as the LEL, which may indicate influence between the samples – i.e., similar compositions – with differences simply being due to different levels of evaporation. Of the bore samples, the alluvial bores BSOC_A2 and BSOC_A5 may exhibit some impact from the seepage(s), whereas the bedrock groundwater bores show little impact. Interestingly, the isotopic signature of BSOC_A3 is comparable to the seepage water, although this may be due to high levels of evaporation.

5.4.5 Surface Water Chemistry

Historically, surface water samples have been collected by MIM for a number of sites within the focus area, with the majority of these in the vicinity of the King Gully and the Diversion Drain. Limited data is available for water chemistry relating to the gullies associated with the BSOC WRD North and South Seepages, which is a function their ephemeral nature and limited water flow.

During the Phase 1 site investigation, water samples were collected from selected locations across the focus area. The sample locations shown on Figure 5-60 and were collected from the seepage points, collection trenches and any pooling water that was observed during the field mapping exercise. These samples were dispatched to ALS Environmental Division in Brisbane for analysis. Table 5-14 presents a summary of the water sample results for selected parameters.

Table 5-14: Summary of Phase 1 site investigation water sample results

Sample ID	Temp	pH	EC	SO_4	F	Al	As	Cd	Co	Cu	Pb	Ni	Zn
	°C	-	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
WRD_Sth_2	19.7	8.64	12,828	9,460	2.7	0.06	0.018	0.0026	0.002	0.158	0.03	0.002	0.245
WRD_Sth_3	28.1	8.24	7,099	3,130	5.7	0.18	0.003	0.0003	<0.001	0.018	0.008	<0.001	0.01
WRD_Sth_4	23.0	8.64	15,630	9,820	4.5	0.02	0.008	0.0018	0.002	0.048	<0.05	0.001	0.015
WRD_Nth_1	29.4	8.69	15,161	6,240	3.9	0.06	0.011	0.0017	<0.001	0.048	0.07	<0.001	0.032
TD3_Sth_1	29.5	8.80	5,535	1,130	1.8	0.02	0.003	0.0006	<0.001	0.032	0.009	<0.001	0.012
TD3_Sth_2	34.7	8.98	20,040	6,320	3.9	2.17	0.058	0.0048	0.007	0.825	0.272	0.005	0.476
TD3_Seepage	28.6	7.32	15,306	9,440	1.3	<0.05	<0.005	0.0426	0.007	0.019	<0.005	0.0045	9.57
TD3_Nth_4	19.0	8.42	24,339	16,700	2.4	<0.05	0.024	0.0035	<0.005	0.211	0.075	<0.005	0.092
KG_DS_1	23.8	9.24	8,924	900	6.2	0.05	0.054	0.0011	0.002	0.217	0.064	<0.001	0.031

Metals as total
Temperature, pH and EC measured in the field

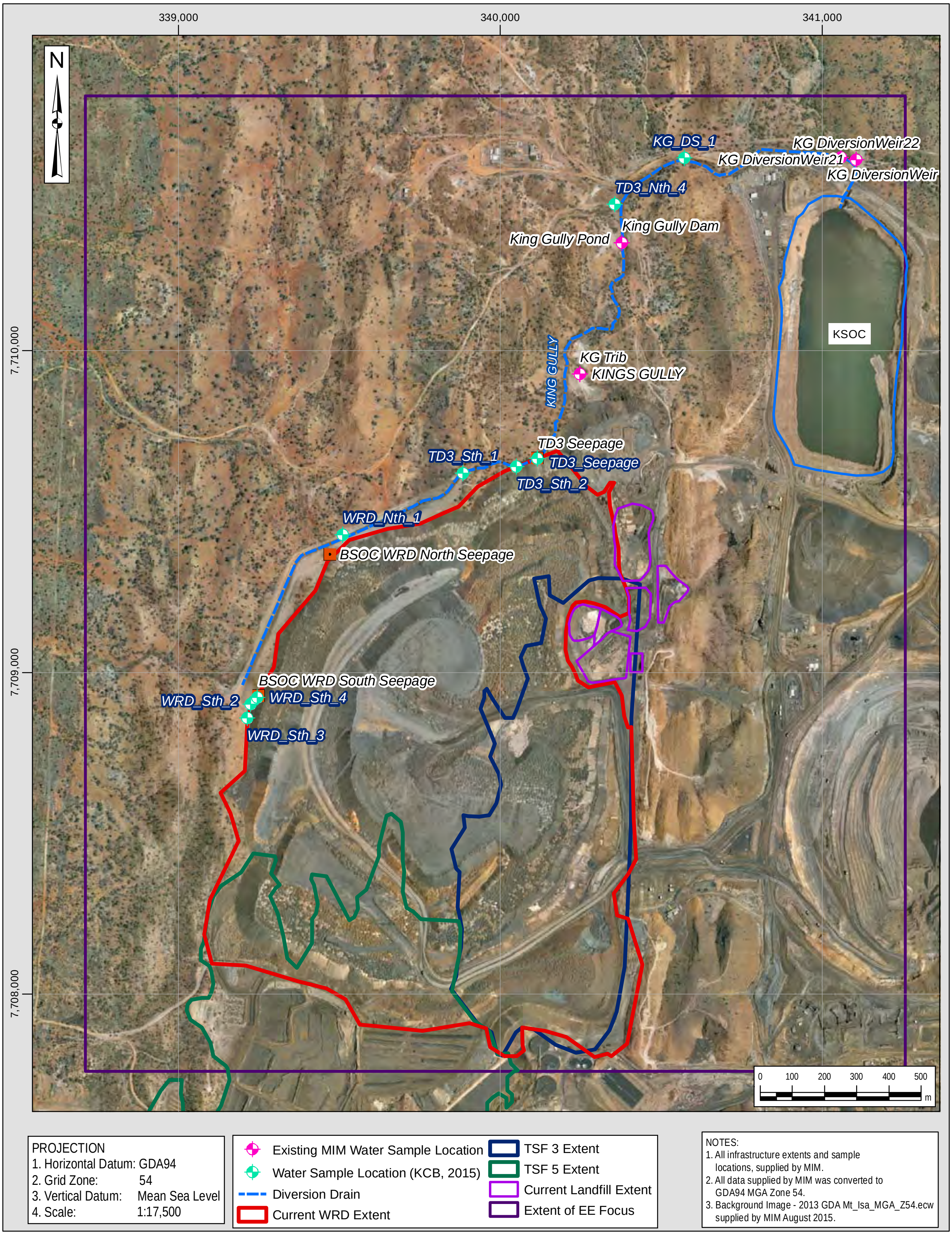

Figure 5-60: Location of water samples collected during Phase 1 site investigation and existing MIM sampling locations

Major water quality parameters are shown for selected surface water locations in Figure 5-61. For clarity, only a selected sample set is shown in Figure 5-60, although it is important to note that the entire dataset was used for this investigation. Samples chosen include: KG_Trib and KING GULLY (close to TD3 seepage), King Gully Pond and King Gully Dam (further along the Diversion Drain) and KG Diversion Weir (furthest away). Water from locations closest to the TD3 Seepage has a similar range of major parameters. In general, the furthest away, KG Diversion Weir samples, show fewer similarities: water from this location is lower in sulphate, higher in sodium and potassium and has a lower EC. A small number of Diversion Weir samples exhibit high EC, which may reflect some influence from the TD3 seepage.

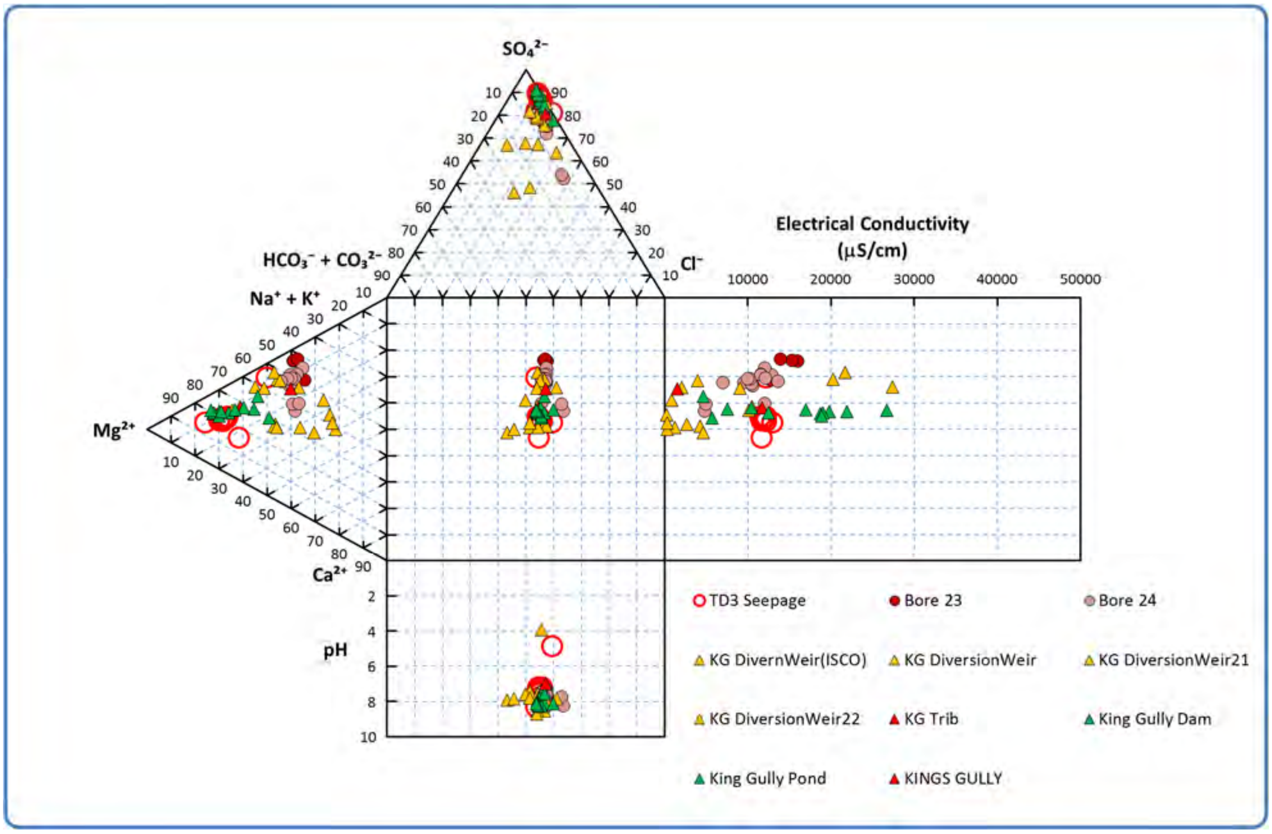

Figure 5-61: Major water quality parameters for selected surface water locations and water quality from TD3 Seepage

As expected, surface water quality is generally poorer the closer the sampling location is to the seepage source. For monitoring points along the Diversion Drain, the samples closest to the TD3 (and/or BSOC WRD North Seepage) Seepage have the highest sulphate concentrations, highest EC and lowest sodium and potassium concentrations. Some distal samples, at the King Gully Diversion Weir have high sulphate (and EC). Geochemical modelling of the seepage water suggests that the 'improvement' in water quality along the Diversion Drain is consistent with precipitation of minerals such as gypsum and zinc: this may explain why the trace element patterns show that BSOC WRD South Seepage, BSOC WRD North Seepage and TD3 Seepage water have high zinc concentrations (> ~ 10 mg/L), whereas most of the groundwater and surface water samples report zinc contents of ~ 0.1 mg/L or less. These results are consistent with the nature of the soil samples collected in the downstream zones of the seepage points.

5.4.6 Mineral Precipitation

Mineral precipitation on the alluvium and bedrock surfaces were observed across the focus area. The presence of precipitation may represent evidence of WRD seepage, however, natural precipitation on bedrock surfaces has previously been identified across the MIM site (CMLR, 2009). As a result, soil samples were collected from the identified precipitation locations and from background locations to support the assessment of the BSOC WRD seepage extent.

The location of where the soil samples were collected is shown in Figure 5-62, with a summary of the soil sample results provided in Table 5-15.

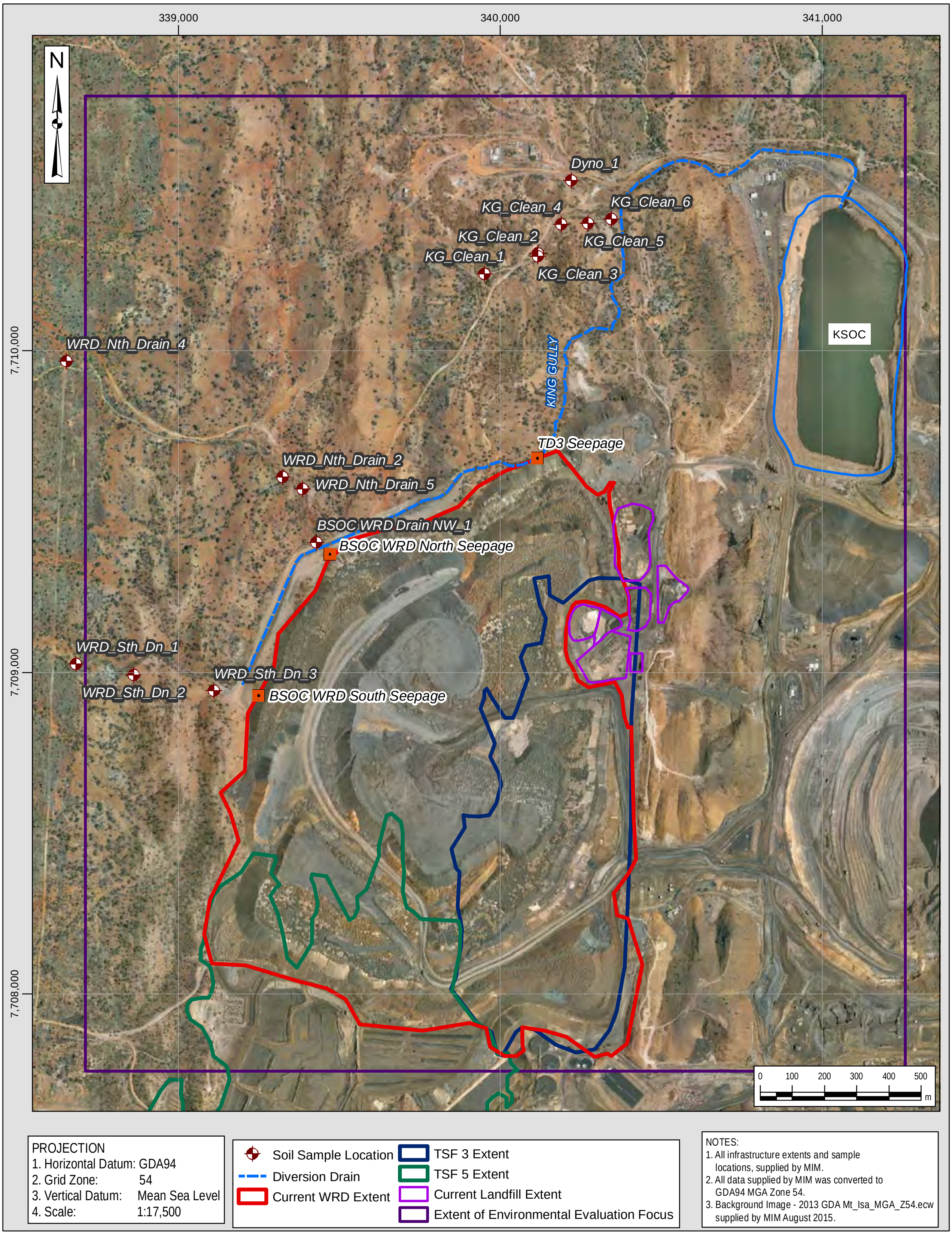

Figure 5-62: Location of soil samples in relation to site infrastructure and seepage locations

Table 5-15: Summary of Phase 1 Soil Sample Results

Sample ID	pH	EC	SO_4	Ca	Mg	Na	K	Cu	Pb	Zn
	-	*µS/cm*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
WRD_Sth_Dn_1	8.6	90	90	30	30	10	10	489	145	97.9
WRD_Sth_Dn_2	8.9	3,290	7,920	80	1,520	3,510	700	2,110	609	356
WRD_Sth_Dn_3	7.8	43,900	245,000	1660	33,600	63,800	7,160	400	635	813
WRD_Nth_Drain_2	9.4	14,300	55,000	700	6,840	15,200	430	222	104	103
WRD_Nth_Drain_4	8	79	120	40	60	90	20	241	102	80
WRD_Nth_Drain_5	8.5	168	270	90	30	40	10	373	138	119
BSOC WRD Drain NW_1	6.8	31,000	61,500	4,040	18,500	21,800	300	1,210	634	410
KG_Clean_1	9.3	97	190	60	30	50	10	261	82	69
KG_Clean_2	10.5	38,800	91,500	30	10	73,400	920	534	132	162
KG_Clean_3	10.2	7,430	17,600	160	190	10,300	320	443	149	144
KG_Clean_4	9.8	17,900	45,300	40	60	25,700	1,540	1,660	505	530
KG_Clean_5	9.8	6,730	17,200	580	490	7,740	130	364	142	146
KG_Clean_6	9.2	24,100	91,700	2,420	8,300	27,300	1,170	495	173	145
Dyno_1	9.9	28,800	44,000	30	10	53,600	1,530	438	137	113

A full description of the sample locations is provided in Appendix II. A summary of the soil sampling results is provided in the following:

- The WRD Nth and Sth samples were collected from the alluvial tributaries downstream of the respective seepage locations (BSOC WRD North and South Seepages).
- WRD_Nth_Drain_4 was collected from the focus area boundary and has since been considered as a 'background' soil sample.
- Samples were collected from the King Gully clean catchment (KG_Clean) where notable precipitation was observed.
- Dyno_1 was taken from a bedrock / alluvial interface with observable precipitation, adjacent to the Dyno Nobel facility.

