Amulsar Gold Project

Acid Rock Drainage Management Plan Report

June 2016

Revision History

Revision	Date	Details	Prepared	Checked	Approved
V1	Aug- 2014	Submittal in Support of 2014 Feasibility Study and ESIA Effort	GRE	MPL	MPL
V2	October, 2015	Submittal in Support of 2015 Feasibility Study and ESIA Revision	GRE	JAN	
V3	May 2016	Analysis of construction material and low grade ore	GRE		

Plan approved by _____ Date _____

Health, Environmental, Safety and Security Manager

The Amulsar Acid Rock Drainage Management Plan Report is a "live" document that will be updated throughout the life of the Project as necessary to reflect the monitoring requirements particular to the current Project phase.

This revision (V2) applies to the **– 2015 Feasibility Study Phase**.

Table of Contents

List of Drawings

Drawing 01: Project Facilities General Arrangement Plan

List of Appendices

Appendix A: Amulsar BRSF Passive Treatment System Design Basis

List of Abbreviations and Acronyms

Mass

gr — gram
kg — kilogram
t tonne — (metric ton)
Mt — million tonnes

Density

kg/m^3 — kilogram per cubic meter
t/m^3 — tonne per cubic meter
gr/cm^3 — gram per cubic centimeter

Length

mm — millimeter
cm — centimeter
m — meter
km — kilometer
in — inch
ft — foot

Area

m^2 — square meter
ha — hectare

Volume

L — liter
m^3 — cubic meter

Time

sec — second
min — minute
hr — hour
da — day
yr — year

Stress/Pressure

Pa — Pascal or N/m^2
kPa — kilonewton per square meter (kN/m^2)
bar — 100 kN/m^2
MPa — 1000 kN/m^2
kN/m^3 — kilonewton per cubic meter
kgf/cm^2 — kilogram-force per square

Other

% — percent

Other (continued)

° — degree
°C — degree Celsius
°F — degree Fahrenheit
1.3H:1V — 1.3 horizontal to 1 vertical
ABA — Acid-Base Accounting
ARD — Acid Rock Drainage
AP — Acid Generation Potential
ASTM — American Society for Testing and Materials
avg — Average
BRSF — Barren Rock Storage Facility
EIA — Environmental Impact Assessment
ET — Evapotranspiration
FOS — factor of safety
g — gravitational acceleration (9.81 m/sec^2)
Golder — Golder Associates
gpm — gallon per minute
GRE — Global Resource Engineering
HESS — Heath, Environmental, Safety and Security
HLF — Heap Leach Facility
ICP-MS — Inductively Coupled Plasma Mass Spectrometer
INAP — International Network for Acid Prevention
k — Permeability Coefficient
Lydian — Lydian International
LV — Lower Volcanics
MAC — Maximum Allowable Concentrations
MIW — Mine Influenced Waters
MWMP — Meteoric Water Mobility Procedure
NAG — Non Potentially Acid-Generating
NNP — Net Neutralization Potential
NP — Neutralization Potential
NPR — Neutralization Potential Ratio
PAG — Potentially Acid Generating
PD — Detention Pond
The Project — Amulsar Project
PTS — Passive Treatment System
ROM — Run of Mine
St. Dev. — Standard Deviation
SPLP — Synthetic Precipitation Leaching Procedure
TDS — Total Dissolved Solids
UV — Upper Volcanics
XRF — X-Ray Fluorescence
WAD — Weak Acid Dissociable
Wk — Week

1   INTRODUCTION

Lydian International Ltd (Lydian) and its wholly-owned Armenian subsidiary, Geoteam CJSC (Geoteam), are developing the Amulsar Gold Project (the Project) in the central part of the Republic of Armenia (RA). The proposed Project will develop the gold deposit via open-pit mining and heap-leach processing using dilute cyanide solution.

A Mining Right (MR) for the Project was granted by the RA government in November 2014. This was based, in part, on the approval of the regulatory Environmental Impact Assessment (EIA) for the Project in October 2014. Some permits also exist for ongoing exploration and development activities with additional permits required for the construction and operation phase. The Project is currently in the early stages of development, with construction activities planned to start during the second quarter 2016 subject to financing.

In parallel with the EIA, an Environmental and Social Impact Assessment (ESIA) was undertaken in compliance with, amongst others, the Performance Standards (PS) of the International Finance Corporation (IFC) and the Performance Requirements (PR) of the European Bank for Reconstruction and Development (EBRD).

In mid-2015, a Value Engineering (VE) and Optimization process was initiated, with Lydian commissioning Samuel Engineering Inc. (Samuel) and other consultants to perform engineering design on several identified VE and Optimization concepts. The objective was to reduce capital expenditure without increasing operating costs or environmental and social impacts. The results from this work done in 2015, which were published in the NI "43-101 Technical Report: Amulsar Value Engineering and Optimization" in November 2015, included reduced capital and operational costs, making the Project more viable in a challenging economic environment.

Changes to the Project design as a result of the VE and Optimization work have resulted in the need to prepare a revision to the new EIA approved in October 2014 and amend the ESIA completed and disclosed in April 2015. The EIA was approved on 28th April 2016. The Project has also been subject to various health, safety, environmental and community/social (HSEC) commitments arising from the ESIA undertaken in compliance with the IFC PS and EBRD PR. The final version of the ESIA, denoted v10, published for public review and comment in June 2016, follows a series of public consultations and disclosure meetings in May & June 2016.

Both the EIA and ESIA make a number of commitments pertaining to the mitigation and management of E&S impacts. These commitments and requirements must be fulfilled as the

Project moves forward. To facilitate implementation, all commitments made in the ESIA have been compiled into a full Commitments Register (CR) which will be used by Lydian for tracking purposes throughout the Project. Although many of the commitments apply to E&S management during Project implementation (construction, operation and closure), some apply to the Project design and engineering phase and must be addressed before construction works starts on site. The implementation of many of the commitments depends not only on the actions of full Project team.

E&S commitments are being managed by Lydian and Geoteam using the Environmental and Social Management System (ESMS). The ESMS includes the Management Plans (MPs), such as this one, that detail requirements that Geoteam and its contractors will follow in order to fulfil the Project's environmental and social commitments. For the purpose of this MP, "Contractor" means any all project participants, such as contractors working in the field on the project including but not limited to drilling contractors, construction contractors, camp service contractors, engineers, fabricators, suppliers, etc. Contractors should implement parts of the plans relevant to their activities, issuing their own management plans in line with the Geoteam ESMS, smaller contractors may fall directly under Lydian's OHSMS and ESMS and subject to specific training in the procedures relevant to the contract.

The Amulsar open pit gold mine will mine through and expose a geologic formation containing sulfide minerals that will produce Acid Rock Drainage (ARD). Geochemical testing and analysis (GRE, 2014) has confirmed that the Lower Volcanics formation (LV) generates acidic leachate through the oxidation of sulfide minerals. This formation comprises approximately 50% of barren rock that will report to the Barren Rock Storage Facility (BRSF) and pit backfill, and will form a similar percentage of exposed post-mining pit walls.

As a result, the Project requires an ARD management plan.

1.1   COMMITMENTS

ID.	Condition/actions	Public Commitment	Monitoring and compliance	Cross references and documentation	Responsibility
CHSS57	Environmental management will be undertaken as per the recommendations of the specialist studies on surface and ground water, soil and land use, and acid rock drainage (ARD).	The Project will identify and manage all potential sources of ARD. Specialist advisors will be retained to advise as appropriate on the management requirements to control ARD throughout the mine life, including the construction, operation, closure and post closure phases	Reporting required for ARD will fully integrated into the EMP and SWMP	Chapter 4.6 - Geology SWWB (App 6.10.1) Groundwater modelling study (App 6.9.1). BRSF Groundwater impact assessment (App 6.9.5)	
SL31	Down-gradient monitoring wells will be regularly sampled to verify that no fugitive solution from the BRSF underdrains or overdrains, and therefore has a potential to contaminate adjacent undisturbed soils.	Integral component of the surface and groundwater monitoring programme.	Monitoring programme is fully integrated into EMP	Monitoring well App 4.8.2 Surface water quality (App 4.9.4)	
SL39	Annual soil sampling for chemical analysis will take place during the operational phase for topsoils adjacent to the open pits, crushing plant, BRSF and HLF.	Continuing monitoring programme will be maintained adjacent to the active areas within the mine.	Monitoring programme is fully integrated into EMP	n/a	

ID.	Condition/actions	Public Commitment	Monitoring and compliance	Cross references and documentation	Responsibility
SW7	Contact water to be discharged to the Arpa River (anticipated from Year 5 of operations) will be treated in a passive treatment system (PTS) to MAC II standards, prior to discharge to the river downstream of the proposed water intake. The system is proposed to comprise a series of ponds, bioreactors and wetlands that will raise pH and remove nitrate, sulphate and metals. 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.	A passive water treatment system will be constructed and fully operational by 2020 and 12 months prior to accepting discharge from contact water ponds with the HLF area.	Monitoring programme is fully integrated into EMP	Amulsar Passive Treatment System (PTS) – design basis (App 3.1)	VPS & SHESS

ID.	Condition/actions	Public Commitment	Monitoring and compliance	Cross references and documentation	Responsibility
GW2 & SW3	The existing subsoil in the footprint of the BRSF will be compacted in place to act as a low-permeability soil liner. This soil liner will restrict infiltration and will direct water that comes into contact with the barren rock to the toe of the BRSF, where the outflow will be collected in the BRSF toe pond and then piped to the contact water pond for treatment and/or to the HLF for use. A NAG barren rock drainage layer placed over the compacted soil liner will inhibit natural groundwater from seeps and springs located beneath the prepared soil liner of the BRSF from coming into contact with PAG waste rock. Any water emanating through the foundation of the dump (from potential seeps and springs) will travel through this layer towards the toe of the facility. At closure, flows will be treated using a passive treatment facility.	The construction of the BRSF will conform to international good practice to contain, control and manage ARD during the operational, closure and post closure phases.	Containment will be verified by and independent third party, through construction quality assurance	Chapter 3 – Project description	PD & EVPS
SW4	Runoff, and discharge via the basal drainage layer (leachate and underlying spring water) from the BRSF will be routed to the toe pond and then to the contact water pond at the HLF.	A closed drainage system will be constructed from the BRSF toe pond to the contact water ponds at the HLF	Site design verification.	SWWB (App 6.10.1)	SHESS

ID.	Condition/actions	Public Commitment	Monitoring and compliance	Cross references and documentation	Responsibility
GW3 & SW5	The BRSF cover will be an engineered evapotranspiration (E/T) cover designed to minimise infiltration by water, and comprising, from top to bottom, topsoil, naturally-compacted clay, and a gravel capillary break layer.	The construction of the BRSF will conform to international good practice to contain, control and manage ARD during the operational, closure and post closure phases.	Containment will be verified by and independent third party, through construction quality assurance	Chapter 3 – Project description	PD, EVPS
GW7	Cover test plots will be conducted during the operation phase to confirm the long-term infiltration rates through the cover systems (at sites where cover is to be placed, e.g. BRSF and HLF). These tests will be used to confirm the proposed cover or recommend modifications to limit recharge.	Ongoing research into the nature of the materials and design of the cover system for the BRSF will inform and validate the design techniques.	Monitoring programme is fully integrated into EMP	Chapter 3 – Project description	SHESS
GW11	Groundwater level and quality monitoring will be ongoing at monitoring wells and springs, including in particular up- and down-gradient of the BRSF and HLF. The purpose of the monitoring will be to evaluate the operational performance of the Project and identify any adverse trends in surface water and groundwater quality or quantity potentially exceeding those estimated by modelling that would require modifications to the mitigation measures.	Integral component of the surface and groundwater monitoring programme.	Monitoring programme is fully integrated into EMP	Monitoring well App 4.8.2 Surface water quality (App 4.9.4)	Site EM

ID.	Condition/actions	Public Commitment	Monitoring and compliance	Cross references and documentation	Responsibility
SW10	The discharge of post-closure residual waters from the BRSF will be treated to meet Category II MAC through the PTS located in the vicinity of the HLF. Water will then be discharged to a series of infiltration galleries within the HLF catchment or to a tributary of the Arpa. The contact water pond will be used to store and manage seasonal flows, controlling discharge to the PTS.	This requirements forms Part of the surface and groundwater monitoring programme.	Monitoring programme is fully integrated into EMP	Monitoring well App 4.8.2 Surface water quality (App 4.9.4) and	Site EM
Geol 1	Construction material extracted from borrow areas will be assessed for ARD potential from these sources, prior to use in construction. Ground investigation of borrow pit areas will inform the both the design of borrow pits and use of material in construction to determine suitability and inform management.	Ongoing studies will confirm the optimal technology and methods for defining NAG and PAG material in the field.	Monitoring programme is fully integrated into EMP	Amulsar Passive Treatment System (PTS) – design basis (App 3.1)	EVPS, SHESS
Geol 2	A programme of sulphur speciation testing will be developed as part of the operational sampling programme, to confirm ARD potential of all mined rock types. The analysis will validate and where appropriate update the EMP to include the ARD operational characterisation programme.	Ongoing research into the nature of the materials and design of the cover system for the BRSF will inform and validate the design techniques.	Monitoring programme is fully integrated into EMP	Amulsar Passive Treatment System (PTS) – design basis (App 3.1)	EVPS, SHESS, Site EM

1.2 REPORT ORGANIZATION

This ARD Management Plan has the following elements:

- Summary of ARD characterization;
- Discussion of ARD sources on site;

- Discussion of ARD mitigation and management methods;

- Summary of predictive modeling; and

- ARD impacts, including mitigation measures.

A project-wide layout of planned mine facilities is shown in Drawing 01 (attached).

2 ROLES AND RESPONSIBILTIES

2.1 GEOTEAM RESPONSIBILITIES

Geoteam is accountable for:

- Monitoring and auditing of the implementation of this plan

- Ensuring contractor performance with respect to the requirements of this plan; and

- Determining appropriate corrective action for any non-compliance in accordance with Geoteam's Compliance Assurance Plan (Ref GEOTEAM-ENV-PLN0226).

Specific accountabilities include the following:

2.2 GEOTEAM PROJECT DIRECTOR

The Project Director is accountable for ensuring that the Project complies with the requirements of this plan, and ensuring that designated managers understand their respective accountabilities and have sufficient resources to carry out their functions effectively. The Project Director is also accountable for reviewing the results of monitoring and review reports to ensure that any identified deficiencies are duly addressed.

2.3 EVP SUSTAINABILITY

- Review the ARD monitoring reports prepared by the Senior Manager Health, Environmental, Safety and Security;

- Approve and submit monitoring reports to the Board

- Approve programme for monitoring to ensure continual improvement of the management plan requirements throughout the life of the Project.

2.4 HEALTH, ENVIRONMENTAL, SAFETY AND SECURITY MANAGER (HESS)

The HESS is accountable for the management of the ARD monitoring program, specifically for the following

- Assignment of personnel to conduct field, office, and lab tasks;

- Ensuring that personnel are adequately trained and equipped to carry out monitoring program functions; in accordance with established procedures

- Ensuring that documentation of field activities is maintained;

- Ensuring that data generated by the monitoring is consistently and accurately captured in a database;

- Ensuring timely analysis of results; and

- Ensuring that appropriate action is taken in a timely manner if environmental degradation is identified.

As work proceeds on adding detail to the overall environmental monitoring program, it may be appropriate to modify this plan to be more specific in assignment of accountabilities to subordinates of the HESS Manager.

2.5 MINE MANAGER

The Mine Manager will be accountable for the management and operation of the BRSF. The manager will make routine inspections of the BRSF and implement the required mitigation measures described in this plan, or any additional measures required following discussion and agreement with the HESS and the Project Director.

2.6 SITE ENVIRONMENTAL MANAGER

The Site Environmental Manager, reporting to the Senior Manager HESS, is responsible for the monitoring requirements defined by this plan, through the EMP including the collation and reporting of monitoring data. The Site Environmental Manager will produce reports submitted to the Senior Manager HESS for approval.

3   SUMMARY OF ARD CHARACTERIZATION

The characterization of the Acid Rock Drainage (ARD) properties of the Amulsar site was first reported by Golder Associates (Golder, 2013). The characterization of ARD was fully-updated by Global Resource Engineering (GRE) (GRE, 2014) to include the results of additional geochemical testing and to report predictive modeling associated with the up-to-date mine planning and ARD mitigation measures (see Section 4.0). The following sections present a summary of the revised geochemical characterization results.

3.1   STATIC TESTING OF MINE WASTE

Static testing defines the ARD-generation and metals leaching potential of a given rock type. The following static geochemical testing was performed:

Table 1: Static Geochemical Testing Program

Material Type	ABA	NAG pH Testing	Bulk Chemistry	Mineralogy	SPLP Effluent Testing	NAG Effluent Testing
Number of Tests Performed						
Barren Rock - Tigranes/ Artavazdes	154	-	97	8	8	8
Barren Rock - Erato	80	50	42	12	9	12
Spent ore - Tigranes/ Artavazdes	6	-	-	-	6	-
Spent ore - Erato	7	7	7	-	7	7
Low Grade Stockpile	2		2			
Borrow materials	8	8	8	-	5	5

Where:

- ABA: Acid-Base Accounting by Modified Sobek.

- NAG pH: Net Acid Generating pH test.

- Bulk Chemistry: mineral composition by ICP-MS whole rock analysis.

- Mineralogy: Mineralogy evaluation via XRF followed by mineralogical analysis.

- SPLP effluent: Synthetic Precipitation Leaching Procedure effluent.

- NAG Effluent: Testing of the Non Acid-Generating (NAG) pH effluent.

3.2   ACID-BASE ACCOUNTING: BARREN ROCK

Acid-Base Accounting (ABA) is a method by which the total potential for acid generation (AP) for a rock sample is compared to the total neutralization potential (NP). It is an industry-standard method for determining the potential for acid generation in a rock type. Table 2 shows the results of ABA testing for the Tigranes/Artavazdes Barren Rock and Table 3 shows the ABA summary for Erato Barren Rock.

Table 2: ABA Summary - Tigranes/Artavazdes Barren Rock

Barren Rock	Statistics	Paste pH	AP TCaCO$_3$/kT	NP TCaCO$_3$/kT	Total S %	Sulfide S %	Sulfate S %
Lower Volcanics	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
Upper Volcanics	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
Colluvium	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

Table 3: ABA Summary - Erato Barren Rock

Barren Rock	Statistics	Paste pH	AP TCaCO$_3$/kT	NP TCaCO$_3$/kT	NAG pH	Total S %	Sulfide S %	Sulfate S %
Lower Volcanics	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
Upper Volcanics	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
Colluvium	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	2.42	0.36	0.28

Table 2 and Table 3 show that the Lower Volcanics (LV) formation has the highest potential for ARD generation with an average sulfide sulfur content of 1.3% for Tigranes/Artavazdes and 2.1% for Erato. The Upper Volcanics have some trace sulfides, but its oxidized nature and low total sulfide concentration (around 0.15%) make it so the low AP of the UV does not realize itself as ARD (See Section 1.6). The colluvium, a low-volume waste type, does not have significant AP.

