EVALUATION OF LYDIAN AMULSAR GOLD MINING PROJECT: ASSESSMENT OF ARD POTENTIAL AND EFFECTS ON SURFACE WATER AND GROUNDWATER

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DISCLAIMER

The opinions expressed in this Report have been based on the information supplied to Blue Minerals Consulting (BMC) by Mr. Harry Bronozian and from publicly available reports and documents. The opinions in this Report are provided in response to a specific request from HB to do so. BMC has exercised all due care in reviewing the supplied information. Whilst BMC has reviewed key supplied data the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. BMC does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this Report and features as they existed at the time of BMC's investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this Report, about which BMC had no prior knowledge nor had the opportunity to evaluate.

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1. SUMMARY AND ASSESSMENT

1.1 Purpose and Scope of Review

The Lydian-owned Amulsar gold mine site is located in mid-southern Armenia with estimated resources of 2,030,000 oz of gold and 13,930,000 oz of silver (total measured and indicated). Construction is due to be completed in January 2018 with mining then commencing (http://www.mining.com/846679-2/). With 40% of capex currently committed (lydianinternational.co.uk/home), this is the first mine Lydian will manage or operate. For Lydian's other mine under consideration (Kela, Georgia) license conditions still require submission of an Environmental Impact Assessment and interim report on potential resources. Geoteam (now Lydian Armenia as of 2016), responsible for preparation and/or consideration of all documentation relating to acid rock drainage in the Amulsar development, is a wholly-owned Lydian company registered in Armenia.

The site of the mine is mountainous (2,800 m). Temperatures vary from over 20°C in summer to –10°C in winter. The site is subject to significant snowfall. Precipitation is estimated on average to be in the order of 670 mm/annum with a typical wet year having in the order of 1,059 mm precipitation (from Table 2.4.2, ESIA, 2016).

> "Groundwater within the Project area feeds springs and recharges the main rivers, which include the Vorotan, Arpa and Darb. Spring and river water is used variously for drinking and irrigation supply, in fish farming and for hydroelectric power generation." (from Non-technical Summary, Evironmental and Social Impact Assessment, June 2016, prepared by Geoteam).
>
> "The Vorotan, Darb and Arpa rivers, located near the Project, are tributaries of the River Araks, which forms the border between Armenia and Iran and flows south-east to the Caspian Sea. These rivers are therefore not part of the natural Lake Sevan catchment. However, an operational tunnel links the Arpa River at Kechut Reservoir and Lake Sevan, to support declining water levels at the latter." (from Section 4.10, NI 43-101 Technical Report Amulsar Updated Resources and Reserves Armenia, March, 2017, prepared by Samuel Engineering)

The role of Blue Minerals Consultancy was to examine the geochemical and acid rock drainage (ARD) testing, conclusions and management plans, to evaluate the suggested impacts, and to suggest further testing to clarify some of these impacts (technical and economic) locally and at Armenian Government level. Our expertise is derived from over 40 combined years of research, analysis and technical advice with 15 companies on ARD mechanisms, outcomes and remediation strategies.

This review is based on the June 2016 Environmental and Social Impact Assessment (ESIA) and the Amulsar Project Geochemical Characterization and Prediction Report – Update, 31st, August 2014 by Global Resource Engineering. The ESIA contains a number of sub-reports undertaken by well recognised international companies: Sovereign Consultancy Inc., Golder Associates, Wardell Armstrong International and Global Resources Engineering using standard, international testing, analysis and modelling. We note that Geoteam CJSC (now Lydian Armenia) is a fully-owned subsidiary of Lydian International Ltd.

We have also reviewed NI 43-101 Technical Report Amulsar Updated Resources and Reserves Armenia March 30 2017 by Samuels Engineering (NI 43-101, 2017) for content related to geochemical characterisation and control of ARD. It contains no new information. The stated purpose of this document is to combine the many disparate documents from different consultants into a consolidated single report. However, where other related relevant information is presented we have included this in the following report, in particular the Recommendations (Chapter 26) are reviewed in Chapter 2.

The following sections summarise our findings under the requested Scope of Work. The detailed analysis in the documents is cross-referenced in this Summary.

1.2 Inventory and Review of Documents

The following nine documents from the Environmental and Social Impact Assessment (ESIA, 2016) were reviewed:

1. Non-Technical Summary June 2016, Wardell Armstrong International (Chapter 3 in this report);
2. Environmental and Social Review Summary (Chapter 4 in this report);
3. Chapter 8 Environmental and Social Management Plan, Wardell Armstrong (Chapter 5 in this report);
4. Appendix 8.19 Acid Rock Drainage Management Plan, Geoteam (Chapter 6 and Chapter 6 in this report);
5. Appendix 3.1 Amulsar Passive Treatment System (PTS) Design Basis, Sovereign Consultancy Inc. 9th Dec 2015. (Chapter 7 in this report);
6. Section 6.9 Groundwater Resources, Golder Associates (Chapter 8 in this report);
7. Section 6.10 Surface Water Resources, Golder Associates (Chapter 9 in this report);
8. Appendix 8.22 Surface Water Management Plan, Geoteam (Chapter 10 in this report);
9. Section 6.22 Impact Assessment Summary, Intersocial (Chapter 11 in this report).

In addition a further two documents are reviewed:

10. Amulsar Project Geochemical Characterization and Prediction Report – Update, 31[s]t, August 2014, Global Resource Engineering (Chapter 5 in this report).
11. NI 43-101 Technical Report Amulsar Updated Resources and Reserves Armenia March 30 2017 by Samuels Engineering (NI 43-101, 2017) (Chapter 2)

Document (10) contains the full geochemical acid rock drainage (ARD) characterisation completed to date. Document (11) is referred to where relevant. However, in light of the extensive recommendations (Chapter 26) made in this document we have reviewed these in Chapter 2.

We also note sections 4.8 Groundwater Resources and 4.9 Surface Waters Composition by Golder Associates in Chapter 4 Environmental and Social Baseline (ESIA, 2016) as these provides baseline existing water quality and pH data. Of further interest is the The Preliminary Mine Reclamation, Closure and Rehabilitation Plan (including costs analysis) which is presented in Appendix 8.18, ESIA (2016).

1.3 Scientific Accuracy and Completeness

The quotes in this section are drawn from Section 6, Geochemistry and Management Plan Conclusions, Appendix 8.19, ESIA, 2016 (section 6.4 herein) unless stated otherwise.

It is agreed that the Lower Volcanics (LV) formation that will be excavated in the Amulsar pits will be acid generating. However, it is stated that this formation

> "shows resistance to the formation of strong ARD and resistance to ARD created by ferric iron oxidation of sulfides."

There is no evidence for this recurring statement. The LV waste reacts normally producing ferric iron. This statement is made on the basis that effluent from three of the five humidity cell leach tests undertaken on LV materials did not drop below 4.5. However, these three samples contained 0.8, 0.2 and 0.3 wt.% pyrite sulfur. Hence, their leach behavior reflects their low pyrite content and not any unusual geochemical resistance.

> "The LV formation has been demonstrated to produce ARD with pH >3.0, sulfate concentrations less than 100 mg/L and total acidity of ~100 mg/L $CaCO_3$ equivalent even after decades of exposure to the ambient environment. The LV produces stronger ARD only under extreme conditions, such as long-term humidity cell tests or oxidation over years in a core box."

This statement, in relation to the previous Soviet processed waste dumps Sites 13 and 27, is not supported. ARD with pH 3.5 is found ***even after*** 65 years. This is strong ARD generated under in situ conditions. Approximately 70% of the pyrite already reacted at these Sites will have contributed to the acidity now found in local seeps and streams but this is not recognised.

> "The Upper Volcanics rock type has some trace sulfides, but its oxidized nature and low total sulfide concentration (around 0.15 percent) make it so the low AP [acid potential] of the UV does not realize itself as ARD." (from 24.3.1 Summary of ARD Characterization, NI 43-101, 2017)

This has not been adequately tested in the inadequate suite of humidity cells or any long-term tests. It is not the conclusion of their own categorisation of 'Uncertain to PAG' (potentially acid generating) not NAG (non-acid generating).

> "The Project will have no net discharge of ARD during operations for the first years of operation. During this period, all ARD will be captured and directed to the PD-8 pond. From the PD-8, ARD will consumed as makeup water on the HLF [heap leaching facility]. The water balance (Golder, 2015) predicts that the ARD storage facilities planned for the site are capable of containing an exceptionally wet year or the 100-year 24-hour storm event without discharge. The water balance also predicts that treatment will be required starting in 2021 in the event of a "wet year" condition. As a precaution, the project will construct a passive treatment system (PTS) to treat and discharge contact water when required during the later years of operation and post-closure."

The PTS is an essential addition to mitigation and is the only treatment proposed for BRSF seepage and runoff. It is to be constructed in year 2019. There are major concerns that this PTS will not be able to neutralise and treat the release from the BRSF, particularly as this has been inadequately characterised, with consequent ARD release to the streams, rivers and water storage below the mine.

> "As a result, the goal of the ARD mitigation plan is to encapsulate the LV material before it can develop the conditions required to generate stronger ARD. This will be accomplished by creating LV encapsulation cells in the BRSF [barren rock storage facility] that are isolated from groundwater, surface water, and precipitation. The BRSF will also be rapidly capped as a concurrent reclamation measure. The LV in pit backfill will be managed with rapid placement of a closure cover. As a result of these measures, the predicted intensity of ARD on site will be mild – on the order of what has been observed in the field discharging from the Site 13 and Site 27 Soviet-era exploration adit waste piles."

This is not 'mild ARD intensity' and would not be acceptable in international planning.

> "Upon closure, BRSF, and Pit Backfill will be covered with an ET (evapotranspiration) cover, which limits the infiltration of water and the diffusion of oxygen. However, both the BRSF and Pit Backfill are expected to leach ARD. The BRSF seepage will report to the PTS that will treat the water to Armenian discharge standards. The pit backfill and open pit seepage will discharge a low volume of ARD to seeps and springs that are impacted by naturally occurring ARD with no net impact to baseline water quality."

The discharge from the pits is unacceptable to the local environment, agriculture and communities using water below the mine. It has no planned treatment or mitigation.

> "LV mine waste will be encapsulated within the BRSF to minimize contact with infiltration, seepage, and oxygen. A minimum five-meter-thick NAG buffer zone serves as the basal encapsulation layer. The upper volcanic NAG waste material also serves as a buffer between the encapsulated waste and all final side slopes, benches and top surfaces." (from section 10.2.1.1 Encapsulation, The Amulsar

Project Geochemical Characterization and Prediction Report – Update, 31st, August 2014, prepared by Global Resource Engineering)

According to the geochemical assessments of the Upper Volcanics these are uncertain to potentially acid generating. There is no NAG, non-acid generating, material.

No details on the geochemical modelling methodology is provided. These are incorrectly reported to be contained in Appendix G of the Amulsar Project Geochemical Characterization and Prediction Report – Update, prepared by Global Resource Engineering Ltd, (GRE, 2014) which contains results of the modelling. They also do not appear to be provided elsewhere.

Acid generation from the mineral jarosite (potassium iron hydroxyl sulfate, $KFe_3(SO_4)_2(OH)_6$) leaching is not recognised in either Appendix 8.19 (ESIA, 2016) or GRE (2014); acid generation from leaching of the extensive mineral alunite (potassium aluminium hydroxyl sulfate, $KAl_3(SO_4)_2(OH)_6$) in the wastes is recognised but is suggested to not be significant. For samples containing high percentages of alunite, the contribution to acidity may be significant at pH above approximately 4.5 and for jarosite above approximately pH 3. On-going lime treatment is required to neutralise acid release from jarosite and alunite in the barren rock storage facility until they are exhausted, as recognised by major international companies, e.g. Rio Tinto (Linklater et al., 2012). These minerals cannot be passivated to reduce acid generation rates and this is likely to last more than 20 years at this site.

In all of the modelling of discharge as groundwater and as surface water, there is no specification of the pH at which the estimates of different species were made. These estimates are essentially meaningless without this central parameter that will determine the precipitated and dissolved species. It is probable that pH 4.5 has been used given the arguments raised regarding background "low pH" (not specified) in streams and rivers and their view that alunite (likely responsible for this pH) does not require ARD treatment. The pH of all modelling should be stated.

In the Barren Rock Storage Facility, there is no effective natural neutralisation capacity in the rock material. However, no mention is made of either sourcing or utilising local neutralising materials which may be available according to:

> "Locally, those [deposits] flanking Amulsar, consist of multiple fining-upward cycles of volcanogenic conglomerate and mass flow breccia, fining-upward to volcanogenic and marly mudstones and locally, thin calcilutite limestone." (from Section 1.4 Geology and Mineralization, NI 43-101 Technical Report Amulsar Updated Resources and Reserves Armenia, March 30, 2017, prepared by Samuel Engineering)

1.4 The Potential for ARD at this Site Based on Similar Geologic Conditions in other Site Histories

Two specific sites may be considered to provide context to the serious environmental damage from ARD and to incomplete or inadequate assessment, planning and mitigation strategies:

- Mt Morgan – inadequate ARD in site planning contaminating rivers and streams and on-going costs (Wels et al., 2004; Appendix 1)
- Brukunga – 8 million tonnes of sulfidic overburden material (2 wt.% S) and exposed, on-going pit wall ARD generation (Cox et al., 2006; Appendix 2).

We note that there is no plan to manage ARD from the open pit walls. This will flow untreated to seeps and springs on the mountainside. The open pit walls are a major cause of the 50-year, on-going ARD release from the Brunkunga Mine requiring government funded treatment of release to agriculture in the of order $1M (Australia) p.a. expected for up to 100 years. **This drainage should be pumped or directed for remediation in the same manner as seepage from the barren rock storage facility prior to discharge to waterways.**

The major issue shown by these examples is that the on-going cost to the Government of Armenia after life of mine may exceed income to the State during operation. Fifty to sixty tonnes of acid per kT of barren waste will require on-going neutralisation. **Estimates of acid generation and neutralisation rates, not just amounts as assessed in these reports, are required to quantify treatment costs.**

We also highlight here excerpts from the review Predicting Water Quality at Hardrock Mines Comparison of Predicted and Actual Water Quality at Hardrock Mines, A Failure of Science, Oversight and Good Practice (Septoff, 2006). This article summarises the works by Ann Maest and Jim Kuipers – Comparison of Predicted and Actual Water Quality at Hardrock Mines: The reliability of predictions in Environmental Impact Statements (Kuipers et al., 2006) and Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties and State-of the-Art (Maest et al., 2005).

The excerpts below from Septoff (2006) highlight the current, frequent, gap between predicted and realised water quality due to ARD:

> ***"Predictions vs. Reality: Mines near Water with Elevated Acid Drainage or Contaminant Leaching Potential are High Risk***
>
> Some mine projects are so high risk that water quality exceedances are a near certainty: those mines that are both near groundwater or surface water resources, and possess an elevated potential for acid drainage or contaminant leaching.
>
> - 85% of the mines near surface water with elevated potential for acid drainage or contaminant leaching exceeded water quality standards
> - 93% of the mines near groundwater with elevated potential for acid drainage or contaminant leaching exceeded water quality standards.
> - Of the sites that did develop acid drainage, 89% predicted that they would not.
>
> ***Prediction vs. Reality: Overall Water Quality Impacts to Ground and Surface Water***
>
> Of the 25 mines sampled:
>
> - 76% of mines polluted groundwater or surface water severely enough to exceed water quality standards.
> - 60% of mines polluted surface water severely enough to exceed water quality standards.
> - At least 13 mines (52%) polluted groundwater severely enough to exceed water quality standards.
>
> ***Predictions vs. Reality: the Failure of Mitigation***
>
> Predictions of the efficacy of mitigation were no more reliable than overall predictions of water quality:
>
> - 73% of mines exceeded surface water quality standards despite predicting that mitigation would result in compliance. The other 4 mines didn't predict the need for mitigation.
> - 77% of mines that exceeded groundwater quality standards predicted that mitigation would result in compliance. The other 3 mines didn't predict the need for mitigation."

1.5 The Likelihood of Impacts

1.5.1 Groundwater Impacts

In the key findings of the post-closure model many of the changes (marked in extracts in our review) in groundwater levels (e.g. as much as 60 m lower), redirection and reduction in springs and streams predicted within and around the mine site, both in operation and after closure, appear to be of considerable magnitude. They would certainly impact any bore water being used in the region and should concern the local communities and local governments.

> "Throughout the Project construction, operation, and closure there are some predicted total losses of springs due to construction of the BRSF and the HLF. These impacts are considered significant. However, the impacts cannot be avoided as the facilities are optimally located.
>
> Significant impact to water quality at springs located around the pits is predicted with respect to beryllium, cobalt, nickel and nitrate as a result of leakage from the pits. The increase in beryllium, cobalt and nickel are a result of the release of these constituents from the backfill. These constituents are naturally present in this mineralised area." (from Section 6.9.7 Mitigation Measures, ESIA, 2016)

These elements are released by the acid reactions in the pits and BRSF. These major additions to apparently already high levels should not be acceptable. Design mitigation measures are proposed to limit the leakage from the pits. No further groundwater mitigation options are presented.

> "There is also a significant impact predicted to groundwater quality adjacent to the Vorotan River as a result of leakage from the pits. The change in groundwater quality is high, and the moderate sensitivity of this receptor results in the significant impact. As noted previously, the end receptors of the predicted change in groundwater quality are surface water and ecology. Therefore, no additional mitigation is presented here to limit or avoid this impact." (from Section 6.9.7 Mitigation Measures, ESIA, 2016)
>
> "There is a potentially significant predicted impact to groundwater input to the Spandaryan-Kechut Tunnel. However, groundwater inflow is not intended to be the main source of water in the tunnel that provides supply to the Kechut Reservoir, so this reduction in quality should not be considered as a material impact to water resources in the area. Therefore, no additional mitigation is presented to limit or avoid this impact." (from Section 6.9.7 Mitigation Measures, ESIA, 2016)
>
> No additional mitigation measures are presented that will alter the outcome of the initial assessment. The surface water and ecology impact assessment chapters (Chapter 6.10 and 6.11) should be read in conjunction with this groundwater impact assessment in order to understand the overall significance of the predicted changes in groundwater quantity or quality." (Section 6.9.8 Residual Impact Assessment, ESIA, 2016)

These are serious, honest admissions that should be considered by the Armenian Government and local authorities for their on-going, long-term impact on communities, agriculture and social acceptance of the mine.

1.5.2 Surface Water Impacts

> "Residual surface water impacts are expected to be minor and relate to the alteration of the flow paths of some mountain streams in the vicinity of the HLF and the BRSF; and localised impacts to water quality within wetland ponds to the west of the pits which includes Benik's Pond. Proposed mitigation measures will reduce but may not eliminate the water quality impact to these ponds. Compensatory measures are also proposed to offset the reduction in water quality. The post-closure status of other surface waters will generally be unchanged from existing and/or below MAC [maximum allowable concentration] II standards based on proposed surface water mitigation; the ecological mitigation measures are expected to improve further environmental conditions." (from Section 6.10.10 Conclusions, ESIA, 2016)

Compensatory measures may not meet community, landholder or small businesses dependent on water quality and supply expectations where income is lost on product quality. It needs to be established that this has been fully explained and considered by these stakeholders.

1.6 Reliability and Effectiveness of the Acid Mine Drainage Mitigation Measures

The ratio of Lower to Upper Volcanics is defined in the waste to be stored and managed in Table 16.4 of NS 43-101 but it is also stated that

> "The estimated mine life is a little under 10 years, however, the model contains a significant portion of inferred material, and drilling has identified additional mineralization below the pits that has not been quantified by detailed drilling."
> (from 1.9 Mining, NI 43-101, 2017).

It is likely that this material will be Lower Volcanics and therefore a source of ARD. Given that the Upper Volcanics will be used in the BRSF to encapsulate the already existing Lower Volcanics it is not clear what mitigation strategies will be used for the further likely Lower Volcanic waste rock. **A complete assessment of any wastes not already considered and planned for is required with geochemical testing and full remediation planning prior to further mining being undertaken**.

> "Effluent monitoring from both the BRSF and HLF will continue for a period of 5 years following construction completion of the respective ET covers." (from section 24.4 Reclamation, Closure and Rehabilitation Plan, NI 43-101 Technical Report Amulsar Updated Resources and Reserves Armenia, March 30, 2017, prepared by Samuel Engineering)

Given that acid seepage is likely to peak after this 5 year interval and may continue for decades this duration of monitoring is insufficient. As pit seepage will make its way into spring waters these also should be monitored both off and on-site. **Monitoring should be**

undertaken on-site and off-site at relevant spring and seeps by an independent organisation over at least a guaranteed period of 10 years.

> "The principal objective of the ESMP [environmental and social management plan] to "operationalise" the commitments to environmental and social (as well as occupational health and safety) management and mitigation as identified by the ESIA to ensure that the Project (including construction, operation, closure and post-closure phases) is undertaken in a manner which maximizes the benefits to, and minimises the negative impacts on, the physical, biological, social and archaeological environments in the Project-affected area." (from Section 8.2 Objectives, ESIA, 2016)

This Chapter assigns management roles and responsibilities throughout the ESMS (environmental and social management system) development and subsequent life of mine, corporate ESH&S (environmental, social, health and safety) policies, OHS (occupational health and safety) management and contractor management.

It is surprising that there is no mention of direct responsibility for ARD control in the document. There is no assigned responsibility for implementation of the Appendix 8.19 planning. Specifically there is no assignment of responsibility for ensuring that the identification and dumping of ARD Lower Volcanics barren rock during operation takes place as specified in Appendix 8.19. This fault is common in poor ARD control in many mines where the Mine Manager, with primary focus on production, can and does override the Environmental Manager in correct dumping, encapsulation and dump management. **This is a serious omission requiring correction.**

1.7 Recommendations Regarding Further Technical Tasks

The findings of these reports (specifically Appendix 8.19, ESIA, 2016 and GRE, 2014) **require further testing and analysis before confidence can be established in the predicted geochemical behaviour and hence appropriateness of ARD mitigation measures. Further tests need to be carried out to determine**:

- It will be essential to have a clear estimate of the ratio of high-sulfide Lower Volcanics to "subordinate sulphide" Lower Volcanics in both deposits.
- Further leach studies should be undertaken to more directly assess the high risk (i.e. high pyritic S) samples and to correlate the leach behaviour against mineralogy to establish predictive assessment. These leach studies should be in the form of kinetic leach columns not humidity cells as has been undertaken to date. This will provide a reasonable measure of net acid generation *rate* since it is this (not nett acid generating potential) that will determine requirements for initial and on-going treatment. This is not measured or discussed.
- The mineralogy of the Lower Volcanics is not complete nor is it matched to acid base accounting, sulfide S or humidity cell testing (as carried out to date). Mineralogy is

required on both low and high sulfide S samples with corresponding acid base accounting and standard kinetic leach column tests (see AMIRA, 2002; not humidity cell tests) over at least 1 year for international acceptance of ARD potential.

- Proposed management of Upper Volcanics also requires much more complete information on mineralogy and kinetic leach column testing on higher sulfide S containing samples (>0.5 wt.%S).
- Sulfidised Lower Volcanics testing during mining is essential to identify this material in disposal.
- The identification (by XRD and petrology) of alunite and jarosite, which are recognised ARD generators, need to be incorporated into the mitigation and treatment design. Definition of the leach rates of alunite and jarosite and their impact on pH are required. The concentration of alunite and jarosite in both Upper Volcanics and Lower Volcanics samples needs to be properly analysed and incorporated into ARD control estimation.
- It appears that evaluation of the local sources of neutralising materials has not been considered even though they may be present in the local geology. An assessment of the viability and availability of these materials should be carried out.

The Recommendations in Chapter 26 of the Samuels Report 43-101 to Lydian (March 30, 2017) make this incomplete characterisation and lack of detailed planning completely clear.

- Thirteen tasks are identified to be required to advance the HLF to detailed design level.
- Fourteen tasks, several major and long-term, are identified for the detailed BRSF design.
- **Three tasks, two of which are long-term,** will be required to advance the geochemical characterisation and ARD management to the detailed design level. **These and our recommendations show that the geochemical characterisation and ARD management are not acceptable in present testing and documentation.**
- In Section 26.6 Water Treatment

  "Unlike active treatment systems, a Passive Treatment System (PTS) must be designed to function under site-specific conditions. **To date, no studies have been performed to ascertain the performance of PTS methods on Amulsar ARD. A process verification study must be performed. This study includes benchscale and pilot-scale tests. The process verification studies are long-duration tests that will start during final design and continue into production."** (our bolding)

  This is not acceptable. This should be complete before production. Changes after production have carry-over consequences for ARD control.
- In Section 26.7 Water Balance

  "Additional studies are required to verify predictive models that were used within the water balance. **Site runoff, evaporation, seep and spring flow, surface water flow, and pit dewatering models all require additional model verification against field data.**"(our bolding).

The mine should not have been approved until these tasks and verification were complete. The detailed ARD assessment and control design has not been done. **Finding out after starting the mine that very high cost on-going treatments are required may seriously alter the value to shareholders and the Armenian Government.**

Our recommendation is therefore that mining is not started until these outstanding areas are properly investigated by independent bodies/consultants with the findings incorporated into an ARD management plan incorporating both government and company responsibilities and liabilities.

1.8 Risk Assessment

> “Another example of “imperfect science, imperfectly applied” is the bias of mine water quality predictions made by consultants hired by the prospective mine operator. This problem is implied by the number of site characterization failures, and by the failure to check the results of past mine water quality predictions.
>
> Regulatory agencies, both federal and state, allow the mining company to select and directly pay consultants to predict mine water quality impacts, and to review and comment on (or even reject) those predictions, prior to release to the agency. It is an understatement to say that consultants heavily influence mine water quality predictions.
>
> Unfortunately, given the client/customer relationship between prospective mine operators and their consultants, consultants are rewarded for having favorable predictions. On the other hand a prediction of poor water quality will usually delay a permit, which increases the permitting costs. While exceptions exist, consultants that predict poor water quality often are not rehired. This perverse incentive is contrary to the spirit of unbiased science, and contrary to the public interest.” (from Septoff, 2006)

The single highest risk of ARD damage at this stage of the mine development is that the **specified mitigation measures are either not implemented or are implanted partially or incorrectly**. The central issue here is to clearly state where the responsibility for oversight of this implementation lies in the company and in the Government. Government responsibility should require independent monitoring of the construction and operation phases outside the company. Any variations should be presented and discussed before implementation. In most cases, getting this wrong in ARD control produces $100sM or more liability or inability to fix the ARD problem after the event.

A major technical risk in most ARD management internationally is the confusion of responsibility between construction phase (Construction Manager), operations (Mine Manager) and waste management (Environmental Manager). In construction phase, meeting schedules can override the planned initial dumps and treatment implementation. This needs to be properly monitored by company senior management with Government oversight to avoid mistakes that cannot later be rectified (as in many mines). In the operations phase, with daily (hourly) focus on production and output, plans for ARD dump construction may be overridden by short-term “necessity” to maintain mining, throughput and profit; usually by the Mine Manager). This requires clear statements of the rights of the Environmental Manager and Government agencies to intervene to protect the plans. The long-term costs of getting this wrong are not only liability but inability to control or rectify the ARD damage to the environment and communities.

All other technical and managerial risks and suggested actions are specified in the preceding sections.

In closure phase, the risk from hundreds of examples internationally is that the company profits decline to below debt level and the local (Armenian) company declares bankruptcy leaving the ARD control for many decades to the government. We note:

> “Lydian owns 100 percent of the Amulsar Project and holds all of the titles, rights, benefits and obligations to the Amulsar Gold Project through their wholly-owned subsidiary Lydian Resources Armenia. In turn Lydian Resources Armenia owns 100 percent of Lydian Armenia CJSC (“Lydian Armenia”), previously Geoteam CJSC (“Geoteam”), an Armenian-registered Closed Joint Stock Company (CJSC), which holds 100percent of the current site related prospecting license and mining license.” (from section 1.1 Introduction, NI 43-101 Technical Report Amulsar Updated Resources and Reserves Armenia, March 30, 2017, prepared by Samuel Engineering)

The major issue shown by these examples is that the on-going cost to the Government of Armenia after life of mine may exceed income to the State during operation. Fifty to sixty tonnes of acid per kT of barren waste will require on-going neutralisation. Estimates of acid generation and neutralisation rates, not just amounts based on sulfide assays, as assessed in these reports, are required to quantify treatment costs.

2. RECOMMENDATIONS (FROM NI 43-101)

We include a summary of Chapter 26 (NI 43-101, 2017) due to its importance in highlighting the lack of overall readiness of this project. The tasks identified by Samuel Engineering are numerous, important and some of them require long-term measurements/analysis. The lists of these tasks help to place in context our proceeding discussions and critiques which are specifically focussed on ARD and water quality management and also section 1.7 where our recommendations, specific to ARD, are listed.

> "The Amulsar deposit has the potential to significantly extend the LOM beyond the current 10-year period. AMC [AMC Consultants] recommends a two phased strategy of high-priority and medium-priority drilling. High-priority drilling is focused on the TAA zone to prevent possible sterilization of inferred and potential resources within this area. The drilling and the evaluation of results for this phase must be completed before Year 4 of the current LOM plan for the Amulsar deposit. Second-phase, medium-priority drilling is focused on the Erato zone. This phase of drilling should start during the commencement of Erato mining or shortly thereafter." (from section 26.2 Geology, Exploration and Resources, NI 43-101, 2017).

A key aspect of the design of the barren rock storage facility and ARD mitigation is the encapsulation of Lower Volcanic by Upper Volcanic barren rock material. There is no discussion presented on how future mining would impact on the current or future ARD mitigation plans particular given that further deeper mining may result in a decreased ratio of Upper Volcanics to Lower Volcanic barren rock.

The following tasks are identified for geochemical characterisation and ARD management (from section 26.5 Geochemistry, NI 43-101, 2017):

- Additional studies are required to determine the residual nitrate in barren rock and spent ore.
- On site kinetic geochemical characterization tests are recommended to verify that waste from Amulsar is naturally-resistant to ferric iron oxidation ARD reactions (a critical conclusion of the current state of the site characterization work). These affordable tests are run by on-site personnel using water quality test kits for analysis. The samples are contained in 20L buckets.
- The ARD management plan requires evapotranspiration covers (ET Cover) on the BRSF and HLF. An ET Cover test cell is required to verify the performance of the designed ET Cover under site conditions.

These recommendations show that the current level geochemical characterisation and planned ARD management are not acceptable in present testing and documentation. The mine should not have been approved until this is complete. The detailed ARD control design has not been done. Finding out after starting the mine that very high cost on-going treatments are required may seriously alter the value to shareholders and the Armenian Government.

It is stated in section 26.6 Water Treatment (NI 43-101, 2017) that

> **"**Unlike active treatment systems, a Passive Treatment System (PTS) must be designed to function under site-specific conditions**. To date, no studies have been performed to ascertain the performance of PTS methods on Amulsar ARD.** A process verification study must be performed. This study includes benchscale and pilot-scale **tests. The process verification studies are long-duration tests that will start during final design and continue into production.** (our bolding)

This is not acceptable. Should be complete before production. Changes after production have carry-over consequences for ARD control.

> "Additional studies are required to verify predictive models that were used within the water balance. Site runoff, evaporation, seep and spring flow, surface water flow, and pit dewatering models all require additional model verification against field data." (from section 26.7 Water Balance, NI 43-101, 2017)

In addition, and most importantly for ARD control, the following tasks are identified as being required for the detailed BRSF design (section 26.4 BRSF, NI 43-101, 2017).

- "Finalizing the surficial geology map of Site 27 by Lydian Armenia. Define the limits of scoria lenses and the extents of areas which will require the placement of low-permeability borrow material.
- Conducting a geotechnical site investigation in the PD-7 pond area to evaluate the subsurface conditions for use in engineering analyses and final designs of the pond.
- Performing additional geotechnical laboratory testing on the Site 27 clayey sand soils (SC) to determine their suitability for in-place reworking to construct the soil liner layers in the BRSF subgrade, or to determine the suitability of areas as a borrow source for clay liner that must be placed on the basalt/scoria outcrops.
- Based on laboratory testing results, perform field trials of in-situ compaction on native clayey material to determine maximum relative compaction and permeability practicable for construction.
- Finalizing the design of the drain system using a larger data set for the measured seep flows in Site 27. Perform an analysis of drain pipe crushing resistance.
- Advancing the design of the BRSF phase 1 and phase 2 access roads.
- Advancing the design of the PD-7T pond.
- Refining the material and labor unit rates, as needed, for use in updating the BRSF capital cost estimates.
- The analyses indicate that the stability of the BRSF slopes is primarily driven by the assumed strength of the underlying clay material. Additional site investigation to determine the distribution, thickness, and strength properties of the clay is required for detailed design and prior to construction of the facility.
- It is well known that the friction angle of rock fill material varies as a function of confining pressure (as demonstrated by Leps, 1970 and others). It is recommended that detailed design analyses apply the barren rock strength as a variable strength function using the Leps methodology, or similar alternative methods.

- Simplified seismic displacement analyses should be performed using current state-of-practice methods for detailed design. Methods such as those developed by Bray, 2007 provide improved quantification of seismic risk relative to pseudostatic methods.
- Additional hydrogeologic characterization is required in the BRSF and should be conducted during the next phase of the geotechnical investigation. Elements of the hydrogeologic investigation should include:
  - Packer tests in BRSF geotechnical boreholes;
  - Well installation in BRSF geotechnical borings;
  - Expanded permeability testing of BRSF soils, the basalt formation, and the LV formation in Site 27.

The BRSF engineering plan is not ready for approval.

The following tasks are listed in section 26.3 HLF (NI 43-101, 2017) as being required to advance the HLF to detailed design level. Many of these tasks have the potential to impact on water quality.

- “Finalizing the surficial geology map of Site 28.
- Measuring the seep flows in Site 28 over several months, including the spring snowmelt period, for use in hydraulic calculations and final designs of the underdrains.
- Geotechnical site investigation in the Phase 1 diversion embankment and pond area to evaluate the subsurface conditions for use in engineering analyses and final designs of the embankment and pond.
- Additional geotechnical laboratory testing on the Site 28 mostly cohesive soils to determine their suitability for in-place reworking to construct the soil liner layers in the leach pad and collection pond composite liner systems.
- Laboratory interface shear strength and load puncture testing on the composite liner systems planned for the leach pad to confirm the suitability of the selected geomembranes for the intended pad and ore heap design. The testing would utilize soil liner material from the Site 28 pad area, and the GCL and drain fill materials intended for pad construction.
- Finalizing the design of the underdrains using the measured seep flows in Site 28. And, designing the collection sump to be located downgradient of the collection ponds into which the underdrains will discharge for monitoring.
- Re-running the stability analyses using the composite liner interface shear strength parameters obtained from the laboratory testing to confirm the acceptable leach pad and ore heap stability.
- Performing the required engineering analyses, including seepage and stability, and finalizing the design of the Phase 1 diversion embankment.
- Advancing the hydrology and hydraulics calculations and finalizing the design of the diversion channels including revetments.
- Updating the HLF water balance calculations, as needed, using updated climatic data, HLF layouts and phasing, and operational data and schedule.
- Advancing the design of the leach pad and collection pond components, including revising the pad layout and phasing and the pond sizes and layouts, as needed, and

designing the pad to process pond spillway and the spillways between the collection ponds.

- Finalizing the leach pad and collection ponds grading plan including the site grading cut limits within Phase 1 pad and the ponds excavation/embankment fill plan.
- Refining the material and labor unit rates, as needed, for use in updating the HLF capital cost estimates."

This set of recommendations shows that the engineering design and operation of the HLF are far from ready for approval. The mine is not ready for approval.

3. NON-TECHNICAL SUMMARY (FROM ESIA, 2016)

"This document is a Non-Technical Summary (NTS) of the Environmental and Social Impact Assessment (ESIA) for the Amulsar Gold Project. It provides a summary of the Project and its related ESIA process and provides information on the systems developed to manage the predicted environmental and social impacts of the Project's activities during all phases from construction to closure." (all quotes in this section are from Non-Technical Summary, ESIA, 2016)

Sections relevant to acid mine drainage and its control are summarised below.

3.1 Barren Rock Storage Facility (BRSF) (from section 2.6.2)

"This large mound will be constructed in layers from placed barren rock. The BRSF will increase in height as the mine develops, and its outer facing slopes will be overlain with soil and revegetated progressively during the life of the mine.