As noted during the Phase 1 site investigation (Appendix II), precipitates were observed along the Diversion Drain that are postulated to derive from the BSOC WRD seepage water. Accordingly, the hydrogeochemical software, Geochemist's Workbench, was used to 'reverse model' the water chemistry that would be expected to be in equilibrium with soil samples with the composition in Table 5-15. In addition, PHREEQC was used to 'forward model' the minerals most likely to precipitate from seepage with a water quality equivalent to that of TD3 Seepage, BSOC WRD North Seepage and BSOC WRD South Seepage. Both methods suggest that gypsum is likely to be saturated in such water, with smithsonite ($ZnCO_3$) also likely to be near saturation. This is in agreement with Forsyth (2014). Figure 5-63 shows the modelled sulphate and zinc concentrations that may be expected if gypsum and smithsonite precipitate from a water with the composition of TD3 Seepage. This suggests that some of the soil samples may be impacted by the influx of seepage water, although this influence is unlikely in the distal samples, such as WRD_Sth_Dn_1, WRD_Nth_Drain_4 and KG_Clean_1.

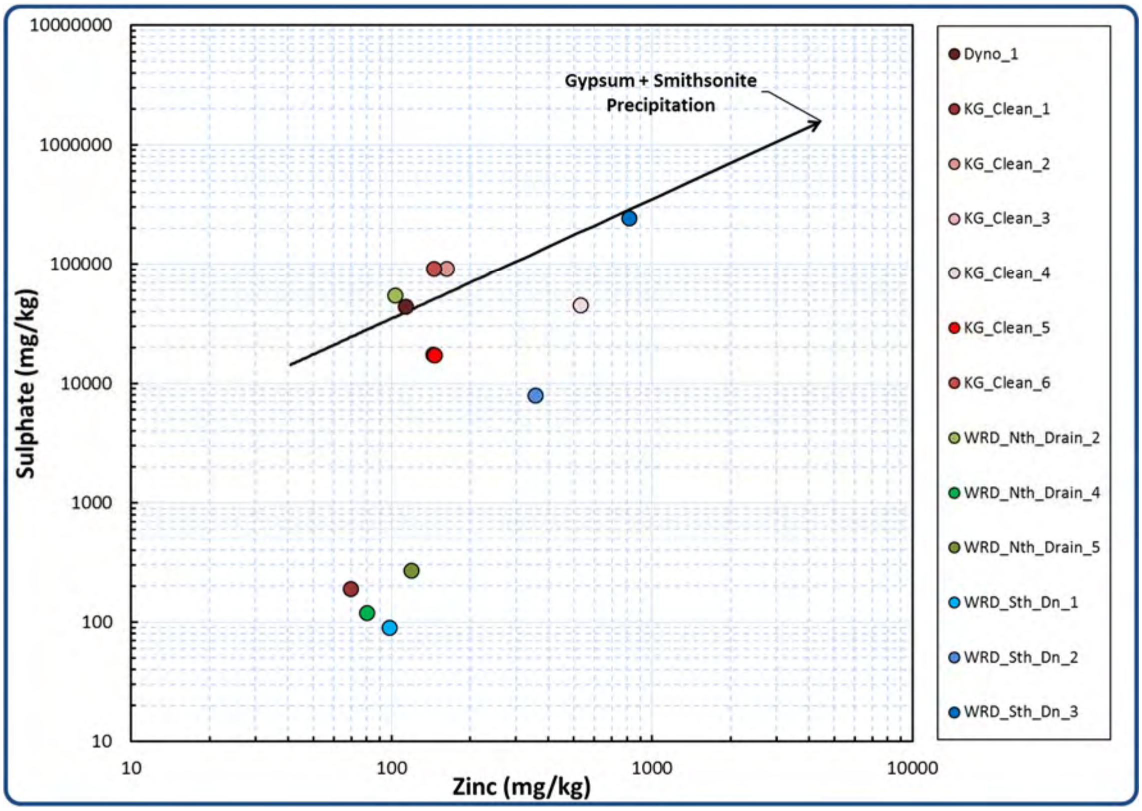

Figure 5-63: Soil zinc and sulphate concentrations. Also shown is the locus of concentrations that may be expected when gypsum and smithsonite precipitate from water with the same composition as TD3 Seepage water

5.4.7 Summary of Water Chemistry

WRD Seepage Water Chemistry

Major and trace element parameters suggest that TD3 Seepage has some similarities to BSOC WRD North Seepage and, while there are slight differences in the levels of certain parameters, both seepage waters are similar to BSOC WRD South Seepage. This suggests that the overlying waste rock has an influence on the TSF3 chemistry and the seepage observed at TD3 and/or BSOC WRD North Seepage is a result of this influence. Stable isotopes provide a hint that TSF5 water chemistry may have an influence on the seepages to the north, but further sampling and testing would be required to confirm this.

Based on the water qualities obtained from kinetic testing of both waste rock and tailings, as well as the measured seepage, there is no basis for clear differentiation between geochemical signatures in the tailings and waste rock seepage.

TSF Seepage Water Chemistry

The trace element 'fingerprint' of TSF5 appears to be similar to that for BSOC WRD South Seepage (cf. Figure 5-37 and Figure 5-44).

TSF3 trace element concentrations, represented here by TD3 seepage, are similar to those from BSOC WRD North Seepage and broadly similar to those from BSOC WRD South Seepage and TSF5 (cf. Figure 5-38, Figure 5-39, Figure 5-44).

Landfill Chemistry

Certain parameters, such as cadmium and manganese, have similar relative proportions in the sludge pit seepage and TD3 seepage. It is possible that there may be some influence from the sludge pit on TD3 seepage, but the extent of any influence is difficult to determine quantitatively without further constraints on the internal geochemistry of TSF3 and the WRD. Further assessment of the groundwater flow system underlying the sludge pits would also be required to confirm the potential seepage contribution to the BSOC WRD landform from sludge pit infiltration.

Groundwater Chemistry

The bedrock bores show little major parameter and isotopic evidence of being impacted by the seepage at any of the three seepage points. Alluvial bores BSOC_A2, BSOC_A3 and BSOC_A5, however, are likely to be impacted. For BSOC_A2, the likely source is BSOC WRD South Seepage; For BSOC_A3, the likely source is BSOC WRD North Seepage; for BSOC_A5, the source of the impact is likely to be TD3 Seepage.

Time-series data show that the long-term monitored bores (e.g. Bore 40) have relatively consistent water chemistry throughout the monitoring period. Of the bores assessed in this report, Bores 23 and 24 are likely to have been impacted by seepage. Distal bores, such as Bore 40, are not impacted. No bedrock monitoring bores in the vicinity of BSOC WRD North Seepage (e.g. BSOC_B3) show geochemical evidence of being impacted, which may suggest that BSOC WRD North Seepage does not migrate to the north-northwest in the bedrock aquifer.

Surface Water Chemistry

Surface water quality appears to deteriorate the closer to TD3 the water is sampled, which may be expected. Some distal surface water samples (e.g., at the King Gully Weir) report high sulphate and EC.

5.4.8 One-Dimensional Analytical Assessment

A one-dimensional analytical assessment was completed using the Ogata-Banks Analytical Solution for 1D advection-dispersion, including retardation. The basis for the analytical assessment is provided in Equation 1 (Ogata and Banks, 1961).

Equation 1:

$$C(x,t) = \frac{1}{2} C_o \left[\operatorname{erfc}\left(\frac{x - \frac{v}{R}t}{\sqrt{4\frac{D}{R}t}} \right) + e^{\frac{vx}{D}} \operatorname{erfc}\left(\frac{x + \frac{v}{R}t}{\sqrt{4\frac{D}{R}t}} \right) \right]$$

Where:

- x = down-gradient location of interest
- t = time of interest
- C_o = source concentration
- v = groundwater velocity

D = dispersion
R = retardation
erfc = complementary error function
C = concentration at a specific location and time

The Ogata-Banks equation was used to determine concentration breakthrough curves at the focus area boundary with consideration of advection and dispersion. This equation was adopted due to the associated conservatism of its application, which have been identified in the assumptions provided below. Sulphate was used as the tracer / migration parameter for this analysis due to the conservative nature of the parameter (i.e. not prone to secondary reactions and attenuation / adsorption mechanisms along the flow path). Analyses were undertaken for each of the aquifers and seepage sources, with selected results discussed below. The following assumptions are made to support the analyses:

- the alluvium and bedrock aquifers act as separate hydraulic units;
- the aquifer systems are represented as intergranular, homogeneous and isotropic (i.e. no lateral or vertical variation in parameter values) – conservative assumption;
- groundwater flow is steady-state;
- groundwater flows towards the north (bedrock aquifer) and west (alluvial aquifer) of the WRD as indicated by the groundwater contours and groundwater level measurements;
- source concentrations of sulphate is assumed to be constant and to be representative of the seepage concentrations from the corresponding seepage locations;
- the timing for each model starts from the corresponding TSF (i.e. TSF3, TSF5) mid-date of operations; and,
- parameters reported in the previous sections were used where available and where not available suitable parameters from other locations were adopted. It is acknowledged that these parameters are representative of current conditions.

A summary of the parameters used in the one-dimensional analytical assessment are shown in Table 5-16, with their rationale / source included.

Table 5-16: Summary of Parameters used in One-Dimensional Analytical Assessment

Area	Parameter	unit	South Alluvium	North Alluvium	TD3 weathered bedrock	TD3 Bedrock	Rationale
Source	Width	m	60	70	580	580	Source width, i.e. BSOC WRD Landform or alluvium width
	Length	m	500	600	1,075	1,075	Source length, e.g. BSOC WRD Landform
	Concentration	mg/L	6,000	8,000	14,500	14,500	Concentration at seepage point / bore
Pathway	Transmissivity (T)	m^2/d	3.5	1	2	1.8	Site investigation sourced permeability data and aquifer thickness
	Groundwater Gradient (i)	-	0.009	0.013	0.013	0.013	Inferred gradient from groundwater contours (Jan, 2016)

Area	Parameter	unit	South Alluvium	North Alluvium	TD3 weathered bedrock	TD3 Bedrock	Rationale
	Effective Porosity (ne)	-	0.3	0.3	0.1	0.05	Estimated porosity for material
	Groundwater Velocity (v)	m/d	0.015	0.022	0.026	0.008	Calculated
	Dispersivity (D)	m	15	35	20	500	Dispersivity, used as a verification parameter based on comparison with bore concentrations
Receptor	Distance	m	1,130	2,000	5,300	5,300	Distance to downstream 'receptor' e.g. Hazledene Creek

The results for the 1D analysis of the alluvium aquifer associated with the BSOC WRD North and South Seepages are presented in Figure 5-64 and Figure 5-65, respectively. TD3 Seepage was not included for analysis as the alluvium in this area is subject to additional seepage contribution from seepage transferred along the Diversion Drain. Additionally, seepage in the alluvium downstream of TD3 Seepage is managed by the Diversion Drain / King Gully, which directs the seepage to discharge into KSOC.

Figure 5-64 and Figure 5-65 also presents the distance to the focus area boundary as well as the ANZECC (2000) livestock guideline concentration for sulphate of (1,000 mg/L). The sulphate livestock guideline concentration was selected for this analysis to represent the extent of potential impact to the groundwater system. TSF5 was used as the source for both assessments based on the historical evidence of seepage / precipitation prior to the placement of the WRD. The source term was applied as a constant in the assessment (i.e. constant sulphate concentration since the establishment of TSF5), which is considered conservative as the source term would have likely increased over time to the concentration that is currently being applied. For the purposes of this assessment it is assumed that seepage commenced at the mid-point of TSF5 operation (1961), however it is unknown when seepage may have commenced. Sulphate concentrations from the respective downstream monitoring bores (BSOC_A3 – BSOC WRD North Seepage; BSOC_A2 and BSOC_A1 – BSOC WRD South Seepage) are also shown with the breakthrough curves to allow verification of the simulation. The following observations are made from the alluvial assessment:

- Migration of seepage beyond the diversion drain (sulphate plume) in the alluvium aquifer downstream of the BSOC WRD North Seepage to reach Hazeldene Creek (2,000 m downgradient of seepage location) is predicted to occur in 2170 (204 years since the mid-point of TSF5 operation).
- The breakthrough curve for the BSOC WRD South Seepage downstream alluvium aquifer indicates that the unmitigated sulphate plume could potentially reach Hazeldene Creek, (1,100 m downstream of BSOC WRD South Seepage), by 2122 (156 years since the mid-point of TSF5 operation).

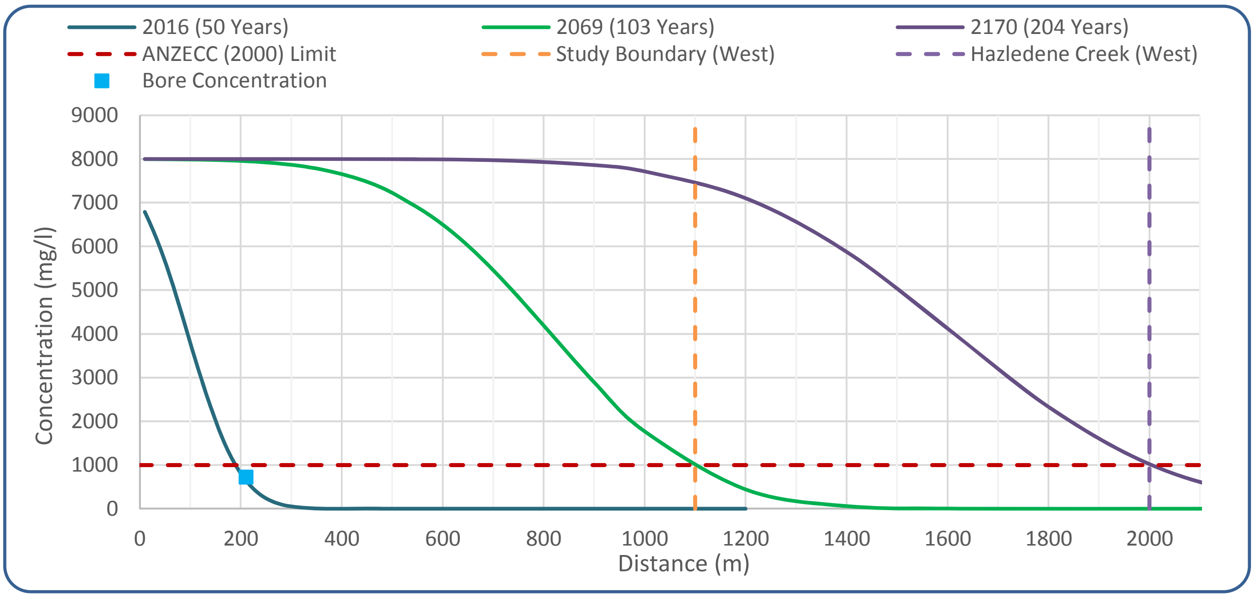

Figure 5-64: Ogata-Banks breakthrough curve for the BSOC WRD North Seepage (alluvium), with sulphate bore concentration from BSOC_A3

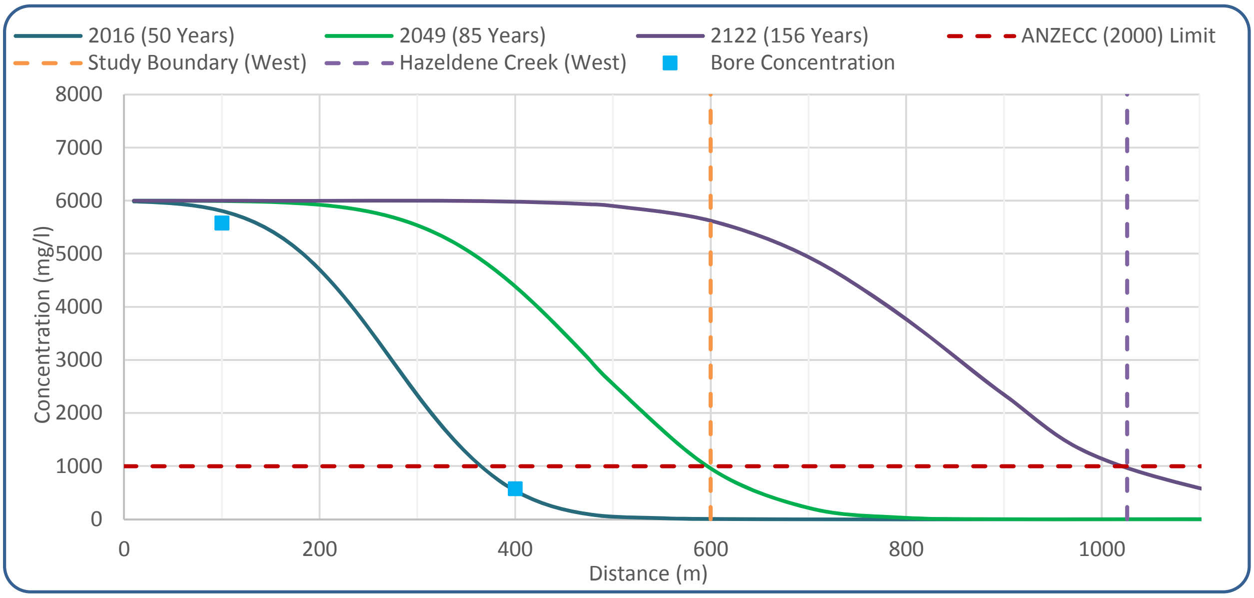

Figure 5-65: Ogata-Banks breakthrough curve for the BSOC WRD South Seepage (alluvium), with sulphate bore concentration from BSOC_A2 and BSOC_A1

The breakthrough curve for the weathered bedrock associated with the TD3 Seepage is presented in Figure 5-66, along with the downstream northern extent of the focus area boundary (1,125 m north of TD3 Seepage). Sulphate concentrations from downstream weathered bedrock monitoring bores (Bore 23, MIOP_02) have been used to verify the TD3 weathered bedrock breakthrough curve, and are included in Figure 5-66. The results from the Ogata-Banks analysis indicate that the 1,000 mg/L Sulphate plume in the weathered bedrock may reach the northern focus area boundary by 2029 (in 13 years, and 76 years from the mid-point of TSF3 operation).