Table 4 shows the typical guidelines for determining which samples have ARD potential based on the ABA results.

Table 4: Screening Guidelines for Acid Generation Potential Prediction

Material Designation:	Comparative Criteria	
	NNP (TCaCO₃/kT)	NPR
Potentially Acid-Generating (PAG)	< -20	< 1
Uncertain	-20 < NNP < 20	1 < NPR < 2
Non Potentially Acid-Generating (NAG)	> 20	> 2

(INAP, 2009)

The Net Neutralization Potential (NNP) is total NP minus total AP. The Neutralization Potential Ratio (NPR) is the ratio of NP to AP. Figure 1 shows the results of the screening criteria in graphical format.

Figure 1: NNP vs. NPR for Tigranes/Artavazdes and Erato Barren Rock
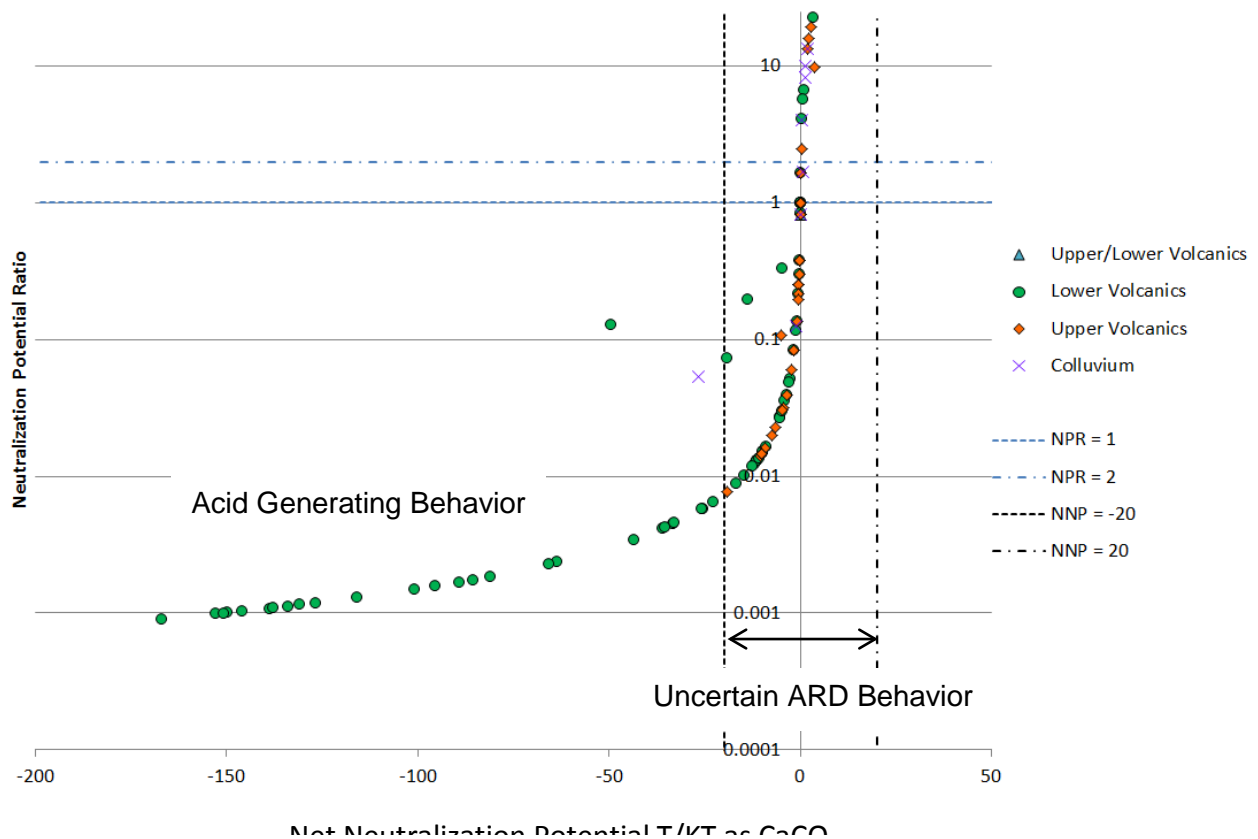
As demonstrated in Figure 1, all of the UV samples fall within the "uncertain" range. This signifies that kinetic testing is required to determine if these samples have ARD generation

potential. Despite the fact that a good portion of the LV samples also fall in the uncertain range, the ABA testing confirms that LV is an acid-generating rock type.

3.3   ACID-BASE ACCOUNTING: SPENT ORE

The spent ore may have the potential to produce ARD. As a result, the Project conducted ABA tests on spent ore from the Tigranes/Artavazdes pit and the Erato pit. The results are in Table 5 and Table 6.

Table 5: ABA Results - Tigranes/Artavazdes Spent Ore (includes one Erato sample)

Sample	Total Sulfur	Acid Soluble Sulfate	Sulfide Sulfur	AP	NP
	%	%S	%	T CaCO$_3$/kT	T CaCO$_3$/kT
MPF	0.04	0.02	0.02	0.63	3.06
GSN	0.58	0.05	0.53	16.50	4.31
FG	0.37	0.06	0.31	9.59	2.69
SB	0.38	0.04	0.34	10.66	2.31
MC0681,2	1.15	0.03	1.13	35.16	1.37
MC0701	0.70	0.05	0.65	20.22	2.50
MC0711	0.38	0.01	0.37	11.63	0.69

Notes:

1. Composite sample

2. Erato sample

Table 6: ABA Results - Erato Spent Ore

Sample	Total Sulfur	Acid Soluble Sulfate	Sulfide Sulfur	AP	NP
	%	%S	%	T CaCO$_3$/kT	T CaCO$_3$/kT
DDA-030	0.95	0.24	<0.01	0.31	0.30
DDA-030	0.14	0.11	<0.01	0.31	0.30
DDA-278	0.74	0.20	0.10	3.13	0.30
DDA-276	1.75	0.32	0.09	2.81	0.30
DDA-290	0.00	0.02	<0.01	0.31	0.30
DDA-340	0.53	0.24	<0.01	0.31	0.30

The testing above does not consider the lime addition to the HLF. Based on the Feasibility Study (Samuel, 2015), the project will apply ~2 kg of lime (CaO) per tonne of rock. This provides

an additional NP 4.0 T/KT CaCO₃ equivalent. Based on the generally low sulphide, sulfur levels (less than 1% in all but one sample), the 100% UV composition of the spent heap, and the abundant residual alkalinity present within the heap leach (the result of the lime addition), it was determined that the spent ore is not expected to present an ARD risk. However, as an added protection, the HLF is to be closed with an Evapotranspiration Cover (ET Cover) and a passive treatment system (the HLF PTS) designed to mitigate the long-term potential of water quality degradation caused by HLF leachate (see Section 5.5).

3.4   ACID-BASE ACCOUNTING LOW GRADE STOCKPILE

The Low-Grade (LG) Stockpile will be placed in two locations: on stripped native soil within the BRSF footprint, and on top of barren rock within the BRSF. Because there is a low probability that low-grade material will not be processed at the end of mine life due to unfavorable economic conditions, it must be evaluated as if it was barren rock.

However, the purpose of the waste characterization program was to evaluate mine waste, and few samples of LG material were collected. LG was classified as ore in the block model and specifically excluded from evaluation (except as spent heap material). Table 6 shows the ABA results from the available LG samples.

Table 7: ABA Results – Low Grade Stockpile Material

Sample	Total Sulfur	Acid Soluble Sulfate	Sulfide Sulfur	AP	NP
	%	%S	%	T CaCO₃/kT	T CaCO₃/kT
ARD-13	0.38	0.15	0.09	2.9	<0.3
ARD-52	0.19	0.12	<0.01	<0.3	<0.3

These sample results are typical of the UV material range (see Table 2 and Table 3). The sulfide sulfur is very low, as is the NP. It is important to note that the LG is overwhelmingly comprised of UV material. Based on an evaluation of the block model, 97% of all LG material (by volume) comes from UV material. As a result, the LG should be considered as statistically identical to UV waste rock. Section 3.11 presents the results of the geochemical characterization by rock type.

3.5   ACID-BASE ACCOUNTING: BORROW MATERIALS

Seven LV samples and one scoria sample were submitted for geochemical characterization to assess their suitability as potential site borrow materials. Table 8 shows the results of the borrow materials testing. Figure 2 shows the sample locations.

Table 8: ABA results for Borrow Materials

Sample	Material Type	Total Sulfur %	Acid Soluble Sulfate %	Pyritic Sulfur %	AP TCaCO$_3$/kT	NP
BH-312	Scoria	0.01	-0.01	0.01	<0.3	18
BH-305	LV	0.12	0.09	0.02	0.6	0.5
BH-303	LV	1.34	0.16	1.16	36.3	<0.3
BH-307	LV	0.11	0.02	0.03	1.1	3
BH-308	LV	4.28	1.02	1.02	31.9	<0.3
BH-604 @ 7.5 to 7.73m	LV	0.06	0.04	0.02	0.6	6.2
BH-606 @ 6.0 to 6.6m	LV	2.37	0.16	0.17	5.3	0.5
BH-608 @ 2.5 to 3.1m	LV	0.18	0.13	0.01	0.4	-0.3

The samples collected were not a random sample set, but instead were selected to characterize areas of concern. In addition, samples BH-604, BH-606, and BH-608 are not in an area of disturbance in the current mine plan. (See Figure 2).

Figure 2: - Borrow Area Sample Locations, and Quarry Locations
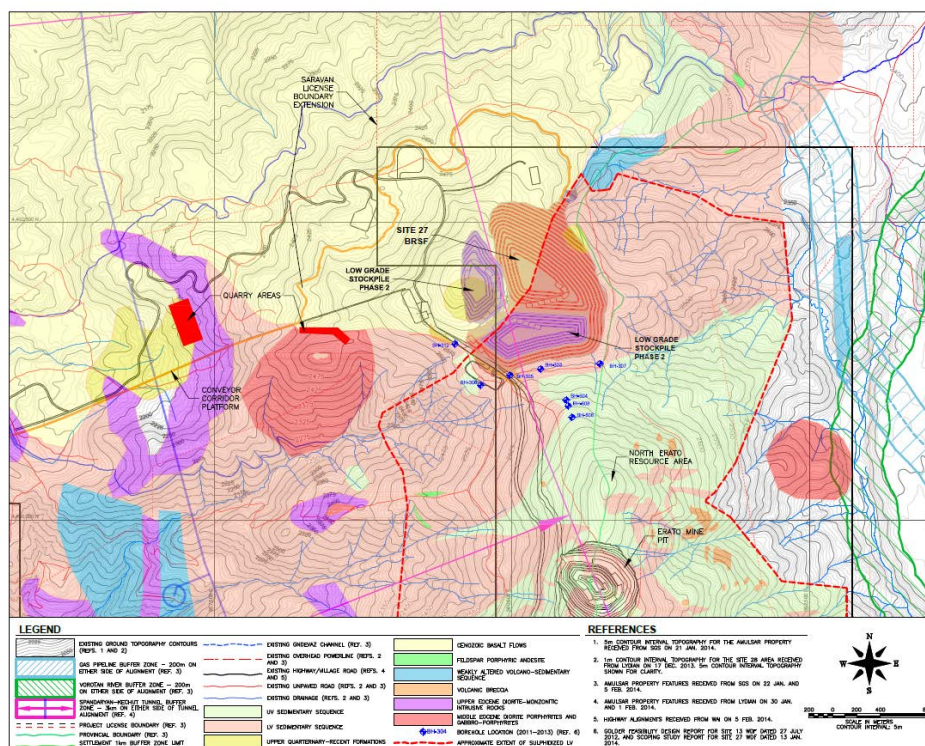
All LV material has not been subjected to sulphidization (a by-product of geothermal alteration). Figure 2 shows the approximate extent of sulphidized LV (SLV) based on drilling, geologic mapping, and testing performed to-date.

It is important to note that the SLV is near and around the mine pits and extends over North Erato mountain, Site 13, and Site 27. However, it does not extend west of Site 27. The contact between SLV and other formations can be identified in Figure 05 of the 2013 Crusher Investigation (Golder, 2013) in which the westernmost extent of LV can be identified between boreholes BH-301 (to the west, without LV) and BH-311 (to the east with LF). As a result, SLV is not expected to be present in the area of rock quarries located to the west along the overland conveyor line.

However, wherever encountered, LV should be tested for total and sulfide sulfur content prior to being used as construction materials due to an ARD and metal leaching potential, unless other mitigation measures are implemented. LV borrow material must be evaluated in the field for sulphides prior to its use as construction material. Section 5.6 discusses field-screening of mine or construction wastes for ARD potential. Scoria, however, appears suitable, although additional characterization work is recommended (see Section 5.6), as only one sample was included in the testing program.

Some in-pit waste materials are also suitable as construction material. The UV and Colluvium lithologic groups contain geochemically suitable characteristics (see Section 3.11).

3.6   WHOLE ROCK ANALYSIS

The analysis of solid-phase composition provides insight into the potential for metals leaching from rocks that form ARD or are exposed to acidic leachate. Solid-phase compositional testing was completed for the Tigranes/ Artavazdes , and Erato barren rock sample populations and for potential Amulsar borrow materials. The following tests were conducted:

- Bulk sample chemistry - Measurement of the total metals concentration of a sample via inductively coupled plasma (ICP) optical emission spectroscopy (ICP-OES) and mass spectrometry (ICP-MS). This allows the concentration of each tested metal in the sample to be compared against bulk concentrations in the crust, to help identify the presence of constituents of potential concern (COPC).

- Mineralogical characterization based on x-ray diffraction (XRD), and reflected and transmitted light thin-section petrography. These tests were conducted for waste samples only, and not for the borrow materials.

For each material group, results were compared to average crustal abundances (Wikipedia, 2015). Metals that exceed average crustal concentrations by greater than five times are highlighted in the following graphics. Five-times the crustal abundance is a useful rule-of-thumb in geochemistry for a cutoff between normal concentrations and elevated concentrations of a metal within a rock (Golder, 2013).

Tigranes/Artavazdes barren rock sample trace metal concentrations are compared against bulk crustal averages in Figure 3.

Figure 3: - Comparison of Average Tigranes/Artavazdes Barren Rock Trace Metal Abundances to Average Crustal Abundances
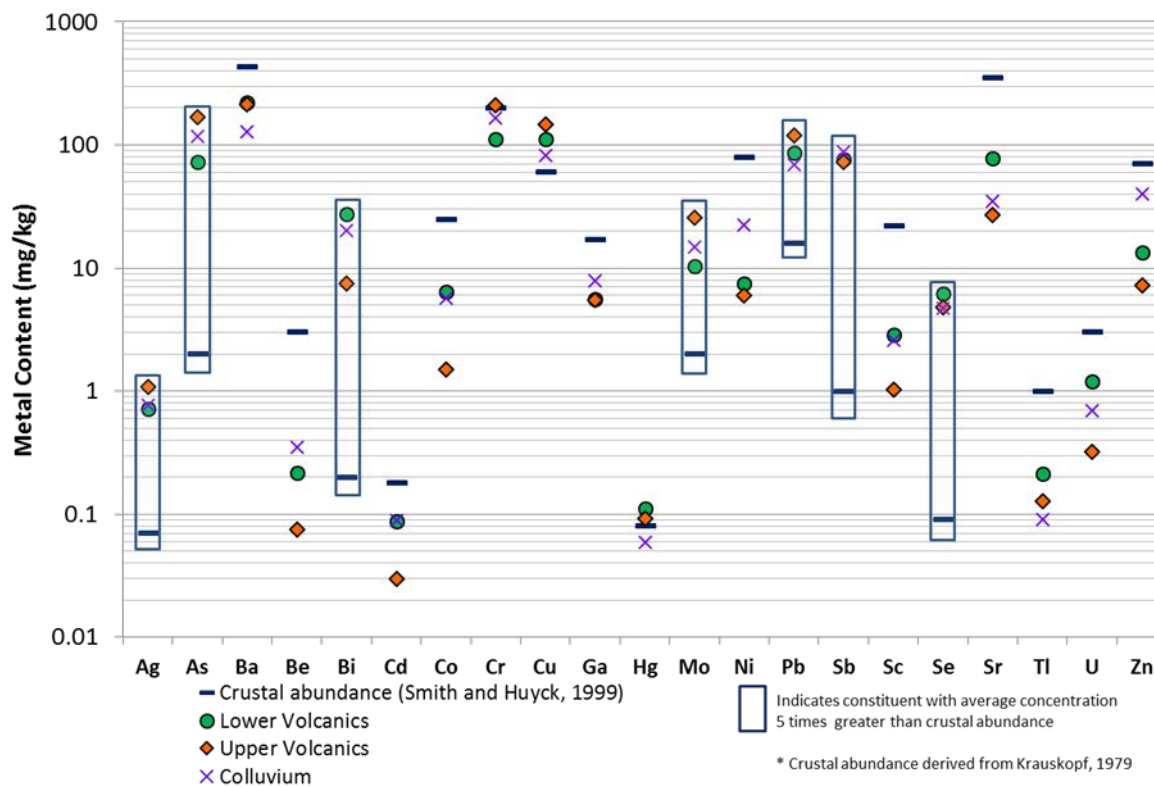
The following elements are present at levels at least five times higher than their crustal average in Tigranes/Artavazdes barren rock samples and therefore are defined as COPCs: antimony, arsenic, bismuth, lead, molybdenum, selenium, and silver. The following metals can be excluded from the COPC list at Amulsar because they are near or below the crustal average: barium, beryllium, cadmium, cobalt, chromium, copper, mercury, nickel, mercury, uranium, and zinc. Figure 4 provides the same information for barren rock samples representing the Erato pit area.