Because of the potential for some of the barren rock excavated from the mine to be acid-generating when coming into contact with water, the BRSF has been designed to prevent the natural flow of surface water and groundwater from coming into contact with the stored rock. Rain water and snow-melt runoff will be prevented from flowing into the BRSF by a network of diversion channels and gulleys. These channels will direct surface water around the BRSF and drain to the Arpa River. Surface water from natural springs that flow within the footprint of the BRSF will be collected through a specialised drainage system in the base of the BRSF. This drainage system will prevent the water from coming into contact with the barren rock.

The BRSF will not be enclosed, so rain and snow will land directly on the barren rock and seep into the facility. The seepage will drain through the BRSF and be contained by a compacted soil liner laid at the base of the facility. This water will then be piped to the HLF for use in the leaching process."

A detailed review of the BRSF and control of ARD is presented in Chapter 8 and Appendix 8.19 (reviewed here in Chapters 4, 5, and 6). There is no new information in this general description.

3.2 What are the Potential Impacts on Water Resources and Water Users? (from section 3.3.2)

> “**Surface Water**
> As noted in Chapter 2.6.2, some of the barren rock associated with the Amulsar ore body has the potential to be acid-generating when coming into contact with water. The risk of generating acid rock drainage increases wherever fresh bedrock is exposed, and this will apply during construction and operational activities. The chemical reaction between water, sulphide in the exposed rock, and oxygen in the air creates acidity. This acidity lowers the pH of the water and changes the mobility of metals. Many toxic metals, such as arsenic, lead, and zinc, are more soluble at a lower pH. This process occurs naturally on the sides of Amulsar Mountain, especially in the areas where exposed red-coloured bedrock is visible, and it is the reason many streams in the area are slightly acidic. The generation of acid rock drainage will be accelerated by mining activities because sulphide will be exposed in the pit wall and in the barren rock excavated from the pit. Testing of Amulsar barren rock has shown that dissolved metals are not of significant concern, but elevated sulphate and decreased pH are common in Amulsar acid rock drainage.”

This same argument that more is not a problem is used here. The testing of Lower Volcanic barren rock for rates of acid release has not been adequate (see Chapter 5 Geochemistry).

> “During the post-closure phase of the Project, there is a risk of the generation of acid rock drainage from the BRSF, which could impact surface water if not properly managed, therefore the drainage from the BRSF will continue to flow to the passive treatment system, following closure.”

The passive treatment system is valuable but needs to be tested in practice against flow and acid generation rates to be confident of closure.

> **“Groundwater**
> Acid rock drainage seeping into the ground from the pit could also impact groundwater quality. This could affect springs near to the pits, and groundwater which supports annual flow in rivers. It is important to note that acid rock drainage is naturally occurring in many springs and seeps on Amulsar Mountain. The possible changes in the quality of groundwater discharging as springs have been assessed through technical studies using computer models, which have found that small changes in groundwater quality will probably occur during low-flow conditions in late summer, autumn, and winter close to the mine pits, but the associated changes to surface water quality will be too small to measure.”

The modelling has not specified the pH of the waters in release.

> “During the operational phase, water infiltrating into the BRSF will have poor quality because of contact with acid-generating waste materials, and nitrogen

from blasting residue. This water may change groundwater quality to the north-west of the facility as it flows towards the Arpa River. Approximately 160 million tonnes of barren rock will be placed in the facility over six years, and because of this rapid placement rate the natural water absorption of the rock will limit infiltration through the facility. In addition, during operations perimeter diversion ditches will be in place to direct run-off water around the BRSF and reduce the potential for water to come into contact with the barren rock in the facility. For the seepage that does occur, assessment shows that flow of groundwater from the BRSF to the Arpa River would take more than 100 years. Many constituents present in water in the BRSF would travel much more slowly than this due to physical and chemical processes within the subsurface, taking thousands of years to travel from the BRSF to the Arpa. Small changes in groundwater quality may ultimately occur, but these changes will not result in any change in surface water quality. The direction of flow of groundwater from the BRSF is such that it will not affect water quality in the Madikenc springs which are used for domestic water supply to Kechut and Jermuk. The quantity of water predicted to seep into the BRSF following closure is small because specially designed cover materials will be placed to limit water infiltration."

A detailed summary of the issues in ground water control is presented in Chapter 7 (reviewed from Section 6.9 Groundwater Resources, ESIA, 2016). No additional information is found in this general description.

3.3 What will be done to Manage or Control Impacts? (from Section 3.3.3)

"During closure, specially designed soil cover systems will be placed over the BRSF, HLF and Tigranes-Artavadzes pit to minimise infiltration. Any acid rock drainage seeping from the BRSF post-closure will be routed to the water treatment system which will be maintained at the HLF. At the HLF, rinsing will continue until residual cyanide is destroyed. The spent ore heap will potentially continue to produce poor quality seepage post-closure, but this impact will be limited to elevated sulphate (a natural salt) or nitrate (the HLF will not produce acid rock drainage). Due to these residual water quality issues during the rinsing period of the HLF, water will be treated through the ADR [adsorption desorption and recovery] facility water processing plant. After the pad has drained down to approximately 2 litres per second of discharge, water leaving the HLF will be switched to a second passive treatment (wetland) system, which will remain in place until discharge water quality meets Armenian surface water discharge standards."

The two passive water treatment systems are important and valuable. This section makes no mention of the serious, continuing ARD from the pits that will be released without treatment as reviewed in Chapter 8 (from Section 6.10 Surface Water Resources, ESIA, 2016). In Section

6.10 it is acknowledged that no mitigation measures will be put in place for the pits and pit walls.

4. ENVIRONMENTAL AND SOCIAL REVIEW SUMMARY (FROM ESIA, 2016)

> "This Environmental and Social Review Summary (ESRS) is prepared by IFC [International Finance Corporation] to disclose its findings and recommendations related to environmental and social considerations regarding potential investments. Its purpose is to enhance the transparency of IFC's activities. For any project documentation or data included or attached herein that has been prepared by the project sponsor, authorization has been given for public release by the project sponsor. IFC considers that this ESRS is of adequate quality for release to the public, but has not necessarily independently verified all of the project information therein. It is distributed in advance of IFC Board of Directors' consideration and may be periodically updated thereafter." (all quotes in this section are from , ESRS, ESIA, 2016)

The sections below appear to be the only references to acid generation in this document.

4.1 PS1 Assessment and Management of Environmental and Social Risks and Impacts

"Identification of Risks and Impacts
Passive Treatment Systems – PTS (engineered wetlands) will be developed to treat contact water (including any Acid Rock Drainage) from Year 5 onwards."

4.2 PS3 Resource Efficiency and Pollution Prevention: Water Management

"Water Management
In terms of water quality, the Arpa River exceeds legislated Armenian maximum allowable concentrations (MAC) of several metals, including cobalt, iron, lithium, manganese, molybdenum and sodium. Water in the Vorotan River exceeds the Armenian MAC for cobalt, iron, lithium and manganese. Some surface water flowing in streams from Amulsar Mountain to the Vorotan and Darb Rivers exhibits naturally acidic conditions (low pH) and elevated metal concentrations, with parameters above MAC including the aforementioned metals plus aluminium, beryllium and copper. This chemistry results from the water coming into contact with the metal-rich ore body beneath Amulsar mountain. The Darb River tends to

be slightly acidic, with some tributaries failing to meet the Armenian MAC for some parameters. During the summer months, when water flow reduces, the water becomes slightly more acidic due to a higher amount of groundwater contributing to the stream flow. Chemical analysis shows low or undetectable levels of organic chemicals that are usually associated with agricultural or other human-generated sources of pollution. Community domestic and municipal water supply is predominantly sourced from springs originating from shallow perched water or from groundwater. Jermuk's water is sourced from four groups of springs, one of which, the Madikenc group, is within the Project area. Kechut is also supplied by the Madikenc springs, which are located approximately 2 km east of the town. Gndevaz, Saravan, Saralanj, Ughedzor and Gorayk are supplied by springs located outside the Project's area of hydraulic influence.

In the project area, groundwater is present in several separate groundwater catchments defined by the rivers surrounding Amulsar Mountain. Groundwater feeds the rivers, particularly during the summer, autumn and winter when little rain falls. Surveys of springs throughout the Project area and in Jermuk, and water chemistry analysis (including major and minor ions and isotope testing) **show that groundwater found beneath the footprint of the project does not supply Jermuk's renowned mineral spring waters. Surveys have identified that groundwater is not directly used for drinking water supply (from drilled wells) within the Project area or in nearby towns and villages."** [our bolding, this text is also largely found within the Non-technical summary, reviewed in Chapter 2]

These statements are drawn from studies carried out by Golder Associates which can be found in section 4.8 Groundwater Resources and 4.9 Surface Waters of ESIA (2016).

"<u>Water Management</u>
Some of the barren rock associated with the Amulsar ore body has the potential to be acid-generating when exposed to the atmosphere and water. The risk of generating ARD increases wherever fresh bedrock is exposed, and this will apply during construction and operational activities. This process occurs naturally on the sides of Amulsar Mountain, especially in the areas where exposed red-coloured bedrock is visible, and it is the reason many streams in the area are slightly acidic. Testing of Amulsar barren rock has shown that dissolved metals are not of significant concern, but elevated sulphate and decreased pH are common in Amulsar ARD. During the post-closure phase of the project, there is a risk of the generation of ARD from the Barren Rock Storage Facility (BRSF), which could impact surface water if not properly managed, therefore the drainage from the BRSF will continue to flow to the passive treatment system, following closure. **These passive systems will require periodic maintenance and replacement of some treatment cells in the post closure phase.**" [our bolding]

Estimated costs for rehabilitation can be found in Appendix 8.18 Preliminary Mine Reclamation, Closure and Rehabilitation Plan. It is stated in Appendix 8.18 that

> "It is anticipated that periodic maintenance (approximately 20-year intervals) to replace substrate in some components of the PWTF may be required. Geoteam will develop a monitoring plan during final design to determine when maintenance is required."

5. ENVIRONMENTAL AND SOCIAL MANAGEMENT PLAN (FROM CHAPTER 8, ESIA, 2016)

This document reviews

> "the principal objective of the ESMP [environmental and social management plan] to "operationalise" the commitments to environmental and social (as well as occupational health and safety) management and mitigation as identified by the ESIA to ensure that the Project (including construction, operation, closure and post-closure phases) is undertaken in a manner which maximizes the benefits to, and minimises the negative impacts on, the physical, biological, social and archaeological environments in the Project-affected area." (from Section 8.2 Objectives, ESIA, 2016)

This Chapter assigns management roles and responsibilities throughout the ESMS (environmental and social management system) development and subsequent life of mine, corporate ESH&S (environmental, social, health and safety) policies, OHS (occupational, health and safety) management and contractor management.

It is surprising that there is no mention of responsibility for ARD control in this Chapter. There is no assigned responsibility for implementation of the Appendix 8.19 planning (reviewed here in Chapter 6). Specifically there is no assignment of responsibility for ensuring that the identification and dumping of ARD Lower Volcanic barren rock during operation takes place as specified in Appendix 8.19. This fault is common in poor ARD control in many mines where the Mine Manager, with primary focus on production, can and does override the Environmental Manager in correct dumping, encapsulation and dump management. **This is a serious omission requiring correction.**

> "The Project's construction phase will last for two years. During the 10 years of operations (including pre-production during the construction phase)…." (from Section 8.3 Project Overview, ESIA, 2016).

> "The physical footprint of the Project's facilities [Figure 5-1] will cover 609 ha, and a further 321 ha in areas that are likely to be disturbed by the mining operations. The total disturbed area will be 930 ha. …..Of this overall total of approximately 1,768ha, about 152ha comprise 274 privately-owned plots that Lydian will gain access to through a land acquisition process (Appendix 8.23):

- Heap leach facility (HLF) area: 252 private land plots consisting of approximately 139 ha of arable land, 22ha of orchards and 14ha of pasture/hay land, to be acquired permanently for the Project…" (from Section 8.3 Project Overview, ESIA, 2016)

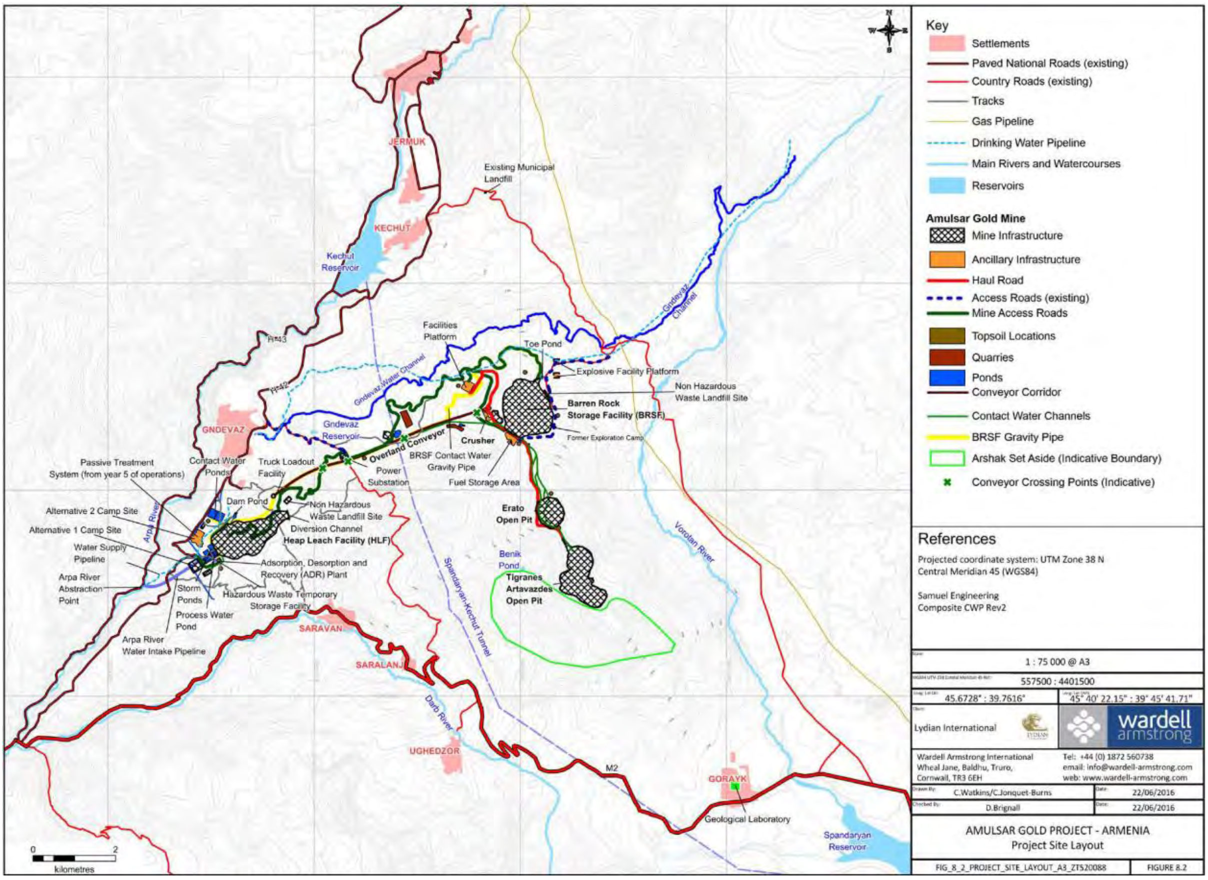

Figure 5-1 Project site layout (from Figure 8.2, ESIA, 2016).

> "The BRSF will include a barren rock storage pad and a toe pond connected via pipeline to the passive water treatment system (PWTS) at the HLF. **Post-closure the PWTS could be relocated down-gradient of the barren rock storage pad if necessary**." (from Section 8.3.3. Construction, ESIA, 2016 – our bolding)

This possible relocation may be in recognition of the possible underestimation of ARD from the LV in the BRSF.

> "At closure the PTS, which would have been operational since year 5 of operations is the preferred option to mitigate the potential formation of ARD from the BRSF. Passive water treatment systems do not require continuous chemical inputs and take advantage of naturally occurring chemical and biological processes to treat ARD (see Appendix 3.1). After the BRSF outflow water has passed through the PTS, the water will be collected and monitored prior to discharge into the natural

environment. The PTS output will comply with RA, IFC and European Union water discharge standards.” (from Section 8.3.4 Operations and Closure, ESIA, 2016)

“Closure and rehabilitation include the reclamation of the open pits, barren rock storage facility, and heap leach pad / ponds, together with the dismantling of infrastructure and restoration of these and other disturbed areas to grasslands that support habitats similar to those currently present within the Project.” (from Section 8.3.4 Operations and Closure, ESIA, 2016)

There is no plan to manage ARD from the open pit walls. This will flow untreated to seeps and springs on the mountainside. The open pit walls are the cause of the 50-year, on-going ARD release from the Brunkunga Mine (Appendix 2) requiring government treatment of release to agriculture of order $1M (Australia) p.a. expected for up to 100 years.

In Section 8.6.2 Lydian HSEC (health, safety, environment, community) Functions responsibility for correct dumping and operation of BRSF, PWS and other ARD control is not defined.

“The Site Environment Manager is responsible for environmental management during construction and operations at Amulsar. Reporting to the Senior Manager HESS, he/she develops the necessary procedures, plans and training requirements for on-the-ground implementation of Lydian environmental policy and the environmental commitments made in both the approved regulatory EIA and the ESIA undertaken to comply with international financing institutions' requirements.

The Environment Manager’s functions include:

- Day-to-day water, noise, air quality, and footprint management, including compliance checking of contractor activities (as per the Compliance Assurance Plan; see Section 8.10);
- Liaison with contractors' environmental staff;
- Management of environmental monitoring and reporting;
- Training of environmental staff and contractors;
- Oversight of biodiversity initiatives;
- Management of the Site Environment Advisors; and
- Oversight of cultural heritage management.” (from Section 8.6.2 Lydian HSEC Functions, ESIA, 2016)

This does not include any explicit role in management of ARD.

6. GEOCHEMISTRY (FROM APPENDIX 8.19 ESIA, 2016; GRE, 2014)

6.1 Introduction

The report by Global Resources Engineering Ltd (GRE, 2014) built on a previous geochemical assessment by Golder Associates in 2013 (not available). The aim of the report by GRE was to provide "an assessment of the long term geochemical and environmental behaviour of various waste types, and assessing the impact of associated site facilities."

The geochemical characterisations described in the GRE (2014) report were a combined set from the initial Golder Associates report and a new suite of samples. Some of the original data was discounted as not being representative of barren rock. The GRE (2014) report was further summarised in Appendix 8.19 of the Environmental and Social Impact Assessment (ESIA, 2016).

We review here the geochemical characterisations undertaken, conclusions drawn from these and discuss further analyses required for acceptable understanding of the ARD characteristics of the likely waste rocks. To the best of our knowledge no further geochemical analyses/interpretation has been carried out.

We do not review Chapter 10 ARD Management and Mitigation Plan: Operation Phase or Chapter 11 ARD Management and Mitigation Plan, Closure Phase (GRE, 2014), as these sections have now been superseded in Appendix 8.19 ESIA (2016) which is reported in Chapter 6). The sources of data, figures and tables from both reports (GRE, 2014; ESIA, 2016) are provided for future cross-reference.

6.2 Geochemical Characterisation Tests

Table 6-1 provides the numbers and types of geochemical tests that have been undertaken.

Eight mineralogical examinations are indicated for the Tigranes/Artavasdes (Tig/Art) samples but nine are provided in the original Table C-1 (GRE, 2014). No NAG pH testing is indicated for Tig/Art, however an average 'NAG pH @ 20.3°C' is provided in Table 7.3 (GRE, 2014) and data is provided in Table D-4 (GRE, 2014). No NAG effluent results were located for the Borrow Materials.

Table 6-1 Sample numbers and characterisation tests (from Table 4-1, GRE, 2014).

Material Type	ABA	NAG pH testing	Bulk chemistry	Mineralogy	SPLP effluent testing	NAG effluent testing	Humidity cell testing
Barren Rock – Tig/Art	154		97	8	8	8	8
Barren Rock - Erato	80	50	42	12	9	12	
Spent ore – Tig/Art	6				6		
Spent ore - Erato	7	7	7		7	7	
Borrow materials	5	5	5		5	5	

Notes on methods:

- Acid base accounting (ABA) testing was conducted using the Modified Sobek Method (Sobek, 1978, with modifications based on Lawrence and Wang, 1996). ABA testing consisted of paste pH, sulfur speciation, acid neutralisation potential (NP).
- We assume that sulfate S is measured via water extraction and sulfide S is measured via acid extraction **but the methods are not given in either document**.
- The synthetic precipitation leaching procedure (SPLP) was based on EPA Method 1312 (2008).
- The net acid generation (NAG) effluent test involves reaction of a sample pulp with a 15 percent hydrogen peroxide solution at a 100:1 solution-to-rock ratio and overnight standing before pH measurement of leachates generated from the net acid generation (NAG) procedure (AMIRA, 2002).
- It is stated that "The NAG and SPLP tests were used to provide estimated upper and lower boundaries, respectively, for predicted future effluent water quality associated with waste materials at the Amulsar site."
- It is stated that "Long-term humidity cell geochemical kinetic tests were performed on Amulsar barren rock (ASTM D5744- 07e1, 2007). This test produces an over-estimate of the acid generation potential and metals leaching potential of a rock over time due to the following issues:
  - The cells are held at a constant temperature of 20°F.
  - The cells are kept at 100 percent humidity for a week, then flushed with 1L of distilled and deionized water;
  - The cells require a 1/4 inch crush size, far smaller than in Run of Mine (ROM) waste." (from section 3.9 Kinetic geochemical testing, Appendix 8.19, ESIA 2016)

This is a misunderstanding. The point of the Humidity Cells is not acid generation potential. It is rate of acid generation. There is no other data presented on this critical factor.

Notes on nomenclature:

- AP – Acid potential = total sulfur content (wt.%) × 31.25 kg $CaCO_3$/tonne (or T $CaCO_3$/kT). The calculation of AP assumes that all S (*i.e*. total sulfur) is potentially acid generating.
- AGP – Acid generating potential = sulfide S (wt.%) × 31.25 kg $CaCO_3$/tonne (or T $CaCO_3$/kT) (assumed definition).
- NP – Neutralising potential, measured using Sobek test (assumed ANP is the same value).
- Total S is composed of pyritic S + non-extractable S + sulfate S.
- Non-sulfate S is composed of pyritic S + non-extractable S.
- NNP – Net Neutralisation Potential = NP–AP or ANP–AGP.
- NPR – Neutralization Potential Ratio =NP/AP or NP/AGP.
- NNP and NPR have been interpreted using criteria given by White et al. (1999 note: the date of 1998 was given in the GRE, 2014 but no reference was provided and one could not be found) and Price (2009) respectively, given in Table 6-2.

Table 6-2 shows the screening guidelines for acid rock drainage generation prediction. This is used to characterise samples based on their ABA characteristics. However, for these samples the neutralising potential is very low and therefore the value of NPR can be very low even when the acid generating potential is small. **For this reason we view the values of NPR with caution.** NNP summary statistical data (Table 6-4 and Table 6-9) are calculated using all data available whereas NPR statistics were "produced after eliminating records with NPR values less than or equal to zero. The Tig/Art NPR results are based on 78 records, the Erato results on 52." (Section 5.6, GRE, 2014).

Table 6-2 Screening guidelines for acid generation potential prediction (from Table 5-6; GRE, 2014).

Material Designation	Comparative Criteria	
	NNP (T $CaCO_3$/kT)	NPR
Potentially acid generating (PAG)	< –20	< 1
Uncertain	–20 < NNP < 20	1 < NPR < 2
Non potentially acid generating (NPAG)	> 20	>2

6.3 Tigranes/Artavasdes Barren Rock

Tig/Art ABA testing was carried out on 10 colluvium (Col) samples, 83 lower volcanic (LV) samples, 54 upper volcanic (UV) samples, and 7 LV/UV samples for which the designation was unclear. The last group were included in the LV sample suite. Results reported as below the detection level were counted as zero. The ABA results are summarised in Table 6-3.

The Sobek test indicates little NP. It is noted in Section 5.1 of the GRE (2014) report that "This is not unusual for a high sulfidation epithermal deposit, where extensive acid leaching during deposit formation frequently removes any original carbonate or aluminosilicate minerals that might have provided neutralization potential."

AP (calculated from total S) is considerably greater in the LV than in the UV or colluvium.

It is also stated in Section 5.1 GRE (2014) that "non-sulfide sulfur species do not contribute to formation of ARD." This statement is made in relation to the identification of alunite (hydrated aluminium sulfate, see Table 6-5) which had previously been considered an acid generating phase in the Golder Associates study (Golder, 2013). This contribution was removed in the calculations of acid generating potential (AGP) presented in the GRE (2014) report. **This assumption is not correct (discussed later).**

Table 6-3 ABA summary Tig/Art barren rock (from Table 5-1, GRE 2014; Table 2 Appendix 8.19, ESIA June 2016).

Barren rock	Statistics	Paste pH	AP ($TCaCO_3$/kT)	NP ($TCaCO_3$/kT)	Total S (wt.%)	Sulfide S (wt.%)	Sulfate S (wt.%)
LV	Mean	4.86	40.94	0.26	2.51	1.31	0.36
	Std. Dev	*1.07*	*60.00*	*1.67*	*2.57*	*1.92*	*0.55*
UV	Mean	5.54	4.30	0.14	0.76	0.14	0.11
	Std. Dev.	*0.70*	*21.39*	*0.85*	*1.40*	*0.68*	*0.20*
Col	Mean	5.79	0.87	0.20	1.07	0.03	0.13
	Std. Dev.	*0.84*	*1.02*	*0.41*	*1.27*	*0.03*	*0.11*

There appears to be considerable grouping of sulfide S in the 1–10 wt.% range for the LV samples (

Figure **6-1**). This would equate to 2–19 wt.% pyrite. In fact, the greatest concentration of sulfidic S in the LV samples is 6.52 wt.% (sample ARD-2, Appendix Table A-1, GRE, 2014) equating to 12.2 wt.% pyrite. In all these samples, serious ARD would be predicted by international standards.

However, in our histogram (Figure 6-2) distribution (compiled from data provided in GRE, 2016 Appendix Table A-1) of sulfide S wt.%, it is found that more than 50% of the samples contained less than 0.3 wt.% – generally considered a conservative cut-off below which the risk of ARD is not considered to be significant. This suggests that this material could be used as NPAG cover material.

In the UV samples greater than 90 % of the sample contain less than 0.3 wt.% sulfide.

It is concluded “that acid-generating sulfide sulfur is not the dominant sulfur species in Tig/Art UV samples, and sulfide is subordinate in many of the LV samples.” (Section 5.1, GRE, 2014). This is demonstrated in Figure 6-1 and also Figure 6-3 which provides a plot of Total S versus AGP. While this statement is true it does not negate the likely ARD generating nature of many of the high sulfide samples. It will be essential to have a clear estimate of the ratio of high-sulfide LV to “subordinate sulphide” LV in both deposits (Tig/Art and Erato). This may already be available if the sampling is representative (as stated in Section 4.0 Summary of Geochemical Characterization Program, GRE, 2014).

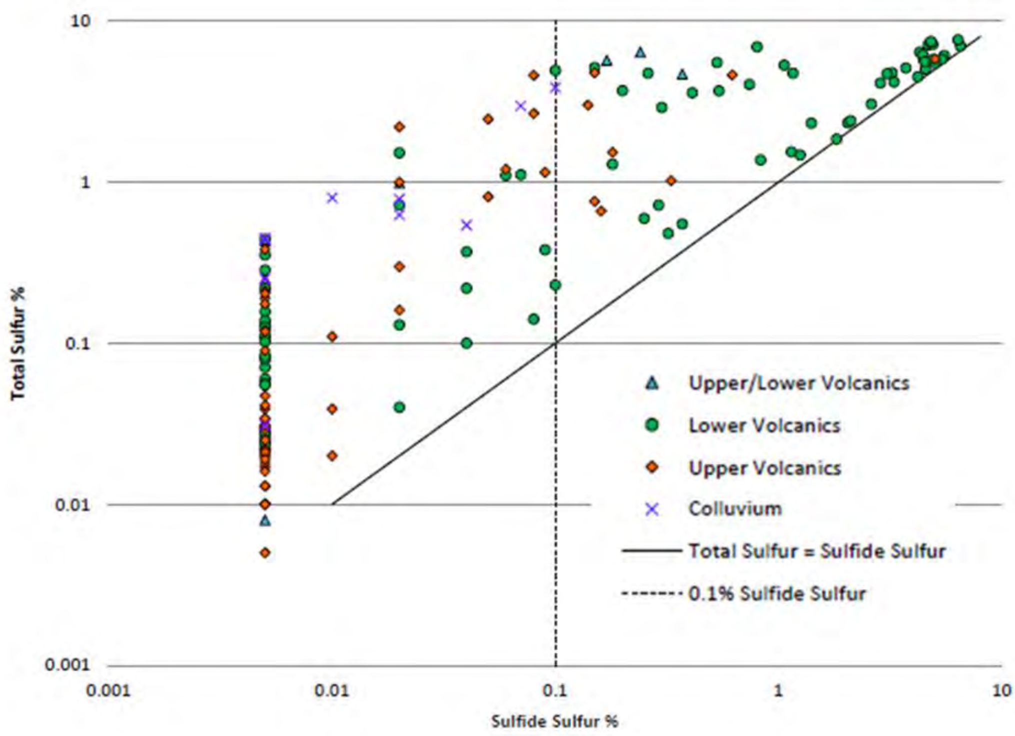

Figure 6-1 Total S (wt.%) versus sulfide S (wt.%) for Tig/Art waste rock (from Figure A1-2; GRE, 2014).

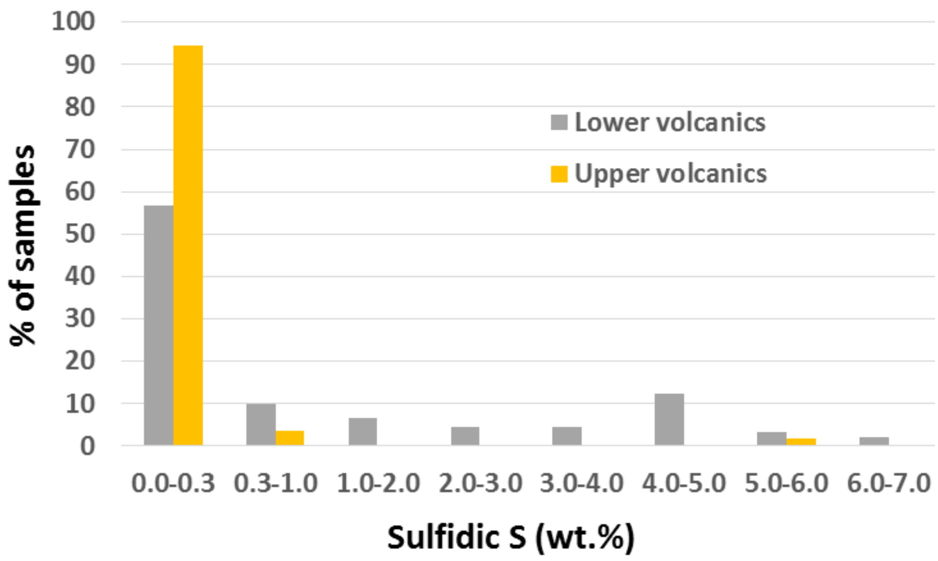

Figure 6-2 Histogram of wt.% sulfide S in LV and UV Tig/Art samples.

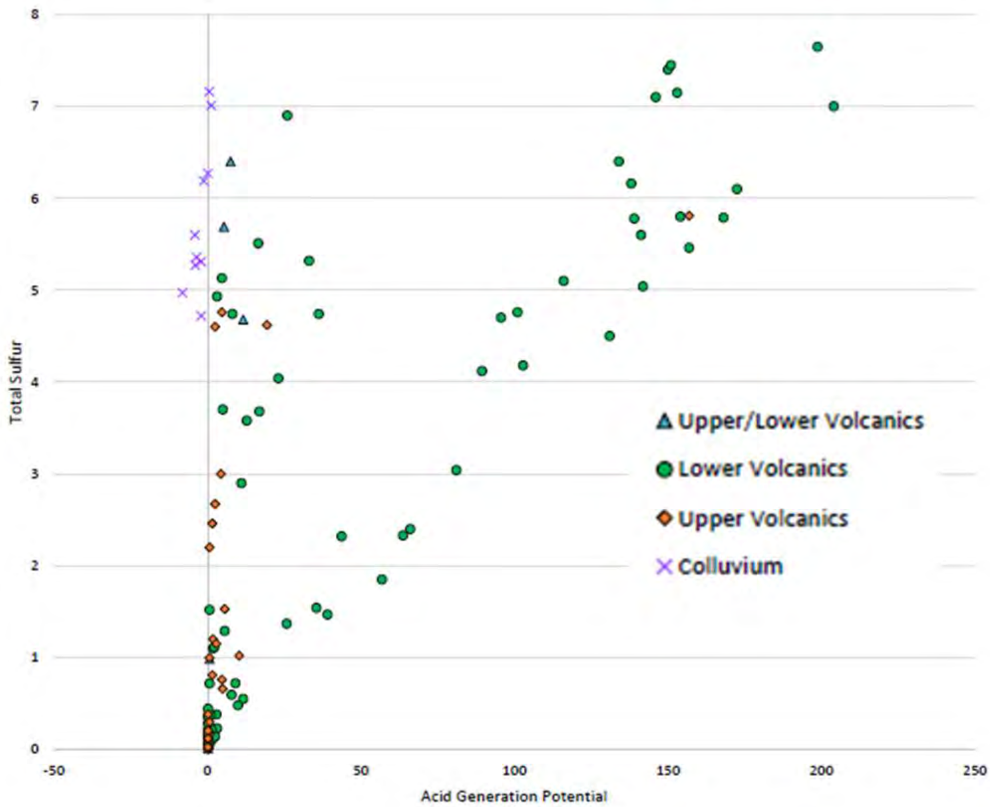

Figure 6-3 Total S (wt.%) versus AGP (based on sulfide S, $TCaCO_3/kT$) for Tig/Art waste rock (from Figure A1-3, GRE 2014).

Table 6-4 provides the statistical analysis of the ABA data (we assume using AGP rather than AP). According to the definitions given in Table 6-2 Lower Volcanics are designated as potentially acid generating and upper volcanics and colluvium both as uncertain to potentially acid generating.

Table 6-4 NNP and NPR for Tig/Art waste rock (extracted from Table 5-7 GRE-2014).

Barren Rock	Statistics	NNP (T $CaCO_3$/kT)	NPR
Lower volcanics	Mean	-41.98	2.30
	Std. Dev.	*61.59*	*13.49*
Upper volcanics	Mean	-4.51	2.27
	Std. Dev.	*22.82*	*8.15*
Colluvium	Mean	-2.32	3.31
	Std. Dev.	*2.80*	*373*

The mineralogy of nine Tig/Art samples was determine using X-ray diffraction analysis and petrology. The largest component of pyrite identified was 10 wt.% (Table 6-5).

Considerable proportions of alunite (and natroalunite) were identified in three (72C, 75C and 77C) of the six Lower Volcanic samples and one of the Upper Volcanics (79C) samples. More moderate (9 wt.%) alunite was identified in a further Upper Volcanic (78C) sample.

In 72C, 74C, 75C, 77C and 79C, most S is defined as non-sulfate (Table 6-6).

In 72C, 75C, 77C and 79C most of the non-sulfate is non-extractable but the only S-containing phase identified was alunite (or natroalunite).

In 74C most S is pyritic which would equate to about 3.9 wt.% pyrite, *cf.* 8 wt.% by XRD.

It is therefore probable that most non-extractable S is in the form of alunite. It is well known and recognised by mining companies, e.g. Rio Tinto (see for instance Linklater et al., 2012) that alunite dissolution does result in acid formation with pH equilibrating at 4–5 via Equation 1-1 (the stoichiometry of reaction is the same for natroalunite except that K is replaced by Na). On alunite dissolution the ratio of acid to sulfate produced is 3/2. It is not recognised in these assessments. It is stated in Linklater et al. (2012) “Management of wastes containing hydroxyl-sulphate minerals should include co-disposal with materials that contain neutralising potential and/or strategies that reduce the water flux through the wastes. This will minimise the flux of acid and contaminants that can be released from the hydroxyl-sulphate minerals.”