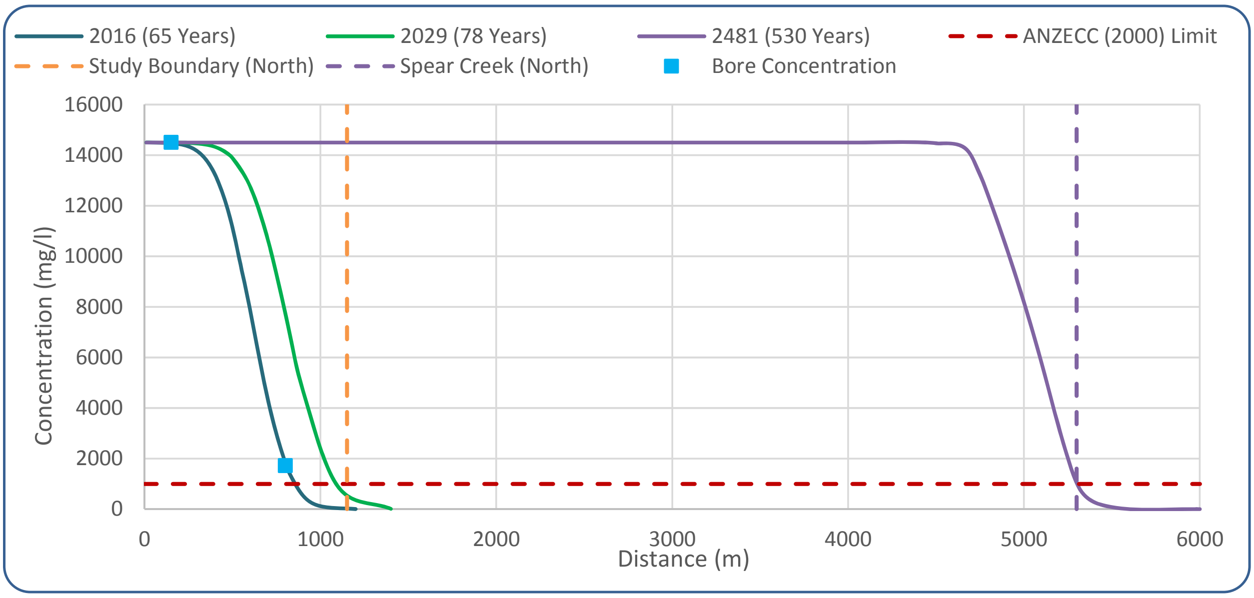

Figure 5-66: Ogata-Banks breakthrough curve for the TD3 Seepage (weathered bedrock), with sulphate bore concentrations from Bore 23 and MIOP_02

The breakthrough curve for the bedrock aquifer associated with the TD3 Seepage is presented in Figure 5-67, along with the downstream northern extent of the focus area boundary (1,125 m north of TD3 Seepage). Sulphate concentrations from downstream bedrock monitoring bores (Bore 24, BSOC_B5, BSOC_B6) have been used to verify the TD3 bedrock aquifer breakthrough curve, and are included in Figure 5-67. The results from the Ogata-Banks analysis indicate that the 1,000 mg/L sulphate plume in the bedrock aquifer could potentially reach the northern focus area boundary by 2061 (in 45 years, and 111 years from the mid-point of TSF3 operation).

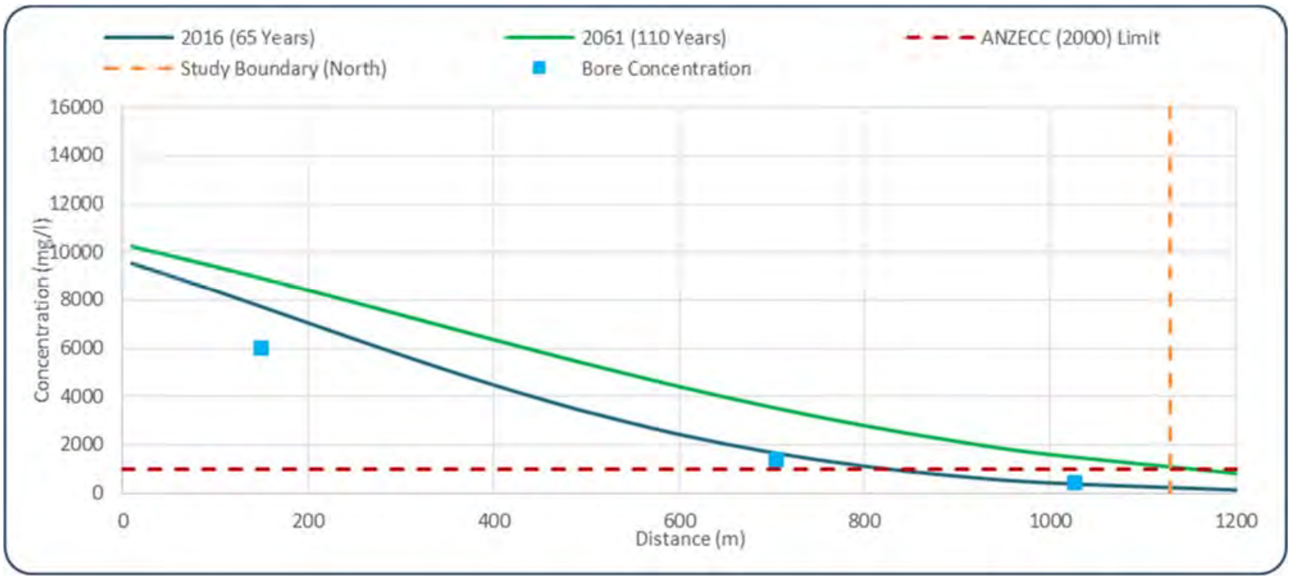

Figure 5-67: Ogata-Banks breakthrough curve for the TD3 Seepage (bedrock), with sulphate bore concentrations from Bore 24, BSOC_B5 and BSOC_B6

BSOC WRD landform seepage into the weathered bedrock and bedrock aquifer, and further downstream migration towards the north of the focus area has been predicted using 1D advection-dispersion modelling and support with water quality monitoring records. For the purposes of this investigation, the prediction of future downstream migration to the northern focus area extent (~1,125 m north of TD3 Seepage) has been undertaken. However, the northern extent of the focus area does not represent a downstream receiving environment receptor for the weather bedrock / bedrock aquifer seepage. Based on the regional groundwater flow direction of the weathered bedrock / bedrock aquifer (towards the north), the downstream receiving environment receptor is interpreted to be Spear Creek. Spear Creek flows in a west to east direction and flows into the Leichhardt River prior to discharging into Lake Moondarra. Spear Creek is approximately 5.5 km north of the TD3 Seepage (4.3 km north of the northern extent of the focus area). One dimensional advection-dispersion modelling indicates that the 1,000 mg/L sulphate plume will reach Spear Creek in 2481 (in 465 years, and 530 years from the mid-point of TSF3 operation).

5.5 Summary of BSOC WRD Seepage Source, Cause and Extent

Item 1 (a), (b) and (c) of the EE notice stated that this investigation should:

> *Identify the source, cause and extent of all seepage that are being, or likely to be released from the Black Star Open Cut Waste Rock Dump (BSOC WRD) to the receiving environment.*

Based on the information presented in this report thus far, a summary of the interpreted (and inferred) source, cause and extent is provided.

5.5.1 Seepage Source

Seepage from the BSOC WRD Landform occurs at three locations around the WRD footprint. These align with natural drainage locations, which are now covered by the WRD. At each of the 'headwaters' of these drainages, spillways from the historical tailings dams (TSF3 and TSF5) were present and are now buried by the WRD.

A review of waste rock and tailings geochemistry and kinetic testing was undertaken in conjunction with a review of BSOC WRD seepage chemistry, as well as historical tailings chemistry data to assess whether a definitive source (either tailings or waste rock) is providing the seepage now observed from BSOC WRD. The MIM landfill sludge pits were also considered as a potential source.

Based on the available chemistry data, the following is concluded:

- TD3 and BSOC WRD North Seepages have similar water qualities and both have similarities to waste rock seepage and tailings seepage characteristics.
- The MIM landfill sludge pits may also contribute, although it is difficult to determine the extent of this contribution quantitatively without further constraints on the internal geochemistry of TSF3 and the WRD. Further assessment of the groundwater flow system underlying the sludge pits would also be warranted to confirm the potential seepage contribution to the BSOC WRD landform from sludge pit infiltration.
- BSOC WRD South Seepage is broadly similar to TD3 Seepage and BSOC WRD North Seepage, but reports water quality that may have some of the characteristics similar to the TD5 pit sample.
- Based on the water qualities obtained from kinetic testing of both waste rock and tailings, as well as the measured seepage, it is interpreted that there is limited basis for clear differentiation between geochemical signatures of the waste rock and tailings in the seepage.

5.5.2 Seepage Cause

To determine the cause of seepage migration from the BSOC WRD Landform, preferential pathways were identified using the available hydrogeological information, historical geophysical surveys and field data collected as part of this investigation.

A two dimensional modelling assessment was also undertaken to assist in determining the cause of seepage migration. This was completed using representative thicknesses of the site infrastructure as well as the underlying geology. Sensitivity analysis for the most uncertain parameters was also undertaken to assess the potential variability in the flux estimates and movement of water.

The cause of seepage has been interpreted as the following:

- Direct seepage movement within alluvial aquifers, which originate under the BSOC WRD landform and are in connection with the alluvium beyond the extents of the landform.
- Seepage into the alluvium, where the diversion drain is constructed across the alluvial aquifers.
- Bedrock seepage from the base of the TSFs as diffuse seepage within the bedrock aquifer, likely to be along the bedrock bedding plane (south-north orientation).

The volume of seepage that is generated, and will continue to be generated, is a function of the net percolation into the WRD and the anticipated piezometric surface within the WRD.

5.5.3 Seepage Extent

The extent of seepage within the alluvium and bedrock aquifers beyond the extent of the BSOC WRD landform has been interpreted (and inferred) based on the understanding of the source and cause of seepage, as well as the site observations and the available water quality data.

Figure 5-68, which presents the seepage within the alluvial aquifers, indicates that the seepage has migrated within the alluvium downstream of both the BSOC WRD North and South Seepages, however, the seepage plumes have not migrated to the focus area boundary. The alluvium associated with King Gully, downstream of TD3, is considered to be saturated with BSOC WRD landform seepage due to the use of King Gully as a seepage management facility, which ultimately diverts seepage into KSOC open pit. As a result of the alluvium associated with King Gully being saturated, certain tributary watercourses, which join from the west, are also partially saturated with BSOC WRD landform seepage.

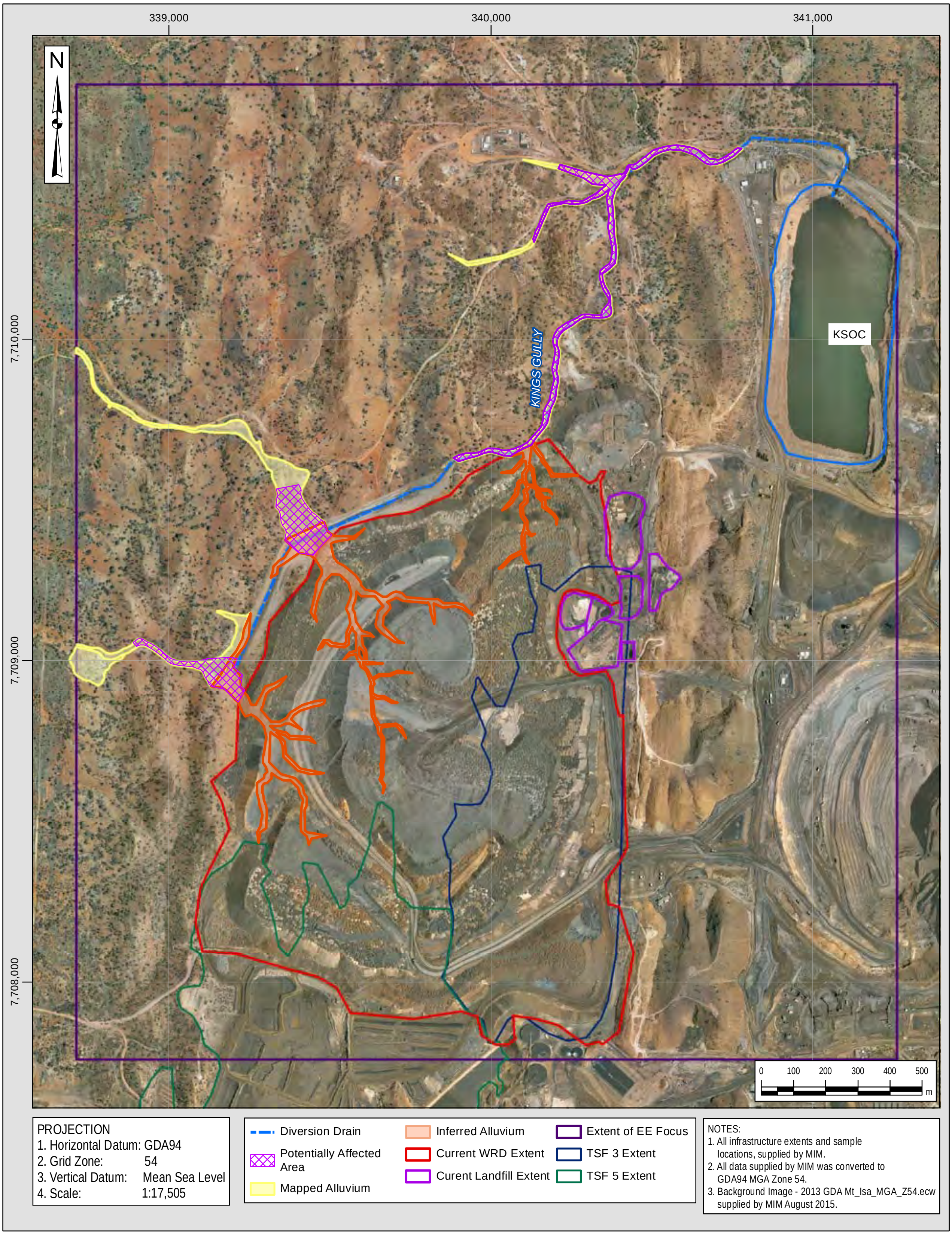

Figure 5-68: Interpreted and Inferred Extent of Seepage within the Alluvium

Figure 5-69 presents the seepage extent within the bedrock groundwater system, with both interpreted and inferred extents shown (dashed line for inferred). Inferred extents have been included due to limited groundwater level and groundwater quality data available for interpretation in these areas where monitoring bores are not present. The seepage plume within the bedrock aquifer extends to the north of TD3 Seepage and the underlying TSF3, however the plume has not yet reached the focus area boundary in the north.

The inferred extent of the bedrock seepage to the east of the BSOC WRD is based on the mid-point between the eastern-most bedrock monitoring bores with sulphate concentrations above 1,000 mg/L (Bore 24, BSOC_B5) and the Mount Isa Fault (interpreted groundwater flow barrier). The inferred western extent of the bedrock seepage has been interpreted based on the mid-point between the western-most bedrock monitoring bores with sulphate concentrations above 1,000 mg/L (BSOC_B1) and the western extent of the EE focus area.

The seepage within the bedrock aquifer in the area northwest of the WRD, downgradient of TSF5, is of a much smaller extent, with seepage contributions to groundwater observed at BSOC_B1 (adjacent to BSOC WRD South Seepage). However, the interpreted seepage plume (based on a sulphate concentration of 1,000 mg/L) has not been identified in the three new monitoring bores (BSOC_B2, BSOC_B3, BSOC_B4) and Bore 40; located to the north of the BSOC WRD landform.

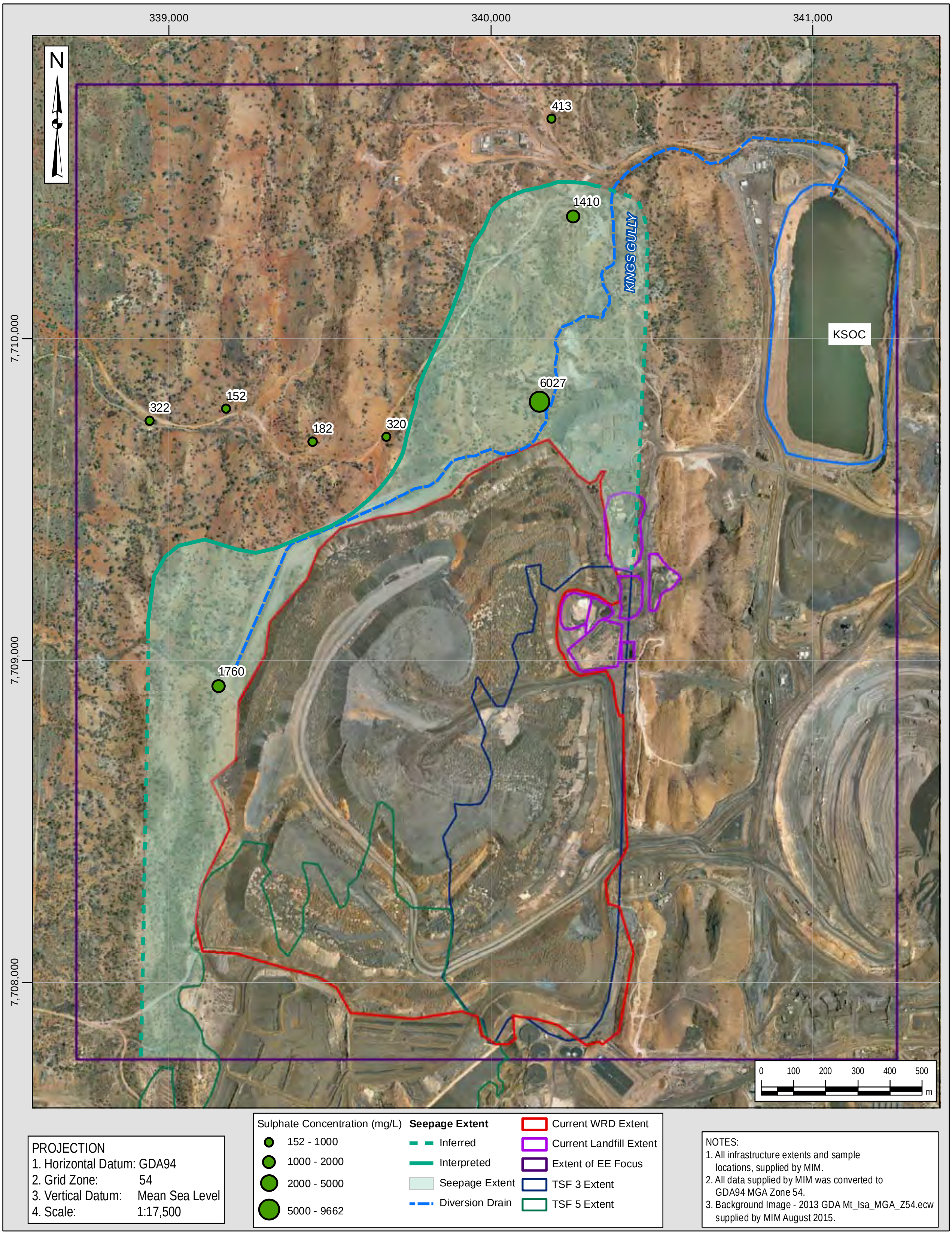

Figure 5-69: Interpreted and Inferred Extent of Seepage within the Bedrock

6 IMPACT ASSESSMENT

This section of the report addresses item 2b, of the EE Notice, which states that the investigation must:

Assess impacts on the receiving environment[10] *and all identified environmental values, the assessment must include consideration of:*

- *Water quality for surface water and groundwater's (including any shallow ephemeral aquifers);* (Sections 6.1.1 and 6.1.2)
- *Sediment quality* (Section 6.1.3)
- *Soils; and,* (Section 6.1.3)
- *Flora and fauna.* (Section 6.1.4)

The impact assessment was undertaken by Amec FW (2016) (flora and fauna, sediment quality / soils) and KCB (groundwater and surface water), based on the previously established environmental values. A summary of the identified environmental values, the identified area of impact and potential impacts are provided in the following sections.