Figure 4: - Comparison of Average Erato Barren Rock Trace Metal Abundances to Average Crustal Abundances
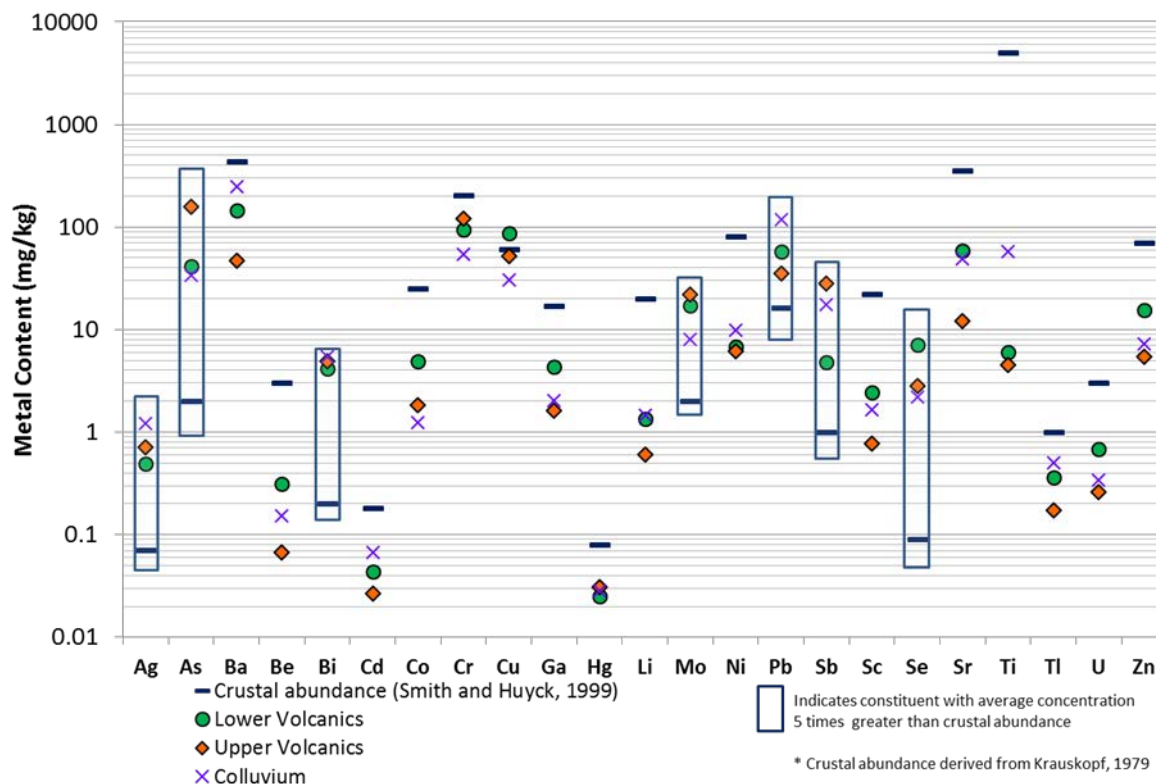
The list of COPCs in Erato barren rock samples is identical to the Tigranes/Artavazdes list. For most elements, the ranges of abundances are similar in Figure 3 and Figure 4, as are the relative abundances of elements.

3.7   MINERALOGY

Quantitative analysis of the mineral content of barren rock samples representing the Tigranes/ Artavazdes and Erato pits was carried out. The Tigranes/Artavazdes data set consists of 5 LV and 3 UV samples, and the Erato data set consists of 5 LV samples, 4 UV samples, and 3 colluvium samples. The mineralogical evaluation included x-ray diffraction (XRD) and transmitted/reflected light microscopy.

Samples from the Tigranes/Artavazdes and Erato sample sets have similar mineralogy, and mineral abundances in the lithologic categories are summarized in Table 9.

Table 9: Summary of Mineralogy Testing

Mineral	Lower Volcanics			Upper Volcanics		
	Detections	Minimum	Maximum	Detections	Minimum	Maximum
Quartz*	10	20	77	7	27	99
Plagioclase	2	8	66			
Alunite	4	6	53	3	9	70
Natroalunite	1	--	45			
Goethite	1	--	2	1	--	15
Hematite	4	Trace	9	5	1	10
Hematite/Geothite				1		3
Jarosite	2	Trace	10	2	Trace	10
Rutile				6	Trace	2
Pyrite	5	Trace	24	4	Trace	Trace
Sericite/Illite	4	Trace	30			
Adularia	2	2	3	3	1	5
Kaolinite						
Smectite	2	3	5			

Table 9 shows evidence that the original mafic volcanic and hypabbysal intrusive rocks have been altered. This can be deduced because of the high percentage of quartz in the samples, and by the total absence of pyroxenes and amphiboles, and by the near-total absence of feldspar. The alteration products of the presumed original ferromagnesian minerals and feldspars are accounted for by the minor iron oxides (hematite, goethite) and clay minerals (smectite, illite, kaolinite, sericite). Presumably the hydrated sulfate minerals (alunite, natroalunite, jarosite) represent alteration and weathering products of precursor sulfide minerals and silicates.

Based on the geology of the site, one would expect to see more quartz in the UV than the LV samples, and more clay in the LV than the UV, but these conclusions are not evident in the samples selected.   Mineralogical analysis was done on too few samples to allow

generalizations to be made on systematic differences in mineral abundance among Lower Volcanics, and Upper Volcanics. Additional mineralogical analysis and discussion can be found in (GRE, 2014).

3.8   METALS LEACHING POTENTIAL SUMMARY

Table 10Table 10 shows the SPLP leaching summary, which is an estimate of potential metal leaching behavior of Amulsar barren rock.

Table 10: SPLP Leaching Summary – Amulsar Barren Rock

Parameter	Units	Arpa Category II Standards	Tig/Art SPLP Results (avg*)	Erato SPLP Results (avg**)
Ammonia as N	mg/L	0.4	0.102	0.172
Arsenic	mg/L	0.02	0.011	0.0007
Barium	mg/L	0.028	0.027	0.073
Biochemical Oxygen Demand	mg/L		2	2
Cadmium	mg/L	0.001	0.002	0.0007
Chemical Oxygen Demand	mg/L		8.2	5.489
Chromium	mg/L	0.011	0.006	0.002
Copper	mg/L	0.021	0.19	1.837
Cyanide (total)	mg/L		0.01	0.01
Cyanide (free)	mg/L		0.005	0.01
Cyanide (WAD)	mg/L		0.01	0.01
Final Fluid pH	pH units		5.953	5.25
Hexavalent Chromium	mg/L		0.012	0.012
Iron	mg/L	0.072	3.423	3.002
Lead	mg/L	0.0101	0.008	0.0005
Manganese	mg/L	0.012	0.04	0.025
Mercury	mg/L		0.0002	0.000045

Parameter	Units	Arpa Category II Standards	Tig/Art SPLP Results (avg*)	Erato SPLP Results (avg**)
Nickel	mg/L	0.0103	0.019	0.012
Nitrate/Nitrite as N	mg/L		0.182	0.159
Orthophosphate as P	mg/L		0.01	0.01
Selenium	mg/L	0.02	0.04	0.0004
Sulfate as SO_4	mg/L		28.273	35.938
Total Suspended Solids	mg/L	6.8		5
Zinc	mg/L	0.1	0.071	0.047

* Based on 10 Samples

** Based on 14 Samples

Table 10 shows that some metals exceed Arpa Category II standards. However, in the list above, only iron exceeds World Bank standards (at 2 mg/L) and some exceedances (such as cadmium) are because the standard is at or below the detection limit in the analysis. Therefore, despite several elements exceed the standards, Table 10 shows that metals leaching is a minor problem for Amulsar barren rock.

Another useful test for determining potential metals leachate is the Net Acid Generating (NAG) effluent test, which is a test of the effluent from the full oxidation of the sample using hydrogen peroxide. It represents the worst-case conditions for metals leaching potential. Table 11 shows the NAG effluent results.

Table 11: NAG Effluent Summary - Tigranes/Artavazdes and Erato Barren Rock

Parameter	Units	Arpa Category II Standards	Tig/Art NAG Results (avg*)	Erato NAG Results (avg**)
Arsenic	mg/L	0.02	0.003	0.001
Barium	mg/L	0.028	0.045	0.109
Boron	mg/L		0.04	0.003

Parameter	Units	Arpa Category II Standards	Tig/Art NAG Results (avg*)	Erato NAG Results (avg**)
Cadmium	mg/L	0.001	0.003	0.0008
Chloride	mg/L	6.88	0.578	1.162
Chromium	mg/L	0.011	0.042	0.021
Copper	mg/L	0.021	0.272	0.453
Iron	mg/L	0.072	55.144	9.251
Lead	mg/L	0.0101	0.003	0.0009
Manganese	mg/L	0.012	0.129	0.058
NAG pH	pH units		3.728	4.342
Nickel	mg/L	0.0103	0.059	0.011
Selenium	mg/L	0.02	0.049	0.007
Sulfate as SO4	mg/L		379.003	83.273
Zinc	mg/L	0.1	0.087	0.015

* Based on 11 Samples

** Based on 17 Samples

The NAG pH effluent test is best used to disqualify metals from concern, but it is poorly-suited to characterize water quality resulting from ARD. The results are compared to a discharge standard to show that samples with a particular metal concentration in NAG pH effluent *below* the discharge standard have a near-zero probability of presenting a water quality concern. For example, the Project is not likely to experience elevated lead, arsenic, or zinc concentrations in ARD-impacted water.

There is potential for metals leaching for barium, copper, iron, manganese, nickel, selenium, and sulfate, but as mentioned above, the effluent from rocks oxidized with hydrogen peroxide does not represent natural conditions and cannot be used in ARD prediction.

3.9   KINETIC GEOCHEMICAL TESTING

Long-term humidity cell geochemical kinetic tests were performed on Amulsar barren rock (ASTM D5744-07e1, 2007). This test produces a conservative estimate of the acid generation potential (PAG) 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% humidity for a week, then flushed with 1L of distilled and deionized water;

- The cells require a ¼ inch crush size for the entire quantity tested; this is a far smaller size distribution than predicted in the Golder Blast Fragmentation Report (Golder, 2015) for Amulsar Run of Mine (ROM) waste.

Long-duration kinetic cell tests using expected ROM material are useful in determining the ARD behavior of rock types. It is generally accepted that a year of kinetic 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 (see Section 5.6).

3.9.1   ARD Geochemical Reaction Kinetics

The kinetics of an ARD reaction are critical in defining the environmental impacts. Two different chemical reactions typically form ARD from the oxidation of pyrite. Equation 1 involves the oxidation of pyrite in the presence of water:

$FeS_2 + 7/2O_2 + H2O = Fe^{2+} + 2SO_4^{2-} + 2H^+$ [1] (INAP, 2009)
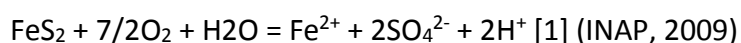
This reaction commonly occurs in LV material tested at the Amulsar site. However, in the kinetic cells, a second reaction dominated the ARD behavior of some cells later in the testing period. This equation involves the oxidation of pyrite by ferric iron (Fe^{3+}). This reaction is much faster, and has a higher stoichiometric ratio between pyrite and acidity (listed as H^+).

$FeS_2 + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+$ [2] (INAP, 2009)
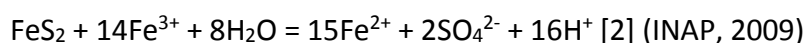
Equation 2 is catalyzed by the bacteria thiobacillus ferroxidants. In subsequent sections, the changeover from ARD dominated by Equation 1 to ARD dominated by Equation 2 is referred to as: "ferric iron oxidation" because ferric iron is acting as a reactant in the oxidation of pyrite.

3.9.2   Humidity Cell Results

Figure 5 shows the pH of the kinetic cell rinsate over time, Figure 6 shows sulfate production over time, and Figure 7 shows iron production over time.

Figure 5: pH vs. Time in Kinetic Cell Tests
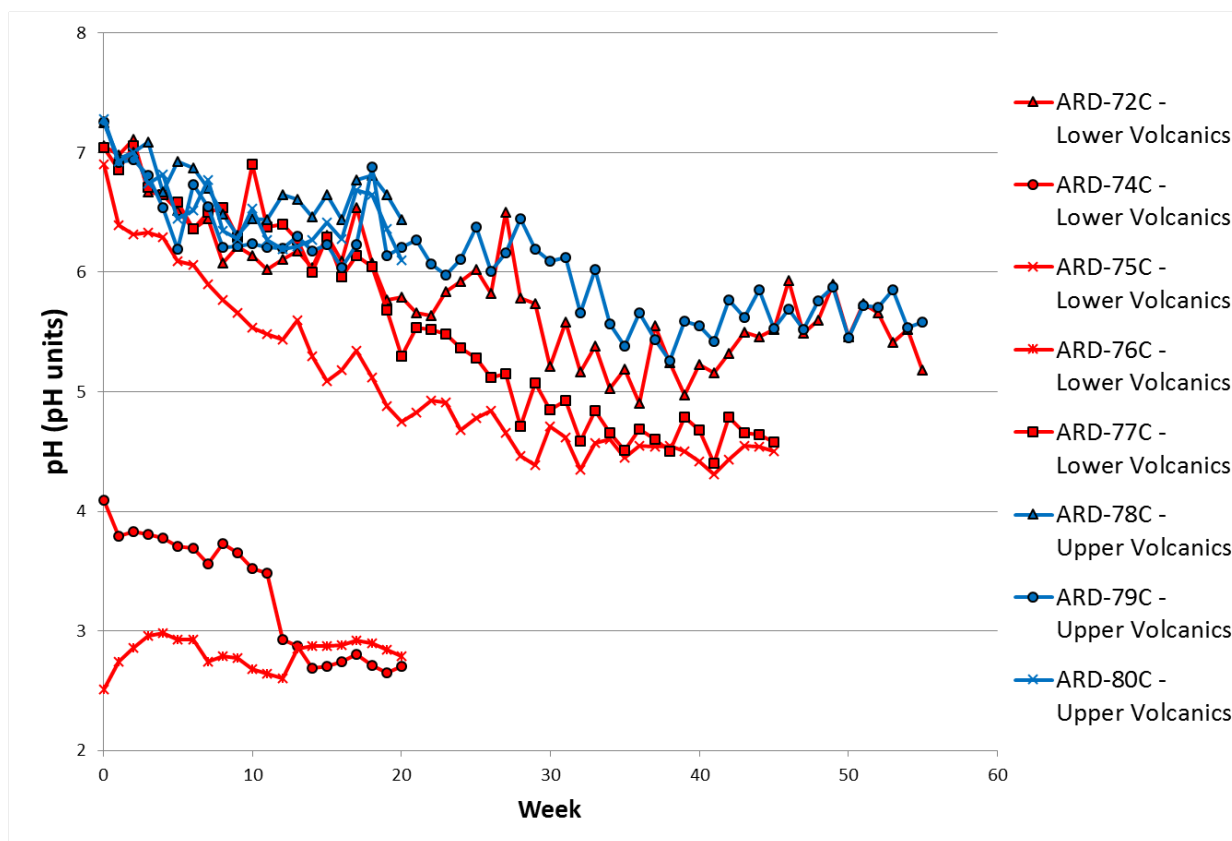
Figure 6: Sulfate vs. Time in Kinetic Cell Tests
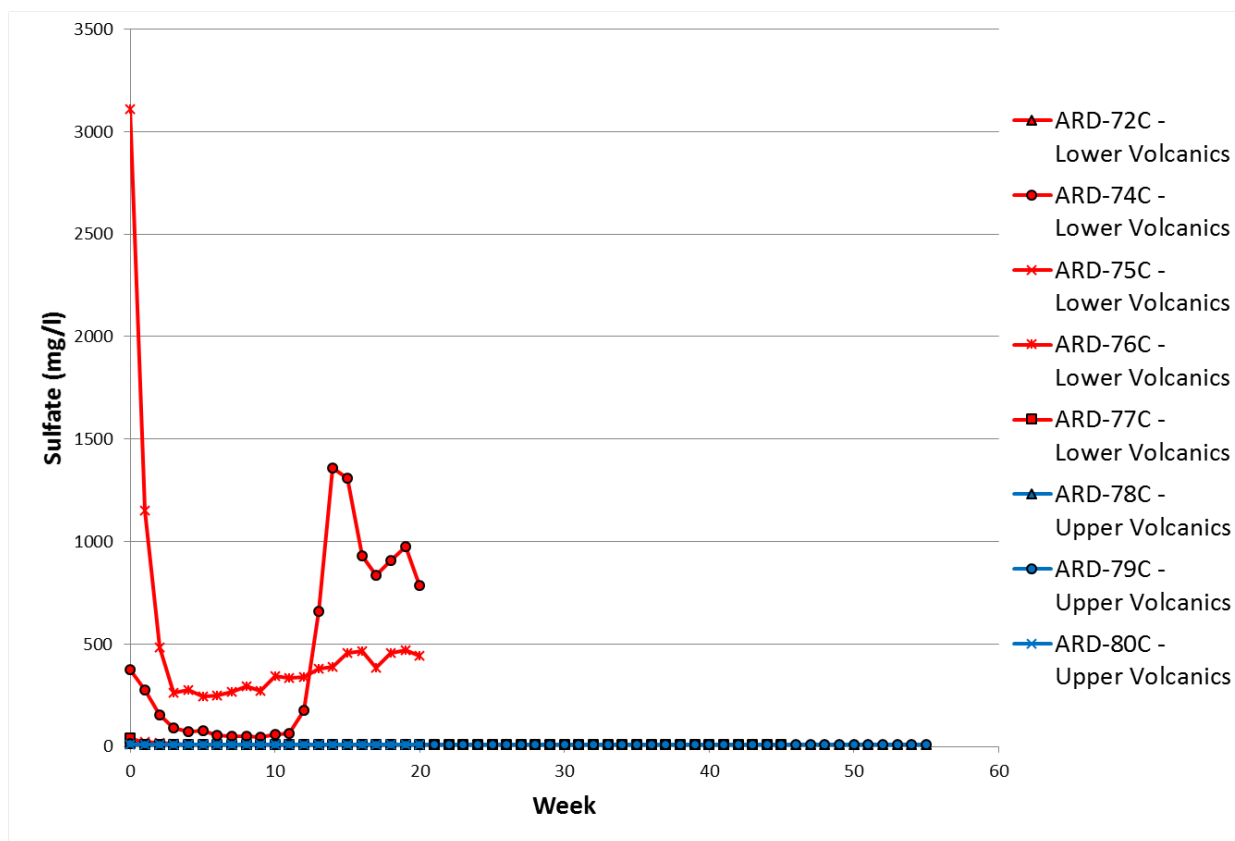
Figure 7: Iron vs. Time in Kinetic Cell Tests
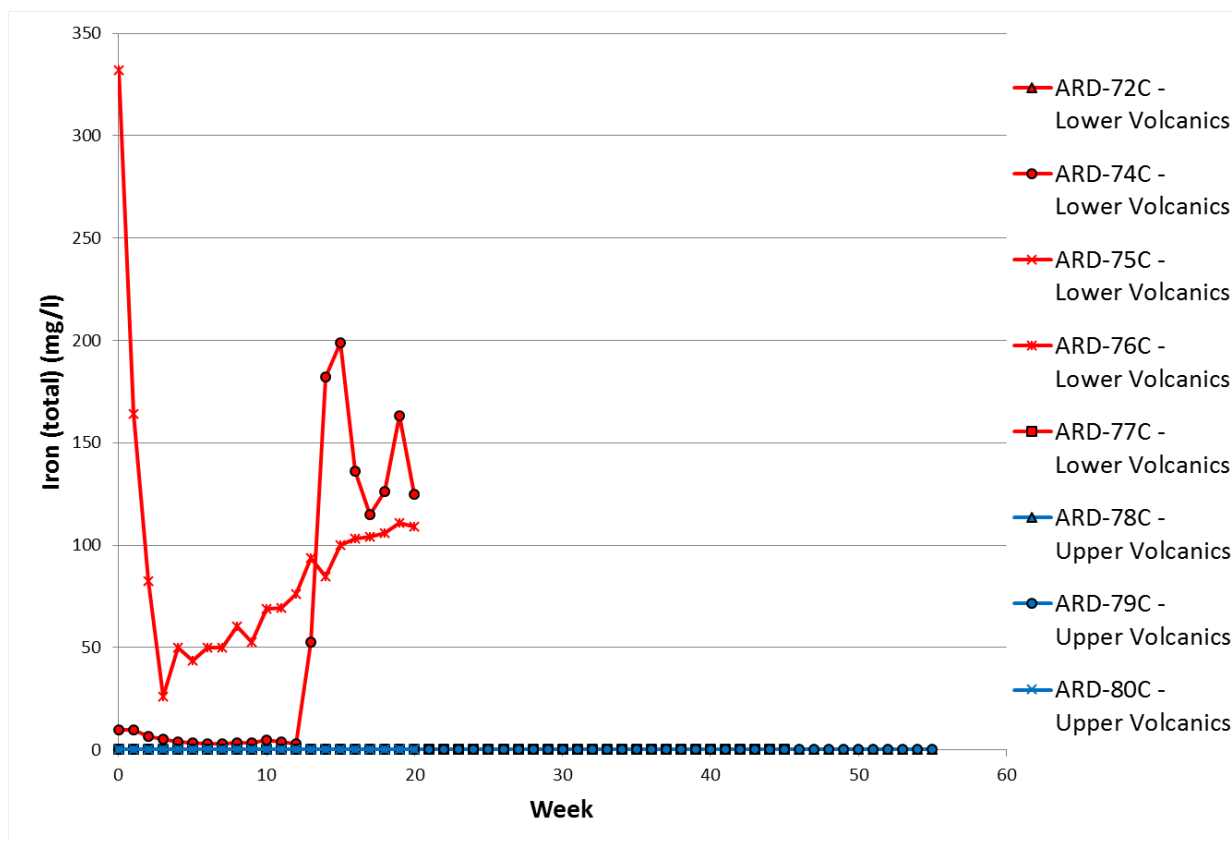
It is clear from Figure 5 through Figure 7 that the ARD potential of the UV does not translate into ARD generation despite the "uncertain" nature of the ABA testing ("uncertain" as defined by Table 4). It is also clear that three of the five LV samples generate no significant sulfate or iron in the humidity cell rinsate (the symbols are obscured behind the UV line in Figure 6 and Figure 7).