$KAl_3(SO_4)_2(OH)_6 + 3H_2O \rightarrow 3Al(OH)_3 + K^+ + 2SO_4^{2-} + 3H^+$ **Equation 6-1**

In Section 9.4 (GRE 2014) it is stated that “The quantity of published alunite studies is not large, but a study from the SME clearly states that alunite should not be added to AP (Hall et al., 1999). Moreover, the Amulsar humidity cell with the highest alunite content (ARD-75C) contained over 50 percent of the mineral, but failed to generate significant acidity after 48 weeks of testing. Alunite appears to be accompanied by slightly acidic waters (~pH 4.8), but has been shown by the characterization to be of low significance to the ARD generation potential of the Amulsar site."

More recently Dold (2017) stated that

> "Another proton source, which is not considered by the standard ARD prediction tests, is the group of Fe(III) hydroxides and Fe(III) hydroxide sulfates (e.g. jarosite-alunite group, schwertmannite) together with metal chlorides and sulfates (e.g. eriochalcite, chalcanthite, rhomboclase),which might be the source of important amounts of acidity in ARD systems. The protons might be liberated due to dissolution equilibrium reaction or due to mineral transformation due to meta-stability of the secondary mineralogy."
>
> "The principal hydroxide buffers in the ARD environment or acid soils are dominated by the most abundant metal cations with the valence 3+; i.e. Fe^{3+} and Al^{3+}. This is due to the ability of three valence cations to hydrolyze, given to their high ionic potential (IP) between 4.65 (Fe^{3+}) and 5.61 (Al^{3+}), forming solid hydroxide minerals like ferrihydrite, goethite, schwertmannite, jarosite-alunite, and gibbsite. These minerals represent buffers, which control the pH at ~4.3 ($Al(OH)_3$; gibbsite), ~3.5 ($Fe(OH)_3$; ferrihydrite, goethite), ~2.5–3.5 (schwertmannite), ~2 (jarosite). Thus, metal hydroxides represent important buffers in the acid pH ranges."

It is correct that alunite dissolution will not result in pH values less than 4–5. However, the alunite will continue to provide a source of acid until completely dissolved and this does require consideration. The sample ARD-75C is discussed further below in the context of the humidity cell testing.

Equation 5-2 for pyrite oxidation by O_2 indicates a ratio of 4/2 protons released for every S dissolved.

$FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$ **Equation 6-2**

If the same equation is written for pyrite oxidation by Fe^{3+} 46 protons are released:

$FeS_2 + 14Fe^{3+} + (91/2)H_2O + (15/4)O_2 \rightarrow 15Fe(OH)_3 + 46H^+ + 2SO_4^{2-}$ **Equation 6-3**

However 42 of these are due to hydrolysis of the reactant Fe^{3+}:

$14Fe^{3+} + 42H_2O \rightarrow 14Fe(OH)_3 + 42H^+$ **Equation 6-4**

And only four of them are due to pyrite oxidation and hence the ratio of acid to sulfate (4/2) release is identical regardless of the nature of the oxidant.

Consequently the statement made in Section 8.1 of GRE (2014) when referring to oxidation of pyrite by Fe^{3+} is incorrect "This reaction is much faster, and has a higher stoichiometric ratio between pyrite and acidity (listed as H^+)." in terms of the interpretation of stoichiometric ratio. Both reaction types represent equal ARD generation. Moreover, the generation of Fe^{3+} is not considered. When oxidation of pyrite by Fe^{3+} is rate limited by the oxidation of Fe^{2+} by

O_2 this process can be slow. Alternatively at pH above 2, little Fe will be present in solution due to the formation of iron oxy-hydroxide precipitates. However, the generation of Fe^{3+} can also be microbially catalysed with resulting sulfide oxidation rates up to six order of magnitude greater (Evangelou and Zhang, 1995).

We note the equations provided in Section 8.1 GRE 2014 do not consider Fe^{3+} hydrolysis process and it is not considered on neutralisation of any metal containing water. The acidity that is released on metal ion hydrolysis is termed metal acidity (as distinct from proton acidity, i.e. pH) and may require considerable neutralisation particularly for elevated concentrations of Al and/or Fe.

If the acid generation by alunite (and this assume to be the non-extractable S component) is considered the acid generation potential could be calculated as:

AGP = (sulfide S (wt.%) + non-extractable S (wt.%) × 0.75) × 31.25 kg $CaCO_3$/tonne (or T $CaCO_3$/kT)

Or alternatively the acid producing sulfur (APS) can be calculated as sulfide S (wt.%) + 0.75 non-extractable S (wt.%) as has been done as a histogram in Figure 6-4 (for comparison to Figure 6-1). This calculation ***will*** almost certainly overestimate the APS but serves to highlight more fully the possible contribution of alunite to total possible acidity. The % of the samples in the < 0.3 wt.% range then shifts from 57 and 94 to 39 and 70 for the Lower and Upper Volcanics respectively. However, whether the dissolution of alunite produces an elevated environmental risk will depend on the natural pH of local waterways and degree of dilution of the effluent (and this is not clearly stated).

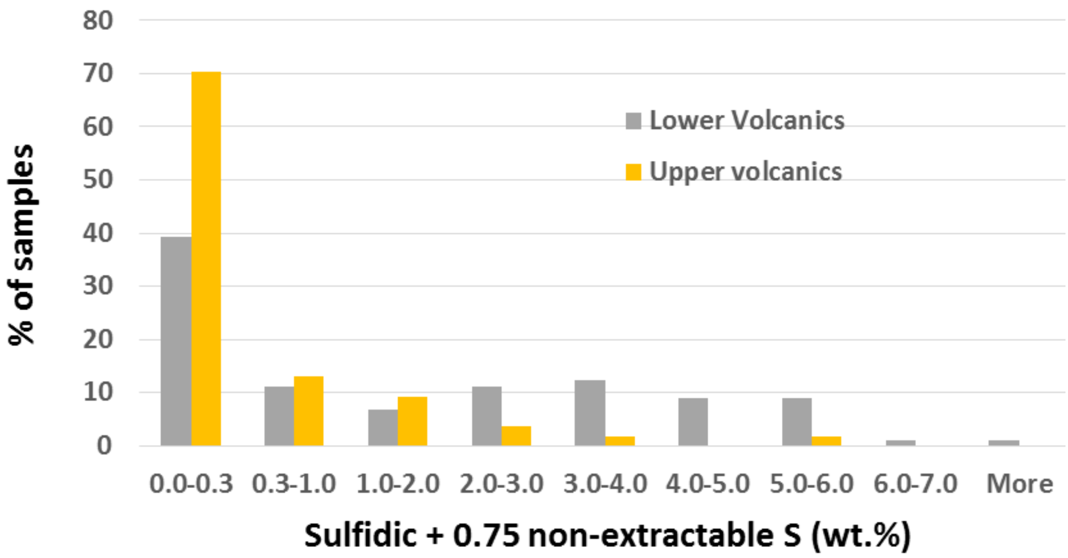

Figure 6-4 Histogram of calculation of acid generating S equivalent to pyrite, assuming that the non-extractable S is alunite.

Table 6-5 X-ray diffraction (XRD) and petrography Tigranes/Artavasdes pit samples mineralogy results (Appendix Table C-1, GRE 2014)

		Lower Volcanics						Upper Volcanics		
		ARD-71C	**ARD-72C**	**ARD-74C**	**ARD-75C**	**ARD-76C**	**ARD-77C**	**ARD-78C**	**ARD-80C**	**ARD-79C**
Plagioclase	$NaAlSi_3O_8$ – $CaAl_2Si_2O_8$	–	–	66	–	–	–	–	–	–
Quartz	SiO_2	46	55	20	35	49	75	86	99	27
Alunite	$KAl_3(SO_4)_2(OH)_6$	–	–	–	**53**	–	**21**	**9**	–	**70**
Natroalunite	$NaAl_3(SO_4)_2(OH)_6$	–	45	–	–	–	–	–	–	–
Hematite	Fe_2O_3	–	–	–	trace	–	3	3	–	–
Hematite/Geothite	$FeOOH$ - Fe_2O_3	–	–	–	–	-	–	–	–	3
Iron Oxide	FeO	–	trace	1	-	-	–	–	trace	–
Rutile	TiO_2	4	trace	<1	trace	-	1	2	trace	-
Pyrite	FeS_2	**10**	–	**8**	-	**10**	–	–	–	–
Sericite/illite	$K_{0.5\text{-}1}(Al,Fe,Mg)_2(SiAl)_4O_{10}(OH)_2\ nH_2O$ - $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}((OH_2,(H_2O))$	17	<1	4	-	30	–	–	–	–
Kaolinite	$Al_2Si_2O_5(OH)_4$	23	–	–	12	11	–	–	–	–
Smectite	$(Na,Ca)(Al,Mg)_6(Si_40_{10})_3(OH)_6\text{-}nH_20$	–	–	1	-	-	–	–	–	–

Table 6-6 S speciation analyses (Table A-1; GRE, 2014), NNP, NPR and comparison of pyrite wt.% based on sulfide S and mineralogy. All in wt.% except where stated otherwise. S analyses for ARD-71C and ARD-76C do not appear in the GRE report.

	Lower Volcanics						Upper Volcanics		
	ARD-71C	**ARD-72C**	**ARD-74C**	**ARD-75C**	**ARD-76C**	**ARD-77C**	**ARD-78C**	**ARD-80C**	**ARD-79C**
Total S		6.9	2.4	3.7		2.9	1.2	0.01	4.6
Pyritic S		0.8	2.1	0.2		0.3	0.06	<0.01	0.08
Sulfate		0.1	0.2	0.2		0.2	0.1	0.01	00.9
Non-sulfate S		6.8	2.1	3.5		2.7	1	<0.01	3.8
Non-extractable S		6	0.03	3.3		2.4	1	<0.01	3.7
Pyrite based on pyritic S		1.5	3.9	0.4		0.6	0.1	<0.02	0.1
Pyrite based on mineralogy		–	8	–	10	–	–	–	–
Humidity cell testing		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SPLP test	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NNP (T $CaCO_3$/kT)		–26	–65	–4.0		–10	–1.5	0	–2.2
NPR		0	0	0.1		0	0.2	1	0.2

Humidity cell tests were conducted on 5 Lower Volcanic and 3 Upper Volcanic samples (Figure 6-5) coinciding with 8 samples on which mineralogy had been carried out (see Table 6-5 for mineralogy and Table 6-6 for S speciation). This number of samples for evaluation of rates of acid release is manifestly insufficient. In control of ARD in the first 10 years, it is rates more than ABA total amounts that determine the mitigation required. This is not acknowledged in the report and the humidity cell testing does not give reliable information on this (as they acknowledge, Section 3.9, Appendix 8.19, ESIA, 2016).

The pH of the effluent from the Lower Volcanic samples ARD-74C and ARD-76C was <3 after 12 weeks. These two samples contained the greatest pyrite concentration of the samples tested (8 and 10 wt.% respectively). Testing of these samples was only carried our for 20 weeks which is insufficient as is stated:

> "it is generally accepted that a year of kinetic [humidity] cell testing will demonstrate with high confidence that a rock sample will or will not generate acid. The test is a logical extension of the static testing because it demonstrates empirically whether the potential determined in the ABA testing will be realized in the field. Geoteam will start this testing as soon as bulk samples of ROM material are available" (from Section 3.9, Appendix 8.19, ESIA, 2016).

This testing will be too late to modify waste rock dumping practice and needs to be done now using the more relevant conditions of kinetic leach columns (Section 3.5, AMIRA, 2002) rather than the humidity cell test procedure, most particularly on the Lower Volcanic wastes.

The highly acid sample ARD-76C is claimed to be

> "heavily oxidized prior to arriving at the lab. This sample shows the worst-case potential for ARD in Amulsar waste, but this cell has little value in determining reaction kinetics." (Section 3.93, Appendix 8.19, ESIA,2016).

This statement is self-contradictory and inexplicable. It is the *unoxidised* LV samples that provide the worst case scenarios. It is possible tht prior oxidation may have generated some ferric ion but this is the normal oxidant for ARD and simply started the process and reaction kinetics earlier.

Their choice of ARD-74C as the model for the LV ARD is based on

> "After 12 weeks, ferric iron oxidation begins and the rinsate has reduced pH, increased sulfate concentrations, and increased iron concentrations. This sample demonstrates that Amulsar ARD, even under ideal conditions, has resistance to ARD. As a result, this sample was utilized in subsequent geochemical modeling to define reaction kinetics (GRE, 2014)." (from Section 3.9.4 Appendix 8.19, ESIA 2016) .

This is simply incorrectly interpreted and again self-contradictory. They properly explain that the oxidant changes form initial oxygen to ferric ion (3–10× rate) as the iron concentration increases. There is no resistance to ARD formation in the sample, simply the evolution from O_2 to Fe^{3+} which is the normal and on-going process.

Lower Volcanic samples ARD-75C and ARD-77C resulted in effluent pH values of between 4 and 5. This is likely due to alunite dissolution as these contained very little sulfide S.

It is stated in Section 3.11 of Appendix 8.19 ESIA (2016) that

> "UV material has leachate slightly lower than circumneutral this is likely due the weathering of alunite. The weathering of alunite is not significant to water quality due to the very slow reaction kinetics and low total acidity produced (GRE, 2014)".

This is possibly correct for sample ARD-79C but suggests that their might be some compositional/reactivity differences between Upper Volcanic and Lower Volcanic alunite.

It is also stated that

> "…three of the five LV kinetic cells showed strong resistance to the formation of ferric iron oxidized ARD. These samples produce consistently mild (pH greater than 4.5) ARD, with low sulfate, nearly zero cumulative acidity, and low iron concentrations despite long-duration testing."(page 38, GRE 2014).

These were 72C, 75C and 77C. These contain 0.8, 0.2 and 0.3 wt.% pyrite sulfur. Hence their leach behavior reflects their pyrite content and not any unusual geochemical resistance.

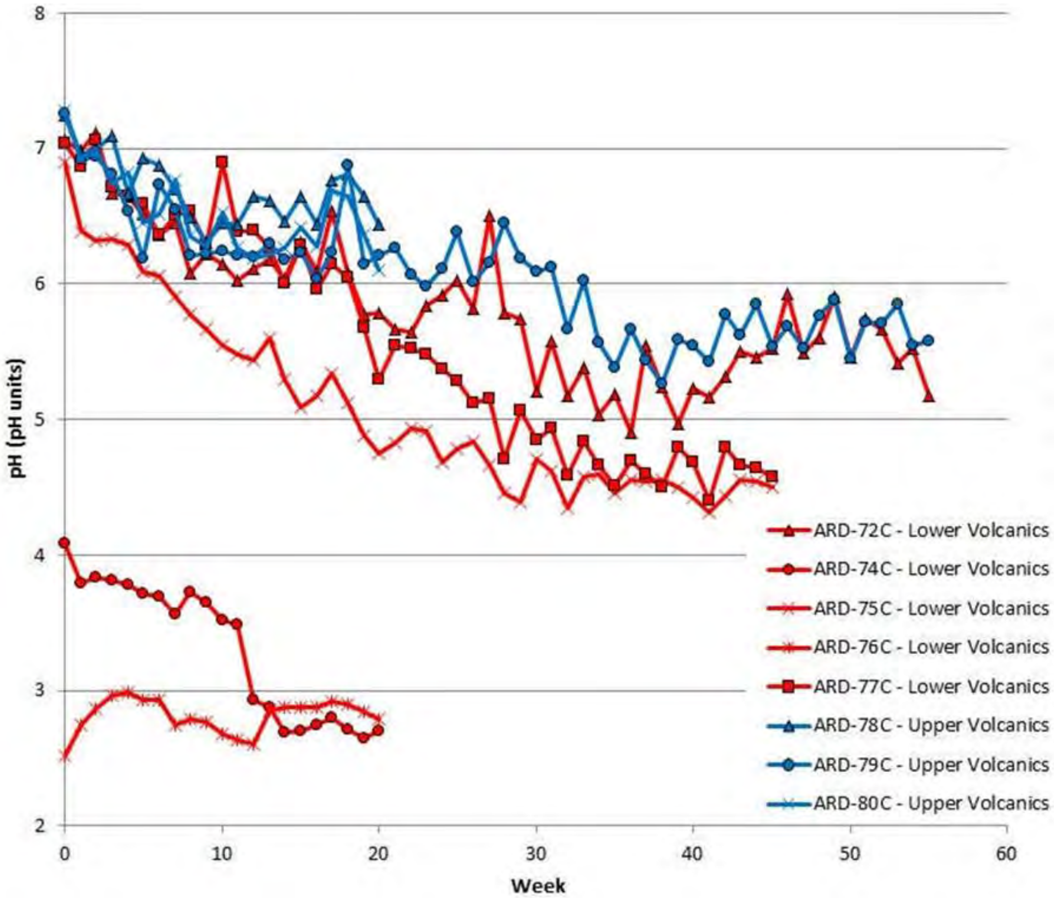

Figure 6-5 pH versus time in humidity cell tests (Figure 8-1, GRE 2014; Figure 5, Appendix 8.19 ESIA 2016).

Antimony, arsenic, bismuth, lead, molybdenum, selenium, and silver were found to be present at levels at least five times higher than their crustal average in Tig/Art barren rock samples (Figure 6-1 from GRE 2014 – not reproduced here).

SPLP tests indicate that iron, copper, manganese and sulfate are COPCs (constituents of potential concern, Table 6-7). NAG testing indicates barium, cadmium, chromium, copper, iron, manganese, nickel, selenium and sulfate may exceed Arpa MAC standard (category II) (Table 6-7). Final NAG pH was on average 3.7. It was stated that "Chromium and cadmium were found only in trace amounts in the NAG effluent test, and were excluded from further analysis." Selenium was not discussed.

We note that NAG testing was carried out a different suite of samples than mineralogy and humidity cell testing: ARD-14 ARD-18 ARD-27 ARD-40 ARD-44 ARD-54 ARD-68 ARD-59 ARD-58 (Table D-2, GRE, 2014). Hence, there is no correlation provided to ABA or other characterisation. This significantly reduces the value of these tests in estimating rates of ARD release based on mineralogy.

Se is now recognised as a serious pollutant causing genetic deformities in fish downstream. Leaching of Se has led to EPA notices and mine closures in Canada. Teck Mining has now committed $600m to a five year clean-up plan for the Elk River area in British Columbia. It has been reported that

> "The study found the selenium levels at five sites in the Elk River Basin downsteam from the coal mines ranged from 10 µg/L to 4 µg/L, compared with levels of less than 1 µg/L upstream of the coal mines.
>
> While B.C. sets the safe level for selenium in drinking water at 10 µg/L maximum, for aquatic life, the safe level is set at 2 µg/L mean.
>
> "The concentrations of selenium observed in the Elk Basin stream and river sites below the effects of mining exceeded both the British Columbia guidelines value of 2 µg/L and the U.S. EPA water quality standard of 5 µg/L," said the report." (CBC, 2013).

The Arpa MAC Standards (Category II) limit for Se is stated to be 0.02 mg/L, i.e. 20 µg/L (Table 7-1 (GRE, 2014). This value is stated as 20 mg/L in Table 7-2, GRE, 2014 but we assume that this is incorrect. **The SPLP tests gave rise to leachates containing on average 0.02 mg/L (20 µg/L), considerably greater than either the British Columbia guidelines for aquatic life or the US EPA limits for drinking water. NAG testing gave rise to an even greater effluent Se concentration at 0.034 mg/L. On the information provided Se is of direct concern in the Tig/Art deposit.** Whether the leaching of Se from the Tig/Art barren rock constitutes an increased environmental hazard would be a function of the existing concentrations of Se in the local waterways through natural weathering of exposed rock and the degree of effluent dilution.

Table 6-7 SPLP results for Tig/Art barren rock materials showing only those elements that exceed the Arpa MAC standard (from Table 7-1 and 7-2, GRE-2014).

Constituent	**Unit**	**Arpa MAC Standards (Category II)**	**IFC Guideline**	**TigArt SPLP results (avg)**	**TigArt NAG results (avg)**
Final Fluid pH	pH units	--	--	5.953	
Barium	mg/L	0.03	--	0.027	**0.045**
Cadmium	mg/L	0.001	0.05	0.00100	**0.00176**
Chromium	mg/L	0.01	--	0.004	**0.042**
Copper	mg/L	0.02	0.3	**0.187**	**0.266**
Iron	mg/L	0.07	2	**3.411**	**55.1**
Manganese	mg/L	0.01	--	**0.040**	**0.125**
NAG pH @ 20.3 °C	pH	--	6-9		3.728
Nickel	mg/L	0.01	0.5	**0.016**	**0.056**
Selenium	mg/L	0.02	--	0.0200	**0.034**
Sulfate as SO4	mg/L	16.04	--	**28.273**	**379**

6.4 Erato Barren Rock

Sampling consisted of 6 Col samples, 29 LV samples, 43 UV samples, and 2 LV/UV samples. The LV/UV samples were included in the LV group for the purpose of calculating statistics, and values reported as below a detection limit are counted as zero.

The ABA results (summarised in Table 6-8) closely resemble those seen for the Tig/Art pit (Table 6-3). As for Tig/Art there is little neutralisation capacity and the Lower Volcanics contain greater sulfidic S than the Upper Volcanics or Colluvium. Mean sulfide S Lower Volcanic values are about a half percent lower than Tig/Art Lower Volcanic samples. The % of samples for Lower Volcanics and Upper Volcanics sulfide S for <0.3 wt.% are similar to the Tig/Art samples Figure 6-6).

As for Tig/Art, Erato waste materials were classified on the basis of average NNP and NPR values (Table 6-9) as potentially acid generating for the Lower Volcanics and uncertain to potentially acid generating for the Upper Volcanics and Colluvium.

Table 6-8 ABA summary for Erato barren rock (from Table 5-2, GRE 2014; Table 3 June 2016 ESIA Appendix 8.19).

Barren rock	Statistics	Paste pH	AP ($TCaCO_3$/kT)	NP ($TCaCO_3$/kT)	NAG pH	Total S (wt.%)	Sulfide S (wt.%)	Sulfate S (wt.%)
LV	Mean	5.00	27.44	0.38	4.28	2.16	0.88	0.38
	Std. Dev	*1.04*	*49.26*	*0.96*	*1.12*	*2.23*	*1.58*	*0.60*
UV	Mean	5.30	5.48	0.27	4.72	0.83	0.18	0.11
	Std. Dev.	*0.60*	*24.62*	*0.85*	*0.50*	*1.43*	*0.79*	*0.15*
Col	Mean	5.75	5.33	1.08	4.92	1.69	0.17	0.20
	Std. Dev.	*0.19*	*11.19*	*0.86*	*0.15*	*242*	*0.36*	*0.028*

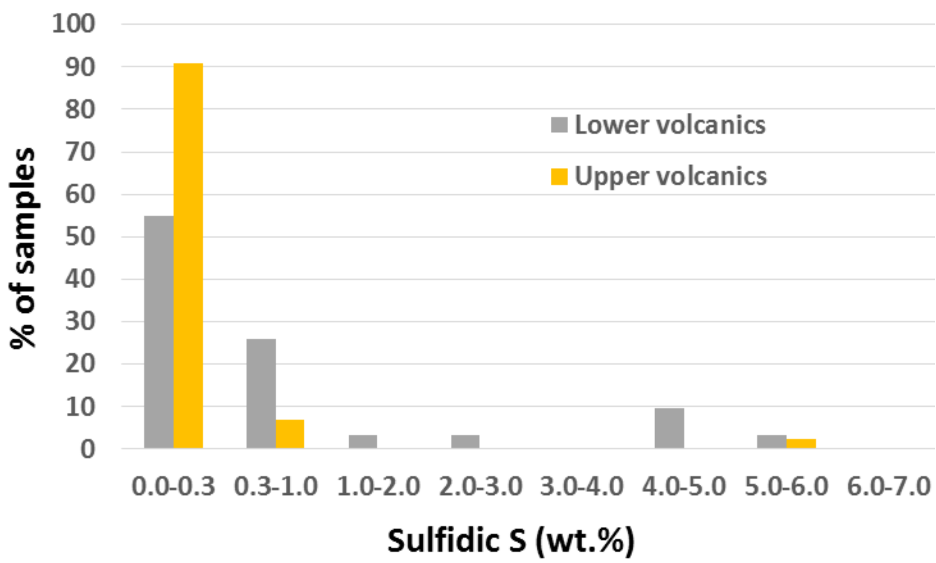

Figure 6-6 Histogram of wt.% sulfide S in Lower Volcanic and Upper Volcanic Erato samples.

Table 6-9 NNP and NPR for Eratos waste rock (extracted from Table 5-7; GRE, 2014).

Barren Rock	Statistics	NNP ($TCaCO_3$/kT)	NPR
Lower Volcanics	Mean	-11.66	1.66
	Std. Dev.	*38.19*	*5.31*
Upper Volcanics	Mean	-4.72	2.53
	Std. Dev.	*28.72*	*5.12*
Colluvium	Mean	0.06	6.26
	Std. Dev.	*2.08*	*6.42*

The mineralogical analyses are provided in Table 6-10 with S speciation and related data for these same samples in Table 6-11. LV-ARGC-57 is shown as having a wt.% pyrite of 24. This is anomalous and appears incorrect on the basis of wt.% sulfide S (Table 6-11) of 4.07 which is the equivalent of 7.61 wt.% pyrite.

Considerable wt.% jarosite was found in two samples (LV-ARG-61 and LV-SA-66). The dissolution of this phase will result in acid generation with equilibration at approximately 2–3 (Dold, 2017). This appears not to have been recognised in the original Golder Associates (2013) report or it is not mentioned in later reports. Even more so than alunite, jarosite requires on-going ARD management as acknowledged by major mining companies (Linklater et al., 2012)

The generation of acidity upon jarosite dissolution is associated with the hydoxylation of Fe^{3+}.

$KFe_3(SO_4)_2(OH)_6 + 3H_2O \rightarrow 3Fe(OH)_3 + K^+ + 2SO_4^{2-} + 3H^+$ **Equation 6-5**

Dold (2017) states with regard to assumptions that sulfides form the only source of acidity

> "For example, a separation of the sulfate mineralogy from the sulfide mineralogy was attempted through the dissolution of sulfates with HCl (Lawrence et al., 1989), which is now better known as the "Modified Sobek test". Both tests assuming that only the sulfides are responsible for proton liberation. This assumption has to be expanded, as Fe(III)oxyhydroxides and Fe(III)oxyhydroxide sulfates like schwertmannite and jarosite, ferrihydrite and goethite, minerals which are often present in the ore geology, tend to acidify the solution due to equilibrium reactions (Alarcon et al., 2014; Dold, 2010), so that this mineralogy must also be included in an ABA (Dold and Weibel, 2013)."

For jarosite dissolution the ratio of acid to sulfate released is 3/2, as for alunite. On calculation of 'equivalent acid generating S' using the wt.% of non-extractable S at a ratio of 0.75 the percentage of Lower Volcanics samples containing less than 0.3 wt.% sulfide (equivalent) decreases from 55 to 34% and the percentage of Upper Volcanic samples decreases from 91% to 70% (Figure 6-7). This calculation represents a worst case scenario and is based on the assumption that all non-extractable S is in the form of either alunite or jarosite. Nevertheless both jarosite and alunite dissolution will continue to result in the release of acid until the dissolution of these minerals is complete. This will be more serious in the case of jarosite dissolution as the pH of the effluent will trend towards equilibrium at 2–3 even if pyrite dissolution is complete.

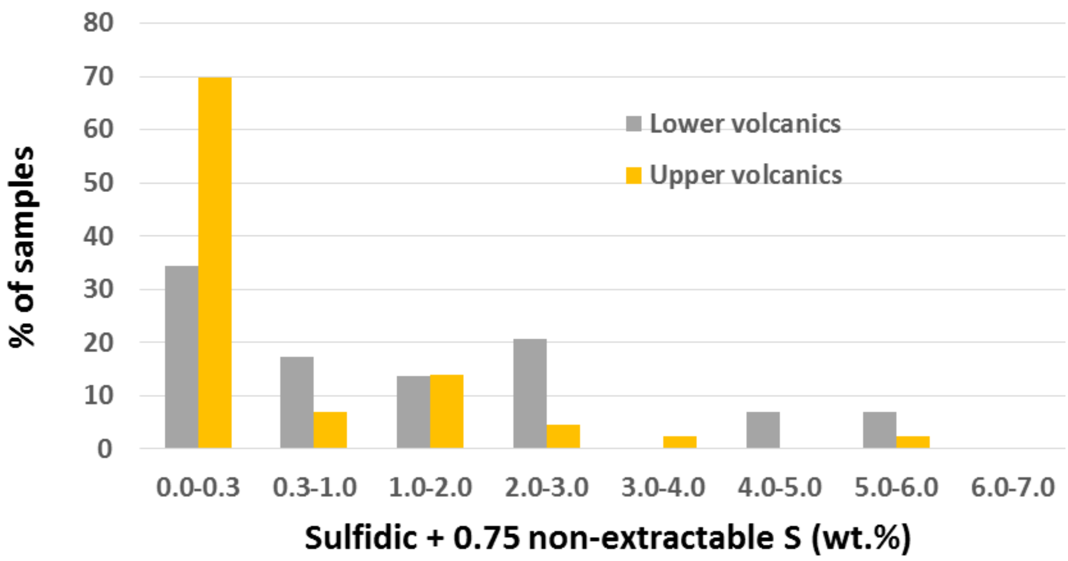

Figure 6-7 Histogram of calculation of acid generating S equivalent to pyrite in Erato barren rock samples assuming that the non-extractable S is alunite or jarosite.

Table 6-10 X-ray diffraction (XRD) and petrography Erato pit samples mineralogy results (Appendix Table C-2, GRE 2014)

		Lower Volcanics					Upper Volcanics				Colluvium		
		BR-SMA-20	**VC-SV-23**	**LV-ARGC-61**	**LV-ARGC-57**	**LV-ARGC-56**	**BT-SM-13**	**BT-SMV-18**	**VC-SA-50**	**LV-SA-66**	**COL-SM-82**	**COL-SA-86**	**COL-UN-85**
Plagioclase	$NaAlSi_3O_8$ – $CaAl_2Si_2O_8$	–		8	–	–	–	–	–	–	–	–	–
Quartz	SiO_2	77	65	53	45	65	40	97	89	53	63	57	88
Alunite	$KAl_3(SO_4)_2(OH)_6$	17	6	–	–	–	22	–	–	–	30	–	Trace
Goethite	$FeOOH$	2	–	–	–	–	–	–	–	15	–	–	–
Hematite	Fe_2O_3	2	6	–	–	9	8	1	5	10	3	8	3
Rutile	TiO_2	trace	–	1	1	1	trace	trace	1	1	1	1	1
Pyrite	FeS_2	trace	–	Trace	**24**	–	trace	trace	trace	trace	trace	trace	trace
Chalcopyrite	$CuFeS_2$	trace	–	–	–	–	–	–	trace	trace	trace	–	trace
Gold		–	–	trace	–	–	–	–	–	–	trace	trace	–
Sericite/illite	$K_{0.5-1}(Al,Fe,Mg)_2(SiAl)_4O_{10}(OH)_2nH_2O$ - $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}((OH_2,(H_2O))$	–	–	–	–	25	–	–	–	–	–	–	–
Kaolinite	$Al_2Si_2O_5(OH)_4$	–	20	25	25	–	30	–	-	10	–	30	7
Adularia	$KAlSi_3O_8$	2	3	–	–	–	–	2	5	1	3	2	1
Jarosite	$KFe_3(OH)_6(SO_4)_2$	trace	–	**10**	–	–	trace	–	–	**10**	–	**2**	–
Illite/smectite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)$	–	–	3	5	–	–	–	–	–	–	–	–

Table 6-11 S speciation analyses (Appendix Table A-2; GRE, 2014), ABA and comparison of pyrite wt.% based on sulfide S and mineralogy. All in wt.% except where stated otherwise.

	Lower Volcanics					Upper Volcanics				Colluvium		
	BR-SMA-20	**VC-SV-23**	**LV-ARGC-61**	**LV-ARGC-57**	**LV-ARGC-56**	**BR-SM-13**	**BR-SMV-18**	**VC-SA-50**	**LV-SA-66**	**COL-SM-82**	**COL-SA-86**	**COL-UN-85**
Total S	2.42	0.92	0.64	6.1	0.36	1.84	0.03	0.07	0.95	5.42	0.14	0.42
Pyritic S	1.07	0.13	0.47	4.07	<0.01	0.12	0.01	<0.01	0.33	0.9	0.03	<0.01
Sulfate	0.21	0.15	0.11	1.92	0.19	0.16	0.01	0.04	0.2	0.72	0.01	0.2
Non-sulfate S	2.21	0.77	0.53	4.18	0.17	1.68	0.01	0.03	0.75	4.7	0.13	0.22
Non-extractable S	1.14	0.64	0.06	0.11	0.17	1.56	0.01	0.02	0.42	3.8	0.1	0.22
Pyrite based on pyritic S	2.00	0.24	0.88	7.61	<0.02	0.22	0.02	<.0.02	0.62	1.68	0.06	<0.02
Pyrite based on mineralogy	trace		trace	24		trace	trace	trace	trace	trace	trace	trace
NAG pH 20.3°C (pH)	5.58	3.81	3.58	2.12	5.47	4.58	4.81	4.17	3.38	4.93	4.95	4.72
NNP (T $CaCO_3$/kT)	–33.4*	–4.2	–14.7	–127	1.1	–3.8	3.5	ND	–10.2	–26.7	0.6	1.6
NPR	0.0	0.1	0.0	0.0	3.3	0.1	9.8	1.0	0.0	0.1	1.7	5.0

* These values are shown as < rather than negative in Appendix Table A2 (GRE, 2014).

The list of elements with elevated concentrations (≥ 5× crustal average) in the Erato barren rock samples is the same as for the Tig/Art barren rock: antimony, arsenic, bismuth, lead, molybdenum, selenium, and silver. Barium, copper, iron, manganese, nickel and sulfate were all shown to leach at greater concentrations than those recommended by the Arpa MAC Standards (category II) (Table 6-12). We note the concentration of Se leaches (0.0073 mg/L for NAG effluent) was much reduced as compared to the Tig/Art samples.

Table 6-12 SPLP results for Erato barren rock materials showing only those elements that exceed the Arpa MAC standard (from Table 7-1 and 7-2, GRE-2014).

Constituent	Unit	Arpa MAC Standards (Category II)	IFC Guideline	Erato SPLP Results (avg)	Erato NAG effluent (avg)*
Final Fluid pH	pH units	--	--	5.250	
NAG pH @ 20.3°C	pH		6-9		4.324
Barium	mg/L	0.03	--	0.073	0.109
Chromium	mg/L	0.01	--	0.002	0.021
Copper	mg/L	0.02	0.3	1.837	0.453
Iron	mg/L	0.07	2	2.995	9.3
Manganese	mg/L	0.01	--	0.025	0.053
Nickel	mg/L	0.01	0.5	0.011	0.01
Sulfate as SO4	mg/L	16.04		35.938	83

* this column was labelled TigArt NAG Results (avg) (one of two columns labelled like this) in Table 7-2, but was the most left-hand column

6.5 Spent Ore

Two sets of spent ore samples were evaluated.

(1) "Seven spent heap leach residue samples from a pilot-scale leaching test were evaluated by Wardell in 2011. The seven samples included three composites, one each from the Tigranes, Artavasdes, and Erato deposits. The remaining four samples represented specific mineralization types, and included gossan material, fault gouge, siliceous breccia and pervasive siliceous iron-oxide in-fill material. ABA results are given in Table 5-3." (from Section 5.4, GRE, 2014).

Sulfide S concentrations obtained for these samples were in the range 0.1–1.1 wt.% (Table 6-13). The greatest sulfide S of 1.13 wt.% was found in the Erato composite sample (MC068) with the other samples averaging 0.37 wt.%. It is noted that there is negligible non-extractable S (i.e. Total S – (acid-soluble S + sulfide S) suggesting non-acid extractable sulfate minerals were extracted during ore processing.

Table 6-13 ABA results for Tig/Art spent ore and one Erato sample (Table 5 Appendix 8.19 ESIA 2016; Table 5-3, GRE, 2014).