Amec FW's Receiving Environment Assessment report is provided in Appendix IV.

6.1 Identified Environmental Values

Environmental values (EVs) have been previously established for key environmental components across ML8058. These EVs have been used to assess potential impact from the BSOC WRD landform seepage.

6.1.1 Surface Water

This section provides a discussion on the water quality criteria that have been proposed based on the understanding of the environmental values for the surface drainages from the site and the receiving environment.

Background to Environmental Values

The Leichhardt River is the main ephemeral watercourse draining the MIM lease area. During the winter months, the majority of water upstream of Lake Moondarra exists as discontinuous pools. Its channel is over 50 m wide and has developed an alluvium thickness typically of 7 m.
The Leichhardt River and tributaries are an important water source for stock, fauna and recreational use.

The portion of the Leichhardt River between the Mount Isa Mines and Lake Moondarra is a water source for stock and aquatic fauna and is also used recreationally for fishing and swimming. Lake Moondarra provides the drinking water supply for Mount Isa, as well as industrial and potable water for Mount Isa Mines. Water extracted from Lake Moondarra is treated to render it potable.

[10] The EE notice defines "receiving environment" as *all groundwater and surface water that are not in disturbed areas authorised by this environmental authority and excludes land within the surface water containment areas.*

Areas surrounding the Leichhardt River support a range of land uses, which may impact on the water quality in the Leichhardt River. These include stormwater and sewage discharges from Mount Isa municipal areas and discharges from Mount Isa Mines. Cattle grazing adjacent to Leichhardt River and recreational activities such as boating, fishing and water skiing may also impact on water quality.

An assessment of the surface water environmental values downstream of the mine sites, the reach of the Leichhardt River catchment between the Mount Isa Mines and Lake Moondarra, as well as Spring Creek downstream of the George Fisher and HHOC Mines, has been divided into three zones (Pink, Green and Blue Zones), which recognise past and present land use activities and the environmental values supported within each zone. The zones are shown on Figure 6-1.

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The water quality criteria for the operational conditions have been developed based on the environmental values for the surface water flows agreed with EHP, shown in Table 6-1 and discussed below.

Table 6-1: Summary of Environmental Values adopted for the EA

Location	Reference Zones (Figure 6-1)		
	Pink Zone	Green Zone	Blue Zone
Slightly to moderately disturbed ecosystem	✓	✓	✓
Suitability of drinking water supply at Lake Moondarra	✓	✓	-
Suitability of drinking water supply	-	-	✓
Suitability of primary contact at Green Zone and Lake Moondarra	✓	-	-
Suitability of primary contact	-	✓	✓
Suitability of secondary recreation	✓	✓	✓
Suitability of agricultural use at Green Zone and Lake Moondarra	✓	-	-
Suitability of agricultural use	-	✓	✓
Suitability of human consumption of aquatic food	✓	✓	✓
Suitability for industrial use at Lake Moondarra	✓	✓	-
Suitability for industrial use	-	-	✓
Protection of cultural and spiritual values	✓	✓	✓

For sections of the Leichhardt River in town and close to the mine discharges, as well as Hazeldene Creek and parts of Spring Creek (see Table 6-1, pink zone in Figure 6-1), the adopted environmental values were as follows:

- Slightly to moderately disturbed ecosystem
- Suitable for drinking water supply at Lake Moondarra
- Suitable for primary contact at Green Zone and Lake Moondarra
- Suitable for secondary recreation
- Suitable for agricultural use at Green Zone and Lake Moondarra
- Suitable for human consumption of aquatic food
- Suitability for industrial use at Lake Moondarra
- Protection of cultural and spiritual values.

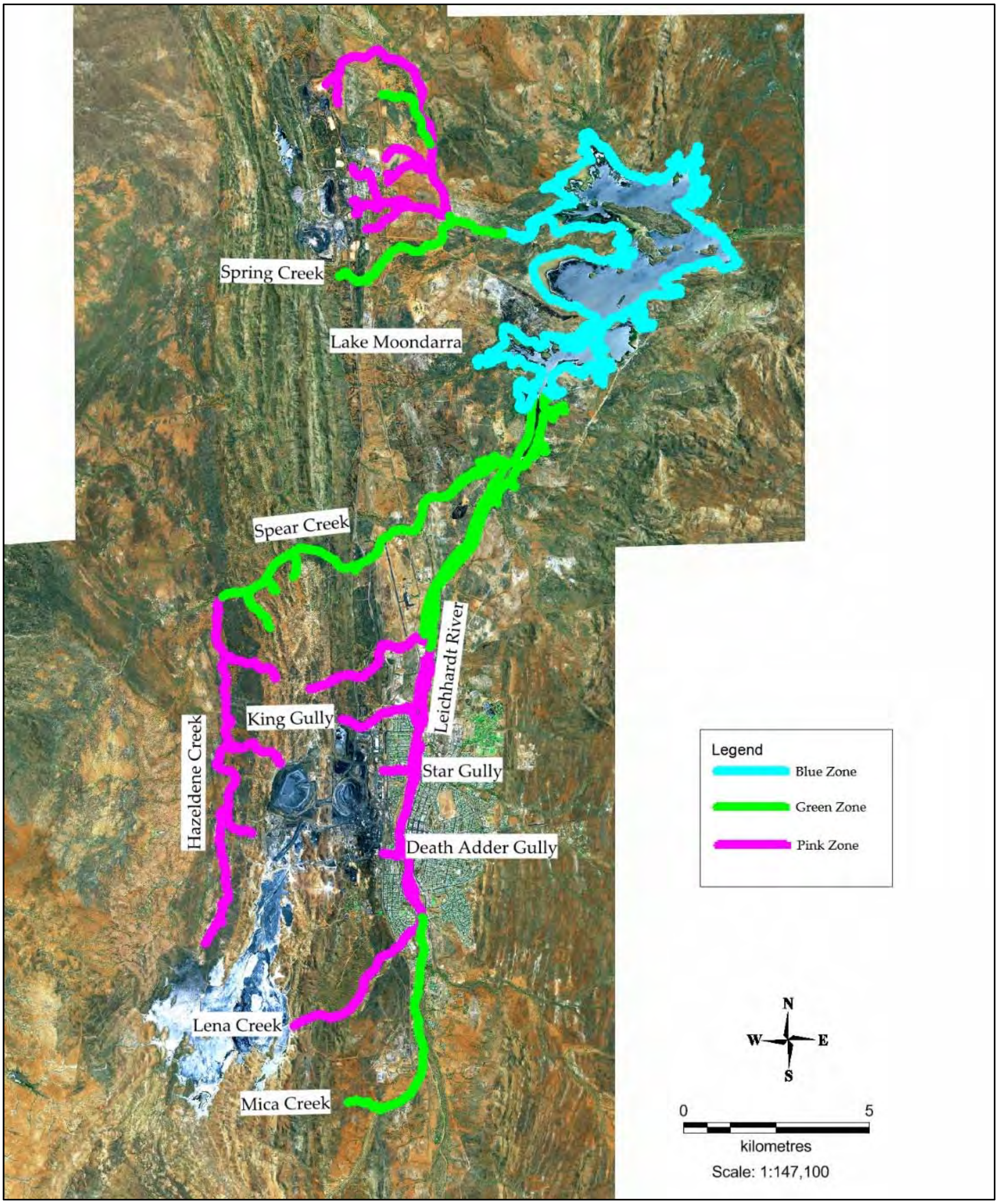

Figure 6-1: Environmental Value Zones for the Leichhardt River

For the above zones, EHP indicated that the Leichhardt River in town is not suitable for primary contact due to quality of the water and that the Mount Isa City Council (MICC) is actively discouraging the use of the water from the river. Furthermore, water from this part of the catchment is not likely to be used in the future for agricultural, industrial, or drinking water supply. However discharges into this part of the river cannot cause the river water or sediment quality to be deteriorated to the extent that these uses are impeded in other parts of the river.

The reaches of the Leichhardt River upstream and downstream of the town site, as well as Spear Creek and parts of Spring Creek, (see Table 6-1, Green Zone in Figure 6-1) the following applies:

- Slightly to moderately disturbed ecosystem
- Suitable for drinking water supply at Lake Moondarra
- Suitable for primary contact
- Suitable for secondary recreation
- Suitable for agricultural use
- Suitable for human consumption of aquatic food
- Suitable for industrial use at Lake Moondarra
- Protection of cultural and spiritual value.

These parts of the catchments are not used or likely to be used in the future for industrial or drinking water supply. However discharges into these parts of the river system cannot cause the water or sediment quality to be deteriorated to the extent where these uses are impeded in other parts of the catchment.

For Lake Moondarra (Blue Zone – see Table 6-1, Figure 6-1) the following applies:

- Slightly to moderately disturbed ecosystem
- Suitable for drinking water supply
- Suitable for primary contact
- Suitable for secondary recreation
- Suitable for agricultural use
- Suitable for human consumption of aquatic food
- Suitable for industrial use
- Protection of cultural and spiritual value.

The EA has been developed for operational conditions to be protective of these environmental values. Compared to the above environmental values, the expectation is that the receiving water quality criteria should vary according to the zones and that permissible concentrations should progressively decrease toward Lake Moondarra, consistent with the defined environmental values. However, the EA Condition H9 presents a single set of interim release limits that currently need to be met at all downstream compliance points. This investigation acknowledges the interim release limits of EA Condition H9, but also identifies that release limit concentrations for the catchments upstream should progressively contain parameter higher concentrations. A comparison between the interim release limits contained in EA Condition H9, drinking water quality criteria (NHMRC, 2011) and stock drinking water quality criteria (ANZECC, 2000) is provided in Table 6-2 for key parameters. In the absence of a groundwater trigger limit for the project site, the stock drinking water quality criteria (ANZECC, 2000) has been applied.

Table 6-2: Comparison of Various Water Quality Objectives / Criteria / Limits

Parameter	Units	EA Stock Exclusion Guidelines^	Drinking Water Guidelines~		Interim Limits for Uncontrolled Releases
			Health	Aesthetic	EA Condition H9
EC	uS/cm	5,970	-	-	1,000
SO_4	mg/L	1,000	500	250	250
Al	ug/L	5,000	-*	200	2,280
Sb	ug/L	-	3	-	3
As	ug/L	500	10	-	13
Be	ug/L	-	60	-	100
B	ug/L	-	4,000	-	370
Cd	ug/L	10	0.2	-	12.5
Cu	ug/L	1,000	2,000	-	86
Cr	ug/L	-	50	-	3
Co	ug/L	1,000	-*	-	6
Pb	ug/L	100	10	-	67
Mn	ug/L	-	500	100	1,900
Hg	ug/L	-	1	-	1
Mo	ug/L	-	50	-	24
Ni	ug/L	1,000	20	-	20
Se	ug/L	-	10	-	10
Ag	ug/L	-	100	-	100
Tl	ug/L	-	-*	-	10
U	ug/L	-	17	-	10
V	ug/L	-	-*	-	99%tile of ref site#
Zn	ug/L	20,000	-*	3000	41.6

^ANZECC 2000
~ NHMRC, 2011
* insufficient data
# Reference sites are the relevant reference sites in Schedule H Table 8 of the EA.

6.1.2 Groundwater

Groundwater EVs have been established across ML8058 (EA EPML00977513 – Amendment Application Supporting Documentation version number 1.6 (MIM, 2015a)) and apply to both alluvium and bedrock aquifers. These EVs include:

- Biological integrity – i.e. maintaining the water quality in the waterways to support existing fauna and flora;
- Industrial use; and,
- Suitability for primary industry including livestock drinking water and small-scale irrigation (gardens).

6.1.3 Sediment / Soil Quality

Specific EVs for sediment / soil quality on ML8058 have not been established, however, EVs for Land Use on ML8058 have been established and can be applied to sediment / soil quality. These EVs have been derived from the EA EPML00977513 – Amendment Application Supporting Documentation version number 1.6 (MIM, 2015a) and EA EPML00977513 – Amendment Application Supporting Documentation version number 1.2 (MIM, 2015b); and, comprise:

- Ecosystem biodiversity, health and significance;

- Integrity of land surfaces, which relates to management and prevention of contamination, stability of surfaces and final landforms, and restoration of disturbed land to appropriate land use; and,
- Cultural and spiritual values.

6.1.4 Flora and Fauna

Flora and fauna EVs on ML8058 are defined in EA EPML00977513 – Amendment Application Supporting Documentation version number 1.2 (MIM, 2015b) as the existing EVs for Land. These EVs include:

- Ecosystem biodiversity, health and significance;
- Integrity of land surfaces, which relates to management and prevention of contamination, stability of surfaces and final landforms, and restoration of disturbed land to appropriate land use; and,
- Cultural and spiritual values.

Further definition of the existing flora and fauna EVs is provided in the Receiving Environment (Flora and Fauna) Assessment report (Amec FW, 2016 – Appendix IV). A summary of the terrestrial flora and terrestrial fauna are provided in the following sections. Due to no permanent or semi-permanent pools of water being present across the focus area; and, considering stream topographies and substrate characteristic results in streams drying out following rainfall events; the presence of an aquatic ecosystem within the focus area is not considered.

Terrestrial Fauna

The area is predominantly disturbed and developed for mining purposes including BSOC WRD, King Gully Dam, Diversion Drain, stockpiles and access roads. The northern boundary, north-west corner, and western boundary of the focus area are mostly undeveloped and mapped as containing remnant vegetation. REs found in the focus area and respective extents are listed in Table 6-3 and illustrated in Figure 6-2.

Table 6-3: Regional Ecosystems in Focus Area (2014 Dry Season; 2015 Wet Season)

Regional Ecosystem	Biodiversity Status
1.11.2a *Eucalyptus leucophloia* (snappy gum) low open woodland. Occurs on steep hills.	No Concern at Present
1.11.3X1b Low open woodland *Eucalyptus leucophylla* often with Corymbia terminalis. Occurs on broad low hills; gently undulating.	No Concern at Present
1.3.4 *Acacia cambagei* low open woodland to woodland on earths in valleys	Of Concern
1.3.7a Riverine wetland or fringing riverine wetland	Endangered
1.5.3 *Eucalyptus leucophloia* (snappy gum) low open woodland and woodland sometimes with shrubby understorey dominated by Acacia spp	No Concern at Present
1.5.4 *Eucalyptus leucophylla* low open woodland on red earths in valleys	No Concern at Present
1.5.4a Low open woodland of *Corymbia terminalis*, scattered shrub layer of Carissa lanceolata and tussock grass ground layer.	No Concern at Present
1.5.6 x2 Low woodland of *Acacia cambagei* with generally sparse ground layer of Triodia longiceps and/or tussock grasses. Bare patches are common	No Concern at Present

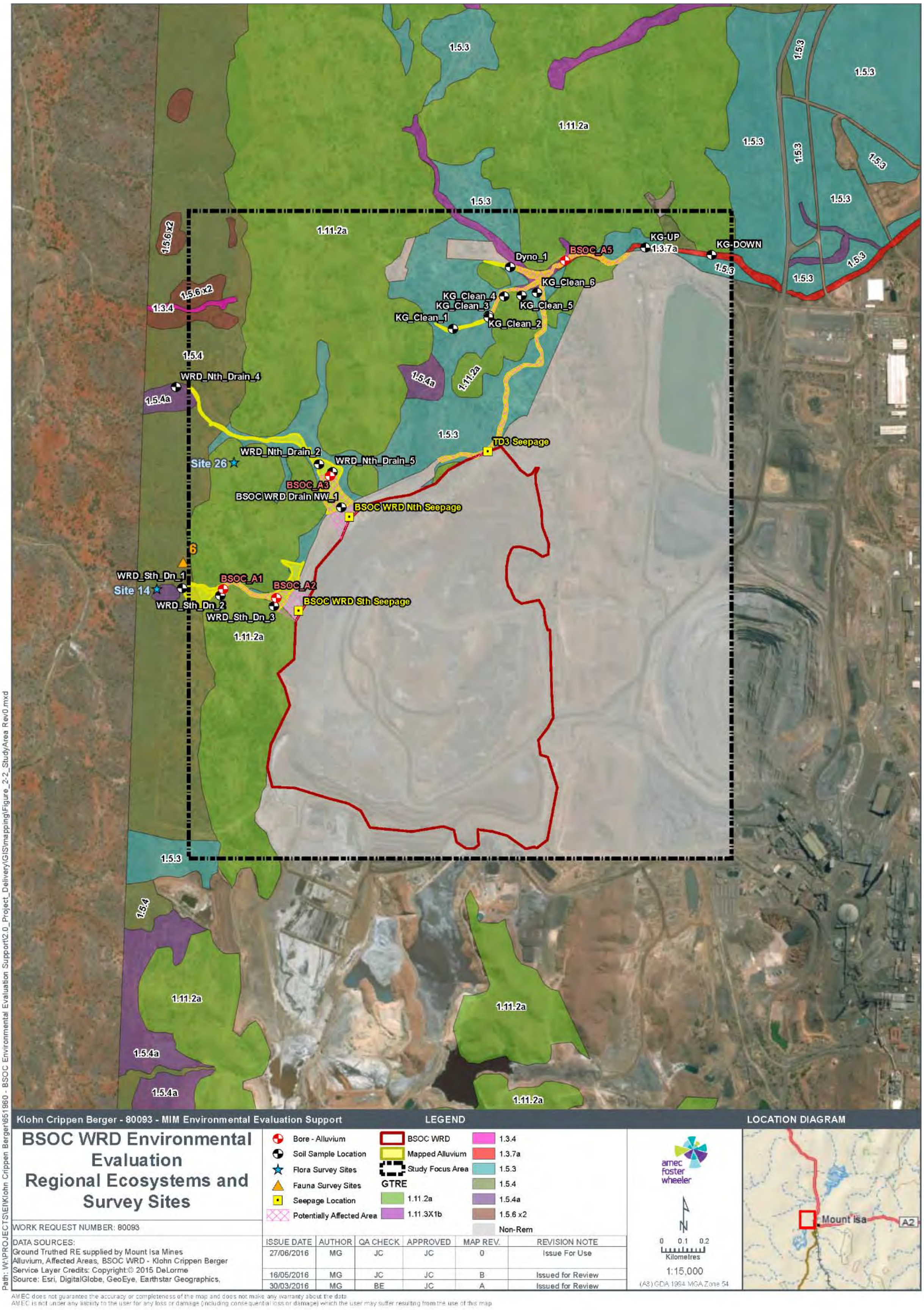

Figure 6-2: Regional Ecosystem Extents in focus Area

Terrestrial Fauna

On the western boundary of the focus area was a fauna survey site located in RE 1.5.4 (Eucalyptus leucophylla low open woodland on red earths in valleys). Fauna surveys included Elliot (A and B) trapping, funnel trapping, pit fall trapping, cage traps, remote camera trapping, nocturnal spotlighting, active herpetile searching, scat analysis and watercourse and waterhole surveys.