The kinetic testing results reveal three different categories of LV samples tested.

Samples that were oxidized prior to testing;

A sample that converted to ferric iron oxidation; and

Samples resistant to ferric iron oxidation.

These samples are discussed below.

3.9.3   Oxidized LV Samples

ARD-76C was 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.

3.9.4   Sample ARD-74C

ARD-74C is the most useful sample in the sample dataset. For the first 12 weeks of the test, the cell oxidizes under oxygenated conditions using Equation 1.

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).

3.9.5   LV Samples Resistant to Ferric Iron Oxidation

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 and iron concentrations despite long-duration testing.

3.10   OBSERVED GEOCHEMISTRY

Two mine waste piles already exist on site. They are in Site 27 and Site 13 These waste piles come from Soviet mineral exploration in the 1950s. The waste piles are made of LV rock and show similar geologic and geochemical characteristics to the mine waste from the Amulsar pits including sulphidization, argillization, and occasional silicification. These waste piles produce ARD; however, the severity of ARD they produce can be classified as moderate to mild. It has a water quality signature similar to LV samples that have not undergone ferric iron oxidation (see Section 2.6.1). Samples of the Site 13 and Site 27 mine waste were collected and analyzed. The results, when compared to the total population of LV, are shown in Table 12.

Table 12: Site 13 and 27 Mine Waste ABA Compared with Amulsar Pits

This updated table counts detection level results as zero for the LV calculations.

Barren Rock	Sample Count	Statistics	AP	NP
			T/KT CaCO$_3$	
LV	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

Barren Rock	Sample Count	Statistics	AP	NP
			T/KT CaCO₃	
		Range	4.37 to 23.43	-1.1 to 0

The average from the LV dataset in the pit is higher, and the median is lower than the Site 13 and Site 27 mine waste. The Site 27 and Site 13 waste is not significantly different from LV samples in the pits despite the fact that the waste piles have been oxidizing for sixty years.

It is apparent that this LV material is relevant to the geochemical study, and can be considered a long-term on-site kinetic cell test that at the very least, can influence the conceptual model and management plan.

Table 13 shows the leachate water quality from the Site 13 and Site 27 Waste Dumps.

Table 13: Site 13 and 27 Mine Waste Leachate, May 2014

Constituent	Unit	Wk 10	Wk 14	SPLP	Soviet Waste	Exploration	Site 13 Baseline
		ARD-74C			Site 13	Site 27	Surface
pH	pH units	3.52	2.69	4.64	4.78	3.28	6.38
Acidity	mg/L as CaCO₃	59	1210	N.S.	15.10	102.00	<D.L.
Sulfate	mg/L	59	1360	46	12.60	43.70	35.70

This leachate water quality has a higher pH, lower sulfate, and lower total acidity than what was observed in the later weeks of the ARD-74C humidity cell test (see Figure 5 through Figure 7). It is clear that after 60 years, the waste in the pile has not shifted over into ferric iron oxidation dominated ARD reaction kinetics.

As a result, the material shows that the LV rock has some natural suppression agent that prevents the formation of ferric iron oxidation. The suppression could be any or all of the below:

- Thiobacillius Ferroxoidants have a much slower sulfide reaction rate in cold climates (Sartz, 2011);

- The argillic texture (with approximately 10% clay content) inhibits the flow of oxygen within the pile, and therefore, oxidation; and/or

- The LV mineral has some residual natural resistance to ferric iron oxidation that is only overcome in the extraordinary conditions of a long-term humidity cell test.

This natural resistance is a critical conclusion of the characterization of Amulsar mine waste.

3.11 SUMMARY OF CHARACTERIZATION

The characterization of mine waste reveals the following:

- UV material is non-acid generating (NAG), despite the existence of trace AP;

- The UV material in the spent heap leach pad is also NAG. It is comprised of UV NAG material, and has been treated with lime until the pH~10.0, offering additional resistance to acidification.

- The LG material is identical to UV waste rock, and as a result, is also NAG;

- 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);

- LV material will likely be acid generating, but appears to be resistant to ferric iron oxidation under field conditions.

Therefore, in all subsequent ARD management and mitigation, the UV material is considered NAG and the LV material is considered potentially-acid generating (PAG).

However, the severity of ARD from the LV material can be mitigated. In fact, the severity of ARD produced by LV material after sixty years of exposure at Amulsar (see Section 3) produces ARD with moderately low pH (>3.0) with low total acidity and total sulfate.   With proper management (see Section 5.0), this natural resistance to severe ARD formation can be exploited to safely and economically manage ARD at Amulsar.

4   ARD   MANAGEMENT   AND   MITIGATION   PLAN: CONSTRUCTION AND OPERATIONS PHASE

The following section describes the ARD management and mitigation plan during the construction and operations phases. Management is defined as the capture, conveyance, treatment, and use of ARD-impacted water. Mitigation is defined as the operational and design elements incorporated into the Project, which expressly minimize both the volume of ARD generated and the severity (defined based on the total acidity, the pH, and the dissolved metals concentrations). 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.

4.1　ARD SOURCES

The main sources of ARD on the Amulsar site during construction and operations include the following:

- Pit water;

- Runoff from LV placed in the BRSF;

- Seepage from LV waste in the BRSF;

- Seepage from LV waste stored in the Tigranes, Artavazdes pits considering the partial backfill of these pits; and

- Runoff from exposed excavation surfaces of LV material.

Each of these sources is discussed in the ARD management plan.

4.2　ARD MANAGEMENT PLAN DURING CONSTRUCTION AND OPERATIONS

Figure 8 shows the sources of all Amulsar ARD (in the red/pink boxes) and the Project's ARD management plan. This flow chart is based on the updated water balance and Surface Water Management Plan, (Golder, 2015). Drawing 01 shows the project facilities in plan view.

Figure 8: ARD Management Plan
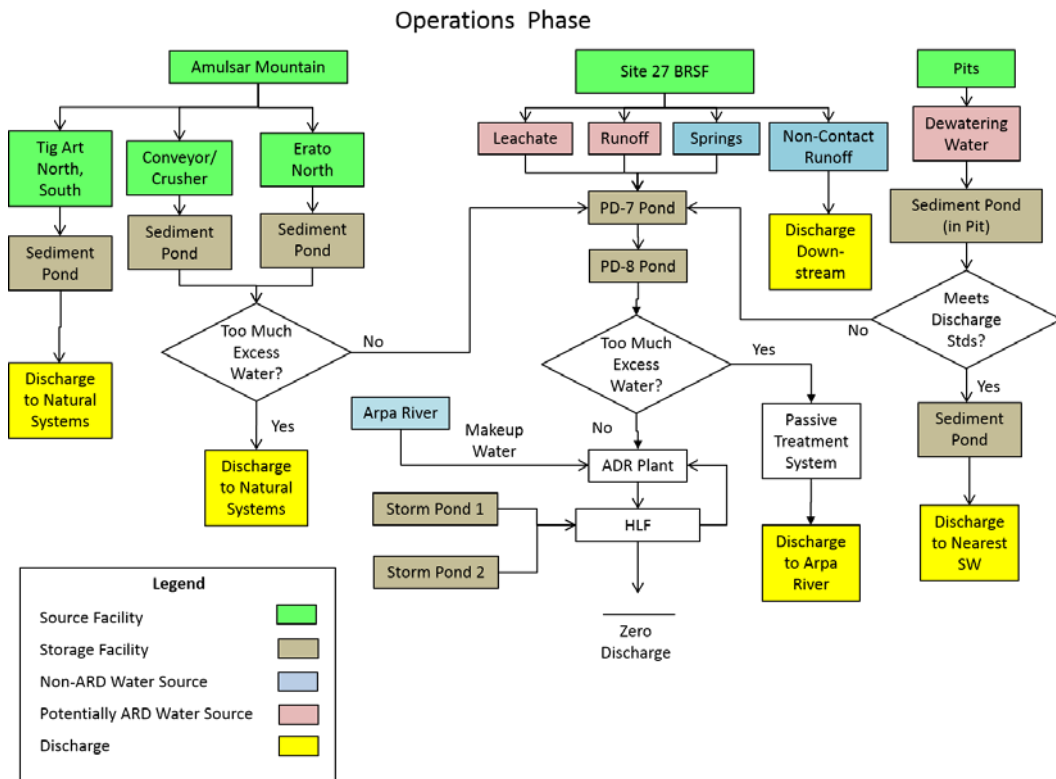
Construction Phase ARD Management Plan During the construction phase, PAG LV material will be identified in the field (see Section 5.6). If the material is to be excavated, it will be placed in the BRSF in a pre-prepared area designed to store construction-phase PAG waste (GRE, 2015). LV cut slopes and faces with PAG potential will be monitored for ARD and will be managed as required. Potential mitigation measures will include a colluvial topsoil cover and concurrent reclamation/revegetation, or selective application of shotcrete.

4.2.1   Pit ARD Management Plan

As seen on the right-hand side of Figure 8, during operations, pit dewatering water from the Tigranes, Artavazdes , and Erato pits is collected together and pumped to the contact water ponds (PD-8) near the Heap Leach Facility (HLF). Any seepage from backfill in the Tigranes and Artavazdes pit during operations will report to the southeast corner of the pit to sumps and piped to PD-8. In all pits, the widespread distribution of LV rocks on the pit walls may prevent separation of runoff from UV and LV rocks. However, if possible, runoff from UV-only slopes will become part of the storm water management system instead of the ARD management system. To be conservative, the analysis performed assumes that all pit dewatering water is ARD.

4.2.2   BRSF ARD Management Plan

The BRSF has four sources of water: mine waste leachate, runoff, seep/spring underflow, and non-contact runoff. Leachate is water passing vertically through mine waste and is expected to be ARD. Runoff that comes in contact with the acid-generating LV waste is also expected to be acidic. Seep and spring water discharging beneath the BRSF is circumneutral, but will mix with leachate beneath the facility. As a result, all flow from the underdrain system or the NAG buffer zone will be mild ARD. Non-contact runoff includes runoff from undisturbed ground within the BRSF during construction and runoff from reclaimed surfaces.

During the life of the BRSF, the goal of the ARD management plan is to minimize the quantity of ARD that must be collected in PD-7. This is done through the separation of contact and non-contact water as much as possible. To this effect, a small pond will be constructed at Phase II toe (PD-7T). This pond must capture mine contact water close to the point of generation and convey it to the PD-8 pond (via pipeline). Water that falls down gradient of these ponds is non-contact water and will flow to natural drainages. Drawings 4 through 11 of the BRSF design report show the BRSF surface water management plan in detail. (GRE, 2015)

Finally, the 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 waste rock.

The Amulsar Project Site-Wide Water Balance (Golder, 2015) shows that PD-7 is sufficiently large to retain peak precipitation and/or peak runoff events sufficiently long to permit conveyance by the pipeline. PD-7 has been designed as a retention structure, not a storage structure. In some extreme cases, the pits must be used as temporary storage of dewatering water and must be allowed to flood until the storm surge passes. This will permit the pipeline to carry more water from PD-7.

4.2.3   ARD Management Downstream from Site 27

From Site 27, ARD is conveyed via pipeline to the PD-8 pond. The pipeline will be a 450 mm (17.7-inch) diameter HDPE pipe. At PD-8, the water will be stored for use in the HLF process. The water is expected to be mildly acidic (see Section 3.10 and (GRE, 2014)) and may require pre-conditioning with sodium hydroxide prior to use as a process make-up water source. PD-8 will have sufficient capacity to manage a 100-year storm event or a 100-year wet year (the

wettest year in a century) without discharge to the environment for the beginning of mine life. However, starting in 2021, water treatment will be required in the event of a wet year. Section 4.6 describes the required Passive Treatment System (PTS).

4.3 BRSF ARD MITIGATION

Several mitigation measures will be used to minimize ARD within the BRSF.

4.3.1 Encapsulation

In order to mitigate the severity of ARD, the BRSF will include segregation and encapsulation of acid generating waste. This is state of the art practice and has been done on many mines throughout the world.

LV barren rock (PAG) will be encapsulated in cells within UV mine barren rock (NAG) in the BRSF to minimize contact PAG will have with infiltration, seepage, and oxygen. The encapsulation involves three elements:

- An underdrain layer to keep PAG above the level of groundwater seepage;
- A top layer of NAG to provide a buffer zone from the atmosphere; and
- Placement of an engineered evapotranspiration (ET) closure cover following completion of final slopes and surfaces to inhibit the introduction of water and oxygen into the core of the BRSF.

The two-to-five-meter NAG underdrain zone serves as the basal encapsulation layer. The thickness of this layer will be 2 meters in the upper-reaches of the BRSF where little surface or groundwater is present, and will thicken to 5 meters further into the BRSF.

Throughout mine life, the PAG cells will be sequentially covered with NAG. This NAG will serve as an isolation buffer between the encapsulated waste and all final side slopes, benches and top surfaces of the BRSF. 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. Drawings 5 through 9 of the BRSF Design Report (GRE, 2015) illustrate the concept of PAG encapsulation described herein. Figure 9 shows a schematic drawing of the PAG material encapsulation on a cross-section that roughly follows the BRSF drainage.

Figure 9: BRSF Encapsulation Concept with Low Grade Stockpile
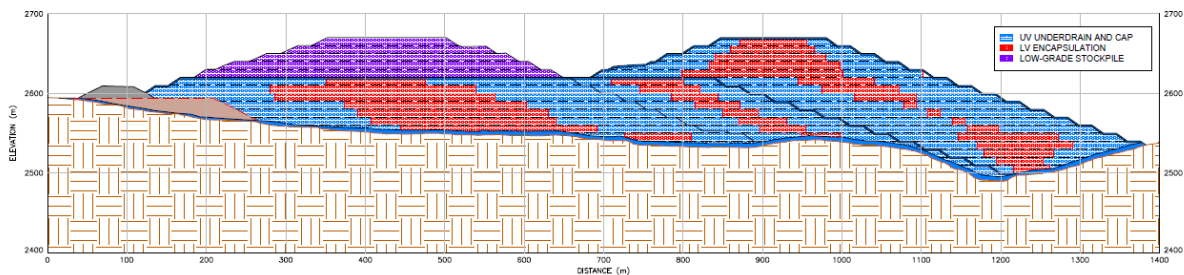
This encapsulation design will increase the mine cost, but it also isolates mine waste from seep and spring discharge, and in conjunction with an ET cover (see Section 3.3.2), isolates the PAG material from precipitation, snowmelt, and oxygen. This is a pro-active investment in final closure of the BRSF.

Seepage modeling (GRE, 2014)has shown the encapsulation to be an effective ARD mitigation measure. Figure 10 is an example part of the model solution, the figure is a close-up near the center of Phase 3 showing the distribution of moisture content and flow vectors at Year 8. The flow vectors show the direction of flow, and their size is proportional to velocity. Within the waste rock body, flow directions are generally downward and flow velocities are modest (in fact, the vectors are not fully visible at the scale of the figure). In the basal NAG layer, which collects the seepage and provides a pathway for its drainage to the pond at the toe, the arrows point to the right and show higher velocities. The results show that the encapsulation is effective – that water flows around and under the PAG material. Predicted flow within the PAG will be very low, and the capillary action of the clay in the PAG contains the ARD. The result is a very low quantity of ARD seepage.

Figure 10: Close-up, Moisture Content Distribution, Year 8
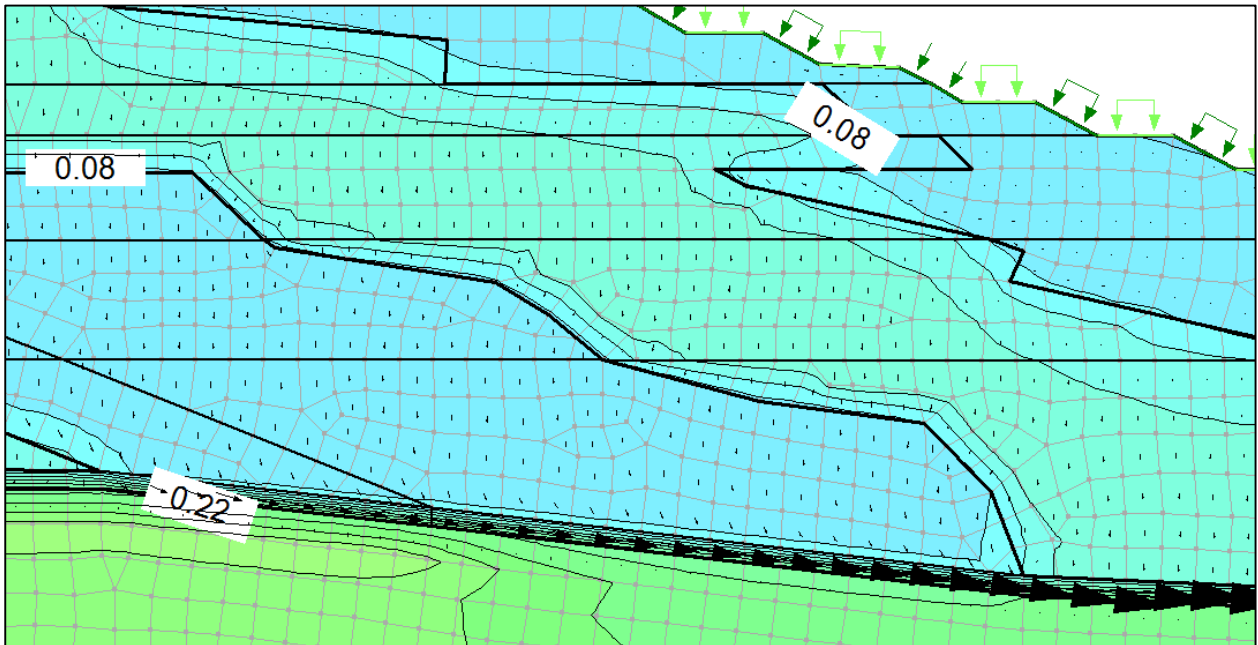
Figure 11 shows the contribution LV seepage makes to the total drainage flow beneath the BRSF.