Sample	Total S (wt.%)	Acid-soluble S (wt.%)	Sulfide S (wt.%)	AP ($TCaCO_3/kT$)	NP ($TCaCO_3/kT$)
MPF	0.04	0.02	0.02	0.63	3.06
GSN	0.58	0.05	0.53	16.5	4.31
FG	0.37	0.06	0.31	9.59	2.69
SB	0.38	0.04	0.34	10.66	2.31
MC068[1,2]	1.15	0.03	1.13	35.16	1.37
MC070[1]	0.7	0.05	0.65	20.22	2.50
MC071[1]	0.38	0.01	0.37	11.63	0.69

1. Composite sample
2. Erato sample

2) Subsequently six Erato spent ore samples from laboratory-scale column leach testing were evaluated by Golder in 2013 (Table 6-14). These samples all contained 0.1 wt.% sulfide S or less. These are unlikely to be an ARD risk, however, some samples (62519, 62528) do contain >0.5 wt.% non-extractable S possibly indicating the presence of alunite or jarosite.

Table 6-14 Erato spent ore ABA results (adapted from Table 5-4; GRE, 2014).

Sample	Total S (wt.%)	Acid soluble sulfate S (wt.%)	Sulfide S (wt.%)	Non-extractable S (wt.%)	AGP (TCaCO3/kT)	ANP (TCaCO3/kT)
DDA-030	0.95	0.24	< 0.01	0.71	0.31	0.30
DDA-030	0.14	0.11	<0.01	0.04	0.31	0.30
DDA-278	0.74	0.2	0.10	0.44	3.13	0.30
DDA-276	1.75	0.32	0.09	1.34	2.81	0.30
DDA-290	0.0	0.02	<0.01	0.01	0.31	0.30
DDA-340	0.53	0.24	<0.01	0.3	0.31	0.30

It is stated that “The SPLP tests indicate that few metals or salts are readily leached into solution, with only iron in concentrations higher than Arpa Category II standards.” (from Section 7.2, GRE 2014). However, it is apparent from Table 6-15 that a considerable number of leachates from both SPLP and NAG effluents tests exceed the Arpa MAC standards (category II).

Table 6-15 SPLP and NAG effluent results for SPLP Tig/Art and Erato spent ore (from Table 7-3, GRE, 2014). Effluent concentrations that are greater than the Arpa MAC standards are highlighted in red.

Component		Arpa MAC standard (category II)	World Bank/IFC EHS effluent standards	TigArt SPLP (avg)	Eratos SPLP (avg)	Eratos NAG effluent (avg)
Aluminum	mg/L	0.144		0.233	1.25	0.1
Ammonia as N	mg/L			0.11	0.1	---
Antimony	mg/L	0.00028		0.00529	0.00996	0.004
Arsenic	mg/L	0.02	0.1	0.033	0.034	0.0052
Barium	mg/L	0.028		0.033	0.072	0.144
Beryllium	mg/L	0.000038		0.001	0.002	0.004
Bicarbonate	mg/L			---	20.3	6.117
Bismuth	mg/L			0.34	0.06	0.06
Boron	mg/L	2		0.01	0.007	0.0017
Cadmium	mg/L	0.001014		0.001	0.002	0.003
Calcium	mg/L	100		7.13	3.9	2.37
Carbonate				---	1	1
Chemical Oxygen Demand	mg/L		150	---	12	---
Chloride	mg/L	6.88		1.14	1	1
Chromium	mg/L	0.011	0.05	0.001	0.006	0.0138
Cobalt	mg/L	0.00036		0.001	0.006	0.006
Copper	mg/L	0.021	0.3	0.003	0.005	0.001
Cyanide (free)	mg/L		0.1	---	0.01	---
Fluoride	mg/L			0.129	0.077	0.08
Gallium	mg/L			---	0.02	0.02
Hexavalent Chromium	mg/L		0.1	---	0.01	---
Hydroxide	mg/L			---	---	1
Iron	mg/L	0.072		0.02	2.95	0.029
Lead	mg/L	0.01014	0.2	0.004	0.02	0.003
Lithium	mg/L	0.003		---	0.02	0.02
Magnesium	mg/L	50		1	0.12	0.3
Mercury	mg/L		0.002	0.0001	0.0002	0.0002
Molybdenum	mg/L	0.00082		---	0.009	0.009
Nickel	mg/L	0.01034	0.5	0.0013	0.01	0.01
Manganese	mg/L	0.012		0.005	0.008	0.04
Nitrate/Nitrite as N	mg/L			0.89	0.75	---
pH	s.u.		6 - 9	7.36	7.22	5.55
Phosphorus	mg/L	0.2		0.143	0.058	0.1
Potassium	mg/L	3.12		1	1.19	0.79
Scandium	mg/L			---	0.002	0.002

Selenium	mg/L	0.02		0.001	0.0016	0.003
Silver	mg/L			---	0.005	0.005
Sodium	mg/L			6.77	7.19	3.24
Strontium	mg/L			0.015	0.02	0.0168
Sulfate as SO4	mg/L	16.04		5.14	4.64	3.33
Thallium	mg/L			---	0.001	0.001
Tin	mg/L	0.00008		0.001	0.05	---
Titanium	mg/L			---	0.018	0.005
Total Alkalinity	mg/L			29.1	20.3	6.12
TDS	mg/L			---	75.5	14.2
TSS	mg/L	6.8	50	---	5	---
Uranium	mg/L			0.01	---	---
Vanadium	mg/L	0.01		---	0.003	0.007
Zinc	mg/L	0.1	0.5	0.013	0.005	0.005

6.6 Borrow Materials

Five borrow materials examine consisted of one scoria (BH-312) sample and four weathered saprolites (Table 6-16).

It is stated

> "The results indicate that saprolite sulfide values are highly variable. The saprolite samples also appear to have significant non-extractable sulfur, probably in the form of alunite or jarosite. The neutralizing potential of the saprolite samples is low. The scoria sample has a low sulfide sulfur content (0.01 percent) and considerable NP." (from Section 5.5, GRE, 2014)

However the non-extractable S values given in Table 5-5 (GRE, 2014) appear to be incorrect with those provided in Appendix Table A-5 being correct (shown in () in Table 6-16).

Hence of the borrow materials examined two contained sulfide S > 1 wt.% with one of these also containing non-extractable S > 2 wt.%. As stated in Section 5.5 (GRE, 2014) some of these materials may reasonably be used as borrow materials but should be tested prior to being put to this purpose.

Table 6-16 ABA results from the borrow materials (adapted from Table 5-5, GRE, 2014). Values from Appendix Table A-5: ABA Borrow Material Results are given in () where they differ from values from Table 5-5.

Sample	Total S (wt.%)	Sulfate S (wt.%)	Pyritic S (wt.%)	Non-extractable S (wt.%)	AGP ($TCaCO_3/kT$)	ANP ($TCaCO_3/kT$)
BH-305	0.12	0.09	0.02	0.04 (0.02)	0.6	0.5
BH-303	1.34	0.16	1.16	1.18 (0.02)	36.3	<0.3
BH-307	0.11	0.02	0.03	0.09 (0.06)	1.1	3
BH-308	4.28	1.02	1.02	3.26 (2.24)	31.9	<0.3
BH-312	0.01	0.01 (-0.01)	0.01	0.01 (-0.01)	<0.3	18

"Arsenic, selenium, and silver are elevated relative to crustal averages in the four saprolite samples, while selenium and silver are elevated in the scoria sample" (from Section 6.12, GRE, 2014). However, barium, copper iron and manganese (Table 6-17) were found to exceed the recommended Arpa MAC standards.

Table 6-17 SPLP results for the borrow materials showing only those elements (mg/L) that exceed the Arpa MAC standard (from Table 7-4, GRE-2014).

Element	ARPA Type II	World Bank/IFC EHS Effluent Standards	Scoria SPLP Results	Saprolitic Andesite SPLP Results (avg)
Barium	0.1		0.16	0.22
Copper	0.05	0.3	0.028	0.101
Iron	0.2		6.3	41.1
Manganese	0.05		0.119	0.078

6.7 Historic Waste Piles – Sites 13 and 27

Two historic Lower Volcanic mine wastes dating form Soviet exploration in the 1950s have also been examined. They are producing "ARD of moderate to mild severity" (from Section 8.4, GRE, 2014). Site 27 leachate pH is 3.3 which is not moderate in terms of metal and other toxic species release in international terms. On the basis of Table 6-18 (Table 8-1, GRE, 2014) it was concluded that a comparison between the ARD from these wastes and the likely ARD from Amulsar Lower Volcanic wastes is valid.

Table 6-18 shows that more than 70% (using average values) of the original AP is likely to have been reacted which is not surprising for 65-year old waste and clearly demonstrates the time-frame for on-going management of these wastes (i.e. 80-90 years) likely falling to the Armenian Government after the mine life.

Table 6-18 Site 13 and 27 mine waste ABA compared with Amulsar pits (Table 8-1 ERA 2014; Table 12 Appendix 8.19 ESIA 2016).

Barren Rock	Sample count	Statistics	AP ($TCaCO_3/kT$)	NP ($TCaCO_3/kT$)
Lower Volcanics	57	Average	37.44	0.29
		Median	5.60	0.00
		St. Dev.	57.58	1.52
		Range	0 to 204	0 to 14.18
Sites 13 and 27	4	Average	10.62	-0.75
		Median	7.34	-0.95
		St. Dev.	8.70	0.50
		Range	4.37 to 23.43	-1.1 to 0

The mean sulfide S wt.% of the Tig/Art Lower Volcanic barren rock samples was 1.31 and for the Eratos LV samples 0.88. The values for Site 13 (0.75, 0.2) and Site 27 (0.14, 0.37) are considerably smaller (Appendix F-2, GRE 2014). This also suggests that a considerable proportion of the sulfidic S in these waste rock dumps has leached resulting in acid generation.

We also note that the non-extractable S in these waste rock piles is small (0.15, 0.09 wt.% S Site 13, 0.06, 0.08 wt.% S Site 27) suggesting alunite or jarosite, if initially present, has largely been dissolved.

In Section 8.4 (GRE 2014) it is stated

> "In contrast to the drainage flowing from the workings that produced the barren rock, the character of water flowing from the waste piles suggests that the LV rock has some natural capacity to suppress initiation of the ferric iron oxidation process under actual site conditions. The suppression could be a function of any or all of the following factors:
>
> - Thiobacillus Ferroxidans has a much slower sulfide reaction rate in cold climates (Sartz, 2011);
> - The historic barren rock's argillic nature (with approximately 10 percent clay content) inhibits the flow of oxygen within the pile, and therefore, oxidation; and
> - The mineral constituents of the LV have resistance to ferric iron oxidation that is only overcome under the conditions of a long-term, laboratory-based humidity cell test. "

This is simply the normal evolution of an ARD dump. There is no evidence of resistance to ARD release.

Table 6-19 shows a comparison between sample leachate characteristics from ARD-74C and that from Sites 13 and 27; importantly sample ARD-74C contains 2.1 wt.% sulfidic S. This should be a cause for concern in that these figures make it clear that wastes now containing considerably less sulfidic S are still releasing appreciable acid after 65 years.

Table 6-19 Site 13 and 27 mine waste leachate May 2014. (From Table 8-2, GRE 2014).

Constituent	Unit	ARD-74C			Soviet waste exploration		Site 13 base line surface
		Week 10	Week 14	SPLP	Site 13	Site 27	
pH	pH units	3.52	2.69	4.64	4.78	3.28	6.38
Acidity	mg/l as $CaCO_3$	59	1210	N.S.	15.1	102	<DL
Sulfate as SO4	mg/L	59	1360	46.2	12.6	43.7	35.7

7. ACID ROCK DRAINAGE MANAGEMENT PLAN (FROM APPENDIX 8.19, ESIA, 2016)

7.1 Introduction

In this section the ARD management plan as described in Sections 4 and 5 of Appendix 8.19 of ESIA, 2016, is reviewed. We note that Appendix 3.1 Passive Treatment System is also contained in Appendix 8.19 as Appendix A: Amulsar BRSF Passive Treatment System Design Basis.

The management and mitigation strategies and implementation plans are predicated on the statement: (from Section 4, ARD Management and Mitigation Plan: Construction and Operations Phase, Appendix 8.19, ESIA, 2016):

> "By reducing the volume and the severity of ARD created by the project, it becomes possible to treat mine effluent to Armenian standards using passive treatment technologies."

The focus is on the sources of the ARD, namely pit water; runoff from Lower Volcanics placed in the barren rock storage facility; seepage from Lower Volcanics waste in the barren rock storage facility; seepage from Lower Volcanics waste stored in the Tig/Art pits considering the partial backfill of these pits; and runoff from exposed excavation surfaces of Lower Volcanics material. Figure 7-1 shows the ARD sources (in the pink boxes) and the ARD management plan.

The ratio of Lower to Upper Volcanics is defined in the waste to be stored and managed is defined in Table 16.4 of NS 43-101 (given here as Table 7-1) but it is also stated that

> "The estimated mine life is a little under 10 years, however, the model contains a significant portion of inferred material, and drilling has identified additional mineralization below the pits that has not been quantified by detailed drilling."
> (from 1.9 Mining, NI 43-101, 2017).

It is likely that this material will be Lower Volcanics and therefore a source of ARD. Given that the Upper Volcanics will be used in the BRSF to encapsulate the already existing Lower Volcanics it is not clear what mitigation strategies will be used for further Lower Volcanic waste rock.

We also note:

> "The Amulsar deposit is situated within a thick package of Paleogene volcano-sedimentary rocks. Locally, those flanking Amulsar, consist of multiple fining-upward cycles of volcanogenic conglomerate and mass flow breccia, fining-upward to volcanogenic and marly mudstones and locally, thin calcilutite limestone." (from section 1.4 Geology and Mineralization, NI 43-101, 2017)

There has been no proposed use of this limestone in BRSF formation or mitigation other than a limestone bed in the post-closure passive wetland treatment system. Lydian have not attempted to examine local lithologies that might be used to control ARD.

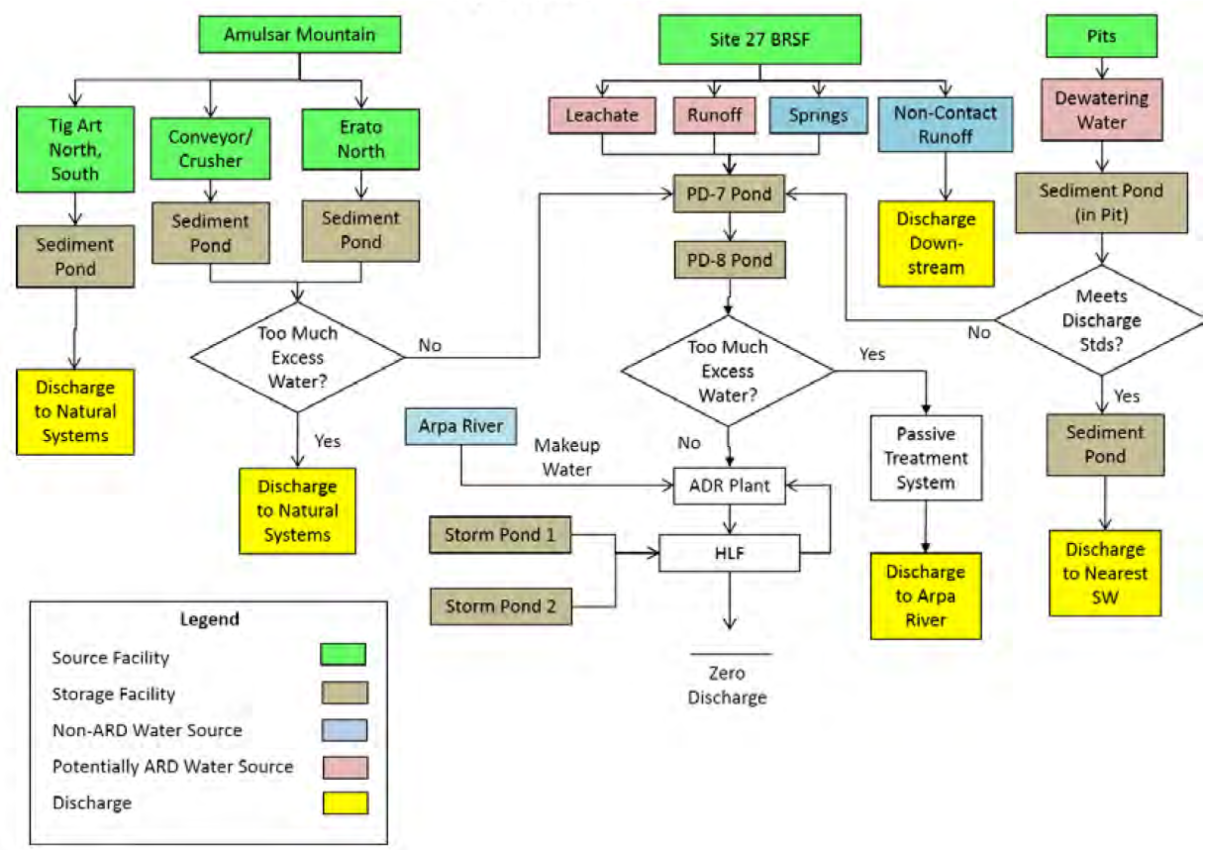

Figure 7-1 ARD management (operations phase) plan (from Figure 8, Appendix 8.19, ESIA, 2016).

Table 7-1 Mine annual production schedule (from Table 16.4., NS 43-101, 2017)

Material	Units	Yr -1	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Totals
Total Ore	K Tonnes	420.3	7,597.8	12,662.5	14,953.9	14,089.2	9,846.0	11,196.1	10,608.9	6,440.0	8,162.9	6,673.5	102,651.2
	g Au/t	0.68	0.87	0.78	0.88	0.85	0.83	0.64	0.83	0.67	0.68	0.80	0.79
	K Ozs Au	9.2	212.1	315.9	421.1	383.3	264.2	229.5	282.4	139.1	178.0	171.0	2,605.8
	g Ag/t	6.20	2.20	5.25	4.41	4.06	2.69	4.96	4.98	2.58	2.18	2.61	3.85
	K Ozs Ag	83.8	537.8	2,136.7	2,119.1	1,841.0	851.6	1,785.4	1,697.0	534.3	571.9	560.8	12,719.4
Lower Volcanic Waste	K Tonnes	259.3	6,643.8	6,607.0	8,746.8	2,151.6	3,705.0	9.0	300.7	629.0	8,328.1	232.5	37,612.9
Upper Volcanic Waste	K Tonnes	698.9	11,298.9	15,396.1	19,353.6	5,695.4	9,375.4	71.1	175.0	900.1	7,439.3	606.3	71,010.0
Coluvium Waste	K Tonnes	25.8	19.1	84.9	27.3	20.9	192.4	0.4	9.2	10.2	0.0	0.0	390.2
Undefined Waste	K Tonnes	1.4	12.6	5.1	1.5	1.0	5.3	0.1	1.7	0.3	0.0	0.0	29.0
Total BRSF Waste	K Tonnes	985.4	17,974.4	22,093.1	28,129.3	7,868.9	13,278.1	80.5	486.6	1,539.7	15,767.4	838.8	109,042.1
Lower Volcanic BF	K Tonnes			0.0	0.0	7,322.8	5,544.7	1,540.2	11,503.2	16,634.8	6,153.5	610.5	49,309.6
Upper Volcanic BF	K Tonnes	0.0			0.0	6,015.0	6,321.0	21,865.3	11,125.8	13,676.2	3,481.8	2,480.7	64,965.8
Coluvium Backfill	K Tonnes			8.8	0.0	0.0	0.0	6.9	356.1	32.1	0.0	0.0	403.9
Undefined Backfill	K Tonnes	0.0			0.0	0.0	0.2	1.0	7.1	2.2	0.0	0.0	10.5
Total Backfill Waste	K Tonnes	0.0		8.8	0.0	13,337.8	11,865.9	23,413.3	22,992.1	30,345.3	9,635.3	3,091.2	114,689.8
Total Waste	K Tonnes	985.4	17,974.4	22,101.9	28,129.3	21,206.6	25,144.0	23,493.9	23,478.7	31,885.0	25,402.7	3,930.1	223,731.9
Total Material	K Tonnes	1,405.6	25,572.2	34,764.4	43,083.2	35,295.9	34,990.0	34,690.0	34,087.7	38,325.0	33,565.6	10,603.5	326,383.1
Strip Ratio	W:O	2.34	2.37	1.75	1.88	1.51	2.55	2.10	2.21	4.95	3.11	0.59	2.18

7.2 ARD Management and Mitigation Plan: Construction and Operation Phase (from Section 4, Appendix 8.19, ESIA, 2016).

> "During the construction phase, PAG [potentially acid generating] LV material will be identified in the field (see Section 5.6). LV cut slopes and faces with PAG potential will be monitored for ARD and will be managed as required. In all pits, the widespread distribution of LV rocks on the pit walls may prevent separation of runoff from UV and LV rocks. Potential mitigation measures will include a colluvial topsoil cover and concurrent reclamation/revegetation, or selective application of shotcrete." (from Section 4.2, ARD Management Plan During Construction and Operations, Appendix 8.19, ESIA, 2016).

A topsoil cover on slopes and faces of the pits with reclamation will be unable to control the ARD generated by the highly active Lower Volcanic material. This would require *in situ* treatment to control the rate of release so that treatment of effluent can cope.

> "Finally, the [BRSF] facility must be concurrently closed at the earliest possible time to prevent runoff from PAG mine waste or infiltration into the mine waste that will become leachate. This is done by placing an engineered closure cover on the BRSF that has 1.0 meters of clayey subsoil covered by 0.2 meters of topsoil (stockpiled during construction) on top of a prepared subgrade of NAG [non acid generating] waste rock." (from Section 4.2.2 BRSF ARD Management Plan, Appendix 8.19, ESIA, 2016).

The adequacy of this depth of cover will depend on the continuous level of saturation limiting oxygen ingress. This needs to be evaluated by an expert on cover design (e.g. Prof. Ward Wilson, University of Alberta) but is likely designed to international standards by Golders.

The design of the BSRF ARD mitigation encapsulation (Section 4.3.1, Appendix 8.19, ESIA, 2016) to include segregation and encapsulation of Lower Volcanic acid generating waste is thorough and appears to be adequate. As stated,

> "this is state of the art practice and has been done on many mines throughout the world. This encapsulation design will increase the mine cost, but it also isolates mine waste from seep and spring discharge, and in conjunction with an ET [evapotranspiration] cover (see Section 3.3.2), isolates the PAG material from precipitation, snowmelt, and oxygen. This is a pro-active investment in final closure of the BRSF." (from Section 4.3.1 Encapsulation, Appendix 8.19, ESIA, 2016).

> "During barren rock placement of phases one though three, adequate coordination will be required to place all PAG material within the core of the BRSF, with a minimum of five meters of NAG material between the termination of PAG material placement and the limit of the ultimate BRSF surface." (from Section 4.3.1 Encapsulation, Appendix 8.19, ESIA, 2016)

> "LV mine waste will be encapsulated within the BRSF to minimize contact with infiltration, seepage, and oxygen. A minimum five-meter-thick NAG buffer zone serves as the basal encapsulation layer. The upper volcanic NAG waste material also serves as a buffer between the encapsulated waste and all final side slopes, benches and top surfaces." (from section 10.2.1.1 Encapsulation, The Amulsar Project Geochemical Characterization and Prediction Report – Update, 31st, August 2014, prepared by Global Resource Engineering)

Figure 7-2, however, appears to show exposure of LV at the surface of the down-grade stockpile but this may represent progressive formation. More importantly the geochemical assessments of the Upper Volcanics in these documents is given as being uncertain to potentially acid generating. There is no NAG, non-acid generating, material.

> "The Upper Volcanics rock type has some trace sulfides, but its oxidized nature and low total sulfide concentration (around 0.15 percent) make it so the low AP [acid potential] of the UV does not realize itself as ARD." (from 24.3.1 Summary of ARD Characterization, NI 43-101, 2017)

This has not been adequately tested in the inadequate suite of humidity cells or any long-term tests. It is not the conclusion of their own categorisation of Uncertain to PAG (potentially acid generating) not NAG (non-acid generating) and suggests that Upper Volcanic encapsulation material is at risk of producing acid on weathering.

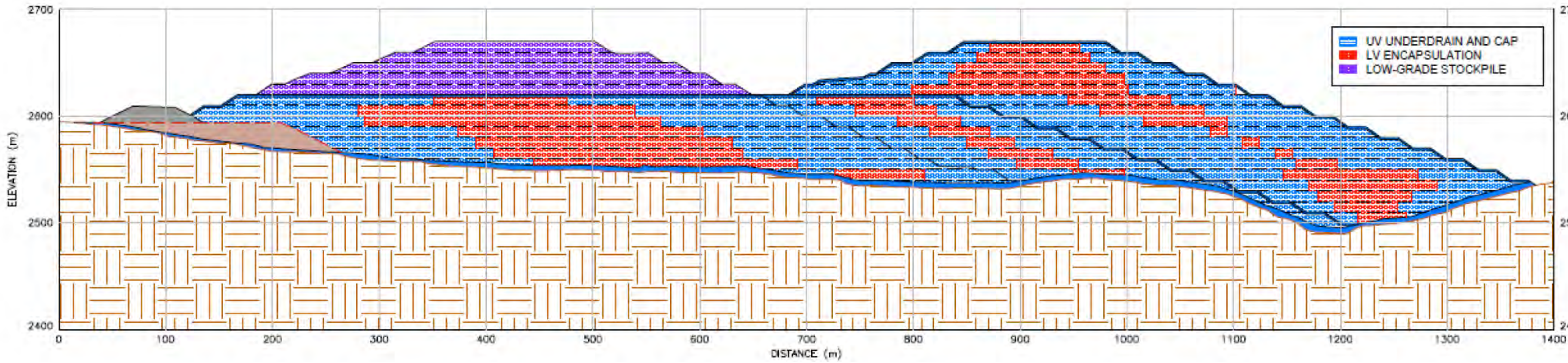

Figure 7-2 Encapsulation concept with low grade stockpile (from Figure 9, Appendix 8.19, ESIA, 2016).

The seepage modelling (

Figure **7-3**) shows that the encapsulation is effective and that water should flow around and under the PAG material. Predicted flow within the PAG itself is low with the capillary action of the clay in the PAG helping to contain the ARD. **Nevertheless, the PAG seepage averages 33% percent of the total flow in the BRSF underdrain (**

Figure 7-4**) so that the full estimation of the ARD characteristics of this PAG seepage are critical to the subsequent treatment.**

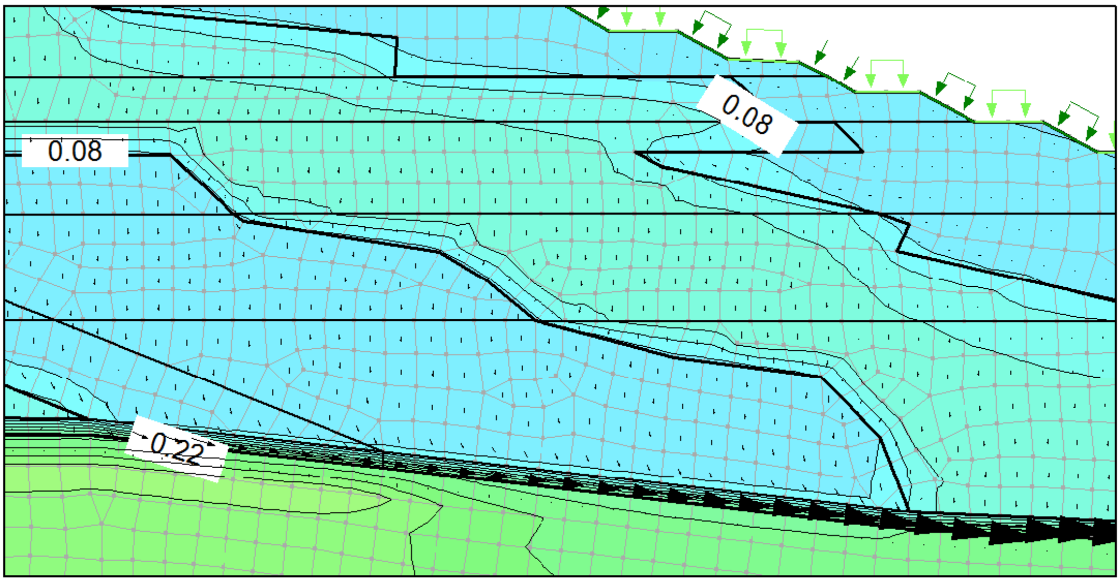

Figure 7-3 Close-up, moisture content distribution, year 8 (from Figure 10, Appendix 8.19, ESIA, 2016).

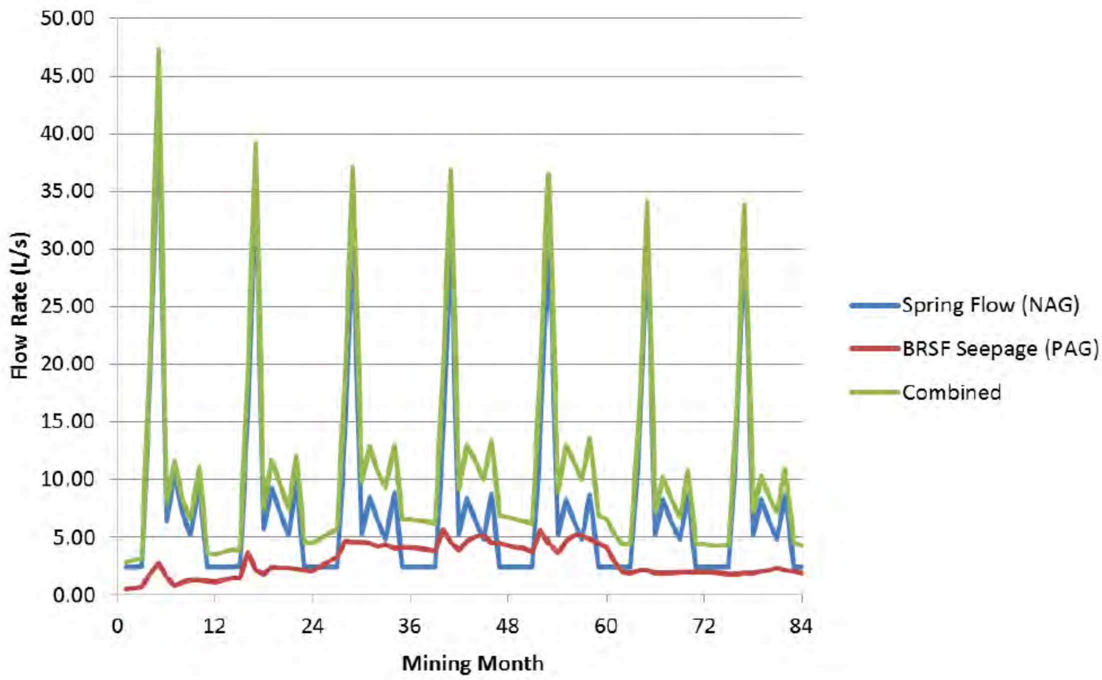

Figure 7-4 BSRF leachate during time (from Figure 11, Appendix 8.19, ESIA, 2016).

The store-and-release ET cover proposed for final closure (Section 4.2, Appendix 8.19, ESIA, 2016) of the BSRF do not have a good record in many placements internationally as researched by Prof. Ward Wilson (University of Alberta). They tend in the longer term and on exposure to high rainfall or snow melt to slump and expose the underlying BSRF. The control of oxygen in the BSRF modelled in Figure 7-5 relies on the ET cover remaining in place.

> "Because the total depth was approximately 1.5 meters, this was the assumed penetration depth for oxygen in the geochemical modelling." (from Section 4.3.3 Oxygen Limitation, Appendix 8.19, ESIA, 2016)

A separate opinion might be sought on this choice compared to compacted soil covers designed for water run-off (e.g. Savage River Rehabilitation Program, Hutchison and Brett, 2006 and http://www.abc.net.au/site-archive/rural/tas/content/2006/s1704113.htm). Both may require periodic (e.g. 10 year) addition or replacement; likely to fall to Government funding.

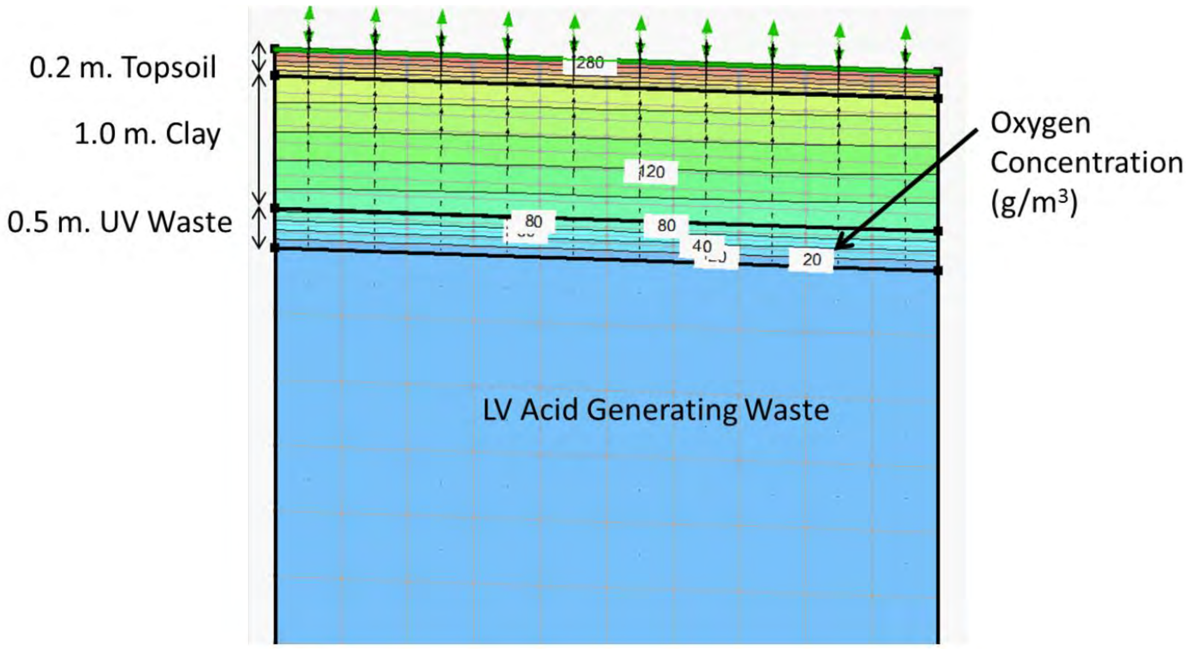

Figure 7-5 Moisture content distribution, year 8 (from Figure 12, Appendix 8.19, ESIA, 2016).

> **"**The Tigranes and Artavazdes pit backfill will receive LV waste from the Erato pit. As a result, the seepage from the pits will produce ARD. The primary mitigation measure for this ARD is to cap the pit backfill with 0.5 meters of clayey soil. This cover is less effective than the ET cover planned for the BRSF, but due to the geometry of the pit, oxygen penetration is impossible through the sides of the facility making a thinner cover possible. The cover is effective in reducing seepage, in limiting oxygen penetration, and in establishing a vegetated reclamation surface. Ultimately, the seepage in the backfill will travel to the regional seeps and

> springs where it will mix with groundwater impacted by naturally-occurring ARD and discharge on the side of Amulsar Mountain." (from Section 4.5 Pit Backfill ARD Mitigation, Appendix 8.19, ESIA, 2016).

Pit backfill ARD mitigation is entirely inadequate and one of the most serious ARD problems worldwide. There is an unfounded, untested assertion on soil cover limiting oxygen penetration. There is also a clear statement that ARD will be released to seeps, springs and groundwater discharging down Amulsar Mountain. No effective treatment is planned (see Figure 7-1).

> "Geochemical modelling has predicted that the mine contact water quality that can be treated with passive treatment methods." (from Section 4.6 Passive Treatment of Mine Contact Water, Appendix 8.19, ESIA, 2016)

This statement depends entirely on the geochemical modelling of the amount and severity of the ARD from the BSRF. There are serious inadequacies in the amount and type of testing in this modelling. If this is underestimated, the passive system will be overwhelmed and the ARD will be released adding to the untreated ARD discharges from the pits. Planning for the BSRF ARD containment is good but this is still an unknown while the kinetics of the ARD release is inadequately measured.