The survey site (RE 1.5.4 Eucalyptus leucophylla low open woodland on red earths in valleys) was dominated by snappy gum (Eucalyptus leucophloia subsp. euroa) with whitewood (Atalaya hemiglauca). A sparse shrub layer of Chisholm's wattle (Acacia chisholmii) was also present. Ground layer was very sparse and dominated by occasional spinifex, with very occasional Ptilotus sp. also present. There were 19 avian species, 2 mammals and 2 reptiles recorded across both dry and wet season surveys. Fauna species observed included:

- Australian raven (Corvus coronoides)
- black-faced cuckoo-shrike (Coracina novaehollandiae)
- common bronzewing (Phaps chalcoptera)
- crested pigeon (Ocyphaps lophotes)
- double-barred finch (Taeniopygia bichenovii)
- grey-crowned babbler (Pomatostomus temporalis)
- little friarbird (Philemon citreogularis)
- rainbow bee-eater (Merops ornatus)
- variegated fairy-wren (Malurus lamberti)
- gecko (Gehyra robusta)
- gecko (Gehyra veriegata)
- common wallaroo (Macropus robustus)
- striped faced dunnart (Sminthopsis macroura).

Based on vegetation communities occurring in the focus area and habitat features present, the area is likely to support limited fauna species. Areas consisting of RE1.11.2a with rocky outcrops on hills may support mammal species, including the purple-necked rock wallaby and common wallaroo. The striped-faced dunnart may utilize areas with lower slopes and alluvium with vegetation communities containing tussock grasses. Birds and reptiles are likely to utilise all areas. In the wet season, when creeks contain some water, fauna species are likely to be drawn to these areas. Microbats are unlikely to utilise the focus area due to a lack of hollow bearing trees and flyways.

6.2 Existing and Potential Impacts

The interpreted BSOC WRD landform seepage plume extents have been correlated with the key receiving environment EVs (Section 6.1) to identify potential impacts on the EVs. A summary of the existing and potential impacts for the key EVs are provided in the following sections.

6.2.1 Surface Water

6.2.1.1 Existing Impacts to Surface Water

The occurrence of the BSOC WRD landform seepages as surface water occurs at each of the three seepage locations where the seepage discharges into the Diversion Drain, or seepage collection trench for BSOC WRD South Seepage. The occurrence of the seepage as surface water is managed by the Diversion Drain, which discharges the seepage water into KSOC pit, mitigating flow into the downstream water course (i.e. Leichhardt River, Hazeldene Creek). Therefore, existing impacts to the receiving environment surface water EVs from the BSOC WRD landform seepage is not been identified.

6.2.1.2 Potential Impacts to Surface Water

Daylighting of groundwater as surface water has been interpreted to occur during the wet season as a result of saturation of the alluvial aquifer and hydraulic connection with the surface water course. Discussion regarding the alluvium aquifer groundwater contribution to surface water is provided in Section 6.2.2, and includes discussion regarding potential impacts to the Surface Water EVs.

6.2.2 Groundwater

6.2.2.1 Seepage Migration Map

Alluvial Aquifer

The interpreted extent of BSOC WRD Landform seepage migration in the alluvial aquifer is provided in Figure 5-68 and is based on groundwater quality monitoring results (Section 5.4.3) and the analytical assessment of groundwater movement within the alluvial aquifer (Section 5.4.8). Based on Figure 5-68, the BSOC WRD landform seepage plume in the alluvium aquifer is ~300 m downstream of BSOC WRD South Seepage and ~200 m downstream of BSOC WRD North Seepage. Seepage migration in the alluvium downstream of TD3 Seepage has been identified in the groundwater quality of BSOC_A5 (~1.2 km downstream of TD3 Seepage), with observational evidence of seepage (e.g. mineral precipitation on surface, surface water pooling in alluvium during dry season) indicating seepage migration beyond BSOC_A5. Seepage migration in the alluvial aquifer of King Gully will ultimately be diverted by the King Gully first flush facility (weir), which diverts seepage in the alluvium into KSOC pit.

Sulphate has been selected as the parameter to represent the extent of the BSOC WRD landform seepage plume, with a trigger level of 1,000 mg/L (ANZECC livestock watering guidelines (ANZECC, 2000)) used to represent the extent seepage. Sulphate was selected due to the conservative nature of the parameter (i.e. not prone to secondary reactions and attenuation / adsorption mechanisms in the groundwater system), therefore, the interpreted extent of the seepage plume is considered conservative.

Bedrock Aquifer

The interpreted extent of BSOC WRD landform seepage in the bedrock aquifer is provided in Figure 5-69 and is based on groundwater quality monitoring results (Section 5.4.3) and the analytical assessment of groundwater movement within the bedrock aquifer (Section 5.4.8).

Bedrock seepage is interpreted to be most prominent to the north of TD3 Seepage (~800 m) and seepage migration to the west of BSOC WRD South Seepage (~300 m). As per the alluvial aquifer seepage assessment, sulphate was selected as the parameter to represent the seepage plume extent, therefore, the same level of conservatism is applied to the interpreted bedrock aquifer extent.

An analysis of migration rates in the bedrock aquifer was conducted to estimate the timeframe required for the development of the current seepage plume and to predict the timeframe required for the seepage plume to reach the northern extent of the focus area (north of TD3 Seepage). The estimated timing for the seepage plume extent to reach the northern focus area boundary is from 2029 (weathered bedrock) to 2061 (bedrock).

6.2.2.2 Existing Impacts to Groundwater EVs

The interpreted seepage plume extents, based on the 1,000 mg/L SO_4 trigger limit, for the alluvium and bedrock aquifers are provided in Figure 5-68 and Figure 5-69, respectively.

The extent of seepage in the alluvium aquifer is interpreted to be 200 m and 300 m downstream of the BSOC WRD North and South Seepages. The nearest downstream receptor with EVs is Hazeldene Creek (surface water EVs (Pink Zone), based on the conservative assumption that the alluvium aquifer contributes to the Hazeldene Creek surface water system), which is located ~2 km and ~1.1 km downstream of the BSOC WRD North and South Seepages, respectively.

These seepage plume extents were interpreted based on groundwater sampling of the monitoring bore network downstream of the BSOC WRD landform (Figure 5-14) following the Phase 2 field investigation program, and subsequent one dimensional analytical modelling (Section 5.4.8). Conservative assumptions were adopted for the one dimensional analytical modelling, including:

- Constant source term concentrations (based on the SO_4 concentration from each of the seepage locations) for the duration of the BSOC WRD landform development (including development of the underlying TSFs); and
- Constant flow velocities within the underlying aquifer (based on interpreted current flow velocities) for the duration of the BSOC WRD landform development (including development of the underlying TSFs).

Therefore, the interpreted seepage plume extents for the alluvium and bedrock aquifers are considered conservative. Additionally, as the one dimensional analytical assessment and associated interpretations are based on monitoring / sampling completed as part of this investigation the interpreted seepage plume extents are considered to represent the current seepage plume extents.

Groundwater usage for industrial use, livestock watering and/or small scale irrigation is not observed within the vicinity of the interpreted seepage plume extents or within the focus area. Additionally, discharge of groundwater to waterways supporting existing fauna and flora communities was not identified within the vicinity of the focus area during the field investigation program. Therefore, existing impacts to the groundwater EVs as a result of BSOC WRD landform seepage has not been identified.

6.2.2.3 Potential Impacts to Groundwater EVs

Section 6.2.2.2 identified that there is no existing impact on groundwater EVs as a result of the interpreted current seepage plume extents in the alluvium and bedrock aquifers (Figure 5-68 and Figure 5-69). Further downstream migration of the sulphate plume may occur over time; and, based on the one dimensional analytical assessment (Section 5.4.8) the predicted migration time for the seepages to reach the downstream receptors are:

- BSOC WRD North Seepage alluvium aquifer seepage plume migration to Hazeldene Creek (2 km downstream of BSOC WRD North Seepage) – 154 years;
- BSOC WRD South Seepage alluvium aquifer seepage plume migration to Hazeldene Creek (1.1 km downstream of BSOC WRD South Seepage) – 106 years; and
- TD3 Seepage bedrock aquifer seepage plume migration to Spear Creek (5.3 km downstream of TD3 Seepage) – 465 years.

Although the one dimensional analytical assessment has predicted migration times for the seepage plumes to reach the downstream receptors, ranging from 106 years to 465 years, periodic monitoring / sampling of the groundwater monitoring bore network downstream of the BSOC WRD landform should be undertaken. Periodic monitoring will provide an understanding of the transient characteristics of the seepage plume. This proposed monitoring program is provided as part of the seepage adaptive management strategy detailed in Section 9.3.

Groundwater levels in the alluvium aquifer are generally below the ground surface (Table 5-1). For the alluvium aquifer downstream of the BSOC WRD North and South Seepages these groundwater levels range from 0.81 mbGL to 2.37 mbGL (note: BSOC_A4 was dry during monitoring). These measured groundwater levels are representatives of levels measured following the Phase 2 field investigation program. However, during periods of high rainfall it is anticipated that the alluvium aquifer groundwater level will rise as a result of direct rainfall infiltration and may potentially rise above the ground surface and contribute to surface water flow. It is interpreted that rainfall infiltration into the alluvium aquifer and the mixing of the alluvium groundwater with the surface water runoff, following the rise of the groundwater level above the ground surface, would result in the dilution of the seepage water quality concentrations. The potential impact to the surface water EVs as a result of alluvium aquifer groundwater contributing to the surface water runoff is considered low due to the dilution of the groundwater quality concentrations by rainfall infiltration and runoff. Additionally, the occurrence of alluvium groundwater mixing with the surface water runoff is considered sporadic and would only occur following high intensity and/or prolonged rainfall events, which are typically isolated to the wet season. Further assessment of the surface water quality from the water courses downstream of the BSOC WRD North and South Seepages is required to assess the potential impacts to the surface water EVs. This assessment has been included as part of the seepage adaptive management strategy detailed in Section 9.3.

6.2.3 Sediment / Soil Quality

6.2.3.1 Existing Impacts to Sediment / Soil EVs

Sediment / soil sampling completed as part of the Phase 1 field investigation program targeted the watercourses due to poor soil development across the focus area and the majority of sediment accumulation occurring adjacent to the watercourses (alluvium). Additionally, the sampling program targeted zones of observable seepage impact (e.g. mineral precipitation on the surface) and downstream locations for assumed background concentrations. Based on the sediment quality results, the presence of BSOC WRD landform seepage influence on the sediment extent (alluvium) is comparable to the seepage plume extent interpreted for the alluvial aquifer (Figure 5-68).

Specific EVs for sediment / soil quality have not been developed for ML8058, however, in this absence the established EVs for Land Use has been adopted. As described above the seepage plume extents identified for the alluvial aquifer is comparable to the influence of the seepage on the sediment / soil quality. Therefore, for the existing impact assessment an area limited to the identified seepage plume (~300 m downstream of BSOC WRD South Seepage and ~200 m downstream of BSOC WRD North Seepage) was applied. No observable or interpreted existing impacts to the ecosystem biodiversity, health and significance (e.g. vegetation die-back) or the integrity of the land surface for associated land use have been identified.

6.2.3.2 Potential Impacts to Sediment / Soil EVs

The existing impact assessment identified in Section 6.2.3.1 indicate that sediment / soil concentrations correlate with the seepage plume extents identified for the alluvial aquifer. Interpretation of the seepage plume extents in the alluvial aquifer are based on monitoring results collected during this investigation, which represents current conditions. One dimensional analytical assessment has predicted that the seepage plume may migrate downstream in the alluvial aquifer over time, indicating that the extent of the sediment / soil quality being influenced by the seepage may increase. However, the potential impact to the Land Use EVs as a result of the sediment / soil quality being influenced by the seepage is considered low. Further monitoring of the seepage plume and downstream EVs should be undertaken to assess potential impacts on the EVs. Details of the proposed monitoring program is provided as part of the seepage adaptive management strategy in Section 9.3.

6.2.4 Flora and Fauna

The assessment of impacts to flora and fauna from the BSOC WRD landform seepage has been based on the potential of uptake of the impacted surface water and groundwater by flora and fauna. Therefore, flora and fauna communities identified by Amec FW (2016) (Appendix IV) have been correlated with the seepage extents identified for the surface water system and the alluvial aquifer (groundwater) to undertake the impact assessment. Groundwater of the bedrock aquifer is considered to be too deep (i.e. 5 m to 12 m – groundwater intersected between 9 m and 42 m (groundwater levels are higher than intersected levels due to confined aquifer conditions)) (see Section 5.2.2.1) for vegetation to source, therefore, the interpreted seepage plume extent in the bedrock aquifer has not been included in the flora and fauna impact assessment.

Flora and fauna EVs have been previously defined in Section 6.1.4. These EVs form the basis of the impact assessment for both existing and potential impacts, a summary of which are provided in the following sections.

6.2.4.1 Existing Impacts to Flora EVs

Groundwater levels in the alluvial aquifer were observed to be 0.81 m to 2.37 m (note: BSOC_A4 was dry during monitoring) below the ground surface. It is anticipated that vegetation within the alluvial extent downstream of the BSOC North and South Seepages may source water from the alluvial aquifer. However, the extent of where impact may occur is limited to the alluvium aquifer seepage extents downstream of BSOC WRD North and South Seepage (~200 m and ~300 m, respectively). Copper concentrations associated with alluvium aquifer seepage have been identified as contaminant of concern for the terrestrial flora, however, the variability of the root uptake process between contaminants of concern, soil characteristics and plant types makes it difficult to be confident that high levels of contaminant of concern will result in impact to vegetation.

Seepage occurs in an area with the following vegetation communities:

- RE11.3X1b Low open woodland *Eucalyptus leucophylla* often with *Corymbia terminalis*. (No Concern at Present Biodiversity Status); and
- RE1.5.3 *Eucalyptus leucophloia* (snappy gum) low open woodland and woodland sometimes with shrubby understorey dominated by Acacia spp. (No Concern at Present Biodiversity Status).

As both of these communities naturally have sparse canopy trees and cover, it is anticipated that the remnant status of vegetation within the identified alluvium aquifer seepage plume extent has not been impacted by the BSOC WRD landform seepage.

6.2.4.2 Potential Impacts to Flora EVs

One dimensional analytical assessment of the BSOC WRD landform seepage plume downstream of BSOC WRD North and South Seepages indicate that seepage plume may migrate downstream in the alluvium aquifer over time (Section 5.4.8). In addition to the potential increase in the extent of the seepage plume an increase in seepage water quality concentrations may also be observed over time across the seepage extents. Therefore, potential impact to terrestrial flora from the BSOC WRD landform seepage may occur, limited to the extent of the seepage within the alluvial aquifer.

Monitoring of vegetation condition was considered to assess impacts in the future, however compared with monitoring water quality this was considered to be a lagging indicator (as some vegetation may take several seasons to show signs of stress from contaminants) and therefore any mitigation measures proposed as a result of water quality monitoring program would be appropriate. Details of the proposed monitoring is provided as part of the seepage adaptive management strategy in Section 9.3.

6.2.4.3 Existing and Potential Impacts to Fauna

Consumption of seepage-influenced water by fauna is considered the pathway for the BSOC WRD seepage to impact fauna. Groundwater in the bedrock aquifer is not identified to discharge to the surface, and therefore, is not considered to impact fauna. In the alluvial aquifer groundwater levels may rise to the surface during periods of high rainfall events (wet season), which may be consumed by fauna. It is anticipated that the rainfall events will dilute water quality concentrations in the alluvial aquifer groundwater, however, during these periods of high rainfall events it is also anticipated that pooled rain water will be accessible to fauna for consumption. Therefore, the existing and potential impact to fauna from BSOC WRD seepage in the groundwater is not anticipated.