Figure 11: BRSF Leachate During Time
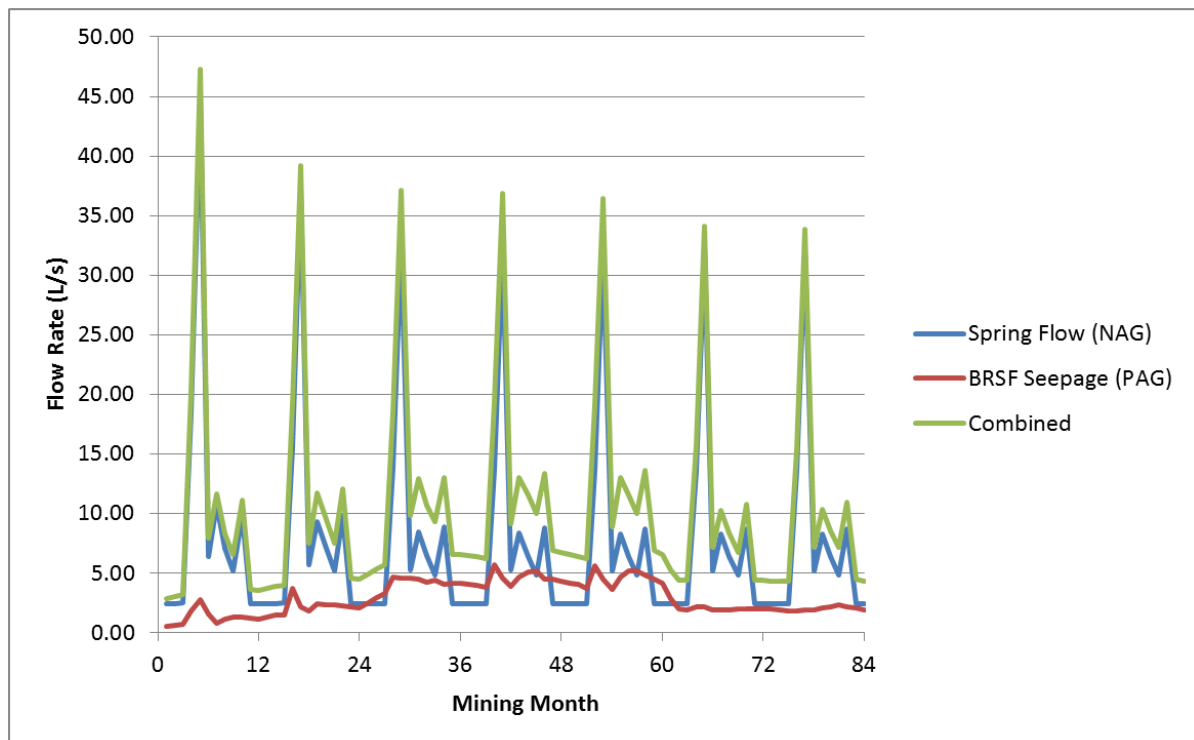
The PAG seepage averages 33% percent of the total flow in the BRSF underdrain.

4.3.2   Evapotranspiration Cover

Once final surfaces of the BRSF are in place, it will be concurrently capped with an Evapotranspiration (ET) cover; an ET cover is an engineered mine waste cover designed to do the following:

*   Minimize infiltrating in to mine waste through the store-and-release of soil moisture through;

*   Trapping moisture in soil storage (underlain with a capillary break of coarse NAG material);

*   Permitting the evaporation of contained moisture from the soil surface; and

*   Facilitating the formation of a vegetative cover to transpire water from the root zone and to prevent erosion.

It is important to note that the ET cover is not designed to augment runoff. Fine-grained clay-like soils are preferred in an ET cover, but the goal is not to create an impermeable cap, but instead to create a functioning soil cover that utilizes soil physics and vegetation to prevent vertical migration of precipitation and snowmelt. The ET cover on mine waste at Amulsar includes a 1.0-meter thick clay layer overlain by 0.2 meters of topsoil. This cover rests on a subgrade of NAG material that acts as a capillary break. The thickness of the cover is sufficient to store spring runoff in soil storage for evapotranspiration in the summer. The cover effectively reduced vertical migration of leachate to less than 1 mm per year. The ET cover is responsible for the decrease in BRSF PAG seepage after mine life (see Figure 11 after 60 months).

4.3.3   Oxygen Limitation

In addition, the ET cover limits oxygen penetration into the waste. GRE utilized Vadose/W, an integrated gas and fluid unsaturated flow model to predict oxygen diffusion into the waste based on pressure gradients, temperature gradients, and the degree of soil saturation. Oxygen consumption rates were taken from the geochemical modeling and represent the oxygen consumed by ARD reactions in the LV material (see Section 2.6). From this analysis, GRE derived an oxygen half-life of 700 days. The results of the oxygen consumption and oxygen diffusion modeling showed that oxygen penetration is limited to the uppermost 0.5 meters of the mine waste. Figure 12 shows the oxygen diffusion at its maximum extent in late summer, when moisture contents in the cover are at the lowest levels they reach prior to winter ground frost.

Figure 12: Moisture Content Distribution, Year 8
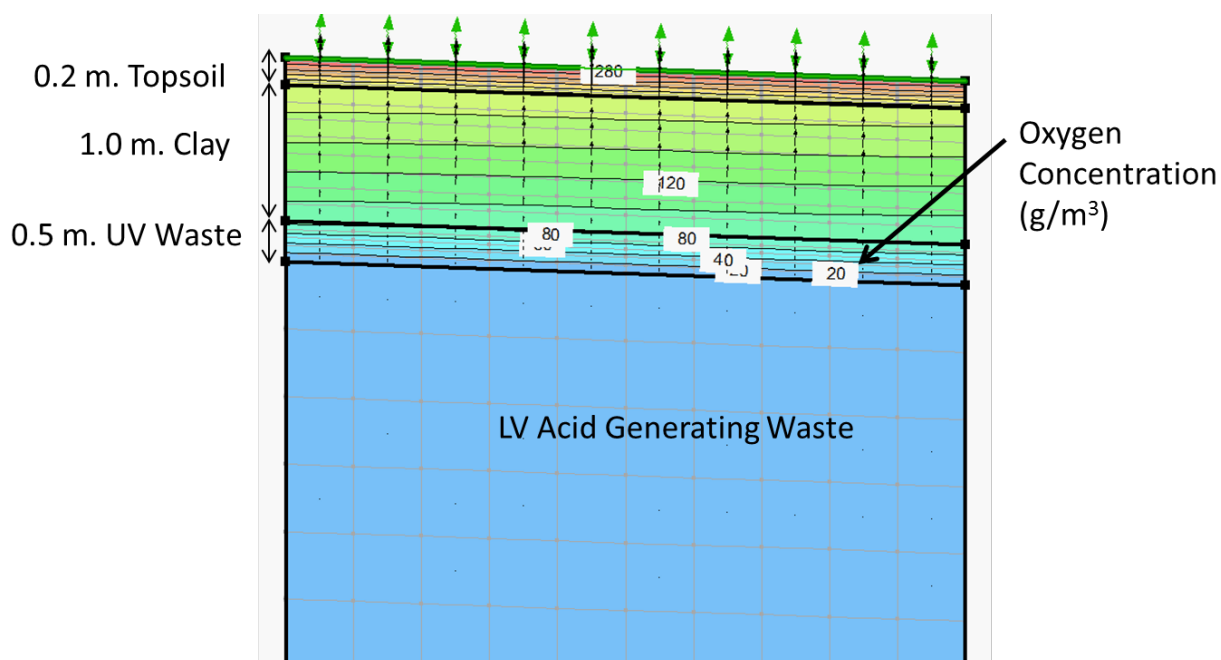
It is clear that the ET cover is responsible for the low oxygen penetration depth into the LV, and thus is the single largest factor in preventing severe ARD from the BRSF. Because the total depth of penetration was approximately 1.5 meters, this was the assumed penetration depth for oxygen in the geochemical modelling.

4.4   PIT DEWATERING ARD MITIGATION

The pit is a fast-moving excavation; each individual bench is not expected to be exposed for more than a single wet season. As a result, ARD mitigation is limited to keeping the pit as dewatered as possible during operations to limit the exposure time of ARD to water prior to waste encapsulation in the BRSF. Even under ideal conditions, the LV waste required 10-12 weeks to "turn ferric" therefore the natural pace of excavation should prevent ferric oxidation. As a result, the natural mining practice of carrying waste to the BRSF and exposing new benches mitigates ARD formation in the pit.

In addition, the mine will incidentally excavate snow from the pits during winter operations. The water balance (Golder, 2015) requires that additional snow be removed as an ARD mitigation measure. Removing snowpack removes water from the pit prior to the spring melt when this water can become ARD.

4.5   PIT BACKFILL ARD MITIGATION

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.

4.6   PASSIVE TREATMENT OF MINE CONTACT WATER

The Amulsar project will construct a Passive Treatment System (PTS) between PD-8 and the HLF. Drawing D02 of the closure plan shows the location and configuration of the PTS.

Geochemical modelling has predicted that the mine contact water quality that can be treated with passive treatment methods. Table 14 shows the anticipated average water quality post-closure.

Table 14: PTS Influent Water Quality

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	3.59E-04
Calcium	mg/l	100	12.5

Quality indicators	Unit	Arpa MAC Standards Quality Category II	Detention Pond
Chloride ion	mg/l	6.88	0.215
Chromium, total	mg/l	0.011	6.60E-10
Cobalt, total	mg/l	0.00036	0.104
Copper, total	mg/l	0.021	9.68E-15
Iron, total	mg/l	0.072	5.65E-07
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	4.01E-13
Phosphate ion	mg/l	0.1	8.07E-12
Potassium	mg/l	3.12	6.39
Selenium, total	mg/l	0.02	0.00874
Silicate ion	mg Si/l	25	4.25E-07
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

As a result, the PTS will be constructed in 2019 to meet anticipated treatment requirements in 2021. The PTS will have the following design components (Sovereign, 2014):

- A pipeline (with flow control devices) to the PD-8 pond to provide the PTS with a steady flow rate for treatment;

- Creation of a nitrogen-reducing bioreactor to treat residual nitrates from explosives;

- The construction of anoxic limestone beds to raise the pH of the water;

- Creation of a sulfate-reducing bioreactor to reduce sulfate concentrations;

- Water polishing and oxygenating steps to treat metals and manganese; and

- Discharge structures towards natural drainages (in this case, the Arpa River) that meet Armenian requirements.

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).

4.7   SUMMARY OF ARD MITIGATION AND MANAGEMENT MEASURES

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). 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). This permits two management options: consumption as HLF makeup water (the preferred alternative) and passive treatment with discharge.

5   ARD MANAGEMENT AND MITIGATION PLAN, CLOSURE PHASE

Figure 13 shows the ARD management plan during the closure phase.

Figure 13: Closure-Phase ARD Management Plan
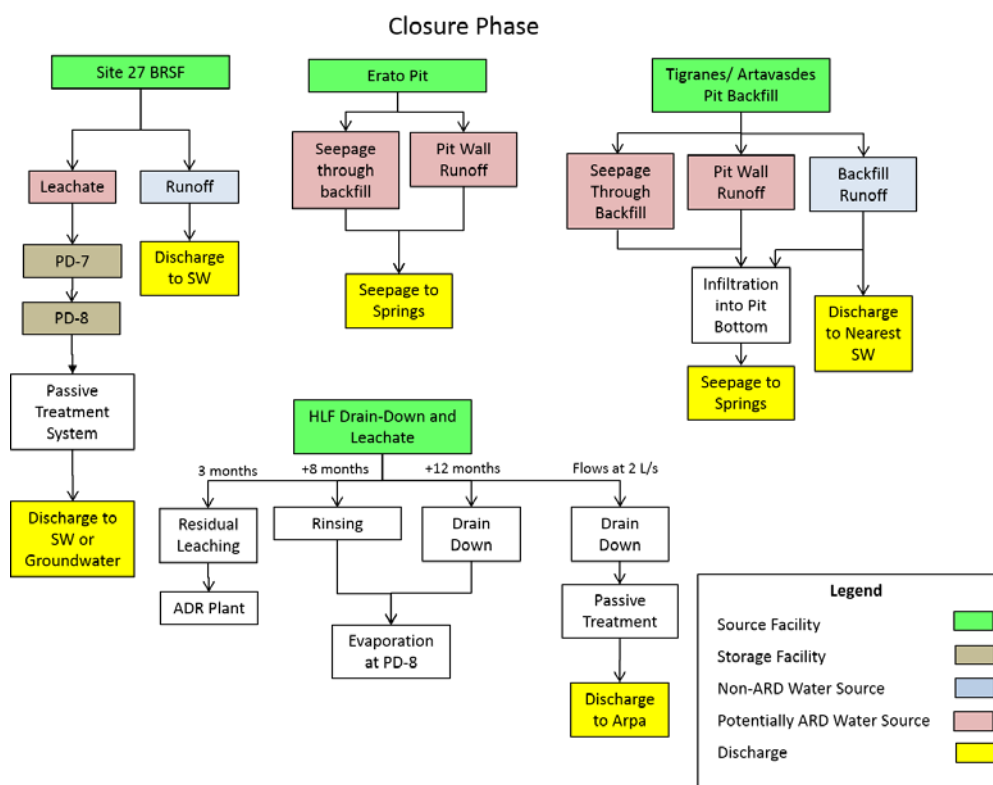
During closure, there will be four discharges of Mine Influence Water (MIW) to the environment. These discharges will be as follows:

- Runoff from reclaimed surfaces;

- Seepage from the BRSF;

- Seepage from the HLF;

- Seepage from the Tigranes/Artavazdes pit; and

- Seepage from the Erato Pit.

5.1   RUNOFF FROM RECLAIMED SURFACES

Runoff from reclaimed surfaces is classified as non-contact water and is not a source of ARD. As such, it will be discharged to the environment without treatment or sediment control. The closure plan (Golder, 2015) describes the water management and erosion control practices that will be applied upon mine closure. For the HLF and the BRSF, sumps will be constructed and maintained that allow the easy separation of toe discharge and surface water. Toe drainage will be treated, and non-contact surface water runoff will be diverted and discharged to the stream course.

5.2   BRSF SEEPAGE

The BRSF seepage (also referred to as toe discharge) is a mixture of mine waste leachate and seep and spring discharge beneath the BRSF. Due to the rapid placement of additional water storage capacity within the waste during construction followed by rapid placement of the ET cover, the BRSF will have low leachate production (see Figure 11).

The majority of the toe discharge comes from seeps beneath the BRSF; and, due to the contribution of ephemeral springs, the seepage peaks in spring. Over time, a fixed pattern will be established. This seepage will be acidic by the mine waste seepage component and must be treated: geochemical modeling has confirmed that the toe discharge has a water quality that can be treated with passive treatment methods. Table 15 shows the anticipated average water quality post-closure.

Table 15: Average BRSF Toe Discharge Water Quality Upon Closure (at PD-7)

Quality Indicators	Unit	Arpa MAC Standards Quality Category II	BRSF Toe Discharge
pH			3.91
Acidity	mg CaCO$_3$/l		159.6
Aluminium	mg/l	0.144	27.6
Arsenic, total	mg/l	0.02	0.0176
Barium	mg/l	0.028	0.0217
Beryllium	mg/l	0.000038	0.00205
Boron	mg/l	0.45	0.00933
Cadmium, total	mg/l	0.001014	3.65E-04
Calcium	mg/l	100	12.7
Chloride ion	mg/l	6.88	0.216
Chromium, total	mg/l	0.011	7.06E-10
Cobalt, total	mg/l	0.00036	0.106
Copper, total	mg/l	0.021	9.70E-15
Iron, total	mg/l	0.072	5.88E-07

Quality Indicators	Unit	Arpa MAC Standards Quality Category II	BRSF Toe Discharge
Lead, total	mg/l	0.01014	0.0411
Lithium	mg/l	0.003	0.0102
Magnesium	mg/l	50	5.19
Manganese, total	mg/l	0.012	0.00164
Nickel, total	mg/l	0.01034	0.0629
Nitrate ion	mg N/l	2.5	2.36
Nitrite ion	mg N/l	0.06	4.03E-13
Phosphate ion	mg/l	0.1	8.04E-12
Potassium	mg/l	3.12	6.49
Selenium, total	mg/l	0.02	0.00888
Silicate ion	mg Si/l	25	4.70E-07
Sulphate ion	mg/l	16.04	98.8
Total phosphorus	mg/l	0.2	0.880
Vanadium, total	mg/l	0.01	0.00241
Zinc, total	mg/l	0.1	0.388

Upon mine closure, the gravity pipeline from PD-7 to the PD-8 pond will be maintained. Water from the BRSF toe will be conveyed to a reduced-size pond for treatment in the PTS. Upon closure, the PTS will have the same design and layout as during operations. Perpetual PTS maintenance and management costs have been included in the closure model.

5.3   TIGRANES/ARTAVAZDES SEEPAGE

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). Figure 14 shows the total discharge from each pit to the aquifer.