> "The PTS design has been included in Appendix A to this report. The system has been designed to meet Armenian discharge standards (see Table 14 [Table 7-2])." (from Section 4.6 Passive Treatment of Mine Contact Water, Appendix 8.19, ESIA, 2016)

The passive treatment system design in Appendix A is from a world expert (James Gusek) and appears to be thorough. If additional kinetic ARD testing confirms the values in Table 7-2and the flow rates are validated, this passive treatment system is a welcome addition to the plan for mitigation and treatment.

Table 7-2 Passive treatment system influent water quality (from Table 14, Appendix 8.19, ESIA, 2016).

Quality indicators	Unit	Arpa MAC Standards Quality Category II	Detention Pond
pH			3.92
Acidity	mg $CaCO_3$/l		157.2
Aluminium	mg/l	0.144	27.2
Arsenic, total	mg/l	0.02	0.0173
Barium	mg/l	0.028	0.0214
Beryllium	mg/l	0.000038	0.00201
Boron	mg/l	0.45	0.00918
Cadmium, total	mg/l	0.001014	3.59×10^{-4}
Calcium	mg/l	100	12.5
Chloride ion	mg/l	6.88	0.215
Chromium, total	mg/l	0.011	6.60×10^{-10}
Cobalt, total	mg/l	0.00036	0.104
Copper, total	mg/l	0.021	9.68×10^{-15}
Iron, total	mg/l	0.072	5.65×10^{-7}
Lead, total	mg/l	0.01014	0.0404
Lithium	mg/l	0.003	0.01005
Magnesium	mg/l	50	5.11
Manganese, total	mg/l	0.012	0.00160
Nickel, total	mg/l	0.01034	0.0618
Nitrate ion	mg N/l	2.5	2.35
Nitrite ion	mg N/l	0.06	4.01×10^{-13}
Phosphate ion	mg/l	0.1	8.07×10^{-12}
Potassium	mg/l	3.12	6.39
Selenium, total	mg/l	0.02	0.00874
Silicate ion	mg Si/l	25	4.25×10^{-7}
Sulphate ion	mg/l	16.04	97.3
Total phosphorus	mg/l	0.2	0.866
Vanadium, total	mg/l	0.01	0.00237
Zinc, total	mg/l	0.1	0.381

> "In summary, the ARD management and mitigation measures at the Amulsar site are designed to take advantage of the natural resistance to the formation of severe ARD (defined as ARD with pH<3 and greater than 1000 mg/L of sulfate)." (from Section 4.7 Summary of ARD Mitigation and Management Measures, Appendix 8.19, ESIA, 2016)

This resistance is unproven and is based on the very limited kinetic (humidity cell) testing undertaken which was not correlated to the actual mineralogy of the samples.

> "Through the use of encapsulation cells within the BRSF, and ET covers on the BRSF and pit backfill, the waste will be isolated from oxygen sources rapidly, thus inhibiting sulfide oxidation. As a result, the ARD that must be managed will have a moderate pH, lower total acidity, lower sulfate concentrations, and lower concentrations of metals (see Table 14 [Table 7-2])." (from Section 4.7 Summary of ARD Mitigation and Management Measures, Appendix 8.19, ESIA, 2016)

This statement is currently unproven.

7.3 ARD Management and Mitigation Plan, Closure Phase (from Section 5, Appendix 8.19, ESIA, 2016)

This closure phase plan confirms that, while the combined BSRF and Site 27 discharge will be treated in the passive treatment system, untreated discharges from the Erato Pit and two Tig/Art pits will be released to springs (

Figure 7-6).

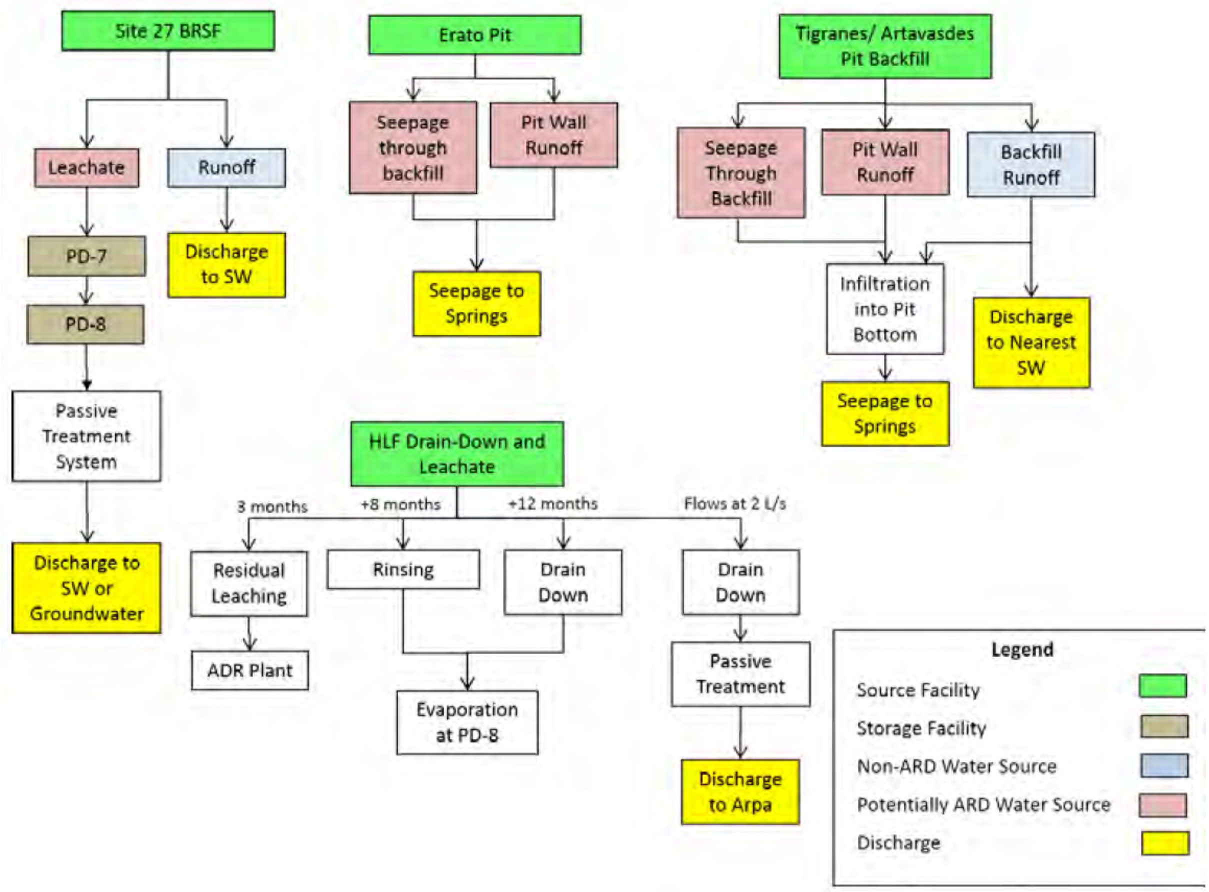

Figure 7-6 Closure-phase ARD management plan (from Figure 13, Appendix 8.19, ESIA, 2016).

> "The pit backfill that will be placed in the Tigranes/Artavazdes pit will create a low volume of ARD seepage upon closure. This seepage will report to seeps and springs on the side of Amulsar Mountain that are already impacted by naturally occurring ARD (Golder, 2014)." (from Section 5.3 Tigranes/Artavazdes Seepage, Appendix 8.19, ESIA, 2016)

Figure 7-7 shows the total discharge (0.8-1.0 L/s) from each pit to the aquifer. The naturally occurring ARD (not defined) in seeps and springs on Amulsar Mountain is used to justify release of much more ARD to the same water flows. This is not reasonable or acceptable practice.

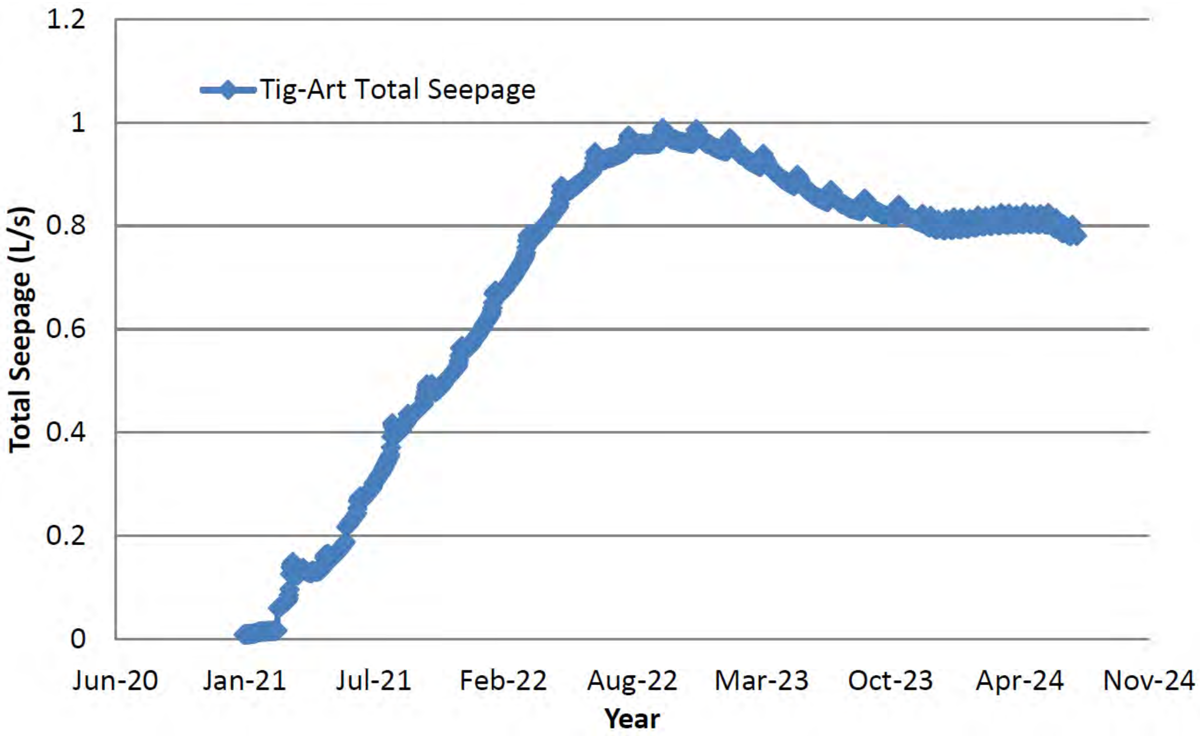

Figure 7-7 Closure phase ARD seepage from Tig/Art pits (from Figure 14, Appendix 8.19, ESIA, 2016).

> "The predicted pH is acidic, with mean values over time of 4.3 and 2.9 for the average and maximum case, respectively." (from Section 5.4 Erato Seepage, Appendix 8.19, ESIA, 2016)

Given the lack of appropriate characterisation of relevant acid producing mineralogies these predictions cannot be assumed to be reliable but they indicate serious ARD after closure.

> "The identification and sorting of PAG and NAG at Amulsar will be critical to the success of the ARD management plan. Construction waste, construction cut-slopes, and barren rock will all be classified by the ARD risk into NAG or PAG rock." (from Section 5.6 ARD Identification and Management, Appendix 8.19, ESIA, 2016).

The Paste pH and NAG tests on visually selected samples with backup ABA testing if needed is probably adequate for this purpose. There is no NAG (non-acid generating) barren rock identified by geochemical testing. The acid generating characteristics are either PAG (potentially acid generating) or 'Uncertain'.

7.4 Geochemistry and ARD Management Plan Conclusions (from Section 6, Appendix 8.19, ESIA, 2016)

> "The Lower Volcanics (LV) formation that will be excavated in the Amulsar pits is acid generating. However, this formation shows resistance to the formation of strong ARD and resistance to ARD created by ferric iron oxidation of sulfides."

There is no evidence for this recurring statement. The Lower Volcanic waste reacts normally producing ferric ion and most likely secondary jarosite into which some of the ferric ion is captured as stored acidity to be released again when pH rises to 4.

> "The LV formation has been demonstrated to produce ARD with pH>3.0, sulfate concentrations less than 100 mg/L and total acidity of ~100 mg/L $CaCO_3$ equivalent even after decades of exposure to the ambient environment. The LV produces stronger ARD only under extreme conditions, such as long-term humidity cell tests or oxidation over years in a core box."

This statement is not supported. ARD with pH 3.5 leachate is found after 65 years of weathering from Site 27, despite an estimated 70% of the sulfidic S having already been reacted. This is strong ARD under in situ conditions. This already reacted sulfidic S will have contributed to the acidity now found in local seeps and streams but this is not recognised.

> "As a result, the goal of the ARD mitigation plan is to encapsulate the LV material before it can develop the conditions required to generate stronger ARD. This will be accomplished by creating LV encapsulation cells in the BRSF that are isolated from groundwater, surface water, and precipitation. The BRSF will also be rapidly capped as a concurrent reclamation measure. The LV in pit backfill will be managed with rapid placement of a closure cover. As a result of these measures, the predicted intensity of ARD on site will be mild – on the order of what has been observed in the field discharging from the Site 13 and Site 27 Soviet-era exploration adit waste piles."

This is not mild ARD – it would not be acceptable in international planning.

> "The Project will have no net discharge of ARD during operations for the first years of operation. During this period, all ARD will be captured and directed to the PD-8 pond. From the PD-8, ARD will consumed as makeup water on the HLF. The water balance (Golder, 2015) predicts that the ARD storage facilities planned for the site are capable of containing an exceptionally wet year or the 100-year 24-hour storm event without discharge. The water balance also predicts that treatment will be required starting in 2021 in the event of a "wet year" condition. As a precaution, the project will construct a passive treatment system (PTS) to treat and discharge contact water when required during the later years of operation and post-closure."

The PTS is an essential addition to mitigation and is the only treatment proposed for BRSF seepage and runoff. It is to be constructed in year 2019. There are major concerns that this PTS will not be able to neutralise and treat the release from the BRSF, particularly as this has been inadequately characterised, with consequent ARD release to the streams, rivers and water storage below the mine. It is assumed that this PTS is to remain effective in perpetuity but the responsibility for functioning and maintenance is not clear.

> "Upon closure, BRSF, and Pit Backfill will be covered with an ET cover, which limits the infiltration of water and the diffusion of oxygen. However, both the BRSF and Pit Backfill are expected to leach ARD. The BRSF seepage will report to the PTS that will treat the water to Armenian discharge standards. The pit backfill and open pit seepage will discharge a low volume of ARD to seeps and springs that are impacted by naturally occurring ARD with no net impact to baseline water quality."

The pits discharge is unacceptable to the local environment, agriculture and communities using water below the mine.

> "The HLF will be covered with an ET cover. The seepage from this facility will also be treated in a passive treatment system during the post closure period. As a result, the site will remain in compliance with Armenian water quality discharge limits following closure through the application of ARD mitigation measures and the use of passive treatment systems."

8. GROUNDWATER RESOURCES (FROM SECTION 6.9, ESIA, 2016)

The area of study to which the modelling of changes to groundwater applies is illustrated in Figure 8-1.

> "The impact assessment addresses the following Project facilities that may impact groundwater:
>
> - The Tigranes-Artavazdes and Erato open pits. The Tigranes-Artavazdes pit will be backfilled during the later years of operation leaving a small southerly pit partially unbackfilled. The Erato pit will be partially backfilled at closure;
> - The Barren Rock Storage Facility (BRSF);
> - The Heap Leach Facility (HLF) and associated adsorption-desorption recovery (ADR) plant; and
> - Additional supporting infrastructure including water storage ponds, water treatment systems, crushers, haul roads, material stockpiles, conveyor and mine buildings."(from Section 6.9.1 Introduction, ESIA, 2016)
>
> "Management of water through the mine life cycle is described in the water management plan. The objectives of the water management plan are:
>
> - To route mine contact runoff water to ponds and collection sumps in order to minimise the release of mobilised sediment;
> - To prevent natural ground runoff and non-contact water from entering disturbed areas and mixing with contact water;
> - To capture contact water runoff from the mine facilities, use in process operations (if possible) and if necessary treat and discharge if the water cannot be used; and
> - To minimise erosion of disturbed areas, and when erosion does occur, to minimise suspended sediment flow to streams."(from Section 6.9.1 Introduction, ESIA, 2016)

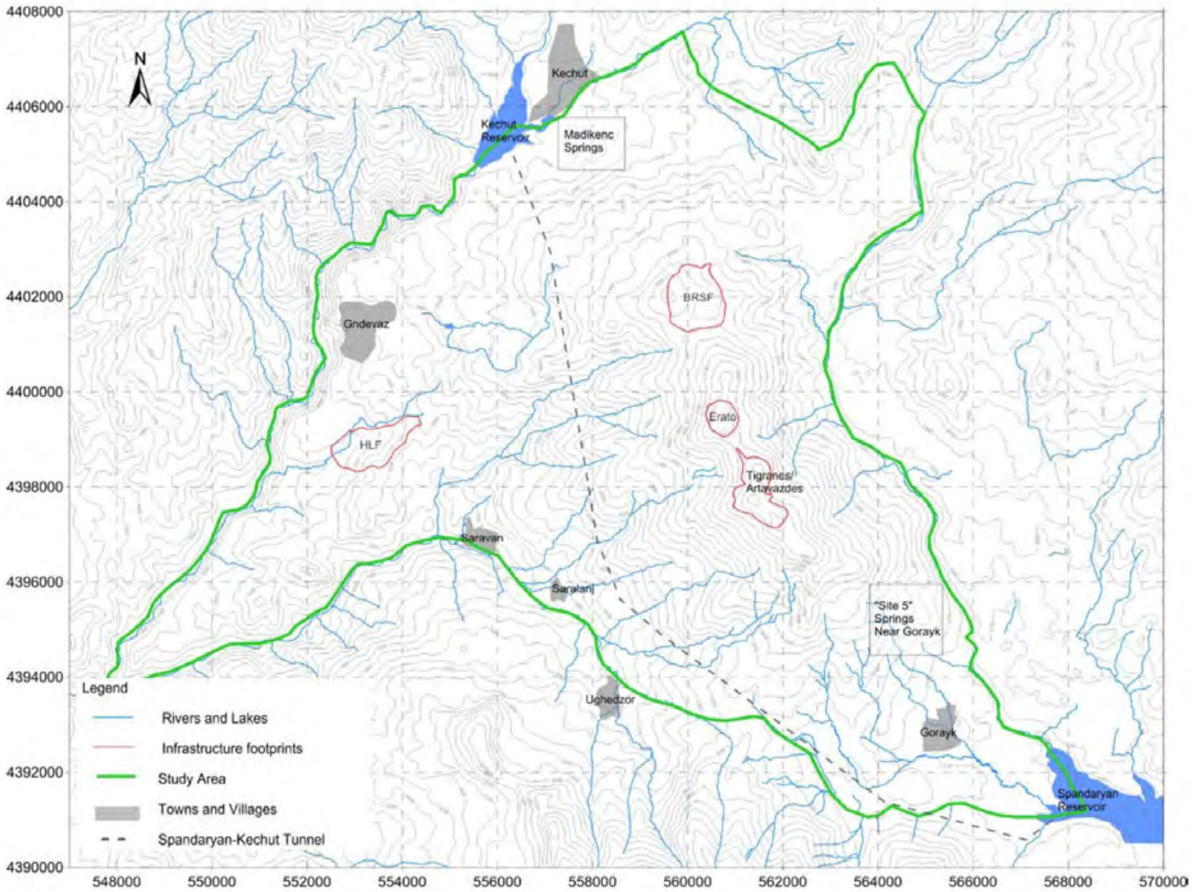

Figure 8-1 Groundwater study area (from Figure 6.9.1. Section 6.9, ESIA, 2016).

8.1 Groundwater Modelling Study (from Appendix 6.9.1, ESIA, 2016)

"The model was first used to determine the large-scale baseline hydrogeological conditions (i.e. before construction and operation). The key findings of the baseline model are summarised below:

- The water table largely mirrors topography, being highest beneath the Amulsar ridge and decreasing to the main river valleys;
- Groundwater flows radially away from the Amulsar ridge. Flow from the Tigranes-Artavazdes peaks is eastward to the Vorotan River and westward to the Darb River. Flow from Erato peak is predominantly to the west to the Arpa River;
- There is a shallow near-surface water table in the bottom of the BRSF valley underlain by argillized Lower Volcanics;
- There is a deep water table (in excess of 100 m below ground level) in the basalts to the northwest and west of the Amulsar ridge;
- Groundwater below the BRSF site flows northwestwards before turning west to discharge predominantly to the Arpa River downstream of the Kechut Reservoir;

- Groundwater flow is westward from the HLF site toward the Arpa River;
- The Spandaryan-Kechut Tunnel intersects the water table throughout its length, but overall the groundwater contribution area of the tunnel is localised. Simulated groundwater flow pathlines indicate that groundwater flow originating from below the Erato, Tigranes and Artavazdes peaks and from the BRSF site flows beneath the tunnel to discharge to the Darb River; and
- The model shows groundwater discharge zones in river and stream valleys, and on the flanks of the Amulsar ridge below an elevation of approximately 2,700 m asl. The groundwater discharge on the flanks of Amulsar ridge is relatively well matched to observed areas of perennial spring discharge." (from Appendix 6.9.1 Groundwater Modelling Study, ESIA, 2016)

The predicted groundwater flow paths in the operational period are shown in Figure 8-2. A summary of important results is given here.

> "However, because of potential uncertainty in model results and the high sensitivity of the Spandaryan-Kechut water supply (Table 6.9.2), **a worst-case analysis of groundwater inflow into the Spandaryan-Kechut Tunnel originating from the pits has been evaluated.** The Spandaryan-Kechut assessment has been undertaken by combining potential impacts to groundwater quality from both the Tigranes-Artavazdes and Erato Pits and the BRSF assessment." (from Appendix 6.9.1 Groundwater Modelling Study, ESIA, 2016 – our bolding)
>
> **"The operational model predicts a decrease in groundwater elevations of between 30 and 60 m in the vicinity of the BRSF because of reduced recharge.** As a result, springs in the BRSF site may no longer flow. **The groundwater discharge to the stream in the BRSF valley is also predicted to decline by approximately 24 %. A decrease in flow of 36 % is predicted in the spring cluster west of the BRSF. Reduced recharge around the HLF results in a predicted decrease in groundwater elevations of between 3 m and 10 m.** There are no perennial springs in this area that are predicted to be affected by this change." (from Appendix 6.9.1 Groundwater Modelling Study, ESIA, 2016 – our bolding)
>
> "A reduction in recharge in the BRSF area is predicted to result in a reduction in water supply to the catchment of the **Kechut (Madikenc) springs. The groundwater model predicts a 10 % reduction in flow at these springs during operation.**" (from Appendix 6.9.1 Groundwater Modelling Study, ESIA, 2016 – our bolding)

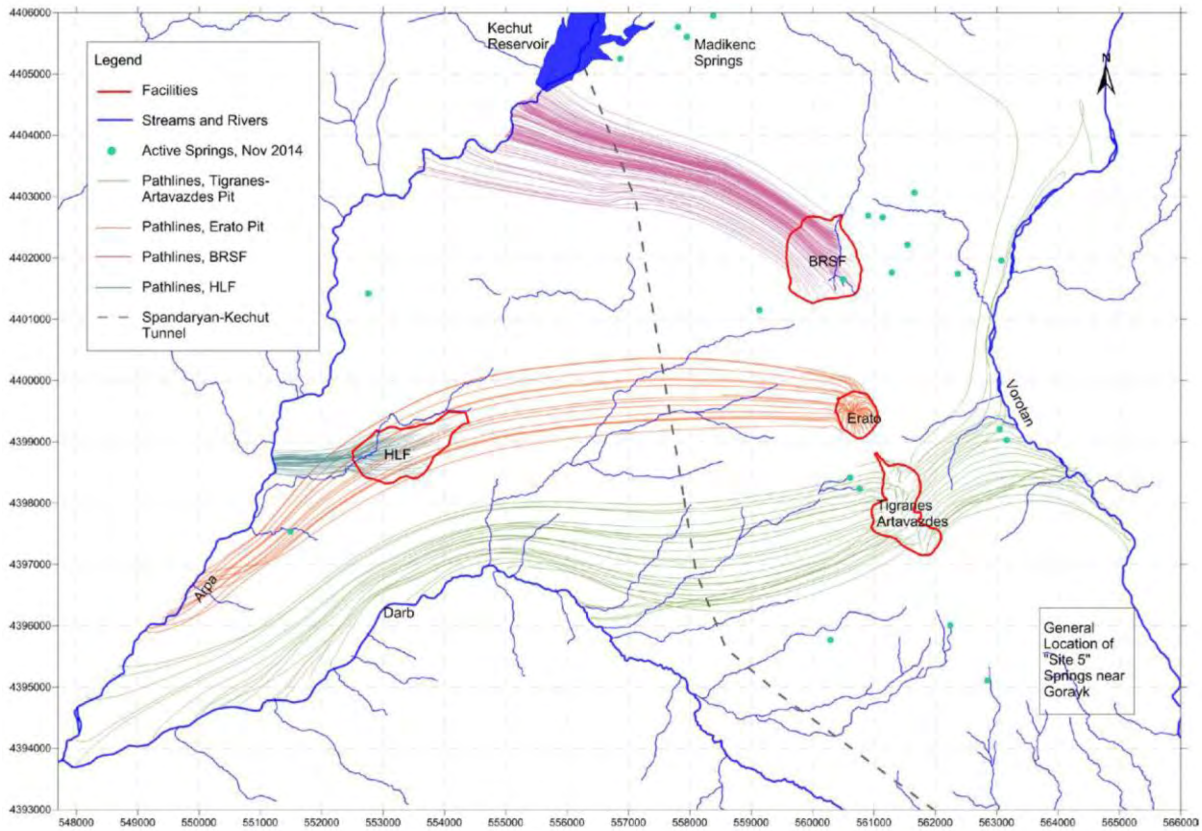

Figure 8-2 Groundwater flow path lines during the operational period (from Figure 6.9.2, ESIA, 2016).

"The key findings of the post-closure model [Figure 8-3] are summarised below:

- There is predicted to be an increase in groundwater levels and perennial spring flow downgradient of the **Erato pit** as a result of increased infiltration in the pit footprint compared to baseline conditions. **Locally (adjacent to the pit), groundwater levels are predicted to increase progressively by approximately 9 m to 16 m**;
- There is predicted to be a decrease in groundwater levels and perennial spring flow, downgradient of **Tigranes-Artavazdes** as a result of decreased infiltration compared to baseline conditions. **Locally, groundwater levels are predicted to progressively decrease by up to 40 m**;
- Some perennial springs that currently flow at a very low rate during winter, particularly in the vicinity of Tigranes-Artavazdes, may become ephemeral (dry during the winter months);
- The flow in the perennial springs around the peak could progressively decrease by between 1 % and 6 % from baseline conditions;
- No perennial springs will be lost around the peak;
- **Reduced recharge in the BRSF site may result in a progressive decrease in groundwater levels of up to 60 m in the southern portion of the BRSF**, the

decrease is anticipated to begin within a few years of construction of the facility due to the reduction in recharge within the footprint, but may occur over many years (see Appendix 6.9.1);

- Groundwater discharge to surface will likely cease in the southern part of the BRSF site;
- **Discharge from springs in the valley west of the BRSF (which includes perennial spring SP68) is predicted to progressively reduce in the post-closure scenario by between 14 % and 20 % in comparison to baseline conditions**;
- Groundwater discharge to the Kechut (Madikenc) springs is conservatively predicted to progressively decrease by approximately 7 % to 8 % over the long term. This change in flow is sensitive to several parameters including the interpreted hydrogeological conditions at and surrounding the BRSF, the recharge rate on the northern end of the Amulsar ridge and the rate of leakage from the BRSF (and, therefore, the change in groundwater elevation beneath the BRSF and the hydraulic gradient in the basalts feeding these springs);
- **Groundwater discharge to the stream in the valley east of the BRSF is predicted to progressively decrease by between 11 % and 21 %;**
- Groundwater discharge to the Spandaryan-Kechut Tunnel is predicted to progressively decrease by between 2 % and 3 %;
- Reduced recharge **across the HLF footprint is predicted to result in a progressive decrease in groundwater levels of up to 13 m on the southeastern boundary**. Similar to the BRSF, this decrease is anticipated to begin within a few years of construction of the facility due to the reduction in recharge within the footprint, but may occur over many years (see Appendix 6.9.1); and
- The change in groundwater recharge is predicted to have minimal impact on groundwater baseflow to the Vorotan, Darb and Arpa Rivers. Model results predict a decrease in groundwater baseflow from catchments within the Project Area of approximately 2 % in the Vorotan River, approximately 2 % in the Arpa River and approximately 1 % in the Darb River." (from Appendix 6.9.1 Groundwater Modelling Study, ESIA, 2016 – our bolding)

We are not expert in hydrogeological modelling but many of the changes (marked in extracts) in groundwater levels (e.g. 60 m lower), redirection and reduction in springs and streams predicted within and around the mine site, both in operation and after closure, appear to be of considerable magnitude. They are likely to impact any bore water being used in the region. They may concern the local communities and local governments.

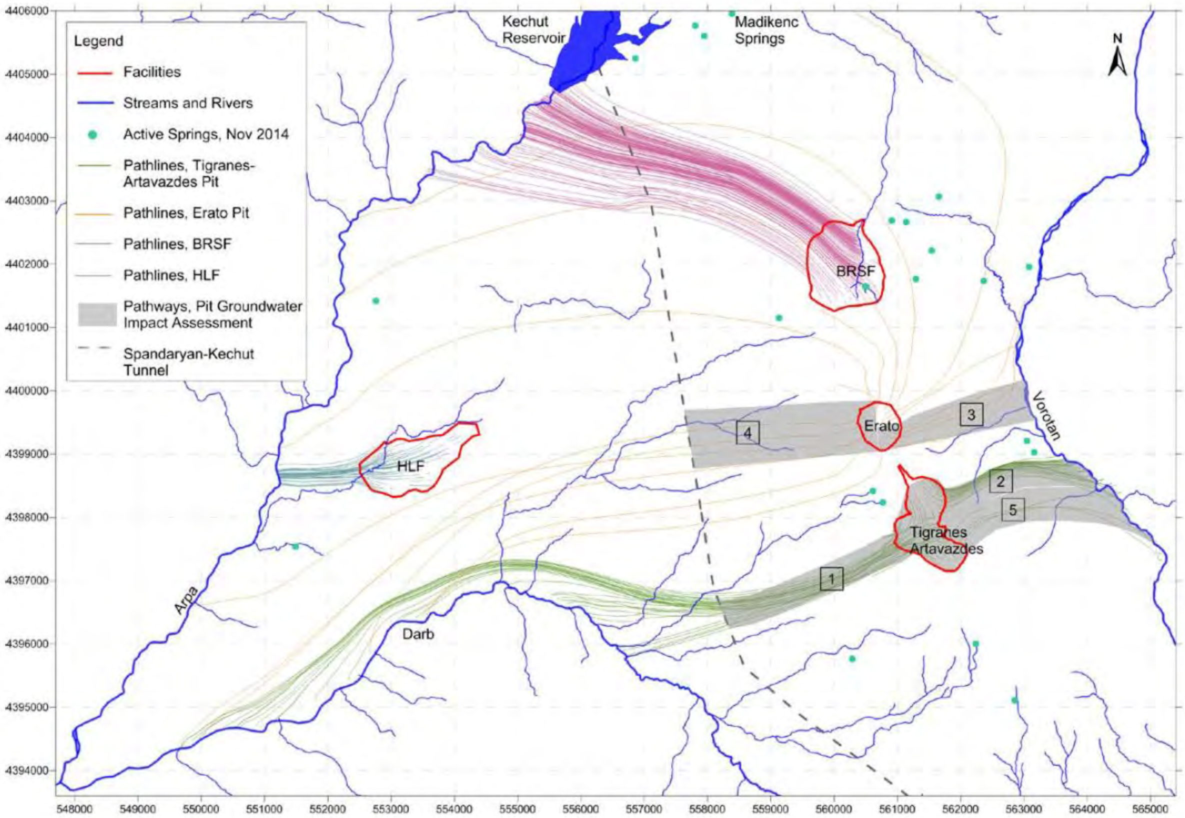

Figure 8-3 Groundwater flow pathlines post closure (from Figure 6.9.3, Section 6.9, ESIA, 2016).

> The groundwater flow model predicts that groundwater originating from below the Erato and Tigranes-Artavazdes pits, and from the BRSF site, will flow beneath the Spandaryan-Kechut Tunnel." (from Appendix 6.9.1 Groundwater Modelling Study, ESIA, 2016)

Changes to the Spandaryan-Kechut Tunnel flow are not predicted to be serious in volume. Groundwater baseflows to the Vorotan, Darb and Arpa Rivers do not appear to be seriously changed in this modelling.

8.2 Assessment of Risk to Groundwater Quality (from Appendix 6.9.3, ESIA, 2016)

> "The purpose of this assessment was to determine the risk to drinking water supplies and the hydrologic system presented by the leakage of mine-influenced water from the pits." (from Appendix 6.9.3 Assessment of Risk to Groundwater Quality from the Tigranes-Artavazdes and Erato Pits, ESIA, 2016)

> "The groundwater flow model indicates that leakage from the backfilled pits is most likely to flow towards Darb River and the Vorotan River. Therefore, the change in groundwater quality at the point of discharge to the Darb River and the

Vorotan River has been calculated." (from Appendix 6.9.3 Assessment of Risk to Groundwater Quality from the Tigranes-Artavazdes and Erato Pits, ESIA, 2016)

Given the sensitivity of the Spandaryan-Kechut water supply, its location downgradient of the pits and potential model uncertainty, the groundwater in the Spandaryan-Kechut Tunnel has also been considered as a receptor for flow from the pits." (from Appendix 6.9.3 Assessment of Risk to Groundwater Quality from the Tigranes-Artavazdes and Erato Pits, ESIA, 2016)

"The risk assessment predicts that because of the long groundwater travel time from the pit area to potential receptors, the peak impacts to receptor groundwater quality is not likely to be observed until the post-closure phase." (from Appendix 6.9.3 Assessment of Risk to Groundwater Quality from the Tigranes-Artavazdes and Erato Pits, ESIA, 2016)

"The predicted peak concentrations of the main constituents evaluated in groundwater are presented in Table 6.9.4. Figure 6.9.3 [

Figure 8-3] shows the flowpaths between sources and receptors. The predicted change in spring water quality has been determined for groups of springs, which are shown in Figure 6.9.4 [

Figure 8-4]. The predicted peak concentrations of the main constituents evaluated in groundwater discharging to the springs are presented in Table 6.9.5." (from Appendix 6.9.3 Assessment of Risk to Groundwater Quality from the Tigranes-Artavazdes and Erato Pits, ESIA, 2016)

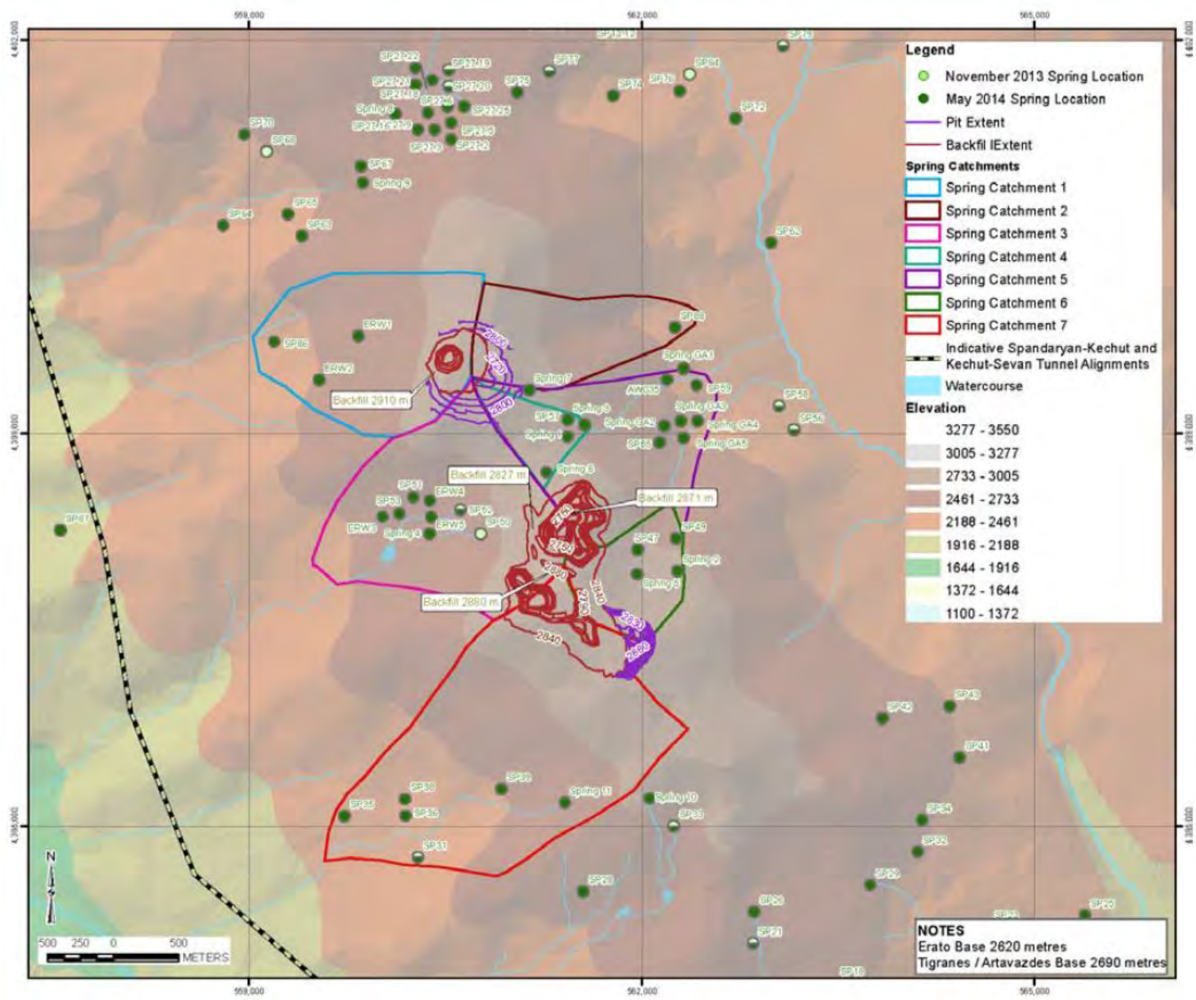

Figure 8-4 Spring catchments used in pit risk assessment (from Figure 6.9.4, ESIA, 2016).