BSOC WRD seepages into the diversion drain occur throughout the year. Access to the diversion drain and seepage locations by livestock is restricted by the property fence located along the western boundary of the focus area. Therefore, existing and potential impacts to livestock from the BSOC WRD landform seepage is not anticipated.

7 BSOC WRD SEEPAGE PREVENTION / REDUCTION

This section of the report addresses item 3, of the EE Notice:

Determine all potential options for the prevention or reduction of any further release of seepage from the BSOC WRD to the receiving environment; for all options providing:

- *A detailed description of each option; and,*
- *Cost for implementation of each option; and,*
- *A timeframe for implementation of each option.*

The interpreted seepage extent in the alluvial and bedrock aquifers is used as the basis to identify, select and develop conceptual designs for mitigation options to prevent / reduce further release of seepage. These mitigation options are summarised in the following sections.

As discussed in Section 6.2 the impact assessment shows that the potential options provided in the following sections are not currently justified. Notwithstanding, potential options are presented here for the purposes of meeting the EE Notice requirements. The adaptive management approach presented in Section 9.3 will determine whether any of these potential options are justified in future. These options could be considered at that time.

7.1 Description of Potential Seepage Mitigation Options

7.1.1 Alluvial Aquifer

BSOC WRD landform seepage in the alluvial aquifer has been identified approximately 200 m and 300 m downstream of the BSOC WRD North and South Seepages, respectively. The nearest downstream receptor with EVs is interpreted to be Hazeldene Creek, which is located approximately 2 km and 1.1 km downstream of the BSOC WRD North and South Seepages; and, the Leichhardt River (downstream of King Gully) to the east. Due to the relatively shallow thicknesses of the alluvial aquifer (~9 m at the BSOC WRD South Seepage and ~3 m at the BSOC WRD North Seepage) and consistent hydraulic parameters across the extent of the aquifer, it is proposed that the most effective approach to mitigate the seepage could be to intercept the groundwater flow. Based on this proposed approach, three seepage mitigation options have been identified:

- Seepage interception borefield;
- Seepage interception trench; and,
- Alluvial aquifer cut-off wall.

An options assessment matrix for the proposed mitigation options, based on the effectiveness, industry leading practice, long-term cost implications (Operating Expenditure (OPEX)) and applicability for the closure strategy is provided in Table 7-1.

Table 7-1: Potential Alluvial Aquifer Seepage Mitigation Options Assessment Matrix

	Effectiveness	Industry Leading Practice	OPEX
Interception Borefield	*Minor seepage migration beyond system possible*	X	X
Interception Trench	X	X	X
Cut-off Wall	X	X	X

* "X" denotes that category is applicable to the seepage mitigation option

7.1.2 Bedrock Aquifer

BSOC WRD seepage in the bedrock aquifer has been identified to the north of TD3 Seepage and to the west of BSOC WRD South Seepage, however, existing and potential impacts to key receiving environment EVs within the focus area have not been identified. The nearest downstream receptor that could potentially be impacted by the seepage in the bedrock aquifer with EVs is interpreted to be Spear Creek, which is located approximately 4.3 km north of the focus area boundary.

Seepage from the BSOC WRD landform into the weathered bedrock / bedrock aquifer, from the TD3 Seepage catchment area (i.e. upstream area of the BSOC WRD contributing to TD3 Seepage) is ~4% (0.05 to 0.16 L/s) of the total flux leaving the BSOC WRD from the TD3 Seepage catchment. Based on the Phase 2 field investigation program, and analysis of the field program results, this seepage is interpreted to be diffuse within bedrock aquifer, flowing preferential to the orientation of the bedrock bedding plane (south to north). The interpreted low seepage rates and the prolonged duration of seepage migration (i.e. approximately 465 years to reach Spear Creek) (Section 5.4.8) is a reflection of the low permeability and limited storage of the bedrock aquifer. The extent of the seepage front is interpreted to be 450 m wide, with a thickness of ~55 m (groundwater was not encountered below 60 m and standing water level at the seepage front is approximately 5 mbGL).

Mitigation of the identified seepage in the bedrock aquifer is limited by the diffuse nature of the seepage characteristics and the interpreted depth of the seepage. The proposed approach for addressing the seepage during mine operational conditions comprises the interception of the groundwater flow in the bedrock aquifer along the seepage front using groundwater bores.

An option assessment matrix for the proposed mitigation option, based on the effectiveness, industry leading practice, long-term cost implications (OPEX) and applicability for the closure strategy is provided in Table 7-2.

Table 7-2: Potential Bedrock Aquifer Seepage Mitigation Option Assessment Matrix

	Effectiveness	Industry Leading Practice	OPEX
Interception Borefield	*Seepage migration beyond system possible*	X	X

* "X" denotes that category is applicable to the seepage mitigation option

7.2 Conceptual Design for Each Option

As discussed in Section 6.2, the impact assessment shows that these potential options are not currently justified. Notwithstanding, conceptual designs for each option are presented here for the purposes of meeting the EE Notice requirements.

7.2.1 Alluvial Aquifer

The conceptual designs for the alluvial aquifer seepage mitigation options (Section 7.1.1) are provided in the following sections.

Groundwater Interception Borefield

The groundwater interception borefield for the alluvial aquifer would comprise a series of production bores installed along an alignment perpendicular to the groundwater flow direction in the alluvial aquifer downstream of both BSOC WRD South and North Seepages. Drilling for the production bores would be completed to below the alluvium profile and into the bedrock. The anticipated maximum depth of the alluvium is ~9 m at the BSOC WRD South Seepage (based on BSOC_A2) and ~3 m at the BSOC WRD North Seepage (based on BSOC_A3). Bore construction would be completed within each drill hole with the construction comprising a screened interval (to allow groundwater inflow) across the entire alluvium profile. The conceptual locations of the proposed interception borefields are provided in Figure 7-1.

Preliminary drilling and hydraulic testing at each of the proposed interception borefields would be required to be conducted prior to installation of the system to confirm the number of production bores, associated bore spacings and pump type / sizing to operate the interception system. Intercepted groundwater would be discharged into the Diversion Drain for surface water management, as per current BSOC WRD seepages.

Although the interception borefield would collect a large proportion of BSOC WRD seepage in the alluvial aquifer, it is anticipated that some seepage may migrate beyond the interception system, as the system would not be able to capture 100% of seepage. Additionally, ongoing operation and maintenance of the interception system would be required.

Groundwater Interception Trench

The groundwater interception trench for the alluvial aquifer would operate in a similar manner to the interception borefield with the exception that a trench to the base of the alluvial profile, and into the upper bedrock, would replace the production bores (Figure 7-1). Each interception trench would be required to be excavated to a minimum depth of 0.5 m into the bedrock. The interception trenches could be a minimum of 1 m wide, however, in order to maintain stability of the trench walls (assuming support structures are not used) a “cut-back” slope of a minimum 2:1 (horizontal:vertical) would be required and maintained for the duration of trench operation. This “cut-back” equates to a trench width of approximately 36 m and 12 m for the interception trenches at BSOC WRD South and North Seepages, respectively.

Once excavated, groundwater flow in the alluvial aquifer would discharge into the excavation trench. A transfer pump, with pump intake installed in the excavation trench, would be required to transfer the seepage water from the trench to the diversion channel.

Preliminary testing of the alluvial material would be required to obtain hydraulic parameters for the assessment of inflow rates into the trench (for transfer pump sizing); and, to support the detailed design of the trench (e.g. trench wall stability, on-going maintenance). Ongoing operation and maintenance of the interception system would be required.

Cut-off Wall

The alluvial aquifer cut-off walls would be conceptually located along the same alignment as the interception borefields and trenches[11] (Figure 7-1). The cut-off walls would comprise a 1 to 1.5 m wide low permeability cement/bentonite slurry that would be installed across the alluvial profile and “keyed” into the bedrock.

The locations of the cut-off walls are indicative and would be subject to site investigations to confirm the extent of the alluvials and the depth to bedrock. A cut-off wall installed across the alluvials would significantly reduce groundwater flow potential within the alluvial aquifer. As groundwater flow in the alluvials downstream of BSOC WRD South and North Seepages is generally east to west, groundwater heads would mound east (upstream) of the cut-off wall and groundwater would express as surface water in the drain. Ideally, cut-off walls would be located either upstream of the current drain alignment or immediately upstream of the drain invert. In the upstream option, intercepted groundwater would be collected and discharged to the drain under gravity. With the cut-off wall immediately north of the current drain invert for BSOC WRD North Seepage, and immediately west of the current drain invert for BSOC WRD South Seepage; intercepted groundwater would discharge directly into the drain.

Based on interpretations to date, significant lengths of the current drain intersect alluvials, for example, at BSOC WRD North Seepage (Figure 5-10). Cut-off wall hydraulic efficiency is, in part, a function of the total wall surface area, i.e., for the same aquifer head conditions, less cutoff wall surface area is better than more surface area. In situations such as BSOC WRD South Seepage, it is assumed that the cut-off wall cannot be located upstream of the drain, and an indicative location is shown downstream of the drain which limits the cut-off surface area required. Cut-off wall locations located downstream of the drain (e.g. Figure 7-1) would require capture of seepage upstream of the wall and pumping back to the drain. Intercepted water could be collected in a shallow well or caisson structure.

Preliminary testing of the alluvium material would be required to be undertaken to allow assessment of:

- Configuration and nature of the contact between the alluvium and bedrock;
- Methodology for trench excavation and slurry installation; and,
- Required cement/bentonite slurry characteristics.

Based on previous experience with cut-off wall installations using low permeability cement / bentonite slurries, it is anticipated that the cut-off wall excavation and slurry installation would be conducted concurrently, minimising the requirement to support the trench walls for prolonged periods while the cut-off wall is installed and cured. The cut-off wall would be required to be installed across the entire alluvium profile and to above the ground surface to mitigate the risk of rising groundwater levels flowing over the cut-off wall. An assessment and subsequent reconfiguration of the surface drainage at each cut-off wall location would be required to manage the rising alluvial groundwater level (upstream of the cut-off wall) to discharge into the Diversion Drain. Following installation, there would be minimal on-going operational costs for the cut-off wall (e.g. downstream monitoring for QA/QC).

[11] Proposed conceptual cut-off wall location is indicative. Field investigations/testing will be required to confirm the cut-off wall locations.

Downstream Monitoring Network

For each of the above mitigation options, a downstream alluvial aquifer monitoring network should be installed to assess the effectiveness of the mitigation measure. This network would comprise of the existing downstream alluvial monitoring bores, BSOC_A1, BSOC_A2, BSOC_A3, BSOC_A4. Monitoring of the proposed monitoring network is to be conducted to assess the effectiveness of the mitigation measure.

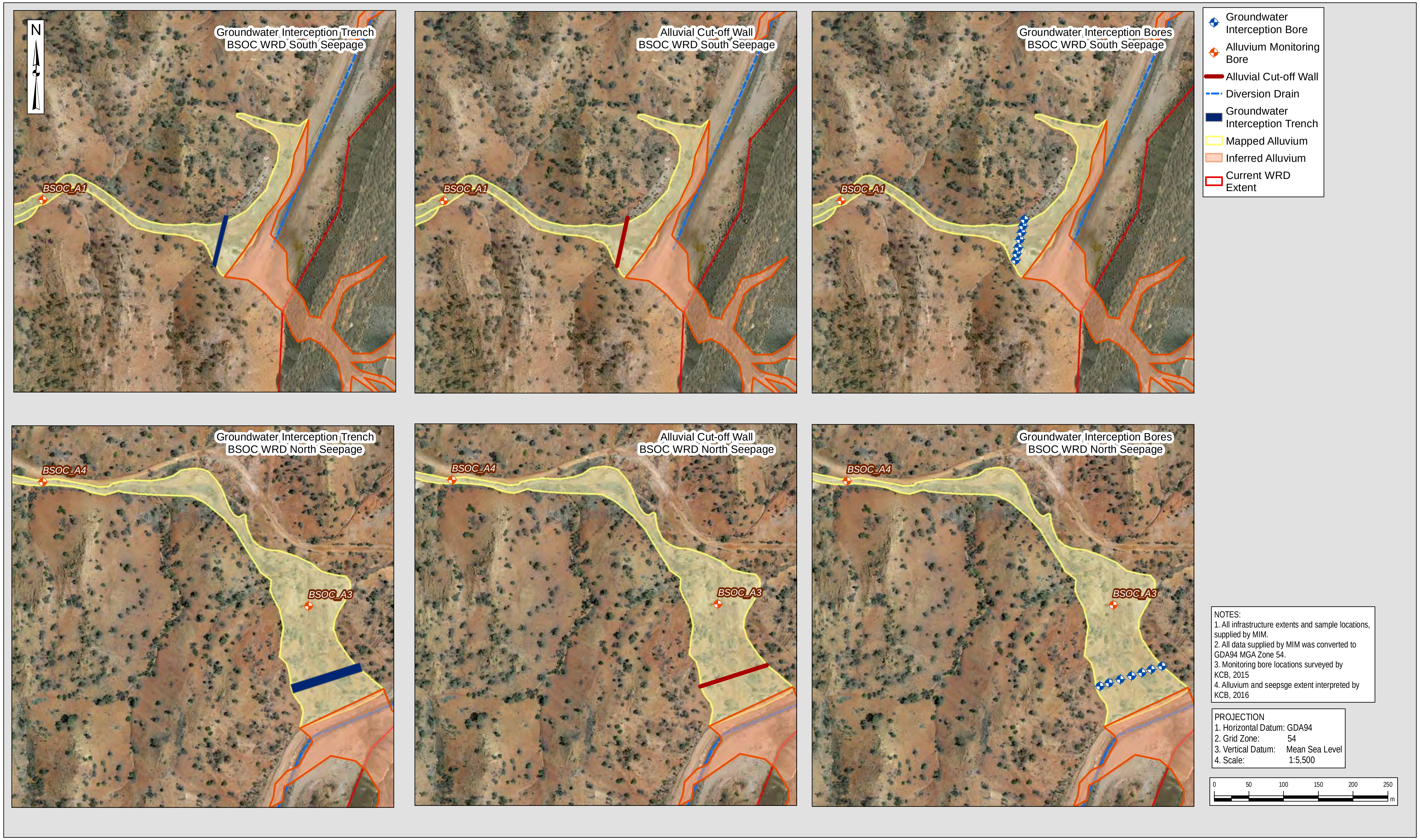

Figure 7-1: Conceptual Design for Alluvial Aquifer Seepage Prevention / Reduction

7.2.2 Bedrock Aquifer

The conceptual designs for the bedrock aquifer seepage mitigation option during mine operations (Section 7.1.2) is provided in the following section.

Groundwater Interception Borefield

The bedrock aquifer groundwater interception borefield would comprise a series of production bores installed to a minimum depth of 60 m (interpreted maximum depth of seepage) aligned perpendicular to the groundwater flow direction across the width of the interpreted seepage migration front (~450 m in length) (Figure 7-2). Production bore construction would comprise a screened interval from the bottom of the production bore to the height of the first water strike encountered during drilling. This would allow the interception of the inflow zones from the first water strike to the base of the interpreted seepage extent. Groundwater abstracted from the interception borefield would be discharged into the Diversion Drain to be managed as per the current BSOC WRD seepages.

Preliminary drilling and hydraulic testing across the bedrock seepage front would be required to confirm the characteristics of the seepage front and aquifer hydraulic parameters to support the design of the interception borefield (e.g. borefield extent, number of production bores) and associated pumping infrastructure. Ongoing operation and maintenance of the borefield would be required to mitigate seepage in the bedrock aquifer.

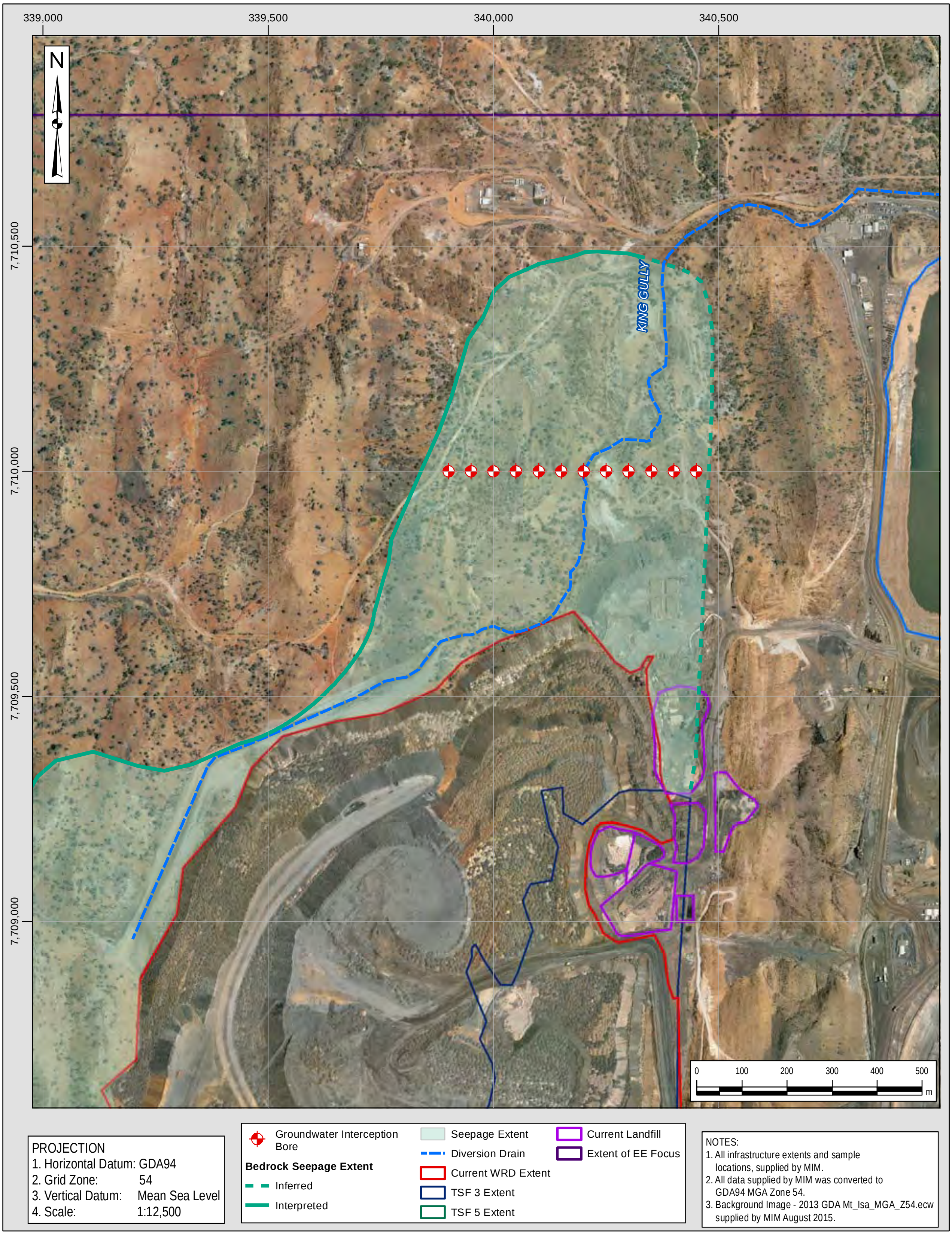

Figure 7-2: Conceptual Design for Bedrock Seepage Reduction / Prevention

7.3 Cost Estimate for Conceptual Mitigation Options

7.3.1 Cut-off Wall – Alluvial Aquifer

The preliminary estimated costs associated with the preliminary works and installation of the alluvial aquifer Cut-off Walls is provided in Table 7-3.