Figure 14: Closure-Phase ARD Seepage from Tigranes/Artavazdes Pits
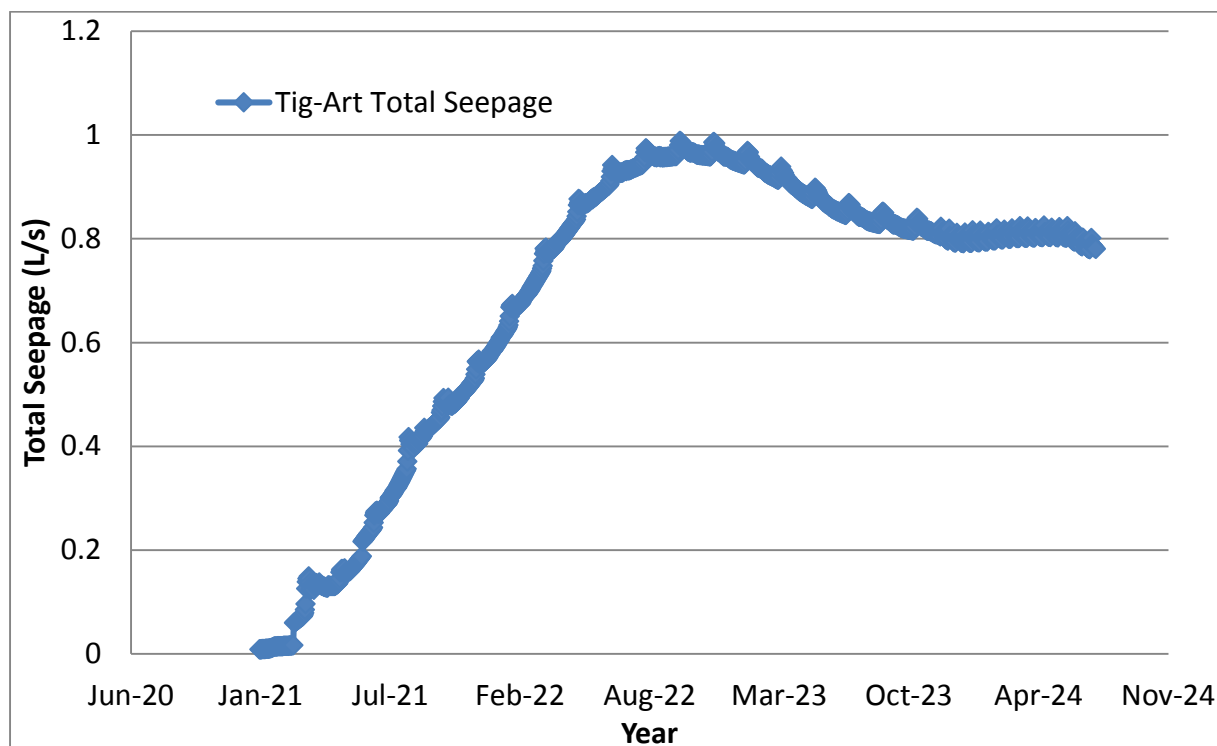
Between project commencement and January 2021, the pits are not backfilled and all water reports to the dewatering system. It is assumed that seepage is negligible during this period. The seepage peaks in August 2022. This is because infiltration into the mine waste is much higher during operations than when the backfill is closed, and because seepage requires time to reach the bottom of the pits. After August 2022, the seepage decreases due to the ET cover. The pits are expected to seep at 0.8 L/s in perpetuity. The water quality predicted in the seeps and springs will be reported by Golder in upcoming reports.

5.4 ERATO SEEPAGE

Post-closure seepage volumes exiting the Erato pit over time are a function of direct precipitation and snowmelt interacting with the blast impacted fracture zone, the pit wall surface and the backfill material. Water quality over time, therefore, is a function of mass loading from these materials to the infiltrating water. Backfill eliminates evapoconcentration as a significant water balance component.

Estimated average monthly seepage volumes from the Erato pit are depicted below and show a range from approximately 7,500 to 45,000 m^3/month with lowest seepage rates occurring during the winter months and highest seepage rates during spring runoff.

Figure 15: Closure-Phase ARD Seepage from Erato Pit
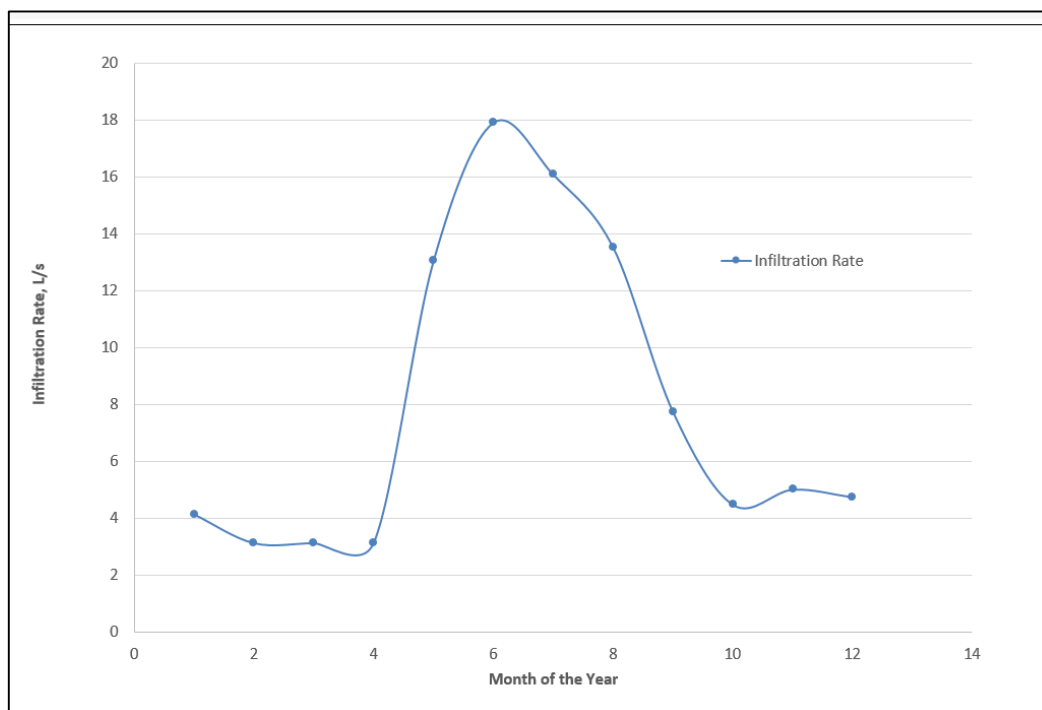
Predicted seepage water quality over a 164 year period of climate record for the average and maximum case indicate the following observations:

- The predicted pH is acidic, with mean values over time of 4.3 and 2.9 for the average and maximum case, respectively. End of simulation pH values reflect the mean values, ranging from 4.4 (average) to 2.9 (maximum).

- The predicted mean Total Dissolved Solids (TDS) is 18 and 440 mg/L for the average and maximum case, respectively. End TDS values range from 12 (average) to 275 (maximum) mg/L.

- The predominant contributor to solution TDS is sulfate. This reflects the results of material characterization testing.

- Given the low pH values, the waters have no alkalinity.

- Highest metal concentrations are observed for aluminum, with mean values of 1 and 28 mg/L for the average and maximum case. This is reasonable and expected for a low pH leachate.

- Other metals with mean concentrations of 0.4 mg/L or greater (for the maximum case) include two chalcophile elements (copper and zinc) and three siderophile elements (manganese, cobalt and nickel), all consistent with leaching of metals as a result of sulfide oxidation.

- Iron concentrations were kept low (<0.05 mg/L for both cases) by schwertmannite (iron-oxyhydroxysulphate) precipitation and barium by barite precipitation.

Average case sulfate concentrations range from 3 to 37 mg/L and mirror the range of sulfate concentrations measured at springs on site. The predicted average case pH range (3.7 to 4.7), however, reflects the more acidic range measured in springs sourced in the Lower Volcanics lithology.

Tables of predicted quality for the average case are as follows:

Table 16: Estimated Erato Pit Seepage Water Quality (Average Scenario)

Element (mg/L)	Estimated Water Quality			
	Minimum	Mean	Maximum	Final
pH	3.7	4.3	4.7	4.4
TDS	4	18	51	12
Alkalinity	0	0	0	0
Acidity	4	14	40	10
Calcium	0.2	0.9	1.8	1
Chloride	0.2	1.3	3	1
Fluoride	0.07	0.3	1.0	0.2
Magnesium	0.06	0.3	0.7	0.2
Nitrogen	0.007	0.04	0.1	0.03
Phosphorus	0.03	0.2	0.4	0.1
Potassium	0.1	0.5	1	0.4
Sodium	0.08	0.4	0.9	0.3
Sulfate	3	12	37	8

Table 17: Estimated Erato Seepage Metal Concentrations over Time (Average Scenario)

Element (mg/L)	Estimated Water Quality			
	Minimum	Mean	Maximum	Final
Aluminum	0.3	1	4	0.7
Antimony	0.0002	0.002	0.003	0.001

Element (mg/L)	Estimated Water Quality			
	Minimum	Mean	Maximum	Final
Arsenic	0.0007	0.004	0.01	0.004
Boron	0.002	0.01	0.03	0.01
Barium	0.003	0.02	0.04	0.01
Beryllium	0.0004	0.003	0.006	0.002
Cadmium	0.0001	0.0005	0.001	0.0003
Cobalt	0.003	0.02	0.05	0.01
Chromium	0.002	0.01	0.03	0.01
Copper	0.02	0.07	0.2	0.05
Iron	0.0001	0.003	0.3	0.0001
Lead	0.008	0.05	0.1	0.04
Lithium	0.004	0.02	0.06	0.02
Manganese	0.004	0.02	0.06	0.01
Molybdenum	0.002	0.01	0.03	0.01
Nickel	0.003	0.02	0.04	0.01
Selenium	0.0001	0.0007	0.002	0.0005
Strontium	0.002	0.01	0.03	0.01
Vanadium	0.001	0.008	0.02	0.006
Zinc	0.005	0.03	0.07	0.02

5.5 HLF SEEPAGE

HLF seepage will not be ARD. However, the drain-down water and seepage from the HLF is not anticipated to meet Armenian Discharge Guidelines without treatment. Therefore, the post-closure management of HLF has been included in this report.

As seen in Figure 13, HLF seepage goes through several stages after the facility is no longer loaded with ore:

- Residual leaching with cyanide;

- Rinsing;

- Drain-down; and

- Final closure.

Residual leaching has two stages: the first stage is with added makeup water and cyanide to extract more gold and silver from the HLF. This will continue until it is no longer economically

viable to do so. The next stage is to rinse with the cyanide present in the system without adding additional reagents or water. This stage also continues until it is no longer extracting enough precious metals to be profitable.

The next stage is rinsing with clean water. This continues until cyanide concentrations are below discharge standards. This will be done in zones on the HLF surface moving from top to bottom, and rinsed areas will be immediately covered by a post-closure ET cover comprising 1 meter of stockpiled topsoil. During this period, the volume of rinse water will be decreased by utilizing the PD-8 as an evaporation pond. During this stage, spray evaporation will be used to decrease the total volume of rinse water.

As soon as rinsing is complete, the HLF will be fully capped and revegetated (see Section 4.3.2). At this point, the water is expected to have the chemistry equal to the worst-case meteoric water mobility procedure (MWMP) sample taken on the spend heap material. The predicted water quality is shown in Table 18.

Table 18: HLF Drain-Down Water Quality After Detoxification

| Wet Chemistry | Units | KCA MWMP Tests on Spent Heap Material | | Arpa II Standards |
		61790	61781	
Alkalinity, Total	mg/L as $CaCO_3$	55	100	
Bicarbonate	mg/L as $CaCO_3$	36	55	10
Carbonate	mg/L as $CaCO_3$	15	33	
Hydroxide	mg/L as $CaCO_3$	<1.0	<1.0	
Aluminum	mg/L	4.6	3.8	0.144
Antimony	mg/L	0.0038	0.032	0.00028
Arsenic	mg/L	0.084	0.27	0.02
Barium	mg/L	<0.010	0.03	0.028
Beryllium	mg/L	<0.0010	<0.0010	0.000038
Bismuth	mg/L	<0.10	<0.10	
Boron	mg/L	<0.10	<0.10	0.45
Cadmium	mg/L	<0.0050	<0.0050	0.001014

Wet Chemistry	Units	KCA MWMP Tests on Spent Heap Material		Arpa II Standards
		61790	61781	
Calcium	mg/L	14	1.6	100
Chloride	mg/L	19	4	6.88
Chromium	mg/L	<0.0050	<0.0050	0.011
Cobalt	mg/L	<0.010	<0.010	0.00036
Copper	mg/L	<0.050	<0.050	0.021
Cyanide (WAD)	mg/L	<0.010	<0.010	
Cyanide (Total)	mg/L	0.045	0.065	
Fluoride	mg/L	1.3	0.5	
Gallium	mg/L	<0.10	<0.10	
Iron	mg/L	<0.050	3.9	0.072
Lead	mg/L	<0.0025	0.0072	0.01014
Lithium	mg/L	<0.10	<0.10	0.003
Magnesium	mg/L	<0.50	<0.50	50
Manganese	mg/L	<0.0050	0.0091	0.012
Mercury	mg/L	0.001	0	
Molybdenum	mg/L	0.018	0.054	0.00082
Nickel	mg/L	<0.010	<0.010	0.01034
Nitrate + Nitrate Nitrogen	mg/L	0.2	0.28	2.5
Total Kjeldahl Nitrogen	mg/L	5	2.3	
Total Nitrogen	calculated	5.2	2.6	
pH	pH units	9.18	9.51	<8.0
Phosphorus	mg/L	<0.50	<0.50	0.1
Potassium	mg/L	12	4.6	3.12
Scandium	mg/L	<0.10	<0.10	

Wet Chemistry	Units	KCA MWMP Tests on Spent Heap Material		Arpa II Standards
		61790	**61781**	
Selenium	mg/L	0.0054	<0.0050	0.02
Silver	mg/L	<0.0050	<0.0050	
Sodium	mg/L	58	52	
Strontium	mg/L	<0.10	<0.10	
Sulphate	mg/L	99	14	16.04
Thallium	mg/L	<0.010	<0.010	
Tin	mg/L	<0.10	<0.10	0.00008
Titanium	mg/L	0.13	0.13	
Total Dissolved Solids	mg/L	250	220	0
Vanadium	mg/L	<0.010	<0.010	0.01
Zinc	mg/L	<0.010	<0.010	0.1

	Parameters included in the HLF Design
	Exceedances of Arpa Standards at or Near Detection Limits

Table 18 also shows the standards required for Arpa discharge. Many of these standards are at or below the detection limit for metals analysis. Subsequent analysis will determine if these trace concentrations are of concern; however, the design has been based on the exceedances shown in red. Aluminium, iron, and sulfate are the primary constituents of concern. It is anticipated that designing the system to this level will be sufficient to manage other trace exceedances including other metals, bicarbonate hardness, and pH.

A Passive Treatment System (PTS) will be constructed down gradient of the HLF to treat post-closure seepage from the HLF. The PTS is designed to treat 2 L/s. This is the predicted post-rinsing steady-state flow rate from the capped HLF. Water flows in excess of 2 L/s that are expected to occur during the rinsing period will be managed by storage and evaporation in the PD-8 pond (see above) or recirculating it on the HLF to provide additional storage (if required). The PTS for the HLF will have all the same elements as the PTS for the BRSF (see Section 3.6), except that it will not have a limestone bed for the regulation of pH nor a nitrogen bioreactor

to treat nitrate. Taking advantage of existing infrastructure that also saves on cost, the PTS at the HLF will be constructed in the HLF storm ponds, barren leach solution pond, and pregnant leach solution pond. After passing through the HLF PTS, the water will meet Armenian discharge standards. It will be discharged to natural drainages, and eventually into the lower Arpa River downstream of the Kechut Reservoir.

5.6   ARD IDENTIFICATION AND MANAGEMENT

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.   Fortunately, this is relatively straightforward at Amulsar. During the site visit, Mr. Breckenridge from GRE was able to easily identify PAG and NAG rock by visual inspection. Figure 16 shows a representative UV (NAG) and LV (PAG) rock side-by-side.

Figure 16: Representative UV and LV Rock Samples

In the UV rock, the iron sulfide minerals have been oxidized to hematite (Fe_2O_3) and no visible sulfides are present. The rock is stained with iron oxide and frequently silicified.   The LV rock has a distinctive grey color and sulfides that can be seen with a hand-lens or the naked eye. It is frequently argillized and is generally softer than UV rock.

The LV and UV material is already defined in the block model, but further refinement of PAG and NAG waste can be done on a bench-by-bench basis in the pit.

Construction waste, road cuts and exposed excavation slopes will be similarly classified as NAG or PAG. GRE anticipates that identification of basalt, scoria, LV, and UV in the greater project area will be obvious and visual inspection will suffice. If uncertainty exists in how to classify barren rock, construction waste, or cut slopes, a number of different tests can be performed. They include:

- Laboratory analysis;

- NAG pH (Sobek, 1978);

- Paste pH (place the sample in distilled water, shake for two minutes, measure the pH);

- Inspection with a mineralogy microscope;

- Scanning with a hand-held XRF.

Laboratory analysis (ABA testing, see Section 3.2) is the best method for ascertaining the disposition of uncertain barren rock, construction waste, or cut slopes. However, this method is slow and costly. The NAG pH test is relatively simple and can be accurately done in the field using a rudimentary on-site laboratory. It also provides results in 24 hours. The NAG pH samples and ABA tests had perfect correlation in which samples they predicted as PAG. If an on-site laboratory is not available, paste pH can be useful in determining ARD potential. Due to the fact that the sulfides must be visible (~0.5%) to be significant, more rigorous visual inspection with a mineralogy microscope may be an effective classification method. Finally, a hand-held XRF may be useful in determining sulfide concentrations in material at Amulsar. However, this will be complicated by sulfate forms of sulfur. Additional evaluation is required to see if this method would be feasible.

Cut slopes with LV material should be covered with colluvium and reclaimed as soon as possible after road or pad construction. This is especially essential on the side slopes of Amulsar mountain which is within the sulphidized zone of LV rocks (Figure 2). Cut slopes that show signs of ARD generation should be treated with shotcrete. The presence of ferric iron sludge (schwertmannite) and low pH runoff is the best indicator of a slope that is producing ARD.   All LV excavation slopes or cuts will be monitored for ARD in the wet season.

On-going rock testing and water quality monitoring will be performed in construction and operations. The following will be performed:

- Additional static testing of borrow materials, construction waste, and construction cut slopes;

- On-site kinetic testing of Amulsar ROM barren rock (see Section 3.8);

- Additional testing of barren rock during operations;

- Expanded testing of nitrate concentrations from ROM rock after blasting studies (see Appendix A).

The testing program will be further elaborated in the Amulsar Environmental Monitoring Plan.

6 CONCLUSIONS

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. 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.

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.

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.

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 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.

7 WORKS CITED

ASTM D5744-07e1. (2007). Standard Test Method for Laboratory Weathering of Solid Materials Using a Humidity Cell. *American Society for Testing and Materials*.

Golder. (2013). *Geotechnical Report, Crusher Area.* Lakewood, Colorado: Golder Associates.

Golder. (2013). *Summary of Geochemical Charaterization and Water Quality Prediction Amulsar Gold Project.* Lakewood, Colorado: Golder Associates Inc.

Golder. (2014). *Spring Survey Interpretaive Report: Update.* London: Golder, U.K.

Golder. (2015). *Amulsar Project Conceptual Closure Plan.* Denver, Colorado: Golder Associates.

Golder. (2015). *Amulsar Project Site Wide Water Balance.* Lakewood, Colorado: Golder Associates Inc.

Golder. (2015). *Amulsar Project, Armenia ROM Fragmentation Study.* Mississagua, ON Canada: Golder Associates.

Golder. (2015). *Amulsar Site-Wide Water Balance and Water Mangment Plan.* Lakewood, Colorado, U.S.A.: Golder Associates.

GRE. (2014). *Amulsar Site Wide Water Balance.* Denver, Colorado: Global Resource Engineering.

GRE. (2014). *Summary Geochemical Characterization and Water Quality Prediction: Update.* Centennial, Colorado: Global Resource Engineering Ltd.

GRE. (2014). *Summary of Geochemical Charaterization and Water Quality Prediction -- Revised: Amulsar Gold Project.* Denver, Colorado: Global Resource Engineering.

GRE. (2015). *Amulsar Barren Rock Storage Facility Design Report.* Denver, Colorado: Global Resource Engineering.