Results of modelling suggest that changes to the tunnel and discharge concentrations to the rivers from the pits will be significant (Table 8-1). As previously, without modelling of the pH, these changes in concentrations are difficult to understand since most of these concentrations depend directly on this estimate.

The more serious issue for agriculture in the area appears to be in spring water discharge and changes to local streams as in Table 8-2 **where the magnitude of changes is very large in several cases (e.g. Co, Be, nitrate >1000%).**

Table 8-1 Predicted changes in groundwater concentrations in the Spandaryan-Kechut Tunnel and prior to discharge to the rivers as a result of leakage from the pits (from Table 6.9.4, ESIA, 2016).

Constituent	MAC II (mg/l) for Vorotan Catchment	Groundwater prior to discharge to Vorotan River			MAC II (mg/l) for Darb/Arpa Catchment	Groundwater in Spandaryan-Kechut Tunnel – Average Flow	Groundwater prior to discharge to Darb River	
		Predicted peak concentration from Pathway 2 Tigranes-Artavazdes Pit Source in mg/l (% change from baseline)	Predicted peak concentration from Pathway 5 Tigranes-Artavazdes Pit Source in mg/l (% change from baseline)	Predicted peak concentration from Pathway 3 Erato Pit Source in mg/l (% change from baseline)		Predicted peak concentration from combined Pathway 1 and 4 pit sources in mg/l (% change from baseline)	Predicted peak concentration from Pathway 1 Tigranes-Artavazdes Pit Source in mg/l (% change from baseline)	Predicted peak concentration from Pathway 4 Erato Pit Source in mg/l (% change from baseline)
Nitrate as N	2.5	5.79 (459%)	1.13 (9%)	n/a	2.5	0.57 (14.1%)	1.87 (274%)	n/a
Sulfate	17.02	34.02 (53%)	22.71 (2%)	25.12 (13%)	16.04	126.14 (0.1%)	127.2 (1%)	126.45 (0%)
Beryllium	5.4×10^{-5}	0.00023 (0%)	0.00023 (0%)	0.0002 (0%)	3.8×10^{-5}	0.0002 (0%)	0.0002 (0%)	0.0002 (0%)
Nickel	0.0105	0.0039 (0%)	0.0039 (0%)	0.0039 (0%)	0.0103	0.003 (0%)	0.003 (0%)	0.003 (0%)
Antimony	0.0005	n/a	n/a	0.001 (0%)	0.00028	0.001 (0%)	n/a	0.001 (0%)
Arsenic	0.02	0.001 (0%)	0.001 (0%)	0.001 (0%)	0.02	0.0068 (0%)	0.0068 (0%)	0.0068 (0%)
Cobalt	0.00028	0.0038 (0%)	0.0038 (0%)	0.0038 (0%)	0.00036	0.00051 (0%)	0.00051 (0%)	0.00051 (0%)
Cadmium	0.00101	0.0005 (0%)	0.0005 (0%)	0.0005 (0%)	0.00101	0.0005 (0%)	0.0005 (0%)	0.0005 (0%)
Chromium	0.0105	0.004 (0%)	0.004 (0%)	0.004 (0%)	0.011	0.005 (0%)	0.005 (0%)	0.005 (0%)
Molybdenum	0.002	n/a	n/a	0.0008 (0%)	0.00082	0.003 (0%)	n/a	0.003 (0%)
Lithium	0.002	0.0017 (19%)	0.0016 (9%)	0.0059 (308%)	0.003	0.0044 (3.1%)	0.0044 (2%)	0.005 (17%)
Tin	0.00016	n/a	n/a	0*	8.00×10^{-5}	0.00011*	n/a	3.92×10^{-6}*

Notes:

n/a – not present in source term. * no baseline concentration to report percentage change. Negligible changes have been highlighted in green; low impacts have been highlighted in yellow; moderate impacts have been highlighted in pink; and high impacts have been highlighted in purple.

MAC II concentrations provided for information only since does not apply directly to groundwater.

Table 8-2 Predicted peak changes in spring water discharge as a result of leakage from the pits (from Table 6.9.5, ESIA, 2016).

Constituent	MAC II (mg/l) for Catchments 1,3 and 7	MAC II (mg/l)for Catchments 2, 4, 5 and 6	Predicted Concentration at Springs in mg/l (% change from baseline)						
			Spring Catchment 1	Spring Catchment 2	Spring Catchment3	Spring Catchment4	Spring Catchment 5	Spring Catchment 6	Spring Catchment 7
Sulfate	16.04	17.02	7.54 (1%)	36.95 (0%)	20.03 (16%)	5.08 (2%)	5.23 (5%)	9.99 (100%)	6.17 (23%)
Antimony	0.00028	0.0005	0.00022 (7%)	0.00021 (2%)	0.00021 (3%)	0.00022 (11%)	0.0002 (1%)	0.0002 (0%)	0.0002 (0%)
Arsenic	0.02	0.02	0.001 (1%)	0.0014 (0%)	0.0011 (18%)	0.00096 (2%)	0.00096 (2%)	0.00093 (43%)	0.0011 (7%)
Beryllium	3.8 x10^{-5}	5.4 x10^{-5}	-5 (32 %)	0.00028 (1%)	0.00038 (89%)	-5 (46%)	-5 (49%)	0.00033 (996%)	0.0001 (248%)
Cadmium	0.00101	0.00101	0.0005 (0%)	0.0005 (0%)	0.00053 (6%)	0.0005 (0%)	0.0005 (1%)	0.00056(11%)	0.00051 (3%)
Cobalt	0.00036	0.00028	0.00059 (12%)	0.0086 (0%)	0.0096 (1714%)	0.00056(20%)	0.0012 (154%)	0.016 (4051%)	0.0043 (760%)
Chromium	0.011	0.0105	0.005 (1%)	0.005 (0%)	0.0044 (1%)	0.0033 (2%)	0.0032 (0%)	0.0027 (0%)	0.005 (0%)
Lithium	0.003	0.002	0.0011 (8%)	0.0022 (1%)	0.0013 (21%)	0.0011 (12%)	0.001 (2%)	0.0015 (52%)	0.0011 (8%)
Molybdenum	0.00082	0.002	0.00085 (6%)	0.00081 (2%)	0.0009 (2%)	0.00068 (11%)	0.00062 (1%)	0.00051(0%)	0.0008 (0%)
Nickel	0.0103	0.0105	0.0031 (2%)	0.0061 (0%)	0.0098 (126%)	0.0025 (3%)	0.0029(18%)	0.011 (526%)	0.0053 (76%)
Nitrate as N	2.5	2.5	0.53 (0%)	0.51 (0%)	3.66 (632%)	0.41 (0%)	0.66 (60%)	5.63 (1274%)	1.83 (266%)
Tin*	8.00 × 10^{-5}	0.00016	0.00042	0.00013	0.00018	0.00061	3.78 × 10^{-5}	0	0

Notes:
* No percentage change calculated as there is no baseline data for this constituent. Negligible changes have been highlighted in green; low impacts have been highlighted in yellow; moderate impacts have been highlighted in pink; and high impacts have been highlighted in purple.No baseline data for tin, values shown

The calculated maximum change in concentration in deep groundwater at point of discharge into the Arpa River (Table 8-3) suggests that the time to peak concentrations of many of the species will be from 700 to more than 1000 years.

Table 8-4 suggests changes in in the Spandaryan-Kechut Tunnel B (94%) and nitrate (67%) only again with no specification of pH (essential).

Again B (437%) and nitrate (311%) increases only are apparently of concern in the modelling of groundwater concentration from BSRF leakage (Table 8-5). This seems very unlikely from an acid rock drainage site and is meaningless without pH specification.

Construction Phase Impacts on groundwater are all judged to be negligible.

Table 8-3 Calculated maximum change in concentration in deep groundwater at point of discharge to the Arpa River (from Table 6.9.6, ESIA, 2016).

Constituent	50%ile Peak Concentration (mg/l)	Time to Peak Concentration (years)	95%ile Peak Concentration (mg/l)	Time to Peak Concentration (years)
Arsenic	$<1 \times 10^{-10}$	1000	5.6×10^{-6}	1000
Copper	N/A	>1000	N/A	>1000
Cobalt	N/A	>1000	N/A	>1000
Antimony	N/A	>1000	$<1 \times 10^{-10}$	1000
Sodium	0.015	59	0.064	81
WAD Cyanide	N/A	>1000	$<1 \times 10^{-10}$	840
NH_3+NH_4 as N	$<1 \times 10^{-10}$	780	$<1 \times 10^{-10}$	384
Nitrate as N	0.018	41	0.11	33

Notes:
N/A – not applicable, parameter did not arrive at receptor inside the simulation period. >1000 – travel time to the receptor for the parameter is more than 1000 years. Positive values indicate an

Table 8-4 Potential change in concentrations in the Spandaryan-Kechut Tunnel from BRSF leakage (from Table 6.9.10, ESIA, 2016).

Constituent	Units	Arpa MAC Standards (II)	Average Quality in AWJ6 (representing current groundwater conditions in the tunnel)	Estimated Concentration in Groundwater in the Tunnel (including input from BRSF leakage)	Increase in concentration as a result of input from BRSF leakage
Aluminium	µg/l	144	72	N/A	0%
Arsenic	µg/l	20	6.76	N/A	0%
Barium	µg/l	28	20.4	N/A	0%
Beryllium	µg/l	0.038	0.2	N/A	0%
Boron	µg/l	450	0.0542	0.1	94%
Cadmium	µg/l	1.014	0.5	N/A	0%
Calcium	mg/l	100	63.9	N/A	0%
Chloride	mg/l	6.88	3.07	3.1	0%
Chromium (III)	µg/l	11	5	N/A	0%
Cobalt	µg/l	0.36	0.505	N/A	0%
Iron(III)	mg/l	0.072	0.404	N/A	0%
Lead	µg/l	10.14	1.99	N/A	0%
Lithium	µg/l	3	4.27	4.3	1%
Magnesium	mg/l	50	9.35	9.4	0%
Manganese	µg/l	12	39.1	N/A	0%
Nickel	µg/l	10.34	3	N/A	0%
Nitrate	mg N/l	2.5	0.5	0.8	67%
Potassium	mg/l	3.12	3.12	3.2	1%
Selenium	µg/l	20	5	N/A	0%
Sulphate	mg/l	16.04	126	126.4	0%
Zinc	µg/l	100	3.78	N/A	0%

Notes:
N/A – constituent will not travel to the receptor within 1000 years.
MAC II concentrations provided for information only since does not apply directly to groundwater.

Table 8-5 Potential increase in groundwater concentration from BRSF leakage (post closure) (from Table 6.9.11, ESIA, 2016).

Constituent	Units	Arpa MAC Standards (II)	Average Quality in AWJ6 (representing current groundwater conditions)	Estimated Concentration in groundwater before discharge to Arpa River (including background)	% Increase in groundwater concentration
Boron	µg/l	450	0.0542	0.3	437%
Chloride	mg/l	6.88	3.07	3.1	0%
Lithium	µg/l	3	4.27	4.5	5%
Magnesium	mg/l	50	9.35	9.4	1%
Nitrate	Mg N/l	2.5	0.5	2.1	311%
Potassium	mg/l	3.12	3.12	3.3	5%
Sulphate	mg/l	16.04	126	127.8	1%

Notes: MAC II concentrations provided for information only since does not apply directly to groundwater.

Table 8-6 on modelling of changes during operational phases finds only the loss of springs under the BRSF during operation to be of significance which appears at odds with their earlier assessment of some major changes in groundwater levels and flows.

Post-closure (Table 8-7), reduction of groundwater levels and a loss of springs under BRSF footprint and HLF areas as well as predicted reduction in flow at perennial springs located to the west of the BRSF are acknowledged as high to moderate magnitudes of change. Decline in groundwater quality of surface water baseflow to Vorotan River catchments as a result of leakage from the pits is also found to be of high magnitude. These very general assessment criteria obscure the actual changes predicted in the earlier Summary of Post-Closure Changes (detailed above) and are not much use in judging potential impacts.

Table 8-6 Potential operational phase groundwater effect significance (including mitigation measures) (from Table 6.9.13, ESIA, 2016).

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Change	Effect Significance	Scale of Significance
Perched Water/ Ephemeral Springs - Pit areas	Medium	Possible reduction in flows as a result of changes within their localised catchment area.	Low	Minor	Not significant
		Leakage from water stored within the pits may decrease water quality.	Low	Minor	Not significant
Perched Water/ Ephemeral Springs - BRSF and Surrounding Area	Medium	Loss of springs under BRSF footprint.	High	Moderate	Significant
		No change in catchment area predicted for springs located in the BRSF area, but outside the BRSF footprint.	Negligible	Negligible	Not significant
		No predicted quality impact predicted for springs located in the BRSF area.	Negligible	Negligible	Not significant
Perched Water/ Ephemeral Springs - HLF and Surrounding Area	Medium	Loss of springs under HLF footprint	High	Moderate	Significant
		No change in catchment area predicted for springs located in the HLF area, bit outside the HLF footprint.	Negligible	Negligible	Not significant
		No predicted quality impact predicted for springs located in the HLF area	Negligible	Negligible	Not significant
Perennial Springs - Pit areas	Minor	Reduction in flows of to the springs due to a reduction in recharge are and groundwater levels.	Low	Negligible	Not significant
		Leakage from waterstored within the pits may decrease water quality.	Low	Negligible	Not significant
Perennial Springs - BRSF and Surrounding Area	Minor	Loss of springs under BRSF footprint	High	Moderate	Significant
		Reduction in flow to spring to the west of the BRSF.	Moderate	Minor	Not significant
		No predicted quality impact.	Negligible	Negligible	Not significant
Perennial Springs - HLF and Surrounding Area	Minor	Reduction of catchment for springs in immediate area.	Moderate	Moderate	Not significant
		No predicted quality impact.	Negligible	Negligible	Not significant
Hydrothermal Springs - Jermuk	High	No predicted change in flows.	Negligible	Minor	Not significant
		No predicted change in quality.	Negligible	Minor	Not significant
Groundwater Used for Supply Purposes – Kechut Springs	Medium	Small reduction in flows predicted as a result of reduced recharge in the BRSF area.	Low	Minor	Not significant
		No predicted change in quality.	Negligible	Negligible	Not significant

Table 8-6 continued

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Change	Effect Significance	Scale of Significance
Groundwater Used for Supply Purposes - Springs North of Gorayk	Minor	No predicted change in flows.	Negligible	Negligible	Not significant
		No predicted change in quality.	Negligible	Negligible	Not significant
Groundwater Used for Supply Purposes – Spandaryan- Kechut Tunnel	High	Predicted reduction in groundwater flow to tunnel of approximately 1 %.	Low	Moderate	Significant^
		Infiltration from pits and leakage from BRSF. No change in quality predicted during the operational phase. Change in quality predicted to occur in closure phase.	Negligible	Minor	Not significant
Groundwater Component of Surface Water Baseflow - Darb River catchment	Medium	Reduction in baseflow predicted to be approximately 1%.	Low	Minor	Not significant
		Infiltration from pits. No change in quality predicted during the operational phase. Change in quality predicted to occur in closure phase.	Negligible	Negligible	Not significant
Groundwater Component of Surface Water Baseflow - Arpa River catchment	Medium	Reduction in baseflow predicted to be approximately 2%.	Low	Minor	Not significant
		Leakage from HLF andBRSF. No change in quality predicted during the operational phase. Change in quality predicted to occur in closure phase.	Negligible	Negligible	Not significant
Groundwater Component of Surface Water Baseflow - Vorotan River catchment	Medium	Reduction in baseflow predicted to be approximately 3`%.	Low	Minor	Not significant
		Infiltration from pits andleakage from BRSF. No change in quality predicted during the operational phase. Change in quality predicted to occur in closure phase.	Negligible	Negligible	Not significant

Notes:

^ Groundwater inflow was not intended to be the main source of water in the Spandaryan-Kechut tunnel that provides supply, so this reduction in flows should not be considered as a material impact.

Table 8-7 Predicted closure phase groundwater effect significance (Including design mitigation) (from Table 6.9.15, ESIA, 2016).

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Change	Effect Significance	Scale of Significance
Perched Water/ Ephemeral Springs - Pit areas	Medium	Potential small reduction in recharge to catchments.	Low	Minor	Not significant
		Springs fed by seasonal snow melt from a small local catchment. No predicted quality impacts in catchment.	Negligible	Negligible	Not significant
Perched Water/ Ephemeral Springs Medium BRSF and Surrounding Area	Medium	Reduction in spring flow due to reduced recharge.	Moderate	Moderate	Significant
		Potential impact from BRSF leakage, but captured water will be treated and discharged water will be MAC II quality or better.	Low	Minor	Not significant
		Springs fed by seasonal snow melt from a small local catchment. No change in catchments predicted.	Negligible	Negligible	Not significant
		Springs fed by seasonal snow melt from a small local catchment. No predicted quality impacts in catchment.	Negligible	Negligible	Not significant
Perched Water/ Ephemeral Springs - HLF and Surrounding Area	Medium	Reduction in spring flow due to reduced recharge.	Moderate	Moderate	Significant
		Potential impact from HLF leakage, but captured water will be treated and discharged water will be MAC II quality or better.	Low	Minor	Not significant
		Springs fed by seasonal snow melt from a small local catchment. No change in catchments predicted..	Negligible	Negligible	Not significant
		Spring feed by seasonal snow melt from a small local catchment. No predicted quality impacts in catchment.	Negligible	Negligible	Not significant
Perennial Springs - Pit areas	Minor	Decrease in water levels leading to up to 6 % reduction in spring flow.	Low	Negligible	Not significant
		Decline in predicted water quality with respect to beryllium, cobalt, nickel and nitrate.	High	Moderate	Significant*

Table 8-7 continued

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Change	Effect Significance	Scale of Significance
Perennial Springs - BRSF and Surrounding Area	Minor	Reduction of groundwater levels and a loss of springs under BRSF footprint	High	Moderate	Significant
		Predicted reduction in flow at perennial springs located to the west of the BRSF.	Moderate	Minor	Not significant
		No predicted pathway from any source to the springs located west of the BRSF.	Negligible	Negligible	Not significant
Perennial Springs - HLF and Surrounding Area	Minor	Reduction of groundwater levels and likely loss of wet areas of ground in HLF area.	High	Moderate	Significant
		No predicted pathway from any source to the springs located west of the BRSF.	Negligible	Negligible	Not significant
Hydrothermal Springs - Jermuk	High	No predicted change in flows.	Negligible	Minor	Not significant
		No predicted change in quality.	Negligible	Minor	Not significant
Groundwater Used for Supply Purposes – Kechut Springs	Medium	Small reduction in spring flow predicted.	Low	Minor	Not significant
		No predicted pathway from any source to the springs.	Negligible	Negligible	Not significant
Groundwater Used for Supply Purposes - Springs North of Gorayk	Minor	No change in recharge in this area predicted, so no reduction in spring flow.	Negligible	Negligible	Not significant
		No predicted pathway from any source to the springs	Negligible	Negligible	Not significant
Groundwater Used for Supply Purposes - Spandaryan - Kechut Tunnel	High	Slight reduction in groundwater input to tunnel predicted.	Low	Moderate	Significant^
		Slight decline in the quality of groundwater inflow into the tunnel if flow from the BRSF and pits is captured.	Low	Moderate	Significant^

Table 8-7 continued

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Change	Effect Significance	Scale of Significance
Groundwater Component of Surface Water Baseflow - Darb River catchment	Medium	Small reduction in flow predicted.	Low	Minor	Not significant
		Small decrease in groundwater quality as a result of leakage from the pits.	Low	Minor	Not significant
Groundwater Component of Surface Water Baseflow - Arpa River catchment	Medium	Small reduction in flow predicted.	Low	Minor	Not significant
		Small decrease in groundwater quality as a result of leakage from the BRSF and HLF.	Low	Minor	Not significant
Groundwater Component of Surface Water Baseflow - Vorotan River catchment	Medium	Small reduction in flow predicted.	Low	Minor	Not significant
		Decline in groundwater quality as a result of leakage from the pits.	High	Moderate	Significant*

Notes:
* Surface water and the ecology that is supported by groundwater are the relevant receptors. See Chapter 6.10 for assessment of surface water as the end receptor, and Chapter 6.11 for ecology.
^ Groundwater inflow was not intended to be the main source of water in the tunnel that provides

8.3 Mitigation Measures (from Section 6.9.7, ESIA, 2016)

Section 6.9.7 Mitigation Measures contains no recommendations on mitigation measures. It acknowledges the high and moderate changes listed above but states that no additional mitigation procedures will be instituted.

> "Throughout the Project construction, operation, and closure there are some predicted total losses of springs due to construction of the BRSF and the HLF. These impacts are considered significant. However, the impacts cannot be avoided as the facilities are optimally located." (from Section 6.9.7 Mitigation Measures, ESIA, 2016)

> "Significant impact to water quality at springs located around the pits is predicted with respect to beryllium, cobalt, nickel and nitrate as a result of leakage from the pits. ….The increase in beryllium, cobalt and nickel are a result of the release of these constituents from the backfill. These constituents are naturally present in this mineralised area." (from Section 6.9.7 Mitigation Measures, ESIA, 2016)

However, these are only released by the acid reactions in the pits and BRSF; this is disingenuous. Design mitigation measures are proposed to limit the leakage from the pits. **No further groundwater mitigation options are presented.**

> "There is also a significant impact predicted to groundwater quality adjacent to the Vorotan River as a result of leakage from the pits. The change in groundwater quality is high, and the moderate sensitivity of this receptor results in the significant impact. As noted previously, the end receptors of the predicted change in groundwater quality are surface water and ecology. **Therefore, no additional mitigation is presented here to limit or avoid this impact."** (from Section 6.9.7 Mitigation Measures, ESIA, 2016 – our bolding)

> "There is a potentially significant predicted impact to groundwater input to the Spandaryan-Kechut Tunnel. However, groundwater inflow is not intended to be the main source of water in the tunnel that provides supply to the Kechut Reservoir, so this reduction in quality should not be considered as a material impact to water resources in the area. **Therefore, no additional mitigation is presented to limit or avoid this impact."** (from Section 6.9.7 Mitigation Measures, ESIA, 2016 – our bolding)

> "No additional mitigation measures are presented that will alter the outcome of the initial assessment. The surface water and ecology impact assessment chapters (Chapter 6.10 and 6.11) should be read in conjunction with this groundwater impact assessment in order to understand the overall significance of the predicted changes in groundwater quantity or quality." (from Section 6.9.8 Residual Impact Assessment, ESIA, 2016)

These are serious, honest admissions (by Golder Associates authors of section 6.9 of ESIA, 2016) that should be considered by the Armenian Government and local authorities for their on-going, long-term impact on communities, agriculture and social acceptance of the mine. Our recommendation is that these issues be addressed fully with appropriate mitigation strategies put in place prior to commencement of mining.

9. SURFACE WATER RESOURCES (FROM SECTION 6.10, ESIA, 2016)

"The impact assessment addresses surface water impacts associated with:

- The Tigranes-Artavazdes and Erato open pits. The Tigranes-Artavazdes pit will be backfilled during the later years of operation leaving the small South Artavazdes pit partially unbackfilled. The Erato pit will be partially backfilled at closure;
- The Barren Rock Storage Facility (BRSF);
- The Heap Leach Facility (HLF) and associated adsorption-recovery (ADR) plant; and
- Additional supporting infrastructure including water storage ponds, water treatment systems, crusher, haul roads, material stockpiles, conveyor and mine buildings." (from Section 6.10.1 Introduction, ESIA, 2016)

The structure, assessment methods and sections are closely similar to Section 6.9 Groundwater Resources, ESIA, 2016 (Chapter 7 herein). The first four sections describe the methodology for the assessment. Sections 5 and 6 describe water management and design mitigation, already reviewed in Chapters 4 and 7 (corresponding to Chapter 8 and Section 6.9, ESIA, 2016).

9.1 Surface Water Impacts (from Section 6.10.7, ESIA, 2016)

"This section presents a discussion on the potential impacts to surface water as a result of the Project; the method of assessment; and the magnitude of the impacts, accounting for mitigation measures implicit in the Project design. Impact significance and scale of significance have been assigned using the matrices in Chapter 6.1 (Tables 6.1.3 and 6.1.4)." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

Results are summarised in successive tables for construction, operation and closure stages.

9.2 Construction Phase (from 6.10.7, ESIA, 2016)

Impact to water quantity of Benik's Pond due to seasonal water abstraction (estimated 1.3 L/s during non-freezing months) for construction supply is considered to be minor (from Table 6.10.6 Potential Surface Water Impacts (Construction) and Significance of Impact (considering Design Mitigation Measures, ESIA, 2016 – not reproduced here). Construction of the BRSF will not reduce the receiving tributary catchment area nor present a risk to the Gndevaz Channel until mine operations commence (though diversions will be in place) except for decrease in water quality as a result of overtopping of the BRSF Toe Pond. All other changes during construction are considered to be negligible.

9.3 Operational Phase (from 6.10.7, ESIA, 2016)

Significant changes during the operational phase are summarised in Table 9-1.

> "Water extraction and reduction of catchment areas will reduce flows in streams and rivers. In addition, the lining of specific facilities (HLF, ponds, etc.) will result in less recharge to the groundwater system below the facilities and consequently lower groundwater levels leading to a reduction in baseflow to springs, streams and rivers, as discussed further in Chapter 6.9. Accidental uncontrolled releases from the HLF, BRSF (including backfilled pits), roads and stockpiles has the potential to impact surface water quality." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)
>
> "Dewatering of the pits is likely to result in a reduction in flow in some of the high-elevation perennial springs on Amulsar (surfacing in the elevation band of 2500 to 2900 m) located in proximity to the pits, which may potentially lead to some springs becoming ephemeral with dry periods during the winter." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)
>
> "The BRSF will reduce the size of the surface water catchment within the Kechut Reservoir tributaries. The magnitude of the impact is considered **low** as the total catchment size of tributaries will be reduced by approximately 8 %." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)
>
> "Prior to construction of the PTS a series of treatment trials will be undertaken, initially at laboratory-scale and then at bench- and field-scale. These trials will use local materials and will be under local climatic conditions to optimise the design and demonstrate that the treatment standards can be met. In the event that the treatment trials demonstrate that there is a risk the PTS may not meet the required MAC II standards a conventional packaged active water treatment plant will be used." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

This statement implies that the active water treatment plant referred to in Chapter 8 Environmental and Social Management Plan (Chapter 4 in this report) may not be installed if the passive water treatment system is able to cope. This will need to be monitored not only in the treatment trials but after this in operation and closure.

Table 9-1 Potential surface water impacts (operations) and significance of impact (considering design mitigation measures) (from Table 6.10.8, ESIA, 2016).

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Impact	Impact Significance	Scale of Significance
Kechut Reservoir Tributaries	Medium	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Low	Minor	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from BRSF.	Negligible	Negligible	Not Significant
Arpa River Downstream of Kechut Reservoir	Medium	Decrease in flow as a result of catchment area reduction and water extraction.	Low	Minor	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from HLF and HLF Detention Pond	Low	Minor	Not Significant
Arpa River Tributaries Downstream of Kechut Reservoir	Minor	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Low	Negligible	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from HLF and HLF Detention Pond.	Low	Negligible	Not Significant
Arpa River Tributaries HLF Area	Minor	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Moderate	Minor	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from HLF and HLF Detention Pond.	Low	Negligible	Not Significant
Darb River	Medium	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Negligible	Negligible	Not Significant
		Decrease in water quality as a result of accidental uncontrolled releaseduring an extreme event from Haul Road, Pit and Crusher Sediment Ponds.	Low	Minor	Not Significant
Darb River Tributaries	Minor	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Moderate	Minor	Not Significant

Table 9-1 continued

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Impact	Impact Significance	Scale of Significance
		Decrease in water quality as a result of accidental uncontrolled release during an extreme event from Haul Road, Pit and Crusher Sediment Ponds.	Low	Negligible	Not Significant
Vorotan River	Medium	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Negligible	Negligible	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release during an extreme event from Haul Road, sediment ponds and mining-influenced water from the pits.	Low	Minor	Not Significant
Vorotan River Tributaries	Minor	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Low	Negligible	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release during an extreme event from Haul Road, sediment ponds and mining-influenced water from pits.	Low	Negligible	Not Significant
Kechut Reservoir	High	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Negligible	Minor	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from BRSF.	Negligible	Minor	Not Significant
Spandaryan Resevoir	High	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Negligible	Minor	Not Significant
		Decrease in water quality as a result of release from Haul Road, sediment ponds and mining-influenced water from the pits.	Negligible	Minor	Not Significant
Gndevaz Reservoir	Minor	Decrease in flow as a result of catchment area reduction.	Negligible	Negligible	Not Significant

Table 9-1 continued

Receptor	Receptor Sensitivity	Potential Impact	Magnitude of Impact	Impact Significance	Scale of Significance
		Decrease in water quality as a result of accidental uncontrolled release from Haul Road sediment ponds.	Low	Negligible	Not Significant
Gndevaz Channel	Medium	Decrease in flow as a result of catchment area reduction.	Negligible	Negligible	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from the BRSF Toe Pond during an extreme event.	Moderate	Moderate	Not Significant
Wetland Ponds within Darb Tributaries including Benik's Pond	Minor	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Moderate	Minor	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from Haul Road, sediment ponds and mining-influenced water from pits.	Low	Negligible	Not Significant
Wetlands within Vorotan Catchment	Medium	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Negligible	Minor	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release from Haul Road, sediment ponds and mining-influenced water from the pits.	Negligible	Minor	Not Significant
Wetlands within Kechut Reservoir Tributaries	Minor	Decrease in flow as a result of catchment area reduction and spring flow decrease.	Moderate	Minor	Not Significant
		Decrease in water quality as a result of accidental uncontrolled release during an extreme event from the BRSF.	Low	Negligible	Not Significant

"The impact in the Arpa tributaries within the HLF Area is considered **moderate** and downstream in the Arpa the impact is considered **negligible**. The water quantity contribution to the Arpa is minimal (<1%) and baseflow in the Arpa is expected to reduce by no more than 1% (noting that the discharge from the PTS from year 5 onwards represents ~0.5% of the estimated low flow in the Arpa). Arpa tributaries downstream of Kechut Reservoir will have no appreciable loss in catchment size, however baseflow contribution from springs may reduce by up to 2% and on this basis the impact is considered **low**." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

"The water supply for the mine will be pumped from the Arpa River, downstream of the fish farms. Make-up water is required in the dry months (January to March and July to December) of most years and increases during the last two years of mining operations because pit dewatering is no longer a source of water. The average pumping rate is estimated to be less than 2% of the baseflow during low flow periods and less than 4% of the low flow baseflow during peak pumping periods. The magnitude of impact as a result of pumping water from the Arpa is **low**." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

"Details of the procedures that will be in place to address cyanide control are presented in the Cyanide Management Plan (Appendix 8.11). The magnitude of the impact to water quality during operations is therefore considered **low**." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

"Any leakage from the HLF entering the Arpa River via groundwater pathways will not lead to a significant change in water quality in the Arpa River. No measurable change is predicted for the majority of parameters, including cyanide. A small measurable change in nitrate, sodium and ammonium may occur, however all changes will be below MAC II standards. The magnitude of impact is **low**." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

"The greatest perceived risk to the Gndevaz Channel (once reinstated and functional) during the operational phase is considered to be from an accidental uncontrolled release from the BRSF Toe Pond during an extreme event, causing a potential impact to the water quality within the channel. Appropriate design mitigation will include appropriate sizing of the Toe Pond to accommodate potential flood events; and monitoring of pond level trigger levels. The magnitude of impact to water quality during operations is considered **moderate.**" (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

The risks described are from floods and pond overload. The water quality impact during operations is defined as 'Moderate' however, this impact is implied to be continuous and

relatively greater in magnitude than the leakage from the HLF. This impact should be addressed through revised planning to enable the impact to be reclassified as low.

> "Impact to the Darb River tributaries is considered **moderate** as the total reduction in catchment area is <1%, and perennial spring flow contributing to tributary baseflow may decrease by to 10 to 36% (significant during low flow periods)." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

> "The decrease in the catchment area providing runoff to Benik's Pond and other wetland ponds is significant and reduction of perennial spring flow is anticipated due to dewatering of the pits (Chapter 6.9). There will be a reduction in catchment area of up to 20% to three small wetland ponds in the tributaries upstream of Benik's Pond. Therefore, in terms of water quantity, the magnitude of the impact is considered **moderate**." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

This issue is found in all three phases (construction, operations, and closure and post-closure).

> "Pumping of water accumulating in the pits will minimise the potential for mining-influenced water to reach springs and nearby surface water on Amulsar. Therefore impacts are expected to be **low**." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

> "Impacts to the Vorotan River are expected to be similar to those presented for the Darb River i.e. a **negligible** impact to water quantity and a **low** impact to water quality. (from 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

> "Wetland areas located adjacent to the Vorotan River and tributaries are considered to have a **low** impact during operations." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

> "The wetland within the BRSF site area (within Kechut tributaries) will be lost as a result of construction of the BRSF, however there are other equivalent wetland habitats within the Project area and therefore the impact is considered **moderate**. Impact to water quality is expected to be **low** because any spring water will be collected for use in the leaching process." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

All other impacts on surface water are expected to be negligible during operation.

9.4 Closure and Post-Closure Phase (from Section 6.10.7, ESIA, 2016)

Most of the issues in surface water changes post closure are the same as those in the operational phase (low to moderate) except for high, on-going impacts of some specific pollutants (below).

> "Reduction of catchment area may continue to reduce flows in streams and rivers; and covering of the BRSF and HLF with a store-and-release evaporative soil cover will result in decreased runoff in these catchments. Reduced recharge over parts of the Project area will lead to a reduction in baseflow to springs, streams and rivers. Accidental uncontrolled and/or untreated releases from the HLF and BRSF (including backfilled pits), have the potential to impact surface water quality." (from Section 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

Some mitigation, additional to the ARD control is planned.