Table 7-3: Alluvial Aquifer Cut-off Wall Preliminary Cost Estimate

Cost Estimate Line Item	Cost
1. Field Testing	$50,000
2. Infrastructure Design	$60,000
3. Construction (Contractor & Materials)	$200,000
4. Construction Supervision	$30,000
5. Pumping Infrastructure Costs (as per MIM cost estimate)	$600,000
Total	**$940,000**
Contingency (30%)	**$282,000**
Total + Contingency	**$1,222,000**

The basis for the above preliminary cost estimate is provided as follows:

- Field testing comprises the undertaking of a geotechnical testing program, including drilling, geotechnical testing (laboratory), hydraulic testing and reporting. A duration of 2 weeks is estimated from the field testing program.
- Infrastructure design comprises the in-office detailed design of both Cut-off Wall infrastructures.
- Cut-off Wall construction costs have been developed based on KCB previous experience with Cut-off Wall installations in unconsolidated materials to a depth shallower than 10 m. The all-inclusive (contractor and materials) unitary rate for the Cut-off Wall construction is $\$250/m^2$ of Cut-off Wall (BSOC South Seepage Cut-off Wall = 450 m^2, BSOC North Seepage Cut-off Wall = 350 m^2).

7.3.2 Interception Borefield – Alluvial Aquifer

A conceptual layout of the alluvial aquifer groundwater interception borefield is provided in Figure 7-1. Nominally, seven interception bores have been proposed for each seepage location (14 interception bores in total), however, this may vary based on the results of the initial drilling and hydraulic testing program. The following preliminary cost estimate for this mitigation option has been developed based on the nominal 14 interception bores (Table 7-4).

Table 7-4: Alluvial Aquifer Interception Borefield Preliminary Cost Estimate

Cost Estimate Line Item	Cost
1. Field Testing	$105,000
2. Infrastructure Design	$75,000
3. Installation (Contractor & Materials / Equipment)	$385,000
4. Construction Supervision	$30,000
Total	**$595,000**
Contingency (30%)	**$178,500**
Total + Contingency	**$773,500**

The basis for the above preliminary cost estimate is provided as follows:

- Field testing comprises the drilling and construction of three test interception bores at each seepage location, hydraulic testing, field supervision and reporting. A duration of 2 weeks is estimated from the field testing program.
- Infrastructure design comprises the in-office detailed design of both interception borefields.
- Borefield installation costs have been developed based on KCB experience with borefield design, drilling contractor rates, bore construction material costs and pumping / reticulation costs.
- Operating costs have not been included with this estimate due to uncertainty regarding the conceptual design (e.g. number of bores, size of pumps etc).

7.3.3 Interception Trench

A conceptual layout of the alluvial aquifer groundwater interception trench is provided in Figure 7-1. The conceptual interception trench sizings have been based on the interpreted alluvium extent and the bedrock interception depth identified during the site investigation program. These sizings include:

- BSOC WRD South Seepage – 50 m (length) x 36 m (width) x 9 m (depth)
- BSOC WRD North Seepage – 100 m (length) x 14 m (width) x 3.5 m (depth)

The width of the trench has been selected based on a cut-back ratio of 2:1 (horizontal:vertical), to maintain stability of the trench walls in the alluvium. The following preliminary cost estimate for this mitigation option has been developed based on the interception trench sizings (Table 7-5).

Table 7-5: Alluvial Aquifer Interception Trench Preliminary Cost Estimate

Cost Estimate Line Item	Cost
1. Field Testing	$45,000
2. Infrastructure Design	$75,000
3. Installation (Contractor & Materials / Equipment) – South Trench	$410,000
4. Installation (Contractor & Materials / Equipment) – North Trench	$195,000
Total	**$725,000**
Contingency (30%)	**$217,500**
Total + Contingency	**$942,500**

The basis for the above preliminary cost estimate is provided as follows:

- Field testing comprises the drilling of three drill holes across the trench alignment at each seepage location, geotechnical testing, field supervision and reporting. A duration of 1 week is estimated from the field testing program.
- Infrastructure design comprises the in-office detailed design of both interception trenches.
- Interception trench costs have been developed based on unitary rates for site preparation, excavation, pumping equipment and reticulation provided in the Australian Construction Handbook (Rawlinsons, 2015).

- Operating costs have not been included with this estimate due to uncertainty regarding the conceptual design (e.g. sizing of trenches, size of pumps etc.).

7.3.4 Interception Borefield – Bedrock Aquifer

A conceptual layout of the bedrock aquifer groundwater interception borefield is provided in Figure 7-2. Nominally, 12 interception bores have been proposed for this network, however, this may vary based on the results of the initial drilling and hydraulic testing program. The following preliminary cost estimate for this mitigation option has been developed based on the nominal 12 interception bores (Table 7-6).

Table 7-6: Bedrock Aquifer Interception Borefield Preliminary Cost Estimate

Cost Estimate Line Item	Cost
1. Field Testing	$140,000
2. Infrastructure Design	$75,000
3. Installation (Contractor & Materials / Equipment)	$495,000
4. Construction Supervision	$50,000
Total	**$760,000**
Contingency (30%)	**$228,000**
Total + Contingency	**$988,000**

The basis for the above preliminary cost estimate is provided as follows:

- Field testing comprises the drilling and construction of five test interception bores (to 60 m depth), hydraulic testing, field supervision and reporting. A duration of 3 weeks is estimated from the field testing program.
- Infrastructure design comprises the in-office detailed design of the interception borefield.
- Borefield installation costs have been developed based on KCB experience with borefield design, drilling contractor rates, bore construction material costs and pumping / reticulation costs.
- Operating costs have not been included with this estimate due to uncertainty regarding the conceptual design (e.g. number of bores, size of pumps etc).

7.4 Timeframe for Implementation of Mitigation Options

7.4.1 Cut-off Wall Option

The anticipated timeframe for the installation of the alluvial aquifer Cut-off Wall seepage mitigation option is provided in Figure 7-3, broken down into key schedule items. The anticipated timeframe indicates an implementation timeframe of 12 months for the Cut-off Walls.

Schedule Items	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Testing Program / Detail Design												
Preparation of Scope of Work												
Invitation to Submit Tenders												
Review of Submitted Tenders												
Finalisation of Contract												
Field Program												
Detailed Design												
Cut-off Wall Installation												
Preparation of Scope of Work												
Invitation to Submit Tenders												
Review of Submitted Tenders												
Finalisation of Contract												
Materials / Equipment Procurement												
Cut-off Wall Installation												

Figure 7-3: Anticipated Alluvial Aquifer Cut-off Wall Installation Timeframe

7.4.2 Alluvial Aquifer Interception Borefields Option

The anticipated timeframe for the installation of the alluvial aquifer interception borefields is provided in Figure 7-4, broken down into key schedule items. The anticipated timeframe indicates an installation timeframe of 11 months for the interception borefields.

Schedule Items	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Testing Program / Detail Design												
Preparation of Scope of Work												
Invitation to Submit Tenders												
Review of Submitted Tenders												
Finalisation of Contract												
Field Program												
Detailed Design												
Interception Borefields Installation												
Preparation of Scope of Work												
Invitation to Submit Tenders												
Review of Submitted Tenders												
Finalisation of Contract												
Materials / Equipment Procurement												
Interception Borefields Installation												

Figure 7-4: Anticipated Alluvial Aquifer Interception Borefields Installation Timeframe

7.4.3 Alluvial Aquifer Interception Trenches

The anticipated timeframe for the installation of the alluvial aquifer interception trenches is provided in Figure 7-5, broken down into key schedule items. The anticipated timeframe indicates an installation timeframe of 10 months for the interception trenches.

	Months											
Schedule Items	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Testing Program / Detail Design												
Preparation of Scope of Work	■											
Invitation to Submit Tenders	■	■										
Review of Submitted Tenders		■										
Finalisation of Contract			■	■								
Field Program				■								
Detailed Design				■								
Interception Trenches Installation												
Preparation of Scope of Work						■						
Invitation to Submit Tenders						■	■					
Review of Submitted Tenders							■					
Finalisation of Contract								■	■			
Materials / Equipment Procurement									■			
Interception Trenches Installation										■		

Figure 7-5: Anticipated Alluvial Aquifer Interception Trenches Installation Timeframe

7.4.4 Bedrock Aquifer Interception Borefields

The anticipated timeframe for the installation of the bedrock aquifer interception borefield is provided in Figure 7-6, broken down into key schedule items. The anticipated timeframe indicates an installation timeframe of 12 months for the interception borefields.

Schedule Items	Months											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Testing Program / Detail Design												
Preparation of Scope of Work	■											
Invitation to Submit Tenders	■	■										
Review of Submitted Tenders		■										
Finalisation of Contract			■	■								
Field Program				■	■							
Detailed Design					■							
Interception Borefield Installation												
Preparation of Scope of Work							■					
Invitation to Submit Tenders							■	■				
Review of Submitted Tenders								■				
Finalisation of Contract									■	■		
Materials / Equipment Procurement										■	■	
Interception Borefield Installation											■	■

Figure 7-6: Anticipated Bedrock Aquifer Interception Borefield Installation Timeframe

8 PREFERRED IMPACT AREA REMEDIATION OPTION/S

This section of the report addresses item 4, of the EE Notice:

Identify a preferred option/s for both the remediation of identified impacts to the receiving environment, and measure to prevent or limit any future impacts. Provide justification for the nominated option/s, which includes assessment against best practice environmental management; and identify a timeframe for implementation of the nominated option/s.

8.1 Preferred Option/s Assessment Results

Impacts to the receiving environment EVs as a result of seepage from the BSOC WRD landform have been assessed for groundwater (alluvial and bedrock), surface water, sediment / soil quality and flora / fauna. Currently, no existing impacts to the receiving environment EVs have been identified and the potential for future impacts will require the implementation of an adaptive management strategy comprising ongoing monitoring, impact assessment and, if required, implementation of a preferred mitigation option/s. Therefore, the immediate implementation of a preferred impact mitigation option/s is not considered necessary.

The monitoring program to be implemented as part of the adaptive management strategy comprises:

- Surface water (within the water course downstream of BSOC WRD North and South Seepages prior to the confluence with Hazeldene Creek):
  - Installation of rising-stage samplers to allow collection of surface water samples following rainfall / surface water flow event, including “first flush” flow and longer-term flow
  - Sample collection should be event-based, with samples collected following rainfall / surface water flow event for analytical testing. New sample bottle should be replaced in the rising-stage samplers immediately following sample collection. The analytical suite for testing includes:
    - Physico-chemical parameters – pH, EC, TDS, Temp, Redox
    - Major ionic constituents – Na, Mg, K, Ca, CO_3, HCO_3, Cl, SO_4
    - N-species – total N, nitrate, nitrite, Ammonia as N
    - Metals – Al, Sb, As, Ba, Be, Bi, Bo, Cd, Cr, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Ag, Sr, Th, Ti, U, V, Zn
- Alluvial aquifer (BSOC_A1, BSOC_A2 – BSOC WRD South Seepage; BSOC_A3, BSOC_A4 – BSOC WRD North Seepage):
  - Groundwater levels – quarterly frequency (to capture seasonal variability); groundwater level data-loggers should also be installed to allow automated daily measurements of groundwater levels,
  - Groundwater quality – quarterly frequency (to capture seasonal variability):
    - Physico-chemical parameters – pH, EC, TDS, Temp, Redox
    - Major ionic constituents – Na, Mg, K, Ca, CO_3, HCO_3, Cl, SO_4

        - N-species – total N, nitrate, nitrite, Ammonia as N
        - Metals – Al, Sb, As, Ba, Be, Bi, Bo, Cd, Cr, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Ag, Sr, Th, Ti, U, V, Zn

- Bedrock aquifer (Bore 23, Bore 24, MIOP1 / S2, BSOC_B1, BSOC_B2, BSOC_B3, BSOC_B4 BSOC_B5, BSOC_B6):
    - Groundwater levels – quarterly frequency
    - Groundwater quality – quarterly frequency:
        - Physico-chemical parameters – pH, EC, TDS, Temp, Redox
        - Major ionic constituents – Na, Mg, K, Ca, CO_3, HCO_3, Cl, SO_4
        - N-species – total N, nitrate, nitrite, Ammonia as N
        - Metals – Al, Sb, As, Ba, Be, Bi, Bo, Cd, Cr, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Ag, Sr, Th, Ti, U, V, Zn
- BSOC WRD landform seepages:
    - Seepage flow rates (Weir 1, Weir 2, Weir 3) – automated monitoring (0.5 minute intervals), quarterly downloads with manual reading for flow verification
    - Seepage water quality (BSOC WRD South Seepage, BSOC WRD North Seepage, TD3 Seepage) – quarterly frequency:
        - Physico-chemical parameters – pH, EC, TDS, Temp, Redox
        - Major ionic constituents – Na, Mg, K, Ca, CO_3, HCO_3, Cl, SO_4
        - N-species – total N, nitrate, nitrite, Ammonia as N
        - Metals – Al, Sb, As, Ba, Be, Bi, Bo, Cd, Cr, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Ag, Sr, Th, Ti, U, V, Zn
- Flora:
    - The monitoring of vegetation condition was considered as a recommendation, however compared with monitoring water quality this was considered to be a lagging indicator (as some vegetation may take several seasons to show signs of stress from contaminants) and therefore any mitigation measures proposed as a result of water quality monitoring program would be appropriate.

At the completion of each quarterly monitoring round, and following the collation of the monitoring data, a review of the monitoring data set, including historical monitoring results, should be conducted. The objective of this review will be to identify potential changes to the BSOC WRD landform seepage characteristics; the seepage plume characteristics; downstream surface water quality and, potential impacts to the receiving environment (surface water quality monitoring and/or seepage plume characteristics). The review will identify whether or not implementation of a seepage mitigation option/s is required.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Seepage Mechanisms and Extent

Data compiled from previous investigations and during the field investigation program were used to conceptualise the hydrogeological system, the BSOC WRD landform and the interaction between these systems. Key components of these systems include:

- Aquifer characteristics in the hydrogeological system
  - aquifer extents
  - groundwater levels and flow gradients
  - aquifer hydraulic parameters
  - groundwater quality
- BSOC WRD landform
  - reconstructed landform, including surfaces for the original topography, the buried TSF3 and the buried TSF5
  - waste rock and tailings geochemistry
  - interpreted hydraulic parameters for the waste material (waste rock and tailings) in the BSOC WRD landform
  - seepage water quality

Conceptualisation of the hydrogeological system and the BSOC WRD landform, as well as the assessment of the waste rock and tailings geochemistry, the seepage hydrochemistry and the downstream groundwater hydrochemistry, provided the basis for the seepage analysis. The combined results of these assessments provided an understanding of the seepage characteristics – the seepage extent, proportion of seepage source contribution, interpreted timeframe of seepage development and predicted timeframe for seepage migration.

Historical groundwater monitoring (levels and water quality) has indicated groundwater mounding within the vicinity of the BSOC WRD landform. Groundwater quality records have indicated increased concentrations of selected parameters from bores within the vicinity of BSOC WRD, which are comparable to parameter concentrations from the BSOC WRD seepages. Both of these items of evidence indicate that seepage migration in the alluvial and bedrock aquifers are driven by seepage / infiltration from the BSOC WRD landform.

BSOC WRD seepage migration has been identified in the alluvial aquifer downstream of TD3 Seepage, BSOC WRD North Seepage and BSOC WRD South Seepage:

- TD3 Seepage – Downstream of TD3 Seepage the extent of the BSOC WRD seepage migration is to the discharge location at the KSOC pit. The alluvial aquifer downstream of TD3 Seepage is saturated as a result of seepage from TD3 Seepage and the collected seepage from the BSOC WRD North and South Seepages discharging into the diversion drain.

- BSOC WRD North Seepage – The extent of seepage migration in the alluvial aquifer downstream of the BSOC WRD North Seepage (alluvial extent to the north) is interpreted to be ~200 m to the north of the diversion drain. This interpretation is based on the groundwater quality results from monitoring bore BSOC_A3 (based on an interpreted seepage extent trigger of sulphate = 1,000 mg/L), and further supported by the lack of groundwater in monitoring bore BSOC_A4.
- BSOC WRD South Seepage – The extent of the seepage migration in the alluvial aquifer downstream of the BSOC WRD South Seepage (alluvial extent to the west of the seepage) is interpreted to be ~300 m to the west of the BSOC WRD South Seepage. Sulphate concentrations from alluvial aquifer monitoring bores located downstream of the BSOC WRD South Seepage (BSOC_A1 and BSOC_A2) indicate that the seepage has migrated beyond BSOC_A2 (~5,500 mg/L) and has not reached BSOC_A1 (~580 mg/L).