INAP. (2009). Global Acid Rock Drainage Guide. *International Network on Acid Prevention*.

Lydian. (2014). *Assessment of HLF Drain Down Volumes and Water Quality.* Gary Patrick, Lydian International Metallurical Consultant.

Samuel . (2015). *NI-43 101 Technical Report On the Amulsar Project, Armenia.* Centennial, Colorado: Samuel Engineering .

Sartz, L. (2011). Weathering of Waste Rock in Different Cimatic Condtions -- A Kinetic Freeze/Thaw and Humidity Cell Experiment. *International Mine Water Association Congress.* Aachen, Germany: IMWA.

Sobek, A. W. (1978). Field and laboratory methods applicable to overburden and minesoils. *U.S. E.P.A. Report EPA-600/2-78-054.*

Sovereign. (2014). *Amulsar BRSF Passive Treatement System Design Basis.* Lakewood, Colorado: Sovereign Consulting Inc.

USACE. (2004). *Earth and Rock-Fill Dams: General Design and Construction Considerations Manual No. 1110-2-2300.* Honolulu, Hawaii: U.S. Army Corps of Engineers.

Wikipedia. (2015, October 20). *Abundance of elements in Earth's crust*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust

8   AUTHORIZATION

Approved By: _____   _____

                    Executive Vice President Sustainability   Date

SOVEREIGN CONSULTING INC.

TECHNICAL MEMORANDUM

Date: December 9, 2015

To: John Naisbitt, Amulsar Project Lead

From :   James Gusek, Guadalupe Fattore

CC: Larry Breckenridge (GRE), File

RE: AMULSAR PASSIVE TREATMENT SYSTEM (PTS) DESIGN BASIS

1.0   INTRODUCTION

Lydian International LTD. (Lydian) proposes to mine gold at the Amulsar Project (the Project) located near Jermuk, Armenia. Gold will be extracted from a lined Heap Leach Facility (HLF) that is irrigated with cyanide solution. The ore will be recovered from two open pits and some of the overburden rock from these pits, which has been characterized by others, will be deposited in an engineered storage facility hereafter referred to as the Barren Rock Storage Facility (BRSF). The site is predicted to produce Acidified Mine Influenced Water (MIW) from Acid Rock Drainage (ARD) reactions primarily from the pit and from the BRSF (GRE 2014a).

Starting in the 5th year of the mine life, the project will have excess MIW.   This water will be directed to a passive MIW treatment system prior to its discharge into the Apra River downstream from the Kechut Reservoir.

The Passive Treatment System (PTS) is designed to treat ~11 L/s. This flow rate is sufficient to manage excess mine water late in the mine life, and it is sufficient to treat the MIW coming from the toe of the BRSF upon closure. Because the influent water quality changes little from the 5th year of mining to closure, the system can easily function during operations and post-closure. Indeed, it is a significant advantage to start the system during operations because it provides more flexibility in startup and more water management options if initial designs underperform. In order to benefit from the storage present in the PD-8 pond, and in order to discharge to a river downgradient from the Lake Sevan catchment, the PTS is located near the HLF downgradient from the PD-8 MIW storage pond. GRE developed predictive models of the operations-phase MIW quality and post-closure BRSF toe discharge water quality (GRE, 2014a and 2014b), and these simulations were used as the design basis for the PTS.

The purpose of this technical memorandum is to provide a summary regarding preliminary plans to implement a PTS to remediate MIW associated with the project during operations and post-closure. The remediation strategy is to collect the MIW from PD-8 during operations, and from the toe of the BRSF upon closure. The MIW will be conveyed via gravity in a pipeline from the PD-8 pond. Any treatment that may

occur in the pond (i.e., assumed oxidation of ammonia to nitrate) renders the pond to be a part of the PTS within the context of this report. Although there will be some equilibration and potentially some biological preconditioning "treatment" that could be initiated in the pond, the main function of the PD-8 pond in regard to the PTS will be for equilibration of flow surges mainly from seasonal variations.

The design is based on Sovereign's current understanding of the site plans and the projected chemical composition of MIW during operations and post-closure. The final design of the PTS would be based on bench and pilot scale test verification which should commence well in advance of large scale operations to validate the key sizing values assumed at this conceptual stage of the treatment system design. Again, this conceptual design is based on professional judgment, Sovereign's experience with similar MIW, and published technical papers referenced herein.

The PTS will be constructed on available sloping ground between the PD-8 pond and the HLF ponds. It is adjacent to the highway to Jermuk. The PTS components will include:

- The PD-8 pond;
- Nitrate Reducing Biochemical Reactor (BCR);
- Aerobic Polishing Wetland (APW) No. 1;
- Sulfate Reducing BCR;
- Sulfide Scrubbing Unit;
- APW No. 2;
- Manganese Removal Beds (MRB); and
- A discharge pipe to the Apra River tributary located downgradient from the HLF ponds.

Preliminary design assumptions follow.

- All flows are gravity-driven.
- The PTS will treat 40 m^3 per hour (11.1 L/sec.
  - During operations the seepage will be a blend of MIW from all sources in the project (Golder 2015). This includes pit dewatering and BRSF seepage.
  - Post-closure the seepage will be a blend of MIW and natural ground water flow occurring in the BRSF footprint that mixes with MIW in the drains beneath the BRSF. Episodic seasonal flows above this design value will be moderated in the BRSF Toe Pond (PD-7) and in PD-8, both of which will act as a flow equalization basin.
- The design flow rate (11.1 L/sec) includes a 30% safety factor.
- Two sequential sets of BCRs will be required. The first set will address elevated nitrate levels derived from blasting agent residue in the barren mine rock. The second set will address expected sulfate levels in the MIW. Both sets will improve the pH to circum-neutral.
- To facilitate long-term maintenance, a typical BCR set is arranged with two identical BCRs plumbed in parallel. Thus, while one BCR is being refurbished (approximately every two decades), the other BCR would continue to function.
- The PTS will be built for low visual impact with the two sets of BCRs buried beneath a vegetated soil cover. This design feature will also protect the components during harsh winter temperatures and from contact with or damage from grazing animals.

The sulfide scrubber unit will be filled with an inexpensive sacrificial metal such as iron provided by:

- A natural mineral source such as limonite or goethite [$Fe(OH)_3$], hematite [Fe_2O_3], magnetite [Fe_3O_4], or
- Zero valent iron (ZVI) derived from a local source of scrap iron such as steel food cans that were procured from the local communities over the life of the mine.

The sulfide scrubber media mixture will also include a locally-available organic component (such as wood chips) to minimize plugging.

The two aerobic polishing wetlands (positioned after each BCR) will be populated with native plant species (including a local species of sphagnum peat moss) and configured to appear like a natural wetland ecosystem as much as practical.

All main conveyance pipes will be buried at least one meter below the prevailing ground surface or be sloped to drain for freeze protection. Long pipe runs will be fitted with camouflaged cleanouts every 50 to 60 meters to allow periodic cleaning or inspection, if the need arises.

Water will be discharged to the nearest feasible seasonal tributary of the Apra River downgradient of the HLF ponds. From these drainages, it will flow to the Arpa River downgradient from the Kechut Reservoir.

Natural springs have been observed within the footprint of the proposed BRSF (Golder 2014a). A portion of the flow discharging from these springs comes from ephemeral springs, and a portion comes from perennial springs. This portion of the ephemeral spring flow is expected to decrease in response to the overlying BRSF which is designed to minimize and as much as practical, eliminate recharge to the shallow groundwater aquifer(s) that feed the natural springs. However, some regional, perennial spring flow is still expected and this flow will mix with nominal infiltration through the barren mine rock in the BRSF.

The expected composition of the MIW was developed by GRE using the PHREEQC mixing model (GRE 2014a). This is discussed further in Section 4. Expected nitrate levels derived from blasting residue in the barren rock were estimated by Golder Associates Inc. (Golder, 2014b).

The general schematic view of the PTS process is provided in Figure 1. All flows to the PTS will be by gravity; the system will be designed to operate unattended.
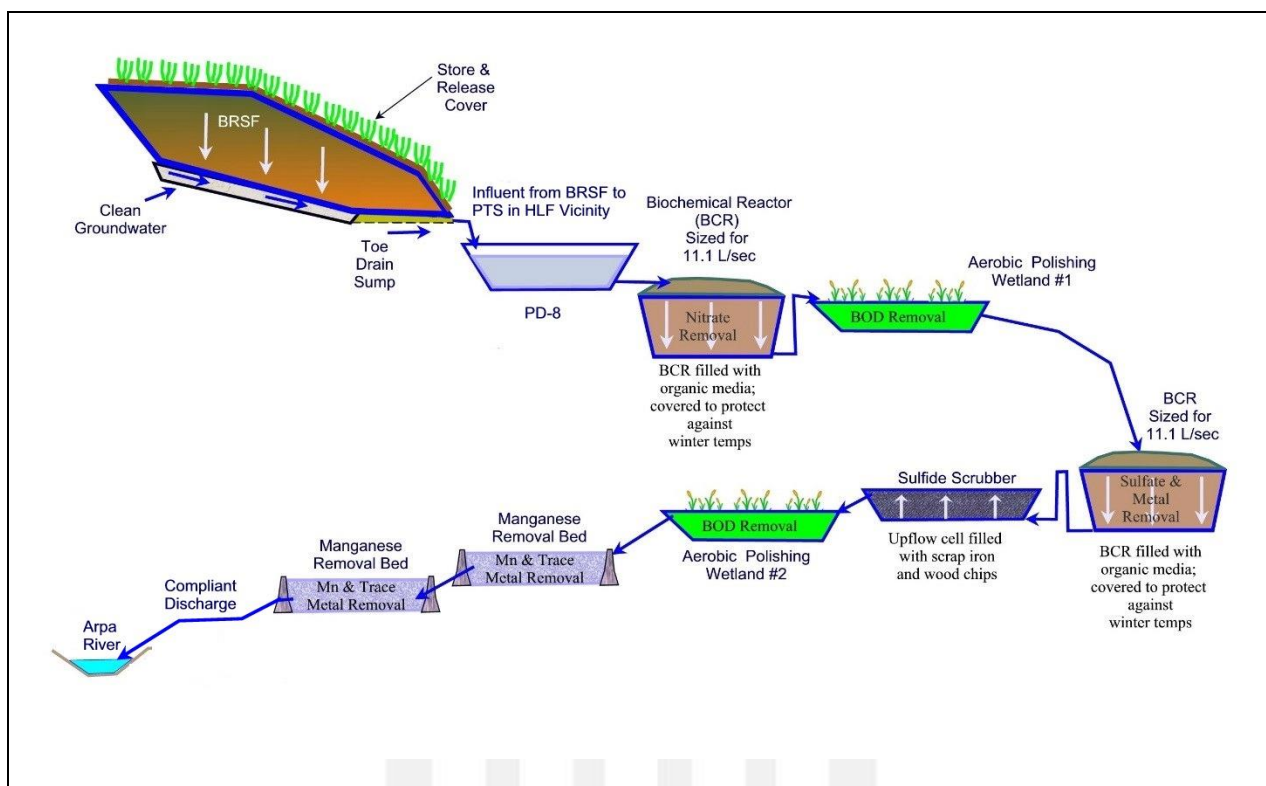
Figure 1 – Conceptual Passive Treatment System Schematic Process Flow Diagram

2.0   PASSIVE TREATMENT BACKGROUND

2.1   General Considerations

The technical literature is replete with references that describe passive treatment processes including Gusek, 2008; Gusek & Figueroa, 2009; and Gusek, 2009. Gusek (2008) proposed the following definition and discussion:

> ***Passive treatment*** is a process of sequentially removing contaminants and/or acidity in a natural-looking, man-made bio-system that capitalizes on ecological, and/or geochemical reactions coupled with physical sequestration. The process does not require power or chemicals after construction, and lasts for decades with minimal human help.

For further information, the publications cited above are recommended; some of these can be downloaded for free from the Internet.

Passive treatment systems are typically configured as a series of sequential process units because no single treatment cell type works in every situation or with every MIW geochemistry.   It is an ecological/geochemical process because most of the reactions (with the exception of limestone dissolution) that occur in passive treatment systems are biologically assisted. Lastly, it is a removal process because the system must involve the filtration or immobilization of the metal precipitates that are formed. Otherwise,

they would be flushed out of the system, and the degree of water quality improvement would be compromised.

Man-made passive treatment systems employ the same principles as do natural wetlands, but they are designed to optimize the competing processes occurring naturally in a wetland ecosystem. Aerobic and anaerobic zones "competing" in a natural wetland are shown on Figure 2.
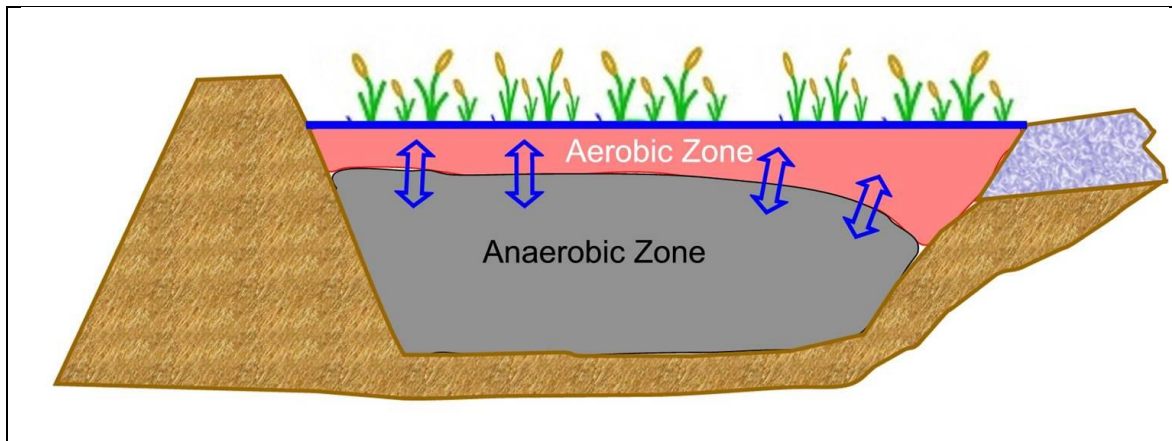
Figure 2 – Natural Wetland Oxidation-Reduction Zones

There are many natural analogues for passive treatment systems, including:

- Ferricrete deposits,
- Iron terraces,
- Bog iron ore (ochre) and metal deposits, and
- Manganocrete deposits.

There are basically three kinds of passive treatment technologies available for treating MIW:

- Abiotic, **limestone-based** methods for treating net-acidic MIW have been effective in adding alkalinity; a subset of this method uses a semi-biological zone to condition MIW for subsequent limestone dissolution.
- **Biochemical Reactors** (BCRs) are typically applicable to metal mine drainage with low to high acidity and a wide range of metals; this technology can function with or without plants to address nitrate and sulfate.
- **Aerobic Cells** containing cattails, other plants, and algae are typically applicable to MIW where iron and manganese and mild acidity are problematic and/or only trace concentrations of heavy metals occur. This method also can be used to polish biochemical oxygen demand (BOD) from BCR effluents and adsorb trace metals on to iron or manganese oxides.

Most passive treatment systems employ one or more of these cell types.

The technical community of regulators and engineers that specializes in passive water treatment should be familiar with the passive treatment "decision tree" that was published by the former US Bureau of Mines (USBM) about 20 years ago. See Figure 3 (Hedin et al., 1994).
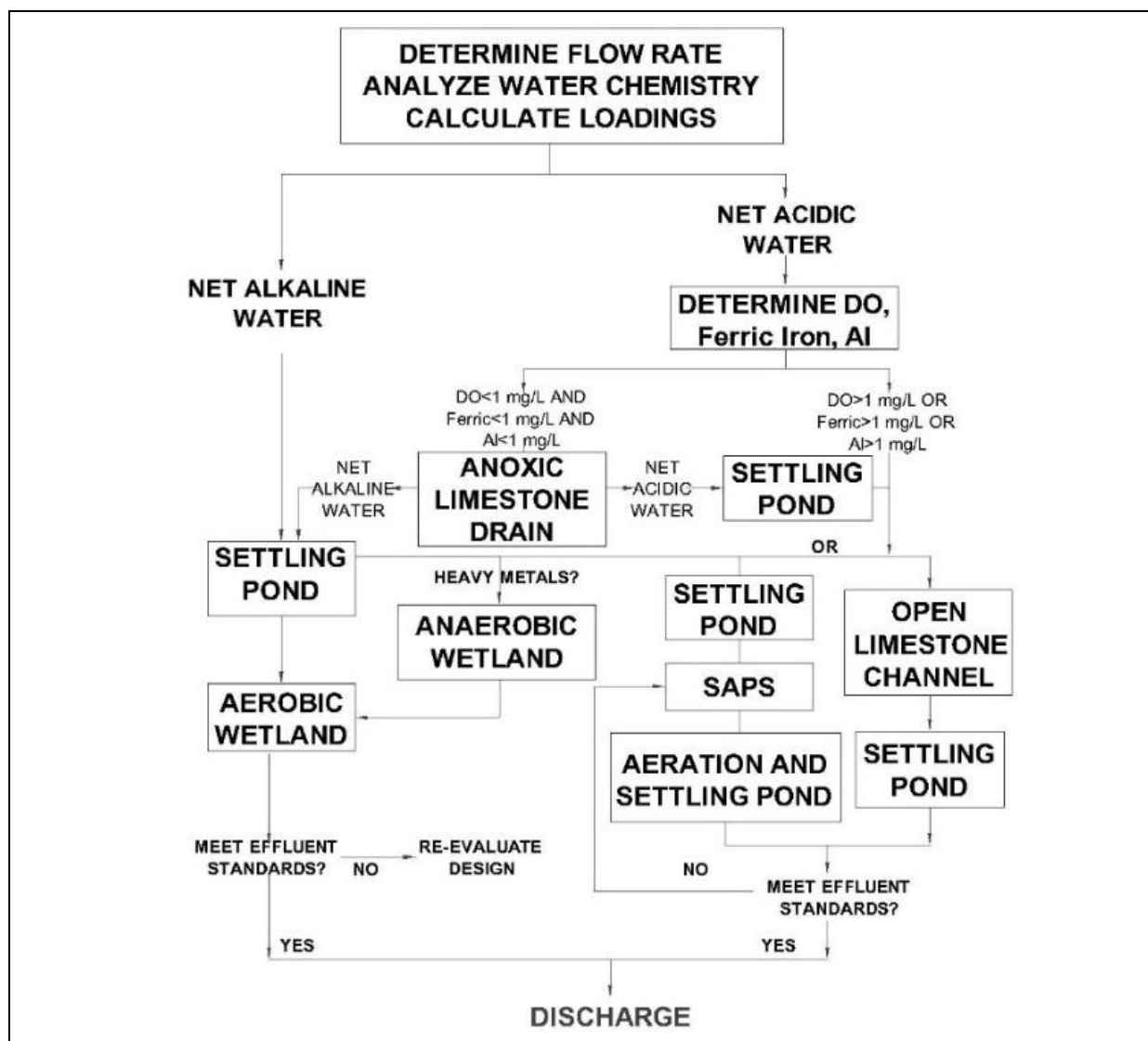
Figure 3 – 1990's Passive Treatment Decision Tree (Focus on coal MIW)

The USBM decision tree was originally intended to address MIW from coal mines. Since then, however, the breadth of passive treatment has expanded to embrace precious and base metal mines, uranium mines, and even gravel pits. Each MIW has its unique signature, either imposed by the natural geochemical conditions of the ore body and surrounding mine waste, or by resource recovery processes that may include heap leaching or traditional hydrometallurgical technologies. In the context of the elements of the periodic table, the decision tree certainly could be improved as it was originally developed to focus on coal geology derived MIW which typically contains acidity/alkalinity, iron, aluminum and manganese. For example, the expanded decision tree could consider residual ammonia or nitrates from blasting, cyanide from heap leach

pad rinsing, trace amounts of selenium, or other parameters that may require passive treatment at a given mine, coal or otherwise.