> "Upon closure a second HLF PTS will be constructed by reusing the HLF Storm Ponds, which will be re-purposed and become part of the wetland system. Negligible impact to receptor catchments is expected post-closure as surface water will discharge to the environment from the pits, HLF and BRSF. Two passive treatment systems will operate on site until any discharge from the BRSF and HLF, separately, to meet MAC II standards unaided." (from 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

> "Concentrations of beryllium and cobalt are predicted to rise above average baseline readings but are already above the MAC II standards. Nitrate and sulphate baseline concentrations are predicted to rise above MAC II standards. Tin will exceed MAC II standards, however no baseline data exist to provide comparison. Given the predicted impact, the magnitude will be **high**." (from 6.10.7 Surface Water Impacts (Design Mitigation Only), ESIA, 2016)

No assessment of these considerable increases on down-stream and river catchment activities appears to have been made. Existing concentrations above MAC II standards do not justify these high releases.

9.5 Surface Water Mitigation Measures and Residual Impacts (from Section 6.10.8, ESIA, 2016)

> "With the appropriate mitigation measures included in the facility designs and operational procedures, most of the identified impact risks will be eliminated or reduced to acceptable levels. The only significant impact predicted (considering design mitigation only) from the impact assessment is to water quality within wetland ponds to the west of the pits (which include Benik's Pond), following closure. No significant impact is predicted during construction or operations. **The magnitude of change for water quality parameters is high, relating to beryllium, cobalt and that for nitrate and sulphate considered moderate. Cobalt and beryllium are naturally occurring within the local geology (and concentrations in Benik's Pond already exceed MAC II standards) and the increase in concentrations is due to the mobilisation of metals from the barren rock backfill**

> **within the pits.** These impacts have been minimised with the design of the backfill cover for the Tigranes-Artavazdes pit but cannot be avoided as the constituents occur naturally within the geology of the pit area and seep/flow into the wetland areas via perennial springs." (from Section 6.10.8 Surface Water Mitigation Measures and Residual Impacts, ESIA, 2016 – our bolding)
>
> "To provide additional mitigation, runoff from the backfilled Tigranes-Artavazdes pit area will, to the greatest extent possible, be diverted to the wetland ponds. However this mitigation may not fully reduce the impacts during low flow conditions. Monitoring during the post-closure period will be used to determine the effectiveness of this additional mitigation measure. **No further mitigation measures are proposed since the water quality parameters with a high impact already exceed MAC II standards. Further mitigation in regards to the effect on aquatic habitat or appropriate compensation are discussed within Chapter 6.11 (Biodiversity).**" (from Section 6.10.8 Surface Water Mitigation Measures and Residual Impacts, ESIA, 2016 – our bolding)

These effects and compensation from pit runoff would need to be reviewed by experts in this area. **Our recommendation is that this pit run off is diverted (or pumped) to the same treatment systems as employed for seepage from the barren rock storage facility for remediation prior to release to waterways.**

9.6 Conclusions (from Section 6.10.10, ESIA, 2016)

> "An impact assessment has been undertaken to assess the effects of construction, operation and closure of the Project with regard to sensitive surface water receptors. The findings of the impact assessment are summarised below:
>
> - Surface water impacts fall under two main categories: water quality and quantity, which result primarily in environmental impacts;
> - Where point discharges to the water environment are proposed these will be compliant with Armenian regulations and/or comparable to baseline;
> - With appropriate mitigation and management measures, the impact of the proposed mine activity on surface water resources will mostly be eliminated or reduced to acceptable levels. Serious impact risks from ARD, mine influenced water, operational pond overflow and flow regime modification are dealt with in the design and construction of appropriate storage and treatment works. Water quality and hazardous material control will be conducted through specification of appropriate equipment and environmental controls and careful management; and

- Residual surface water impacts are expected to be minor and relate to the alteration of the flow paths of some mountain streams in the vicinity of the HLF and the BRSF; and localised impacts to water quality within wetland ponds to the west of the pits which includes Benik's Pond. **Proposed mitigation measures will reduce but may not eliminate the water quality impact to these ponds. Compensatory measures are also proposed to offset the reduction in water quality.** The post-closure status of other surface waters will generally be unchanged from existing and/or below MAC II standards based on proposed surface water mitigation; the ecological mitigation measures are expected to improve further environmental conditions." (from Section 6.10.10 Conclusions, ESIA, 2016 – our bolding)

Compensatory measures may not meet community, landholder or small businesses (for instance local tourism related to spas, lakes, rivers; water sports operators; fisheries/fishing etc.) dependent on water quality and supply expectations where income cannot is lost on product quality. It needs to be established that this has been fully considered by these stakeholders.

10. SURFACE WATER MANAGEMENT PLAN (FROM APPENDIX 8.22, ESIA, 2016)

"This Surface Water Management Plan (SWMP) has been prepared for Lydian by Golder Associates (UK) Ltd (Golder) to define how surface water within the Project area will be managed, where required, during the construction and operation of the mine. The SWMP addresses surface water management procedures and application of relevant mitigation measures identified in the ESIA recently undertaken." (from Section 3 Purpose, Appendix 8.22, ESIA, 2016)

"The effective management of surface water runoff during the development of mineral resources at the Amulsar Project is critical to the protection of downstream water resources. The use of hydraulic and sediment control structures as part of the Project's surface water management is intended to achieve the following primary objectives:

- To route runoff to ponds and collection sumps in order to minimise the release of mobilised sediment;
- To minimise natural ground runoff and non-contact water from entering disturbed areas and mixing with contact water;
- **To capture contact water runoff from mine facilities, for re-use in the process;**
- **To treat excess contact water in a passive treatment system (PTS) to Armenian Maximum Acceptable Concentration (MAC) II water quality standards prior to discharge;** and
- To minimise erosion of disturbed areas; and, when erosion does occur, to minimise suspended sediment flow to streams."

(from Section 4 Scope, Background and Context, Appendix 8.22, ESIA, 2016 – our bolding)

These are the only objectives (in bold) relating, in part, to ARD control. Contact water runoff is defined as surface water runoff derived from the mining, pit dewatering, potentially acid generating (PAG) waste rock, truck shop facility and heap leach areas. Best practice has been used by Golder Associates in the design and implementation planning of this water management plan.

"The volume of contact water generated will be minimised by diverting surface water runoff from natural areas (non-contact runoff) around Project-impacted areas back to natural drainages downstream of the Project areas." (from Section

5.1 Segregated Capture and Routing of Noncontact and Contact Runoff (Surface Water Conveyance), Appendix 8.22, ESIA, 2016)

The issue in this Water Management Plan is the same as that in the ARD Control Management Plan. Contact water runoff is defined as surface water runoff and will include ARD derived from the mining, pit dewatering, potentially acid generating (PAG) waste rock and heap leach areas. Excess water from these sources will be released to natural drainages downstream of the Project areas. Mining and pit dewatering ARD will be untreated before release.

11. Impact Assessment Summary (from Section 6.22, ESIA, 2016)

> “Table 6.22.2 to Table 6.22.19 present summaries of potential environmental and social impacts and Project benefits, by discipline. The summary impact tables are provided to facilitate use of the ESMP [environmental and social management plan] and to provide context for the various initial management plans developed during the ESIA preparation and presented as appendices to this chapter. Where necessary, monitoring plans have been or will be developed to verify that impact mitigation and benefit enhancement activities are complying with design goals and regulatory requirements.” (from Section 6.22 Impact Assessment Summary, ESIA, 2016)

The only references to ARD are in the sections of Table 11-1 and Table 11-2. They cross-reference Appendix 8.19 ARD Management Plan (Chapter 6 herein) and “Appendix 8.23 Surface Water Management Plan” (probably meaning Appendix 8.22, Chapter 9 herein) already reviewed in detail.

They do assess Significance of Effect in Contamination of Soils for ARD as Major without mitigation, Moderate with mitigation (short term) and Minor with mitigation (long term). Specific Monitoring Requirements are specified for both Soil Contamination and Perched water / Ephermal springs in open pit areas, HLF and BRSF areas.

Table 11-1 Soils – summary of potential impacts and effects (extracted from Table 6.22.7, ESIA, 2016)

Environmental / Social Impact	Potential Impact	Geographical Coverage	Relevant Performance Standard / Requirement	Project Phase			Primary Receptor	Control / Enhancement Measures	Significance off Effect: Without Mitigation					Significance off Effect: With Mitigation (Short Term)					Significance off Effect: With Mitigation (Long Term)					Specific Monitoring Requirements	Management Plan Reference
				Construction	Operations	Closure and Rehabilitation			Very High	Major	Moderate	Minor/ negligible	Positive	Very High	Major	Moderate	Minor/negligible	Positive	Very High	Major	Moderate	Minor/negligible	Positive		
Contamination of Soils	Changes to the soil chemistry and quality from equipment and vehicle use and materials handling through spills and leaks from handling materials	Local - site wide	PS3, PR3	X	X	x	Land, surface water, groundwater	Follow spill prevention and response plan, ICMC guidance – including training personnel on site, line all chemical and fuel storage areas and bund them, PPE, containment and cleanup supplies readily available			■					■						■		Yes	PSRP (Appendix 8.9), CMP(Appendix 8.11), FMP (Appendix 8.8) and Environment Policy(Appendix 8.1)
	ARD	Local - site Wide	PS3, PR3		X	X	Land, surface water, groundwater	ARD management plan		■						■						■		Yes	ARDMP(Appendix 8.19) EPSRP (Appendix 8.9) and SoWaMP (Appendix 8.13)

Table 11-2 Groundwater – summary of potential impacts and effects (extracted from Table 6.22.8, ESIA, 2016)

Environmental / Social Impact	Potential Impact	Geographical Coverage	Relevant Performance Standard / Requirement	Project Phase: Construction	Project Phase: Operations	Project Phase: Closure and Rehabilitation	Primary Receptor	Control / Enhancement Measures	Significance off Effect – Without Mitigation: Very High	Without Mitigation: Major	Without Mitigation: Moderate	Without Mitigation: Minor/ negligible	Without Mitigation: Positive	Significance off Effect – With Mitigation: Very High	With Mitigation: Major	With Mitigation: Moderate	With Mitigation: Minor/negligible	With Mitigation: Positive	Specific Monitoring Requirements	Management Plan Reference
Construction and Operation (where temporary, Pre-closure)	Perched water / Ephermal springs in open pit areas, HLF and BRSF areas.	Local	PS1, PS3, PS4, PR1, PR3, PR4	X	X		Ground water	See Section 6.9 and relevant Management Plans (appendix 8.23 Surface Water Management Plan and 8.19 ARD Management Plan)											Yes	SWMP (Appendix 8.23) and ARDMP (Appendix 8.19)

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13. APPENDIX 1 MT MORGAN

In: Jarvis, A. P., Dudgeon, B. A. & Younger, P. L.: mine water 2004 – Proceedings International Mine Water Association Symposium 2. – p. 235-245

Mt Morgan Mine – a case study of ARD impacted groundwater

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Abstract

The Mount Morgan Mine is an historic mine site located in Central Queensland, Australia. The mine closed in 1990 after the re-treatment of 28 Mt of tailings, which were placed into the open cut pit. Mining at Mount Morgan has resulted in the exposure of sulphide-bearing mine waste at surface which produces acid rock drainage (ARD) and has heavily impacted portions of the adjacent Dee River. Historic stream channels draining the mine site (often filled-in with tailings, slag and/or waste rock) and associated structures in the underlying bedrock appear to represent a preferred pathway for mine-impacted groundwater into the Dee River. The groundwater draining the minesite has low pH (2.5-3.5) and highly elevated concentrations of magnesium, sulphate, aluminium, iron, copper, zinc and various trace metals (Cd, Cr, Co and Ni). While a seepage interception and pump-back system (SIS) is currently in place, the amount of ARD entering the groundwater system and ultimately reaching the Dee River is potentially substantial and requires quantification. This paper summarizes the results of a detailed hydrogeological study of the Mt Morgan minesite which included the installation of 19 monitoring bores, hydraulic testing, water level and water quality monitoring and groundwater modeling. Using the results of this study, it is estimated that the amount of groundwater seepage by passing the SIS and entering the Dee River and underlying aquifer is about 1.8 L/s. This seepage rate is significantly smaller than the amount of seepage currently intercepted (13.8 L/s) suggesting a very high efficiency of the existing SIS.

Christoph Wels1, Laura Findlater1, Shannon Shaw1, Tania Laurencont2

1 Introduction

The Mount Morgan Mine is an historic minesite, located 40 km SSW of Rockhampton, in Central Queensland, Australia (Fig. 1). The mine site is adjacent to the Dee River, which flows between the mine and the township of Mount Morgan, into the Don and Dawson Rivers and thence into the Fitzroy River. Mining commenced at this site in 1882 to recover gold, but considerable quantities of silver and copper were also discovered. During the 108-year life of the mine approximately 262 t of gold, 37 t of silver and 387,000 t of copper were recovered from underground and open cut operations. The mine closed in 1990 after the re-treatment of 28 Mt of tailings.

The site is characterised by the environmental problems associated with Acid Rock Drainage (ARD), which impact the site and the Dee River downstream of the mine. In January 2000 the Department of Mines & Energy (now NRM&E) proposed a 10-year conceptual plan for rehabilitating the site and embarked on a 2-3 year program of studies to identify the key contaminant sources, understand water movement on-site and impacts on the Dee River, and to develop a range of rehabilitation scenarios (Unger and Laurencont 2003).

As part of this program, a detailed hydrogeological investigation was initiated in 2003. The primary objectives of this study were (i) to quantify the amount of seepage by-passing the existing seepage interception system and entering the Dee River and (ii) to provide guidance in the overall site rehabilitation strategy. This paper summarizes the results of the initial field investigation.

2 Background

2.1 Climate and Hydrology

The climate at the site is seasonal, with average maximum daily temperatures ranging from 32°C in January to 23°C in July (OKC 2002). The long-term average annual rainfall is approximately 740 mm with a large amount of the annual rainfall occurring during the wet summer months (November – May). The long-term average annual potential evapotranspiration (PET) is estimated to be about 1840 mm.

The Mount Morgan minesite is located in the Dee River catchment. The areas disturbed by mining lie on the west side of the Dee River for a distance of approximately three kilometers downstream from its junction with Dairy Creek (Fig. 1). The total minesite catchment area contributing runoff

Mt Morgan Mine – a case study of ARD impacted groundwater

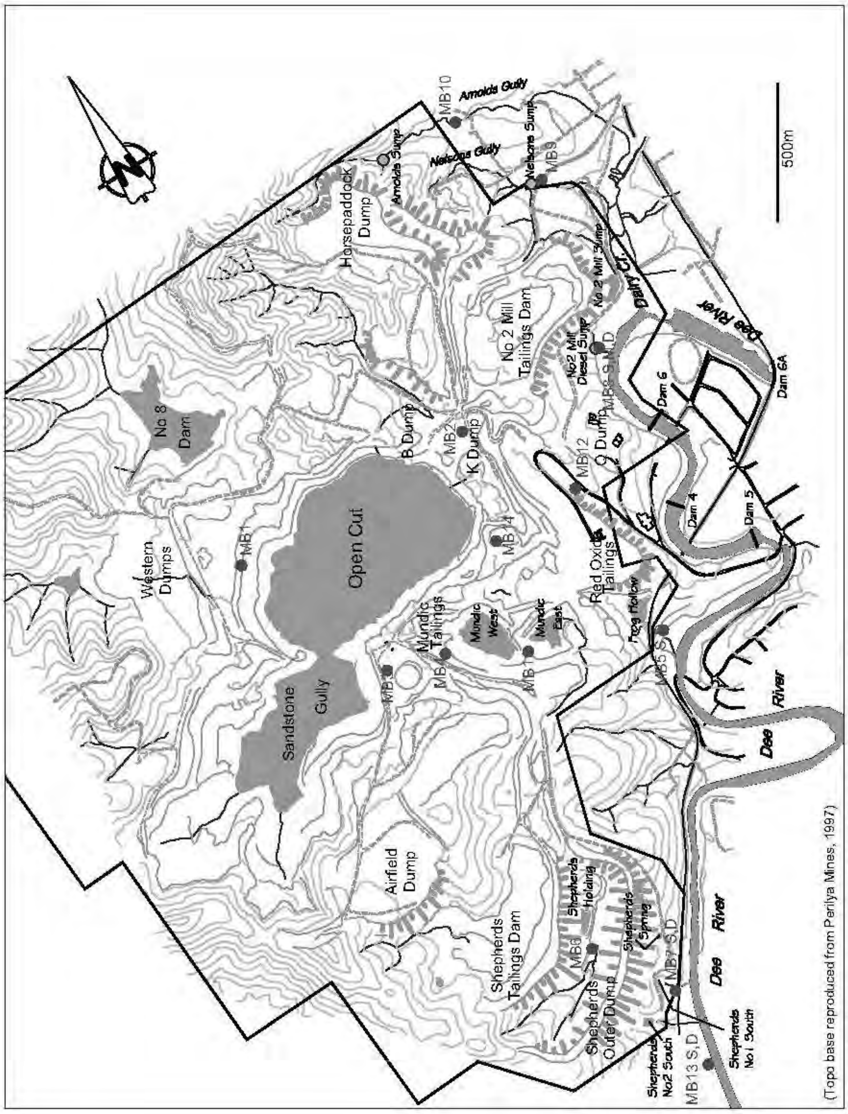

Fig. 1. Site plan for Mt. Morgan Minesite.

to the river is estimated to be 3.5 km^2 (EWL Sciences 2001).

The streamflow in the Dee River is highly seasonal with short duration runoff events (i.e. a few days of peak flows ranging from 25 to >250 ML/day) typically during the wet season and extended periods of no, or near-zero, surface flow during the remainder of the year (EWL Sciences, 2001).

2.2 Geology

The geology of the Mount Morgan gold-copper deposit has been described in detail by Taube (1990, 2000). The major lithological units encountered on the minesite include the Mount Morgan tonalite, the banded mine sequence (interbedded tuff, sediments, chert and jasper) and the upper and lower mine pyroclastics (quartz feldspar lithic tuff). The latter three units comprise the mine corridor volcanics. The Mount Morgan orebody occurs at and below the level of the banded mine sequence, extending well down into the lower mine pyroclastics.

All of the country rock formations are considered to have no primary permeability and any secondary permeability is believed to be controlled by structure (fractures and/or faults). No information, however, was available on the hydrogeological properties of these structures and/or associated fractures. The area is also cut by a series of north-west and north-east trending dykes that serve to compartmentalize the area and further inhibit deeper groundwater discharge from the minesite (Forbes 1990 quoted in Water Studies 2001).

2.3 Mine Waste Units

Figure 1 shows the various mine waste units, including the open cut pit and sandstone gully (both now flooded), various overburden and waste rock units and historic tailings dams. Table 1 lists the estimated tonnage of waste rock and tailings stored in the various mine waste containment units (after Taube 2000). The open cut was excavated into the northern flank of the Mundic drainage. It has a surface area of approximately 34.5 Ha and maximum depth of approximately 200 m (relative to the current rim). The open cut was backfilled between 1982 and 1990 with 28 Mt of retreated tailings, the majority of which was removed from Sandstone Gully.

The "Sandstone Gully" represents a wide valley in the upper reach of Mundic Creek, which was historically used as a repository for tailings. Starting in 1982, the historic tailings were dredged from Sandstone Gully and treated using the carbon-in-pulp (CIP) process before being backfilled

Table 1. Summary of mine waste units, Mount Morgan Mine.

Waste Rock Unit	Estimated Tonnage (Mt)	Tailings Unit	Estimated Tonnage (Mt)
Horse Paddock Dump	15	Reprocessed Tailings (OCSG)[a]	28
Airfield Dump	24	Mundic Red Tailings	0.63
Western Dump	25	Mundic Grey Tailings	0.97
Shepherds Dump	21	No. 2 Mill Tailings	2.1
B&K Dumps (& others)	8.4	Shepherds Tailings	3.9

a. OCSG = Open Cut & Sandstone Gully.

into the open cut. After final closure in 1990, the partially backfilled open cut (and Sandstone Gully) were allowed to flood further by natural inflows (surface runoff and groundwater inflow) and by pumping ARD impacted seepage back into the open cut.

The overburden and waste rock was placed in five major containment areas (Fig. 1). The bulk of waste rock from the Open Cut is estimated to be acid-forming based on the depth of weathering of the original profile. This material contains up to 10% sulfur with the major sulphide minerals being pyrite, chalcopyrite, and pyrrhotite (EWL Sciences, 2001). Since waste types were not segregated during mine life, it can be presumed that all areas of waste rock on site are potentially acid-generating with very low acid-neutralising capacity.

The Mundic tailings were placed into the historic drainage channel of Mundic Creek (between the open cut and Frog Hollow), whereas the other tailings were placed into tailings dams (see Fig. 1 for location). Anecdotal evidence suggests that tailings were initially deposited in the Mundic drainage without proper containment. EWL Sciences (2001) reviewed limited geochemical testing data available for the tailings material. Elutitration tests showed that the Mundic Red tailings were unreactive whereas the Mundic Grey tailings are highly reactive and can release significant amounts of sulphate, iron, aluminium and copper. As much as 50% of the released copper was readily leachable during the initial washing step (EWL Sciences 2001).

2.4 Seepage Interception System

Acidic seeps have been observed discharging from the various mine waste units for an extended period. Over the years, the mine operators developed a seepage interception system (SIS) to capture acidic seepage and pump it back to the open cut pit. The SIS consists of 8 sumps, which collect toe seepage and/or shallow groundwater. Most sumps are located along the eastern edge of the mine waste units, often located within original creek channels, in which mine waste had been placed.

The majority of seepage at Mount Morgan is collected in the Mundic Creek area, i.e. in the sumps referred to as "Mundic West" and "Frog Hollow" (see Fig. 1 for location). These sumps are located in the Mundic creek valley, originally draining Sandstone Gully. This valley was historically used for tailings discharge and was subsequently overdumped with as much as ~50 m of waste rock and slag. The majority of seepage intercepted in Mundic West (~7 L/s) and Frog Hollow (~4-6 L/s) is believed to be originating from the backfilled open cut pit/sandstone gully.

3 Field Investigation

A detailed field investigation was carried out between May and July 2003, consisting of drilling, monitoring well installation, hydraulic testing and water quality sampling. Subsequently, a routine monitoring programme was implemented to determine seasonal variations in groundwater levels and groundwater quality.

3.1 Methods

In total, 19 monitoring wells were drilled and completed as a part of the field investigation (see Fig. 1 for location). Down-hole percussion drilling was carried out for the majority of wells completed in natural formation, while a 127 mm TUBEX system was used for bores completed in loose, unconsolidated alluvium or mine waste material. In all boreholes, air was used as a "drilling fluid" to determine the yield and water quality (pH and electrical conductivity) of groundwater encountered at different depths.

Slug tests and/or pump tests were performed on the majority of monitoring wells to obtain estimates of the in-situ hydraulic conductivity (K) of the materials in the vicinity of the well. The slug tests were interpreted us ing the Bouwer and Rice (1976) and the Cooper et al (1967) analytical methods. Air-lift 'pump tests' were performed on selected high yielding bores. The pump test data were analysed using the Cooper and Jacob method (1946), which allows an estimation of transmissivity (= K x screen length) from the maximum drawdown observed.

Routine water quality monitoring (quarterly sampling) of the bores commenced in June 2003 (MB3 and MB4 were first sampled in October 2003). Additional samples were taken in seeps and sumps across the site (representing part of the SIS) and at several private wells on the east side of the Dee River (representing "background" water quality). All samples were analysed by ALS Environmental Laboratories in Brisbane. Laboratory measurements include bulk parameters (pH, alkalinity and acidity), major cations and anions (sulfate, chloride, calcium, magnesium, sodium, potassium) and dissolved metals (Al, As, Be, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Se, and Zn). Major chemistry parameters were determined on the raw (unfiltered) sample while dissolved metals were determined on filtered (0.45 mm), acidified, sub-samples.

3.2 Results

3.2.1 Hydrostratigraphy

Drilling confirmed the spatial distribution of the major lithologies (volcanics and intrusives) described by others. In both lithologies, the profile consisted of ~2-10m of unconsolidated material (in-situ weathered saprolite and/or alluvium/colluvium) over 5-10 m of fractured bedrock over competent (tight) bedrock.

The results of hydraulic testing are summarized in Table 2. The various hydrostratigraphic units showed characteristic differences in permeability. The permeability of the saprolite is controlled by the fines content and varies from 7×10^{-7} m/s in clay rich material (MB7S) up to 1×10^{-6} m/s in coarser material (MB11). Higher permeabilities were observed in shallow monitoring wells MB5S and MB8S and are believed to reflect the presence of historic (coarse) tailings within the screening interval. The alluvial deposits in the Dee River and the underlying fractured bedrock have a relatively high hydraulic conductivity (5×10^{-6} to 1×10^{-5} m/s) and are therefore capable of transmitting significant quantities of groundwater relative to Dee River baseflow.

The lowest K values (~2×10^{-7} m/s) were obtained for the deeper, tight volcanic bedrock with very limited fracturing and/or weathering (e.g. MB4D, MB8D and MB5D). Generally, higher K values (1×10^{-6} m/s) were obtained for wells screened in fractured, minimally altered tonalite (MB10). The permeability of the fractured tonalite may be generally higher than in the fractured volcanics because the volcanics weather to clay, which would tend to seal individual fractures.

3.2.2 Groundwater Levels

Groundwater flow is inferred to follow natural topography, with groundwater flowing from the mine site in an easterly direction towards the Dee River Valley (Fig. 1). The primary source of recharge for the local groundwater system is inferred to be seepage from the various mine waste units, in particular seepage from the flooded Sandstone Gully/Open Pit along the historic Mundic valley and seepage from the Shepherds and No. 2 Mill Tailings Dams (Fig. 1). Seepage from the various waste rock dumps may also contribute significantly to groundwater recharge.

The hydraulic gradients vary considerably across the site, ranging from ~2% in the Mundic delta (near Frog Hollow) to as high as ~10% in the Shepherds reach. In general, the hydraulic gradients correlate fairly well with pre-mining topography with higher gradients observed along the steeper side slopes and smaller hydraulic gradients observed along the flatter drainage channels (Arnolds Creek, Nelsons Creek) and the Dee River valley.

The nested monitoring wells installed in the vicinity of the Dee River indicate only very small (or negligible) upward hydraulic gradients, suggesting that deeper groundwater originating from the Mt Morgan minesite is not discharging directly into the Dee River. Instead, the deeper groundwater (in fractured bedrock) is discharging into a more permeable aquifer along the Dee River valley.

Little information on groundwater flow is available for the upland areas (upgradient of the Sandstone Gully/Open Pit). No water was encountered during drilling of MB1 (located immediately up-gradient of the open cut, see Fig. 1) to a depth of 55 m, some 2 m below the lake level in the open pit. The monitoring well has remained dry since start of monitoring suggesting that the groundwater flow in the upland areas might be limited to small, perched zones in valley fill and/or occurs at greater depth in bedrock.

3.2.3 Groundwater Quality

The groundwater quality observed at Mt Morgan is summarized in Table 2. The water quality of the open cut, selected sumps and the Dee River is shown for comparison. Most groundwater on the Mt Morgan mine site is heavily impacted by acid rock drainage (ARD) from various sources (open cut, waste rock and tailings seepage) resulting in highly elevated TDS relative to background water quality in the area. The dominant ions are generally sulphate, magnesium, calcium and (if acidic) aluminium. The extent of acidification (and thus metal concentrations) in the local groundwater varies significantly depending on the proximity to ARD sources and/or buffering capacity of the local lithology. As a first approximation, the groundwater on the Mt Morgan mine site can be grouped into four categories according to the degree of impact by ARD:

1. Type 1: Highly acidic groundwater with low pH (<4.0), very high acidity (>3,000 mg/L $CaCO_3$) and highly elevated concentrations of dissolved metals (in particular Al, Fe, Cd, Cu, Mn and Zn);
2. Type 2: Acidic groundwater with low pH (<5.0), moderate to low acidity (<3,000 mg/L $CaCO_3$) and highly variable concentrations of dissolved metals (typically low in Al, Cu and Zn but elevated in Fe and Mn);
3. Type 3: Buffered groundwater with elevated pH (>5.0), high to moderate alkalinity (<1,000 mg/L $CaCO_3$) and low concentrations of most dissolved metals (except Mn);
4. Type 4: Un-impacted groundwater with circum-neutral pH (7.0-8.0), moderate to low alkalinity (< 500 mg/L $CaCO_3$) and low TDS (including dissolved metals).

Note that Type 4 groundwater was not encountered on the mine lease but is inferred to be present upgradient of all mine-impacted areas (based on water quality observed in "background" wells located off the mine site).

Despite the overall impact of ARD, the groundwater quality shows significant spatial variation across the mine site. Groundwater in the Mundic & Linda Creek drainage system is generally acidic but shows significant local variability in water quality (predominantly Type 1 and Type 2 water). Groundwater entering the Dee River system in this reach (MB5S/D) has a very poor water quality (very high Al, Cu, Fe, Mn, and Zn) and is clearly impacted by seepage from Mundic Creek and Linda Creek.

Groundwater in the Shepherds Drainage Area is highly acidic (Type 1 water) suggesting limited (or exhausted) buffering capacity in the local bedrock. Groundwater entering the Dee River along the Shepherds reach (at MB7S/D) has very high TDS and acidity and highly elevated dissolved metals (in particular Al, Cu and Zn). This groundwater is likely caused primarily by seepage from the Shepherds Outer Dump.

Groundwater downstream from No 2 Tailings Dam is also acidic with Type 1 water in shallow groundwater (tailings) and Type 2 water in deeper groundwater (bedrock). Groundwater entering the Dee River system in this reach (MB8S/D) shows highly elevated Fe and Mn concentrations and is clearly impacted by seepage from the No. 2 Tailings Dam.

Groundwater in Nelson's Gully (MB9) and Arnold's Gully (MB10) is well-buffered (Type 3 water) with low concentrations of dissolved metals. Carbonate minerals present in the bedrock (tonalite) are responsible for

Table 2. Summary of initial water quality survey, June 2003.

List of Samples	Major Chemistry								Dissolved Metals					
	pH	TDS mg/L	Acidity mg/L	SO42- mg/L	Cl mg/L	Ca mg/L	Mg mg/L	Na mg/L	Al mg/L	Cd mg/L	Cu mg/L	Fe mg/L	Mn mg/L	Zn mg/L
Open Cut - Mundic System														
Open Cut	2.72	21,300	5,990	12,600	584	526	1,380	813	860	<0.10	43.9	288	101	29.2
MB3[a]	3.44	15,730	5,350	11,600	568	459	1,420	770	618	0.145	47.6	116	89	26.4
MB4[a]	3.56	45,770	n/a	36,100	140	437	3,650	330	2,520	0.663	18.6	2,000	422	138.0
MB14	5.28	9,490	246	5,970	37	447	1,170	172	9	<0.050	91.2	1.7	101	11.5
Mundic West[a]	2.91	21,890	7,660	16,800	326	464	2,010	662	1030	0.187	58.4	352.0	134	41.8
MB11	3.32	25,400	3,170	15,000	199	465	3,050	334	295	0.13	20.4	137	391	29.1
Frog Hollow[a]	2.94	18,390	6,530	14,000	207	445	1,530	276	734	0.278	94.7	948	109	41.6
MB5S	3.11	17,000	6,790	14,010	124	538	1,400	151	954	0.25	124.0	883	92.4	26.4
MB5D	3.66	16,300	4,270	10,510	133	513	1,290	274	503	0.20	72.5	747	132.0	21.0
Linda Creek														
MB2	2.39	15,700	7,120	12,500	72	420	1,480	136	879	0.03	45.0	338	61.1	15.8
MB12	5.75	9,570	5,870	5,870	94	503	1,050	308	5	<0.050	0.6	24	230	4.0
Shepherds area														
MB6	3.76	11,900	3,020	8,290	52	448	1,170	192	556	<0.050	13.8	2.6	74.4	11.2
MB7S	3.21	54,100	24,600	41,700	128	568	4,050	114	4,760	0.09	89.0	21.4	265	43.6
MB7D	3.02	54,600	26,900	38,500	95	527	3,430	62	4,810	0.07	87.8	128	229	39.5
No 2. Tailings Dam														
MB8S	3.63	26,400	8,210	18,400	130	524	2,370	194	946	0.11	30.3	1,920	153	39.3
MB8M	6.34	17,600	544	12,300	145	531	2,770	554	5	<0.050	<0.10	251	71.6	3.2
MB8D	3.87	20,900	3,020	11,600	215	550	1,940	302	205	0.02	3.2	939	118	15.0
Nelson's & Arnolds Gully														
MB9	7.42	10,100	146	5,760	65	713	1,260	368	<1.0	<0.020	<0.10	0.9	0.07	<0.10
MB10	7.04	37,700	293	23,810	151	550	6,340	308	8	<0.050	<0.10	<0.10	301	1.2
Dee River System														
Dee River @ Kenbula	3.22	5,780	1,430	3,740	34	261	487	121	223	0.06	20.5	5.83	34.1	6.94
MB13S	7.59	5,090	47	2,900	112	635	427	271	1.1	<0.005	0.07	1.18	2.36	0.1
MB13D	6.38	27,200	231	18,300	165	460	4,460	469	5	0.05	<0.10	<0.10	345	5.8
Background Groundwater														
Private Bore	8.03	644	13	74	116	72	32	104	0.2	<0.005	0.16	0.11	0.32	0.03
Private Bore	7.87	300	6	50	8	14	9	58	<0.1	<0.005	0.03	<0.01	0.09	<0.01

a. First sampled in October 2003.

the buffering of the local groundwater in this area. However, groundwater in Arnold's Gully shows much higher TDS (higher SO4 and Mg) than in Nelson's Gully suggesting significantly higher ARD loading (presumably seepage from Horsepaddock Dump and recharge from the highly contaminated Arnolds Creek).

Groundwater in the Dee River Valley (in the alluvial aquifer as well as underlying fractured bedrock) at Kenbula weir is also well-buffered (Type 3 water) due to the presence of carbonate minerals in the alluvial sediment and underlying fractured bedrock (tonalite). Note however that groundwater in the alluvial sediments is significantly more dilute than groundwater in the underlying fractured bedrock, likely due to mixing with the Dee River water. The buffering in the "Dee River aquifer" represents a major attenuation mechanism, which limits the current release of metals into the Dee River and the downstream environment.

4 Discussion

4.1 Conceptual Model of Groundwater Flow

A generalized conceptual model of groundwater flow at the Mt Morgan mine site was developed based on the results of the 2003 field investigation. The conceptual hydrogeological model for the Mt Morgan mine site is illustrated in Fig. 2 and is summarized below.

The local aquifer system can be subdivided into the following hydrostratigraphic units: (i) mine waste material (waste rock and/or tailings); (ii) highly weathered bedrock ("saprolite"); (iii) partially weathered, fractured bedrock, and (iv) tight bedrock ("basement rock"). In general, the majority of groundwater flow occurs in permeable mine waste (where placed in topographic lows they may saturate) and in shallow bedrock (saprolite and fractured bedrock). The deeper bedrock (say >20 m below original ground surface) is typically significantly less permeable and does not carry significant amounts of groundwater flow.

Historic drainage channels (e.g. Mundic Creek, Linda Creek) typically represent areas of preferred groundwater flow owing to the historic placement of more permeable mine waste, the presence of more permeable colluvial/alluvial deposits, and/or the presence of fracturing and/or leaching in the underlying bedrock.