BSOC WRD seepage migration in the bedrock aquifer was interpreted based on the groundwater quality results from monitoring bores installed in the weathered bedrock / bedrock aquifer, including bores installed as part of the Phase 2 field investigation program targeting previously interpreted discrete geological structures. As per the alluvial aquifer, a sulphate concentration of 1,000 mg/L was adopted as an indicator of the seepage front. Weathered bedrock / bedrock aquifer water quality results indicate that the BSOC WRD seepage extent is generally localised to the BSOC WRD landform with two zones of seepage migration; to the north of TD3 Seepage, and to the west of BSOC WRD South Seepage. Bedrock aquifer seepage migration extends to the north of TD3 Seepage to ~800 m and seepage migration to the west of the BSOC WRD South Seepage to ~350 m.

The analytical results were compared to the existing groundwater quality data. Analytical contaminant transport analyses were undertaken to assess the travel time of the seepage migration front, and to predict the timing of further migration of the seepage. For conservatism sulphate was used as the contaminant parameter, while the extent of the focus area was used as the receptor for the simulation. The nearest receiving environment receptor to the focus area for the alluvium aquifer is Hazeldene Creek and the Leichhardt River (2 km and 1.1 km downstream of the BSOC WRD North and South Seepage, respectively); and, Spear Creek, which is located a 5.3 km to the north of TD3 Seepage. The analytical assessment is based on the assumption that seepage commenced during the development of underlying TSFs (i.e. TSF3 for TD3 Seepage; and, TSF5 for BSOC WRD North and South Seepages). The analytical assessment results indicate that the seepage migration in the bedrock aquifer to the north of TD3 Seepage has taken ~63 years to develop; and based on the current migration rate the seepage front may reach Spear Creek (~5.3km) in another 465 years.

Water quality data from impacted groundwater monitoring bores, BSOC WRD seepages and tailings seepage water (TD5 pit) were assessed to identify the source of the BSOC WRD seepages and the downstream impacted groundwater. This assessment indicates that both BSOC waste rock leachate water and tailings seepage water (both TSF3 and TSF5) are likely to be contributing to seepages from the BSOC WRD landform.

9.2 Seepage Mitigation Options Evaluation

The impact assessment shows that these potential options are not currently justified. Notwithstanding, potential options are presented here for the purposes of meeting the EE Notice requirements.

Mitigation options to prevent / reduce seepage in the alluvial and bedrock aquifers have been identified. These mitigation options, associated costs and anticipated implementation schedule are provided in the following:

- Alluvial aquifer seepage mitigation:
  - Interception borefield; $773,500; 11 months
  - Interception trench; $942,500; 10 months
  - Cut-off Wall; $1,222,000; 12 months
- Bedrock aquifer seepage mitigation:
  - Interception borefield; $988,000; 12 months

9.3 Potential Impact Mitigation

Current impacts to the receiving environment EVs as a result of the BSOC WRD landform seepage have not been identified. The potential for impacts to the receiving environment EVs in the future is uncertain and will require the implementation of an adaptive management strategy comprising the undertaking of an ongoing monitoring program, impact assessment and, if required, implementation of a preferred seepage mitigation strategy. As a result, the immediate implementation of a preferred impact mitigation option/s is not considered necessary.

10 CLOSING

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of Mount Isa Mines Limited. (Client) for the specific application to the Black Star Open Cut Waste Rock Dump Environmental Evaluation. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. In this report, Klohn Crippen Berger has endeavoured to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

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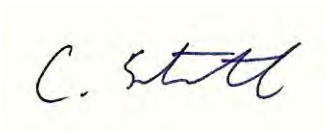

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GLOSSARY OF TERMS

Aquifer: Permeable earth material such as porous sediments or fractured hard rock, saturated with groundwater. The permeability should be such that it is capable of conducting and yielding usable quantities of groundwater to a borehole(s) and / or springs. An aquifer is 'a geological formation which has structures or textures that hold water or permit appreciable water movement through them'.

Aquitard: A confining bed that retards, but does not completely stop the flow of water to or from an adjacent aquifer. Although it does not readily release water to boreholes or springs, it may function as a storage chamber for groundwater.

Chemical attenuation: The capacity of aquifer solids to remove dissolved or suspended contaminants from groundwater and retain them.

Confined aquifer: An aquifer which is overlain by a confining layer of low permeability. The groundwater is confined under pressure greater than atmospheric pressure such that if the aquifer is penetrated the water level may rise above the top of the aquifer.

Confining layer/unit: Geologic material with little permeability or hydraulic conductivity.

Contamination: The introduction into the environment of any substance by the action of man.

Darcy's Law: Darcy's Law is used to calculate the rate at which groundwater is moving in porous media. It states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path and is defined by the following equation:

$$Q = T\,i\,w$$

where:

Q = Discharge

T = Transmissivity

i = Groundwater gradient

w = Length of groundwater unit perpendicular to flow

Dewatering: The process of removing water from an underground mine or open pit, or from the surrounding rock or non-lithified materials. The term is also commonly used for the reduction of water content in concentrates, tailings and treatment sludges.

Dilution: To diminish the concentration by mixing one mass with another. For example, the mixing of one flow of water with another flow to obtain a flow with an intermediate aqueous concentration. This process is used to reduce the concentration of metals or other potentially deleterious contaminants in the more concentrated flow. Dilution may take place by diffusion and dispersion. Dispersion mechanisms include turbulent flow in a river or creek, or currents and wind generated mixing in lakes.

Dissolution: The process whereby solid matter dissolves in a liquid. For example, the dissolving of limestone (calcium carbonate) in rain and groundwater. See also solubility.

Ecosystem: An interconnected and interacting system comprising living organisms – including animals, plants, fungi, and microorganisms - and their non-living environment.

Environmental: The interrelated physical, chemical, biological, social, spiritual and cultural components that affect the growth and development of living organisms.

Geochemistry: Study of the distribution and abundance of elements in *minerals, rocks, soils,* water and the atmosphere.

Geology: The study of the earth, its history and the changes that have occurred or are occurring and the rocks and non-lithified materials of which it is composed and their mode of formation and transformation.

Grain: Crystals or multi-crystal fragments within a *lithified matrix*. For example, sand grains in sandstone and quartz grains in sand sized particles.

Groundwater: The water in the aquifer.

Humidity Cell Test: A *kinetic test* procedure used primarily to measure rates of *acid generation* and *neutralization* in *sulphide* bearing *rock*. Critical test conditions include detailed pre- and post-test sample characterization, running the test for sufficient duration, aerobic weathering conditions, the use of excess drainage to fully dissolve the soluble products of primary *mineral weathering* and conducting the necessary analyses on the drainage to model *mineral* solubility. The accuracy of the subsequent prediction will depend on the test procedures, the *sample* composition, the validity of the various assumptions and the manner in which the analytical data is interpreted. Details of the test protocols are critical to the interpretation and must be included with the results. The standard methodology is to place a *sample* of *rock* (about 1 kg) into an enclosed vertical plexiglass column and expose the *sulphides* within the *rock* to 3 days each of humid and dry air. On the seventh day, the test material is flushed and resultant *leachate sample* is collected and analyzed to determine its chemical composition. Results from the chemical analyses of the leachate are used to calculate primary mineral reaction rates.

Hydraulic conductivity: Describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation. Saturated hydraulic conductivity, Ksat, describes water movement through saturated media.

Hydraulic gradient: The change in hydraulic head or water level over a distance.

Hydraulic head: The height above a datum (such as sea level) of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system.

Hydrogeochemistry: The study of the chemical processes and reactions that govern the composition of water in relation to its interaction with rocks and the aquifer.

Kinetic Test: A procedure used to measure the magnitude and/or effects of dynamic processes including rates of reaction, material *alteration* and *drainage chemistry* and loadings that results from *weathering*. Unlike *static tests*, kinetic tests measure the performance of a *sample* over a prolonged period of time. Material composition and/or environmental conditions are often simplified or controlled to permit measurement of the physical, chemical, or biological characteristics, processes or relationships which are of interest. Kinetic tests have many different forms and locations, including *lysimeters*, field test pads, *leach columns* and *humidity cells.* In ML/ARD studies, the most common form of kinetic tests are laboratory procedures designed to determined the quality of water and rates of reaction resulting form the interaction of water and the mine material Tests can be divided into two categories, those designed to simulate *drainage chemistry* (e.g. *leach columns*) and those designed to measure primary reaction rates (e.g. *humidity cell test*).

Leaching: Dissolution of substances in the soil and removal by percolating water.

Leach Column: A *kinetic test* designed to simulate the *leaching* and secondary *mineral* precipitation and dissolution that determine *drainage chemistry.* In a leach column, the test material is placed in some form of tube and subjected to natural *leaching* in a field test or an artificial *leaching* regime in a laboratory study. Columns are most commonly set up in the laboratory. Laboratory studies attempt to simulate the important aspects of field *weathering* conditions. Secondary *mineral* precipitation and dissolution in the areas of *leaching* may be detected through changes in *leachate* composition. Columns may be constructed of plexiglass to allow the observation of changes in colour or other physical properties. Post-test analysis of the test materials may be used to evaluate changes in the solid phase, spatial variability and/or the *mineral* factors controlling *drainage chemistry*. The accuracy of the subsequent prediction will depend on the test procedures, the *sample* composition, the validity of the various assumptions and the manner in which the analytical data is interpreted. Details of the test protocols are critical to the interpretation and must be included with the results.

Lithology: The systematic description of sediment and rocks, in terms of composition, texture and internal structure.

Metal: A class of chemical elements generally characterized by ductility, malleability, luster and conductivity of heat and electricity including alkali, alkali earth, *base, heavy* and *precious metals*. See also *metalloid*.

Metal Leaching: The extraction of soluble *metals* by percolating solvents. *Leaching* may be natural or induced. Primary *mineral weathering* commonly accelerates *metal dissolution* and removal in *minesite drainage*.

Minor Element: Those elements that commonly occur in geologic materials at concentrations of 0.1 to 1 wt%. Usually includes manganese, phosphorous and titanium.

Model: A formalized expression of a theory, event, object, process or system used for prediction or control; an experimental design based on a casual situation that generates observed data. A model can be viewed as a selective approximation which by the elimination of incidental detail, allows some fundamental, relevant or interesting aspect of the real world to appear in a generalized form.

Particle: Separate fragments in an unconsolidated *matrix*. For example, the particle of various sizes in iwaste rock *and* till. To avoid confusion, it is recommended that use of the term *grain* be limited to crystals or multi-crystal fragments within a consolidated *matrix*. For example, sand grains in sandstone.

Particle Size: The dimension of *particles*. Commonly measured by sieving, settling velocities and image analysis. Particle sizes include the various types of coarse fragments (>2 mm), such as boulders, stones and gravel, and the different *soil-sizes* (<2 mm), *sand* (2mm – 62.5 µm), *silt* (2 µm – 62.5 µm) and *clay* (<2 µm).

Permeability: Refers to the ease with which a fluid can pass through a porous medium. In hydrogeology, permeability is often used synonymously with hydraulic conductivity, which specifically refers to the ease with which water is transmitted through a porous medium. It is defined as the volume of water discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as $m^3/m^2/d$ or m/d).

pH: The negative logarithm to the base 10 of the hydrogen ion activity [H^+] in solution.

Preferential flow: The preferential movement of water through more permeable zones in the subsurface.

Primary aquifer: An aquifer in which water moves through the original interstices of the geological formation, e.g. pores between sand grains. This type of porosity is termed primary porosity.

Rainfall Recharge: Recharge derived from rainfall; see below.

Receiving Environment - The EE notice defines “receiving environment” as *all groundwater and surface water that are not in disturbed areas authorised by this environmental authority and excludes land within the surface water containment areas*.

Recharge: The addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.

Redox Conditions: A measure of the theoretical electron activity of an *environment*. A high redox potential indicates *aerobic* conditions. A low redox potential indicates oxygen poor or reducing conditions.

Rock: Naturally formed, solid mass of one or more *mineral, amorphous* inorganic matter or organic matter.

Saturated zone: That part of the geological stratum in which all the voids are filled with water under pressure greater than that of the atmosphere.

Secondary aquifer: An aquifer in which water moves through the secondary interstices, which are a result of post-depositional processes, such as joints and faults.

Sediment – Solid fragmental materials, both inorganic and organic, that have been deposited after being transported by air, water, or ice, chemically precipitated from solution or secreted by organisms.

Seepage - The EE notice defines "seepage" as *any liquid originating from the Black Star Waste Rock Dump footprint regardless of its contaminant concentration that has the potential to enter the receiving environment.*

Soil zone: The usually thin upper surface layer of the earth's crust comprising living organisms, organic matter, decomposed rock or unconsolidated sediments, water and gases with properties attributable to the interaction of its parent material, time, climate, fauna and flora.

Solubility: The quantity of solute that dissolves in a given volume and type of solvent, at a given temperature and pressure, to form a saturated solution. The degree to which compounds are soluble depends on their ability and that of the other dissolved *species*, to form ions and aqueous complexes in a particular *drainage chemistry*.

Speciation: The chemical form in which an element is present or the process whereby various states or forms of an element become differentiated into ions.

Species: A chemical entity such as an ion, atom or molecule.

Sorption: The attachment of an ion, molecule or compound to a charged surface of a particle, usually a clay or organic matter.

Storativity: The storage coefficient or storativity is a measure of the volume of water per volume of aquifer released as a result of a change in head. For confined aquifers, the storage coefficient is equal to the product of the specific storage and aquifer thickness.

Sulphate: A *mineral*, compound or ion containing the SO_4^{2-} functional group in which sulphur is in the +6 oxidation state.

Sulphide: A *mineral*, compound or ion containing the S_2^{2-} or S^{2-} functional group in which sulphur is in the -1 or -2 oxidation state. Sulphide minerals also contain *metals* (e.g., pyrite, FeS_2, galena, PbS or chalcopyrite, $CuFeS_2$) or *metalloids* (e.g. arsenopyrite, FeAsS).

Sulphide Oxidation: Exothermic *oxidation* of chemically reduced *sulphide* (S_2^{2-} or S^{2-}) to a partially or fully oxidized form, such as *sulphate* (SO_4^{2-}). One indication of *sulphide oxidation* is elevated *sulphate* concentrations in *drainage*.

Sulphide-Sulphur: Sulphur occurring in the *sulphide* oxidation state. The analysis for sulphide-sulphur is one in a series of sulphur analyses that are a part of Acid Base Accounting. Expressed as % S.

Tailings – The ground *rock* waste product from a *mill* or *process plant*, the materials remaining after the economically valuable elements are removed from the *ore*. Ti remove the valuable elements, blasted *rock* typically goes through several steps of crushing and extraction or washing. The *tailings* usually leave the *mill* as a *slurry* of *sand sized* and/or *silt sized particles* in water. *Tailings* are commonly stored in a surface *impoundment* but can also be placed sub-aqueously in natural water bodies or backfilled into *underground workings.*

Total Sulphate-Sulphur: All sulphur occurring as *sulphate*. One in a series of sulphur analyses that are a part of Acid Base Accounting. Expressed as % S.

Total Sulphur: All the sulphur in a *sample*. One in a series of analyses that are a part of Acid Base Accounting. Expressed as % S. See also *sulphide-sulphur, acid leachable sulphate0sulphur, total sulphate-sulphur, organic-sulphur, del % S*.

Trace Elements: Those elements that commonly occur in relatively small concentrations, such as boron, cadmium, and cobalt. Elements that commonly occur in geologic materials at concentrations of less than 0.1 wt% or in water at concentrations less than 1 mg/L. Includes all *precious metals* and *base metals*, with the exception of aluminum and iron. See also *major elements* and *minor elements*.

Transmissivity: Transmissivity is the rate at which water is transmitted through a unit thickness of aquifer under a unit hydraulic gradient (Driscoll, 1986). It is the product of the hydraulic conductivity and the contributing thickness of the aquifer to flow.

Unconfined aquifer: An aquifer whose upper surface (water table) is free to fluctuate.

Unsaturated zone: That part of the geological stratum above the saturated zone in which the voids contain both air and water.

Waste Rock: Rock with insufficient amounts of economically valuable elements to warrant its extraction, but which has to be removed to allow physical access to the *ore*. *Waste rock* is typically blasted into smaller *particles* to allow its removal by truck and shovel. Disposal occurs in *sub-aerial* or *subaqueous* surface *dumps* or *backfill* to *open pits* or *underground workings*. In *heap leaching*, spent *ore* is sometimes referred to as *waste rock*. In coal mining, *waste rock* may be referred to as “spoils”, “gob”, or “rejects”, terms which can also apply to waste materials from the density separation and the *wash plant*. See also *coarse refuse, fine refuse* and *mined-rock piles.*

Waste Rock Dump: A *mined rock pile* containing *waste rock*.

Water Balance: A term used in the context of mining to describe an inventory of *drainage* inputs and outputs, water volumes and the rate of flow. The water balance should be provided for each *mine component* that is an *ML/ARD* concern and for the site as a whole, at selected periods throughout the *mine*’s history.

Water Table: The top of an unconfined aquifer, where the aquifer is fully saturated and the water pressure is equal to atmospheric pressure. Usually measured in metres below ground level or below top of casing.

Water Quality: Chemical and physical properties defined by measureable attributes of water, *sediment* and aquatic life, compared to a standard or criterion. See also *drainage chemistry* and *receiving environment objectives*.

Weathering: The processes by which *particles, rocks* and *minerals* are altered on exposure to surface temperature and pressure and atmospheric agents such as air, water, and biological activity.

Whole-Rock Elemental Analysis: *Assays* which measure the total concentration of cations in the solid phase. Common procedures include XRF and wet chemical digestion methods. Concerns include accuracy, detection limits and, for wet chemical digestions, the potential for incomplete digestion.

APPENDIX I

Environmental Evaluation Approach

APPENDIX II

Site Investigation Report

APPENDIX III

Seepage Weir Design Report

APPENDIX IV

Receiving Environment (Flora and Fauna) Assessment