The backfilled and flooded Open Cut/Sandstone Gully (OCSG) represents an important local source/sink for groundwater and seepage on the mine site. Groundwater originating upgradient of the OCSG (including seepage from Dam 8 and Western Dumps) discharges into the Open Pit. At

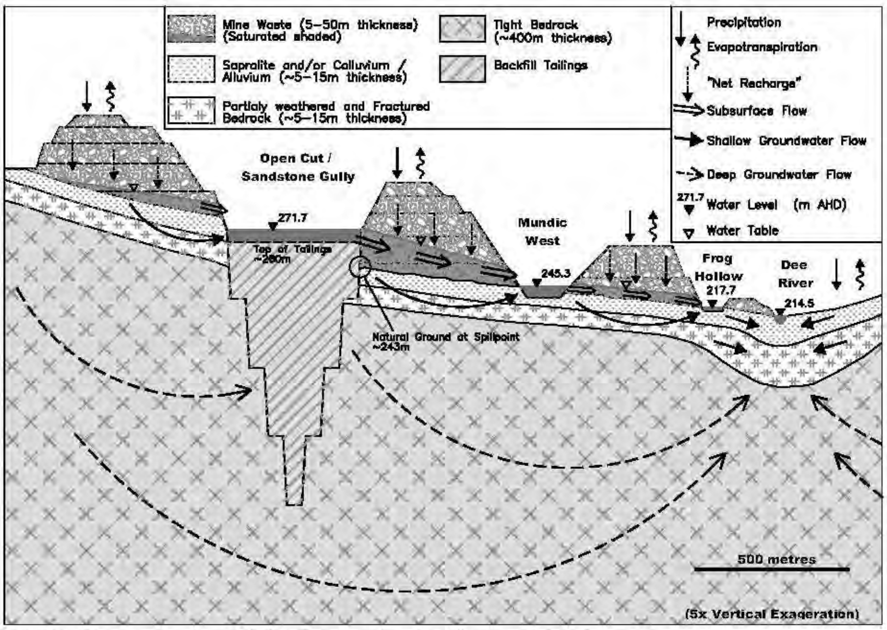

Fig. 2. Conceptual model of groundwater flow at Mt Morgan.

the same time, the flooded OCSG represents an important source of recharge to the groundwater system downgradient of the OCSG. The majority of seepage occurs along the Mundic Valley (through permeable mine waste). There is no indication, however, of seepage from the Open Cut towards Linda Gully.

The primary source of recharge to the groundwater system (other than seepage from the OCSG) is via net infiltration (precipitation – evapotranspiration) into the natural ground and mine waste units (waste rock dumps and tailings impoundments). Net infiltration into mine-disturbed areas is believed to be significantly higher than in undisturbed areas due to the unconsolidated nature of the material (increasing surface infiltration) and lack of vegetation (reducing evapotranspiration).

The Dee River aquifer is believed to represent a discharge zone for regional groundwater flow. In other words, significant movement of groundwater beyond the Dee River valley (towards the west) is not believed to occur (note that this hypothesis is primarily based on water quality data rather than water level measurements).

4.2 Estimate of Open Cut Seepage to SIS

The conceptual model suggests that seepage from the Open Cut/Sandstone Gully represents a major source of current seepage to the seepage interception system (and potentially the Dee River) (Fig. 2). A quantification of seepage from the Open Cut was required to evaluate the net benefit of alternative rehabilitation options for the open cut (e.g. dry backfill vs. water cover). Water quality data were used to estimate the relative contribution of seepage from the Open Cut/Sandstone Gully to the seepage intercepted along Mundic Creek and Linda Creek.

Figure 3 shows a scatter plot of chloride versus sodium for various water samples collected from monitoring wells, seeps and sumps in the Mundic Creek/Linda Creek area in June 2003 (where missing, results from October 2003 are shown). It can be seen that the open cut water is significantly enriched in sodium and chloride compared to local groundwater not influenced by open cut seepage (e.g. MB2 and MB14). The majority of groundwater and seepage samples show intermediate concentrations of sodium and chloride along a "mixing line" between those two "end-members". The elevated concentrations of sodium and chloride in the open cut are likely due to the use of reagents containing sodium (primarily NaCN and NaOH) and chloride during tailings reprocessing.

Sodium and chloride were used as tracers to estimate the relative contribution of seepage from the Open Cut/Sandstone Gully to various seeps and groundwater using the following mixing equation:

$$\%\ \text{Seepage from Open Cut} = \frac{(C_{obs} - C_{net\ recharge})}{(C_{open\ cut} - C_{net\ recharge})} \quad (1)$$

where C = concentrations of sodium or chloride in mg/L. The results of the mixing calculations are summarized in Table 3.

The mixing calculations suggest that seepage from the Open Cut represents about 79% of all seepage intercepted in Mundic West but only about 25% of the seepage intercepted in Frog Hollow (under baseflow conditions). Assuming seepage extraction rates of 7.0 L/s and 4.0 L/s for Mundic West and Frog Hollow under current baseflow conditions (Greg Bartley, pers. Comm.), the total amount of seepage from the Open Cut currently intercepted in the SIS would be about 5.5 L/s (Mundic West) plus 1 L/s (Frog Hollow) for a combined total of about 6.5 L/s.

Note that the concentrations of Na and Cl observed in the Linda Creek area (MB2, MB12 and Slag Dump Seepage East) were generally much lower than those in the Open Cut and Mundic Creek area suggesting only

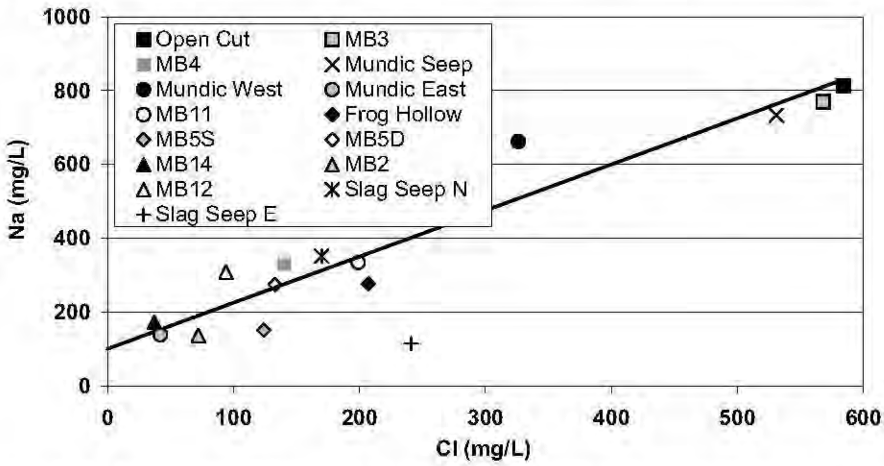

Fig. 3. Sodium versus chloride in open cut and downstream monitoring wells.

minor contributions (if any) from the Open Cut to this drainage. Similarly, low concentrations of Na and Cl were also observed in seepage in the Shepherds area (MB6, MB7S/D) suggesting that seepage from the Open Cut to this part of the mine site is also insignificant (data not shown here).

In summary, our analysis suggests that seepage from the Open Cut/Sandstone Gully is primarily restricted to the Mundic Creek valley. Seepage from the Open Cut to the SIS has been estimated to be about 6.5 L/s (based on water quality), representing only about 60% of all seepage extracted in the Mundic area. The remaining 40% represent subsurface flow (discharging as toe seepage) and groundwater flow (discharging into the sumps below natural ground). While some of this seepage may represent water released from storage in the natural aquifer material, the majority likely represents seepage released from storage in the mine waste units ("net recharge").

4.3 Estimates of Seepage to Dee River System

One of the primary objectives of this study was an assessment of the amount of seepage by-passing the existing seepage interception system and entering the Dee River. A preliminary assessment of these seepage rates was made using Darcy's Law. For this purpose, the Dee River was subdivided into three reaches (Table 4). For each reach, representative estimates of hydraulic conductivity, saturated thickness and hydraulic gradients were used to estimate groundwater flow to the Dee River.

Table 3. Estimated contributions of Open Cut/Sandstone Gully.

Location	Tracer Concentration (Baseflow)[a]		Seepage from Open Cut (%)		
	Cl (mg/L)	Na (mg/L)	Cl used as tracer	Na used as tracer	Average
Sources (Endmembers of Mixing Model)					
Open Cut	584	813	100%	100%	100%
assumed back-ground	0	100	0%	0%	0%
Upper Mundic Valley					
MB3	568	770	n/a	94%	94%
MB4D	140	330	24%	32%	28%
Mundic Seep North	581	700	99%	84%	92%
Mundic Seep ("Waterfall")	531	728	91%	88%	89%
Mundic West	n/a	662	n/a	79%	79%
Middle Mundic Valley					
MB14	37	152	6%	7%	7%
MB11	199	323	34%	31%	33%
Mundic East	n/a	136	n/a	5%	5%
Lower Mundic Valley					
Slag Dump See-page North	n/a	351	n/a	35%	35%
Frog Hollow	n/a	276	n/a	25%	25%
MB5S	124	145	21%	6%	14%
MB5D	133	285	23%	26%	24%
Linda Creek					
MB2	60	130	10%	4%	7%
MB12	85	331	14%	32%	23%
Slag Dump See-page East	241	118	41%	2%	22%

a. Average of June and October 2003 sampling rounds.

Table 4 summarizes the input parameters and resulting estimates of seepage from the mine site to the Dee River along the three reaches. These Darcy calculations are based on a limited number of boreholes and hydraulic testing data and therefore have to be considered preliminary. Nevertheless, they illustrate that the majority of seepage to the Dee River likely occurs as shallow seepage, in particular along old stream channels, which have been in-filled with relatively coarse tailings during the early stages of mining. Additional drilling would be required to better delineate the extent of these tailings deposits and to refine these preliminary seepage estimates.

Table 4. Estimates of seepage to Dee River (including underlying aquifer system).

Dee River reach	Aquifer unit	Linear length of reach (m)	Hydraulic gradient (m/m)	Aquifer thickness (m)	K (m/s)	Estimated seepage from minesite (L/s)
Dee River Dams (Dams 6, 4 and 5)[a]	Saprolite/Tailings[a]	650	0.013	5	9.E-06	0.38
	Fractured bedrock	1650	0.013	20	4.E-07	0.17
Mundic Reach	Saprolite/Tailings[b]	150	0.023	5	5.E-05	0.79
	Fractured bedrock	750	0.023	10	4.E-07	0.07
Shepherds Reach	Saprolite	800	0.1	5	7.E-07	0.28
	Fractured bedrock	800	0.1	10	2.E-07	0.16
					TOTAL	1.85

a. Permeable tailings present only along Dam 6 reach.
b. Permeable tailings believed to be present only in historic Mundic & Linda Creek channels.

The total seepage from the Mt Morgan mine site to the Dee River has been estimated to be about 1.8 L/s (160 m^3/day). This seepage rate is orders of magnitudes less than streamflow observed during runoff events in the Dee River (typically 300 to 3,000 L/s). However, this seepage can provide a substantial contribution to the Dee River during extended dry spells. During these periods, the Dee River has no “measurable” surface flow, but some underflow in the very permeable stream sediments below Kenbula weir undoubtedly occurs.

Note that the SIS currently collects about 13.8 L/s during baseflow conditions (Greg Bartley pers. Comm.). These calculations would suggest that the SIS currently intercepts about 90% of all seepage from the site.

5 Conclusions and Future Work

The hydrogeology of the Mt Morgan mine site has been profoundly altered by historic and recent mining activities. Excavation, backfilling and flooding of the Open Cut/Sandstone Gully (OCSG) has resulted in significant subsurface flow though the fill material placed in Mundic Valley (above the natural ground surface). This subsurface flow represents as much 79% of all seepage intercepted in Mundic West and 25% of seepage intercepted in Frog Hollow (for a combined total of about 6.5 L/s) under baseflow conditions.

In addition, placement of waste rock and tailings in other parts of the mine site has significantly altered the recharge pattern to the groundwater system. Seepage from these mine waste units now represents a major component of the overall recharge to the local groundwater system.

The total amount of groundwater seepage entering the Dee River system (Dee River and underlying aquifer) has been estimated to be about 1.8 L/s. This seepage rate is significantly smaller than the amount of seepage currently intercepted (13.8 L/s) suggesting a very high efficiency of the existing SIS. Detailed monitoring of groundwater levels and groundwater quality is currently on-going to evaluate the seasonal variation of groundwater flow and seepage rates to the Dee River system.

The results of the 2003 field investigation were used to develop a numerical groundwater flow model for the Mt Morgan mine site (in progress). The observed groundwater levels and the estimated seepage rates provide calibration targets for this model. Once calibrated, this groundwater flow model will be used to obtain independent estimates of seepage bypassing the SIS and reaching the Dee River system. This groundwater flow model will also be used to evaluate the influence of alternative rehabilitation strategies on seepage rates to the SIS and contaminant loading to the Dee River system.

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14. Appendix 2 Brukunga Pyrite Mine

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SUCCESSFULLY LOWERING THE RISKS AND COSTS ASSOCIATED WITH THE LEGACY OF THE ABANDONED BRUKUNGA PYRITE MINE, SOUTH AUSTRALIA[1].

Ray Cox, Peter Grindley, Jeff Taylor and Sophie Pape[2]

Abstract. Pyrite (FeS_2) and pyrrhotite (FeS) were mined by open pit methods at Brukunga, South Australia, between 1955 and 1972. Eight million tonnes of waste rock (2 wt.% S) and 3.5 Mt of tailings (1.7 wt.% S) were produced. Oxidation of this material, and remaining in-situ rock mass, has resulted in acid drainage (pH<3) with elevated sulphate and dissolved metals. Prior to June 2003 this acid drainage entered Dawesley Creek making the water unsuitable for livestock and irrigation use for up to 20 km downstream. The site is now under the care of the State Government.

A lime neutralization plant commissioned by the State Government in 1980 and currently operated by Primary Industries and Resources South Australia (PIRSA), a government body, was built to address water quality issues on site and reduce downstream impacts in Dawesley Creek. Construction of a drain in June 2003 diverted flow from Dawesley Creek around the mine enabling all acid drainage to be retained, collected and treated on site. Upgrade of the existing plant to High Density Sludge (HDS) mode resulted in additional improvements in water quality, increased reagent efficiency and reduced overall treatment costs, including a 50% cost savings on sludge handling and disposal. An additional plant has been commissioned to cope with increased treatment volumes brought about by improvements in the containment and collection of acid drainage from the site.

Having substantially reduced the water quality risks to downstream users PIRSA's ongoing rehabilitation of the site is aimed at lowering the acid load entering the treatment plants. Future stages in the rehabilitation program include plans to move and cap waste rock piles and to continue to revegetate the site. This will further reduce treatment and sludge handling costs while maintaining water quality for users downstream of the site.

Additional Key Words: minesite rehabilitation, acid and metalliferous drainage (AMD), High Density Sludge (HDS), lime treatment plant

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Introduction

The Brukunga pyrite mine is located 4 km north of Nairne and 40 km east of Adelaide in the Mount Lofty Ranges of South Australia (Fig. 1). Iron sulfide (pyrite and pyrrhotite) was mined at the site between 1955 and 1972. During mining operations, two large waste rock piles were generated from approximately 8 million tonnes of sulfidic overburden material (2 wt.% S), and a valley-fill tailings facility adjacent to the mine was filled with 3.5 million tonnes of sulfidic sand-tailings (1.7 wt.% S) (PIRSA, 2003a).

Acid and Metalliferous Drainage (AMD) has been a significant issue at the Brukunga mine as a result of the oxidation of pyrite and pyrrhotite minerals within the waste rock piles, tailings facility and the unsaturated zone of the in-situ rock mass. This process continues to generate acidic water at the site, with pHs of 2.5-2.9 and highly elevated SO_4^{-2} and metal concentrations recorded between September 1999 and December 2003.

Until June 2003, acid drainage entered Dawesley Creek, which flowed directly through the Brukunga mine site. Elevated levels of SO_4^{-2} and metals (eg. Al, Fe, Cd, and Mn) were carried downstream into Mt. Barker Creek, Bremer River and finally into Lake Alexandrina, making the water unsuitable for livestock and irrigation use up to 20 km downstream of the mine site. PIRSA are working to reduce risks and lower treatment costs associated with the abandoned mine.

Site History

The 'historic' Brukunga mine has not been worked since the mine closed 31 May 1972. The mine was established in the 1950's as a source of S to be converted to H_2SO_4 for use in the manufacture of superphosphate fertilizer. At the time superphosphate fertilizer was in demand due to the poor quality of Australian soils and the expansion of post-war agricultural activities.

The development of the mine was encouraged and sponsored by both the State and Commonwealth Governments as part of the drive for self-sufficiency and full employment. The State Government fostered the formation of the company, Nairne Pyrites Pty Ltd, a consortium of three fertilizer manufacturers and a mine operator; ie. Cresco Fertilisers; Adelaide Chemical Co; Wallaroo–Mt Lyell Fertilisers; and The BHP Company.

The mine commenced production in June 1955 and continued for 17 years, closing on the 31st May 1972. The mine produced 5.5 million tonnes of Fe sulfide (pyrite and pyrrhotite) ore at ~380,000 tonnes per annum. The ore had a grade of 11% S and was crushed and processed on site to produce a 40% S concentrate.

Iron sulfide was quarried from the side of two steep hills using a power shovel and trucks. The mine concentrate was trucked to a rail siding at Nairne and then railed to Snowdens Beach, Port Adelaide where it was converted to H_2SO_4. Imported phosphate rock was treated with the acid to produce superphosphate fertilizer to sustain South Australian agriculture.

To encourage mining of pyrite for production of sulphuric acid, the Commonwealth paid a bounty via the Sulphuric Acid Bounty Act, 1954 and the Pyrites Bounty Act, 1960. Only two mines were established in Australia specifically to mine pyrite ore, ie. Brukunga and the King Mine at Norseman, Western Australia. In the late 1960's cheaper sources of sulfur became available mainly due to Canada's refining of 'sour natural gas'. The government withdrew the pyrite subsidy on 31st May 1972 and both pyrite mines ceased mining operations on the same day.

Figure 1. Location of the Brukunga Pyrite Mine and key site features.

Following mine closure, the crushers and metallurgical plant were dismantled and the mine office and workshops later became the start of the Country Fire Service (CFS) State Training Headquarters. The remaining quarry bench is 1.8 km long with 2 high walls 70 and 85 m laid back at 45° and 50°. The 8 Mt of rock removed to access the pyrite was discarded to form the north and south waste rock piles. A small rock pile, south-east of the open cut, has been rehabilitated.

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Concentration of the sulfide ore on site involved crushing and grinding the ore to a fine sand, with 80% passing a 75 μm sieve. This produced a total of 3.5 Mt of mill tailings that was pumped to the eastern side of Nairne Road to fill a shallow farm valley. The tailings at the front edge are 30 metres above the valley floor and covers an area of 28 hectares.

After closure in 1972, Nairne Pyrites Pty Ltd employed two caretakers to collect and pump acid drainage to a large evaporation lake on the tailings facility. In February 1974, a summer storm caused the lake to overflow and it was soon realised that water levels could not be controlled solely by evaporation. The Department of Mines and Australian Mineral Development Laboratories (AMDEL) began to investigate site water quality issues. In August 1977, the State Government accepted responsibility for rehabilitation of the site.

In September 1980, the government commissioned a lime treatment plant to treat the acid water. The Department of Engineering and Water Supply (EWS) were appointed the operators and within 5 years of successful treatment a 10 ha lake of acid water was removed from the tailings facility. The plant was then used to treat acidic seepage percolating through the tailings embankment and acid drainage transferred by 12 float-activated pumps from various locations around the quarry bench and waste rock piles. The collected water is held in two ponds located at the base of the tailings embankment. Polluted water from the holding ponds is pumped to the plant by a range of six varying capacity screw-pumps mounted in parallel. Feed to the plant (from 17 kL/hour to a peak of 50+ kL/hour) is controlled by operating one or more of these pumps.

Prior to 2003, where possible, contaminated water from Dawesley Creek was diverted, via the collection ponds, through the lime treatment plant before being discharged back into the creek. However, the capacity of the treatment plant was frequently exceeded due to high flows in Dawesley Creek, especially during the wetter winter months.

Despite all the work done from 1980 to 2003 to intercept and treat acid drainage, only approximately half the pollution from the site was treated. The remnant 50% or ~600 tonnes/year of SO_4^{-2} escaped to pollute the flow in Dawesley Creek (PIRSA, 2003b).

Site Issues

The main environmental risk at Brukunga is caused by the natural oxidation of pyrite and pyrrhotite minerals within the waste rock piles, tailings facility and unsaturated zone of the in-situ rock mass, producing acid drainage that may enter Dawesley Creek.

In 1993-94 the Australian Nuclear Scientific and Technology Organisation (ANSTO) were engaged to provide an estimate of how long the oxidation would continue. Temperature and oxygen concentrations were monitored in a series of boreholes drilled into the tailings and rock piles, and results indicated that acid-forming reactions are likely to continue for between 240 and 750 years (ANSTO, 1994).

In March 1999, the Brukunga Mine Site Remediation Board (BMSRB) replaced the technically based 'Brukunga Taskforce' placing emphasis on local community involvement in developing new management solutions to lower the risks associated with the acid drainage. The BMSRB advises the State Government Minister for Primary Industries and Resources on strategies for environmental improvement and has representatives from the Dawesley Creek

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Catchment Landcare Group, the District Council of Mount Barker, a local community representative, and members from PIRSA (Minerals and Energy Division).

In 2001, after considering various studies, the BMSRB recommended a $26M (AUD) 10 year program of new initiatives to the Minister and government (PIRSA, 2002). The government accepted the program involving: 1) creek diversion and containment of site acid drainage, 2) doubling the peak acid treatment capacity and 3) decreasing the acid seepage by relocating / capping waste rock piles.

Containment of site acid drainage

As a priority of the remediation program, acid drainage produced on site had to be contained and the amounts entering the local waterways substantially reduced. The key to this was the diversion of Dawesley Creek, and containment of acid runoff and seepage on site.

In June 2003, Stage 1 of the program, construction of the Dawesley Creek diversion, was successfully completed. The diversion isolates Dawesley Creek from the pollution generated at the mine site. The 1.7 km diversion includes 780 metres of 1.5 metre diameter reinforced concrete pipes, 175 metres of High-Density Polyethylene (HDPE) plastic pipe and 750 metres of drilled and blasted open channel (Fig. 2). The original section of creek, adjacent to the waste rock piles, now provides a sink for the collection of acid drainage that previously flowed directly into the creek. Construction of the drain resulted in an immediate improvement in water quality in Dawesley Creek downstream of the mine for the first time in 50 years.

Figure 2. Dawesley Creek diversion drain. Laying pipe for the underground segments of the drain (right) and open channels (left).

On completion of the Dawesley Creek diversion it became possible to intercept 90-95% of the pollution, with most of the loss occurring during high rainfall events. During these high rainfall events, any loss of acid drainage off site was substantially diluted.

Slaked-lime Treatment Plant

The vast improvements in the capture and containment of acid drainage on site brought about by the Dawesley Creek diversion required the upgrade of treatment facilities to cope with the increased treatment requirements. Stage 2 of the remediation program required the doubling of the peak acid treatment capacity of the site. This was achieved by upgrading the existing plant and commissioning of a new plant.

Existing Plant

The existing treatment plant was designed to treat 20 kL of acid drainage per hour, but has dealt with flow rates between 10 and 35 kL per hour. Treatment requirements are greatly affected by seasonal and local rainfall events. During summer the plant is often shut down, but during the wet winter months (June through September) the plant operates 24 hours/day and 7 days/week to maintain water levels in the North and South AMD holding ponds.

Untreated water typically has low pH (2.5-2.9), high conductivity (6,970-11,800 µS/cm), high concentrations of SO_4^{-2} (8,240-14,000 mg/L) and elevated Al, Cd, Cr, Cu, Fe, Pb, Mn, Ni and Zn. This water is pumped from the North AMD holding pond (Fig. 3) into the first of three 12 kL reactor tanks (Reactor 1) in the treatment plant (Fig. 4).

Carbide lime slurry is mixed in a 50 kL below ground tank (Fig. 5), and dispensed to Reactor 1 as required to achieve a pH of approximately 9.5 in water exiting the plant. The carbide lime is a form of hydrated lime that is a by-product of the acetylene manufacturing process. The reagent therefore contains minor impurities (eg. CaC_2) that is not present in conventional hydrated lime. Carbide lime slurry is delivered to the site by road tanker 3 days a week. Excess slurry is stored in an evaporation pond to the west of the plant. Partially-dried carbide lime from the evaporation pond is transferred to one of two above-ground temporary storage areas. When required, the partially-dried carbide lime is added (with water) to the 50 kL below ground lime slurry tank. Annual consumption of reagent is variable but averages approximately 600 dry tonnes per annum.

Figure 3. Acid drainage from the site is pumped to the North AMD holding pond (shown) prior to treatment.

Figure 4. Reactors 1, 2 and 3 as viewed from the thickener tank (existing plant).

Water from Reactor 1 flows by gravity to Reactor 2 and (subsequently) to Reactor 3. The use of three reactor vessels provides the retention time required for the completion of the treatment reactions. Water exiting Reactor 3 then flows into a below ground sump. When the sump is full, water is pumped up to a 390 kL thickener / clarifier tank. Flocculent is dispensed into the stream of water from the below ground sump before it enters the thickener / clarifier tank (Fig. 6). Clear supernatant water from the thickener / clarifier tank overflows to a clarification pond before being released into Dawesley Creek, downstream of the mine site.

Figure 5. Below ground hydrated lime storage, mixing and dosing system.

Figure 6. Thickener / clarifier tank.

Settled sludge in the base of the thickener / clarifier tank is either recycled into Reactor 2 or pumped to one of two sludge ponds located on the tailings facility. The low-density sludge exiting the plant prior to its upgrade was between 3 and 5 wt% solids.

Prior to its upgrade the existing plant treated 54,258 kL and 123,098 kL of low pH water in 2002 and 2003 respectively. This treatment required 484 and 723 dry tonnes of carbide lime respectively. Increased treatment volumes in 2003 corresponded to the higher rainfall and the diversion of Dawesley Creek in June 2003, which enabled virtually all AMD from the site to be collected for treatment. The pH of water exiting the thickener / clarifier tank in 2003 ranged from 7.5 to 11.0 (average 9.2). The pH decreased significantly in the clarification pond (minimum 6.5, average 8.6, maximum 10.2) and further decreased prior to being released to Dawesley Creek (minimum 6.0, average 7.5, maximum 9.3). The low-density sludge produced contained approximately 4.4 wt% solids.

Operating in Low Density Sludge (LDS) mode the pH increased from 2.7 to around 7.4-8.4 after addition of lime to the AMD in Reactor 1. Electrical Conductivity (EC) decreased from 10,300-10,410 μS/cm to 4,180-5260 μS/cm, and the water had become highly reduced, with oxidation-reduction potential (ORP) values as low as -246 mV. Variation in pH, EC and ORP with depth in Reactor 1 indicated that mixing was inefficient.

As water flowed from Reactor 1 to 3 the pH generally decreased (eg. 10.9-9.3) along with the EC (eg. 4,300-3,933 μS/cm), and the water became less reduced (eg. ORP increased from -148 to -80 mV).

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Thickener / clarifier tank overflow water was characterised by relatively high pH (8.9-10.0), lower EC (3,833-3,857 μS/cm) and still relatively reduced water (eg. ORP values -78 to +21 mV).

Water in the clarification pond had significantly lower pH (6.5-8.0) and higher EC (4,348-4,460 μS/cm), indicating the presence of mineral acidity in the thickener / clarifier tank overflow water.

Tests carried out by Earth Systems (2004) indicated that metal removal efficiencies of at least 98 wt.% are likely to have been routinely achieved in the existing plant when it was operating in Low Density Sludge (LDS) mode. Low concentrations of redox sensitive soluble components (Fe and Mn) accounted for the residual 2 wt.%. As a result of this low soluble metal content, treated water was being discharged from the plant with low level acidity values (10-100 mg/L $CaCO_3$). Approximately 1.5 to 2 log unit falls in pH were being recorded between the plant overflow and the Dawesley Creek discharge as a result of ongoing oxidation and related acidification of the treated water.

Upgrade of existing plant

The identification of several inefficiencies in the existing plant was detailed in a report commissioned for Stage 2 of the site remediation works (Earth Systems, 2004). Key inefficiencies included: 1) the incomplete oxidation of AMD during the treatment process, which allowed water to be discharged with residual mineral acidity, and 2) large volumes of low density sludge that presented storage and handling problems.

To address the low levels of redox sensitive soluble metals being discharged from the plant, modifications were made to fully oxidize the treated water stream. Tests were conducted on the plant operating in LDS mode with oxygen supplied via a compressor. This resulted in very low to below detection metal concentrations and high residual alkalinities (1,300-3,600 mg/L $CaCO_3$ equivalent) in the discharge stream. As a result a high capacity air blower (115-130 m^3/hour was added to the existing plant (Reactor 2 and 3).

Issues associated with sludge production and storage were addressed by converting the plant to High Density Sludge (HDS) mode. Conversion to HDS mode was achieved by pre-treating the raw acid water feed in Reactor 1 with high volumes of alkaline sludge from the thickener / clarifier tank. This raises the pH to 6.5 before new lime slurry is added in Reactor 2. Recycling of sludge within the treatment plant has improved reagent efficiencies and reduced sludge volumes by increasing the sludge density. An advanced polymer flocculant AN905MPM is added to the thickener tank to assist settling and further increase sludge density.

The sludge produced in the plant is recirculated for the pre-treatment of the raw acid feed for around 5 or 6 days or until a sludge density of 30 - 35 wt.% solids is achieved in the thickener tank. This is empirically determined by increased torque load on the thickener rake. A batch of the high density sludge is then discharged from the thickener for about 8 hours and pumped to the sludge drying ponds to allow for evaporation of residual water.

Most of the modification to the existing plant was completed at minimal cost. Aeration of the reactors required the purchase of an air blower while conversion of the plant to HDS mode required the redirection of a number of pre-existing pipes.

<u>New plant</u>

In May 2005, a second parallel series of 3 larger reaction vessels was installed to effectively double the treatment capacity of the plant (Fig. 7). This new plant also operates in HDS mode and has a design capacity of 25 kL/hour. The installation of the new plant and upgrade to the existing plant was completed at a cost of $750,000 (AUD). Improvements in sludge density and settling characteristics enabled the existing thickener to accommodate the sludge output of both plants.

Figure 7. New treatment plant showing second parallel series of reaction vessels (upper left) with existing upgraded plant (lower right).

Commissioning of the new plant along with the upgrade of the existing plant has greatly improved the efficiency of reagent use. Recent estimates suggest that the volume of AMD treated per dry tonne of lime reagent is increasing and results also indicate an improvement in the water quality being discharged.

<u>Sludge</u>

Conversion of the existing plant to HDS mode has lead to a reduction in the volume of sludge produced and costs savings in the order of $30,000 (AUD) per annum related to the settling pond desludging requirements (Fig. 8). Sludge from the thickener / clarifier is now being produced at up to 42 wt.% solids with the HDS process in comparison to 3-5 wt% prior to the upgrade of the existing plant. This equates to a reduction of greater than 50% in the total volume of sludge produced.

Examination of the treatment sludge indicates it is dominated by crystalline material (65-75%) of which gypsum ($CaSO_4.2H_2O$) is the dominant phase (Raven and Keeling, 2000; Wollard, 2003 and Earth Systems, 2004). Other phases present include minor bassanite ($2CaSO_4.H_2O$), quartz (SiO_2) and calcite ($CaCO_3$).

When the plant was operating in LDS mode, the north and south sludge ponds located at the back of the tailings facility were dislodged every summer to provide space for the following years production of sludge. The increased sludge density, resulting from the HDS process and other plant modifications, will reduce the frequency at which these ponds are dislodged from annually to every 2-3 years. This represents an estimated cost saving of between 50 and 66% on dislodging costs alone.

Figure 8. Sludge pond. Low-density sludge prior to plant upgrade partly fills one of the two sludge ponds (upper left). Sludge pond full of partially air dried sludge prior to desludging (upper right). High-density sludge entering the sludge pond after plant upgrade (lower left and right).

An additional benefit of the increased density of the sludge is less water is being pumped out to the sludge ponds. Estimates conducted by Earth Systems (2004), based on volumes of sludge produced and available sludge storage volumes indicated that substantial volumes of water within the sludge ponds are lost by means other than evaporation. This water loss is most likely due to infiltration through the walls and base of the sludge ponds. Given the sludge ponds are situated on top of the backfilled tailings facility, the water had been infiltrating into the tailing sand and contributing to the seepage from the base of the tailings embankment. An increase in sludge density and decrease in water in the sludge ponds is likely to reduce the volume of water seeping from the tailings embankment and therefore reduce the volume of water requiring treatment.

Potential on site applications for the sludge are being examined. Currently some of the treatment sludge is being successfully used as a growth medium or soil amendment. It is also being considered for use as a water shedding cover for the tailings facility.

Tailings

Rehabilitation and revegetation of the tailings facility commenced in 1987 with trials using a thin (30 to 50 cm) soil and rubble layer spread over the tailings. Each year several thousand native tube-stock seedlings have been planted. The vegetation has reduced surface erosion, improved the visual appearance, and provided habitat for native fauna. In addition to this the capping and revegetation of the tailings facility has acted as a store and release cover, forming an evapo-transpiration layer that serves to reduce the deep percolation of rain into the tailing sand. Moisture is temporarily held in the root zone of the plants and from there it evaporates or is drawn up into the vegetation. This has greatly reduced deep percolation and hence the quantity of acid seeping from the toe of the tailings embankment. Measurements of depth to ground water in boreholes recorded each year indicate that the tailings facility is continuing to dry internally. This is also confirmed by decreasing quantities of seepage measured at a v-notch weir below the tailings embankment.

Following the ongoing efforts of PIRSA staff to lower seepage from the tailings embankment, the seepage contributed only 50 wt.% (28,031 kL) and 25 wt.% (25,169 kL) of the total acidity load to the existing treatment plant in 2002 and 2003 respectively (Earth Systems, 2004). Tailings embankment seepage is likely to have contributed the majority of the acidity load arriving at the plant prior to decommissioning of ponds on top of the tailings facility and revegetation of its surface.

A great deal of the success of the revegetation program was due to the use of 'biosolids' from the annual clean out of Waste Water Treatment Plants and from daily truckloads of wet sludge cleared from local domestic septic tanks. The biosolids were spread thinly over the tailings facility surface, contributing to increasing soil cover and providing moisture, nutrients and bacteria necessary to invigorate healthy plant growth.

Figure 9. Aerial view of the progressive rehabilitation of the tailings storage facility. Far left: 1973, 12 months after closure of the site. Middle: 1985, remaining acid water on tailings facility after initiation of treatment in 1980. Right: 1997, revegetated surface of the tailings facility.

Waste Rock

The third stage in the rehabilitation works at the Brukunga site involves the reduction of acid generation and seepage on site. The key to this will be the rehabilitation of the waste rock piles on site. Currently waste rock piles are located along the base of the open cut bench and have not been capped. This allows uncontrolled infiltration of water into the piles, and results in seepage of acidic drainage generated within the piles (Fig. 9).

Figure 9. Waste rock piles at the Brukunga site, to be rehabilitated during Phase 3 of the remediation program.

A number of options are being considered for rehabilitation of the waste rock piles. These range from capping of the existing piles to completely relocating the waste rock, either on or off site. A proposal is currently being considered to relocate the 8 Mt of waste rock back to the open cut and blend it with imported limestone marl. At present, cost estimates place this option at \$3M/year (AUD) over 7 years. On completion of the waste rock relocation and remediation, it is envisaged that acid seepage from the mine site will significantly diminish, resulting in greatly reduced ongoing treatment and maintenance costs.

Summary

Rehabilitation and treatment plant upgrade works have significantly improved the water quality downstream of the Brukunga mine site, dramatically reducing the off site risks associated with acid generation on site. In the process, upgrade of the AMD treatment plant from a Low Density Sludge to a High Density Sludge system, has resulted in significantly reduced costs (>50% ie. \$30,000 (AUD) per annum) associated with sludge handling and disposal. Recent estimates also suggest improvements in reagent efficiency, with a higher volume of AMD treated per tonne of lime reagent used.

Future rehabilitation plans are now focussing on reducing ongoing treatment costs further by lowering the acid load entering the plant. This is being addressed by plans to relocate and cap the exposed waste rock piles and continue to revegetate the site.

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Acronyms

AMD	Acid and metalliferous drainage
AMDEL	Australian Mineral Development Laboratories
ANSTO	Australian Nuclear Scientific and Technology Organisation
AUD	Australian dollars
AN905MPM	Specific type of advanced polymer flocculent
BMSRB	Brukunga Mine Site Remediation Board
CFS	Country Fire Service
EC	Electrical Conductivity
EWS	Department of Engineering and Water Supply
HDPE	High-Density Polyethylene
HDS	High Density Sludge
LDS	Low Density Sludge
ORP	Oxidation-reduction potential
PIRSA	Department of Primary Industries and Resources South Australia

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