The 2014 updated version of the Passive Treatment Decision Tree is provided in Figure 4.
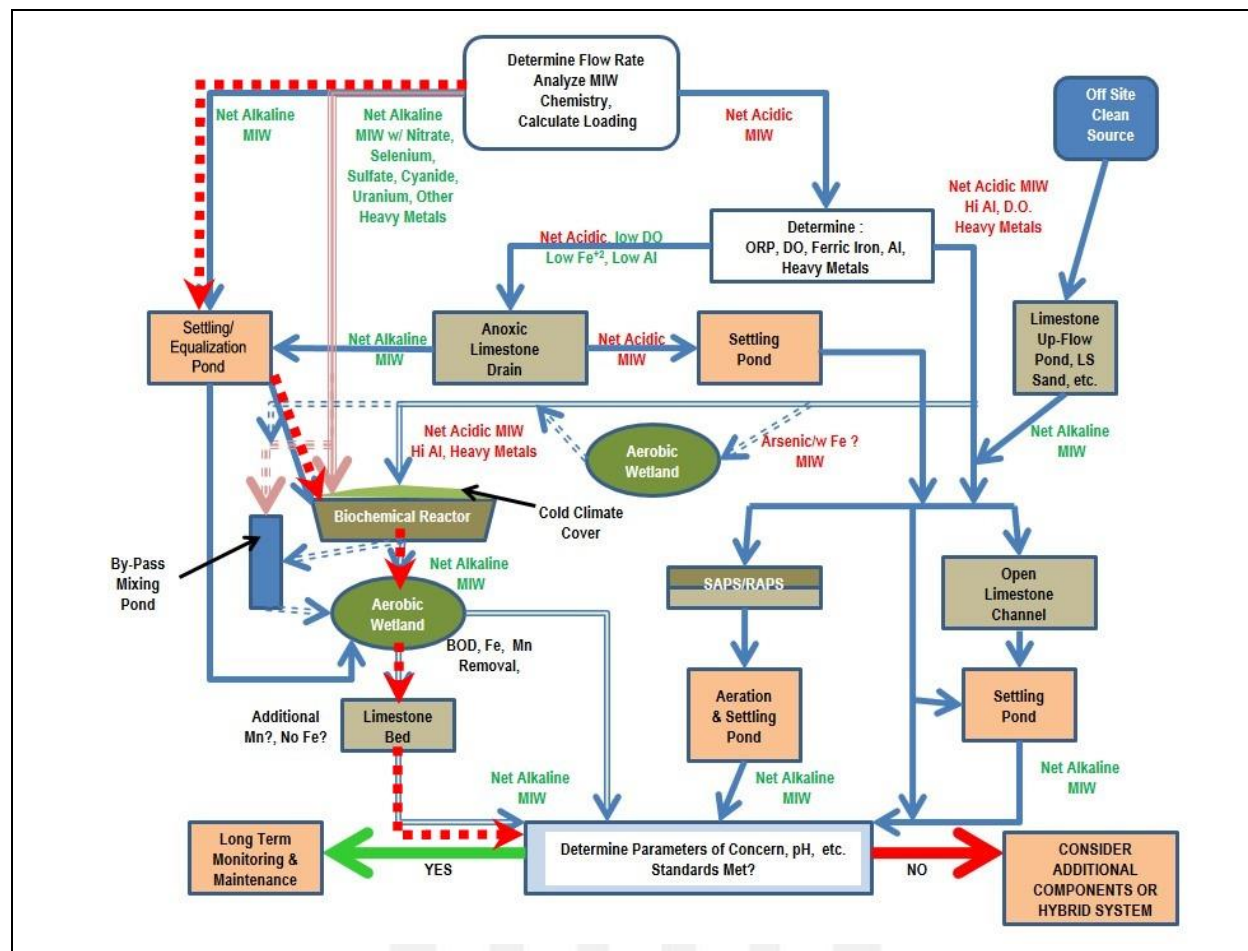
Figure 4 – 2014 Passive Treatment Decision Tree (Focus on metal mine and coal MIW)

Note that Figure 4 addresses MIW containing nitrate and sulfate (primary constituents of concern in the MIW) which are shown being addressed along the decision flow path (bold red arrows) in the biochemical reactor with a cold-climate cover. While the MIW is not projected to be net alkaline, it is expected to be only mildly acidic and is shown following the net alkaline PTS component selection flow path for convenience in Figure 4.

As discussed in Section 4.0, the MIW contains more than nitrate and sulfate. Developing an individual decision tree for each MIW element or suite of elements and their species would be a daunting task and would probably introduce more confusion where simplicity is desired.

Instead, a suite of "Periodic Tables of Passive Treatment" have been developed as useful design tools to satisfy the need to embrace a larger range of MIW chemistries. Gusek (2009) developed the first of these "custom" periodic tables; it focused on identifying passive treatment methods (under either oxidizing or reducing conditions) that have been observed to work on specific elements or species of elements typically found in MIW. The concept was subsequently re-visited (Gusek, 2013) with a closer focus on adsorption phenomena and other processes. Both of these papers are included in Appendix A.

2.2   Special Considerations

Sulfate removal from MIW containing trace metal concentrations is a special design challenge. While the sulfate reducing BCR is quite capable of converting sulfate (SO_4^{-2}) to sulfide ion (S^{-2}), this reaction is reversible. Certain bacteria are known to oxidize sulfide back into sulfate and the process gains in the sulfate reducing BCR would be lost unless the dissolved sulfide is sequestered. The sulfide scrubber shown in Figure 1 is filled with a sacrificial metal (scrap iron) and an organic component (e.g., wood chips). The wood chips are present to preserve the already anoxic conditions and to prevent plugging; the scrap iron or other inexpensive iron-containing material will scavenge the sulfide ion and an iron-sulfide residue will be formed. The iron and organic components comprising the scrubber media can be flexible. Other inexpensive iron-bearing materials could include raw iron ore such as magnetite or hematite (iron oxides). Straw, corn stalks, winery waste, or other locally- or regionally-available agricultural wastes could be substituted for the wood chips.

This passive process has not seen wide usage but available unpublished bench and demonstration scale data suggest that it is appropriate at the Amulsar PTS site.

Nitrate removal in a BCR is not dependent on the presence of metals. Nitrate is reduced to atmospheric nitrogen (N_2).

3.0   PASSIVE TREATMENT DEVELOPMENT

3.1   A Brief History

Nature has been passively removing dissolved metals from acidic to net alkaline water for eons; examples include pyrite occurrences in coal beds, bog iron ore (limonite) and copper deposits (McDonald et al 1976). Elevated levels of metals in wetlands have been used extensively as a geochemical prospecting technique (Salmi 1955, 1959). Wetlands and bogs have long been recognized as nature's method of improving water quality. Contaminant reductions can occur through the precipitation of hydroxides, precipitation of sulfides and pH adjustments and other reactions/processes. Local conditions, oxidation state, and water and substrate chemistries dictate whether these natural reactions will occur under oxidizing (aerobic) or reducing (anaerobic) conditions.

It has been about 35 years since the pioneering work of a group of researchers at Wright State University documented water quality improvements in a natural Sphagnum peat bog in Ohio that was receiving low pH, metal laden water (Huntsman et al., 1978). Independently, a group at West Virginia University found similar results at the Tub Run Bog (Lang et al., 1982). At the same time, scientists in Minnesota documented trace metal removal in a natural wetland receiving drainage from a nickel ore stockpile (Eger et al, 1980).

Early passive treatment work was focused on coal geology derived MIW, primarily in the Eastern US. A number of research groups evolved, including: the former U.S. Bureau of Mines, the Tennessee Valley Authority, and various academic communities including Penn State, West Virginia University, and the Colorado School of Mines (Wildeman et al., 1993 and Hedin, 2002). As of 1988, all seemed to agree that there were a number of biogeochemical mechanisms involved in metals removal and water quality improvements in wetland type environments (either natural or man-made), but there was some disagreement on which mechanisms were the most important. For coal mine systems characterized by moderate amounts of iron and manganese, aerobic systems dominated by plants and limestone appeared to be the best means of raising pH (via photosynthesis and neutralization reactions) and precipitating iron through hydrolysis reactions. Researchers in the western USA, primarily Wildeman, Klusman, and Cohen at the Colorado School of Mines, considered sulfate reducing bioreactor (aka biochemical reactor) systems the most appropriate for metal mine ARD. According to personal observations by this author, two "camps" had evolved, each thinking that they had the magic bullet.

The American Society of Surface Mining and Reclamation (ASSMR) Conference in Durango, Colorado in 1991 was important, for the different "camps" collaborated for the first time, presenting a short course on passive treatment. Each camp had the opportunity to present its case and view what the other camp's approach had to offer. The course was well attended and many participants stayed after its official end, despite long travels home. It is safe to say that both camps came to recognize the strengths and weaknesses of the two approaches and how the two could be integrated into hybrid systems to treat a variety of ARD/MIW situations. Subsequently, researchers including Andre Sobolewski (1997), Wildeman and Pavlik (2000), Eger et al. (1980), ITRC (2003) and others have documented the ability of natural wetlands to remediate ARD.

Thus, in the past two decades, a number of passive treatment milestones have been achieved (see Gusek and Wildeman, 2002) and a standard passive treatment system (PTS) practitioners' "tool box" has evolved and continues to evolve as new challenges are met and overcome.

Full scale passive treatment systems are common in the coal mining region of the eastern United States and are increasingly used in metal mining areas. One of the largest passive systems was built in 1996 to treat 1200 US gpm (76 L/s) of lead mine drainage (Gusek et al., 2000).

3.2   Supporting Documents – The GARD Guide

The GARD Guide (Global Acid Rock Drainage Guide) was sponsored by the International Network for Acid Prevention (INAP) with the support of the Global Mining Alliance; whose members represent most of the international mining community. The guide deals with the prediction, prevention, mitigation and treatment of drainage produced from sulfide mineral oxidation, often termed ARD or MIW.

The GARD Guide is intended as a state-of-practice summary of the best practices and technology to assist mine operators, regulators, and stakeholders to address issues related to mine drainage.

Methods used to passively treat mine drainage issues at Amulsar are consistent with the "state of the art" recommendations found in the GARD guide and other guidance documents in the technical literature.

4.0   PTS DESIGN VALUES

4.1   Treatment Flow Rates

Sovereign has assumed a PTS design flow with at 40 m^3/hour or 11.1 L/sec. This is a 30% safety factor applied to post-closure predicted flow rates (GRE 2014a and GRE 2014 b).   This steady flow rate would be delivered to the PTS with a floating weir intake unit that will be installed in the PD-8 pond. This inexpensive design feature could be included during the PD-8 pond construction and engaged upon site closure.

4.2   Expected Operations-Phase Water Quality entering the PTS

The influent water quality modeling is presented in the Geochemical Characterization and Water Quality Prediction Report (Update) from September 2014 (GRE 2014a). Table 1 shows the expected operations-phase influent water quality based on geochemical modeling.

Table 1: Predicted Influent PTS Water Quality during Operations

Quality indicators	Unit	Arpa MAC Standards Quality Category II	Worst-Case Operations-Phase Mine Contact Water
pH			3.92
Acidity	mg CaCO$_3$/l		157.2
Aluminum	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	3.59E-04
Calcium	mg/l	100	12.5
Chloride ion	mg/l	6.88	0.215
Chromium, total	mg/l	0.011	6.60E-10
Cobalt, total	mg/l	0.00036	**0.104**
Copper, total	mg/l	0.021	9.68E-15
Iron, total	mg/l	0.072	5.65E-07
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	4.01E-13
Phosphate ion	mg/l	0.1	8.07E-12
Potassium	mg/l	3.12	**6.39**
Selenium, total	mg/l	0.02	0.00874
Silicate ion	mg Si/l	25	4.25E-07
Sulfate 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**

Values that exceed standards are shown in bold.

A geochemical model must always be compared to any available on-site data to determine if the model is accurately simulating the concentrations of trace metals. As a result, the values in Table 1 were compared to existing ARD coming from mine waste in Site 13 and Site 27 (shown in Table 2).

Table 2: Chemistry of On-Site ARD and Baseline Water Quality

Constituent	Unit	Historic Waste Leachate, May 2014		Site 13 Baseline Surface Water May 2014
		Site 13	Site 27	
pH	pH units	4.78	3.28	6.38
Acidity	mg/l as $CaCO_3$	15.1	102	<DL
Aluminum	mg/L	0.176	2.27	0.18
Arsenic	mg/L	<0.001	<0.001	0.003
Barium	mg/L	0.0096	0.0054	0.0161
Boron	mg/L	<0.010	<0.010	<0.010
Cadmium	mg/L	<0.0005	<0.0005	<0.0005
Copper	mg/L	0.0000075	0.0000543	0.0000057
Iron	mg/L	0.363	3.22	3.73
Lead	mg/L	<0.001	<0.001	<0.001
Manganese	mg/L	0.022	0.0152	0.382
Nickel	mg/L	<0.003	0.0035	<0.003
Sulfate as SO4	mg/L	12.6	43.7	35.7
Zinc	mg/L	0.0225	0.0307	0.0325

The geochemical model appears to under predict iron and manganese. As a result, the PTS considers a worst-case water quality that incorporates the prediction in Table 1 with the empirical data in Table 2 whenever Table 2 values exceed those in Table 1. This ensures an influent water quality that is firmly grounded in the empirical site data. Background receiving water quality was not considered even though some values in background exceed Arpa II standards.

4.3   Expected Post-Closure BRSF Seepage Chemical Parameters.

Upon closure, only seepage from the BRSF will be directed to the PTS. Using the same geochemical modeling techniques as applied to Section 4.2 (GRE 2014a), the post-closure BRSF seepage water quality was predicted (see Table 3).

Table 3: Predicted BRSF Toe Drain Seepage Chemistry and PTS Management Zone

Parameter	Units	Initial/ Feed Value	PTS Management Zone
Conventional Parameters			
pH	s.u.	3.5	NO_3-BCR
Total suspended solids	mg/L	UNK	PD-7
Nitrate (as N)	mg/L	42	NO_3-BCR
Sulfate	mg/L	105	NO_3-BCR & SO_4-BCR

Parameter	Units	Initial/ Feed Value	PTS Management Zone
Sulfide (from SO$_4$-BCR)	mg/L	32	Sulfide scrubber
BOD (from BCRs)	mg/L	10	Aerobic Polishing Wetlands 1 & 2
Dissolved Metals			
Aluminum (Al)	mg/L	2.27	NO$_3$-BCR
Barium (Ba)	Mg/L	0.005	SO$_4$-BCR
Cobalt (Co)	mg/L	0.006	SO$_4$-BCR
Copper (cu)	mg/L	0.054	SO$_4$-BCR
Iron (Fe)	Mg/L	3.22	SO$_4$-BCR
Manganese (Mn)	mg/L	0.002	Manganese Removal Bed
Zinc (Zn)	mg/L	0.307	SO$_4$-BCR

4.4   Discharge Chemistry Targets

The treated water is targeted to meet the discharge criteria as provided in Table 4 below.

Table 4: Treatment Chemistry Targets - Monitoring Point PTS Effluent

Parameter	Units	Category II Arpa River MAC Values
Conventional Parameters		
pH	s.u.	6.5 to 9.0
Total suspended solids	mg/L	15.0
Nitrate (as N)	mg/L	2.5
Sulfate	mg/L	16.04
Sulfide (from SO$_4$-BCR)	mg/L	N.D.
BOD (from BCRs)	mg/L	N.D.
Total Metals		
Aluminum (Al)	mg/L	0.144
Barium	mg/L	0.028
Cobalt (Co)	mg/L	0.036
Copper (Cu)	mg/L	0.021
Iron (Fe)	mg/L	0.072
Manganese (Mn)	mg/L	0.012
Zinc (Zn)	mg/L	0.10

The conceptual PTS has been designed with several redundant processes. If additional processes (e.g., peat polishing cells) are required to meet the above targets, they would likely be appended to the aerobic polishing wetland #2, the final unit in the PTS.

5.0   TREATMENT PROCESSES

As shown in Figure 1, the proposed PTS will consist of seven units. The units are characterized with respect to the predominant aerobic (oxidizing) or anaerobic (reducing) conditions within the cells as follows:

Oxidizing/Aerobic Conditions
- equalization pond (PD-8),

Reducing /Anaerobic Conditions
- aerobic polishing wetland #1,

- aerobic polishing wetland #2, and
- manganese removal bed.
- nitrate reducing biochemical reactor,

- sulfate reducing biochemical reactor, and
- sulfide scrubber.

Discussions of the processes/conditions expected in each portion of the PTS follow.

5.1   Constituents of Concern Removal Kinetics in Aerobic Zones of the PTS

The PD-8 is expected to behave like an aerobic wetland because of its large surface area and relatively shallow depth (fully mixed, no stratification). Aerobic wetlands are engineered treatment systems that are designed to mimic the treatment processes that occur in naturally-occurring wetlands. Aerobic wetlands can treat a variety of constituents including suspended solids, biochemical oxygen demand (BOD), and metals (Kadlec and Knight 1996).

5.1.1   Ammonia Oxidation to Nitrate

According to Golder (2014b), nitrogen loading from MIW is projected to be dominated by two species: ammonia and nitrate, proportioned about equally between them. The nitrate-BCRs are ineffective in removing ammonia. However, the expansive area and long retention time provided by the PD-8 pond is expected to oxidize the ammonia present to nitrate, thus pre-conditioning the MIW for the first de-nitrifying BCR.

5.1.2   Metals (if present) Removal

If appropriately sized, aerobic wetlands can remove iron and manganese via iron hydroxide and manganese oxide precipitation, respectively. Metals removal from wetlands is typically calculated as a mass area loading factor with units of grams per day per square meter ($g/d/m^2$) or gdm, whose origin is described below. Some technical references cite this value in units of grams per square meter per day ($g/m^2/d$).

5.1.3   Biochemical Oxygen Demand (BOD)

BOD removal in metal mine PTS applications is required down gradient of the BCR units, as these effluents are typically anoxic and contain dissolved organic carbon. Typical BCR effluent BOD values typically decrease to about 10 mg/L after about five to 10 pore volumes are treated. Thereafter, the rule of thumb for BOD removal is about 1.3 m^2 of aerobic wetland water surface per liter per minute (L/min) of flow. Due to the cold climate at Amulsar, this value was conservatively quadrupled to 5.2 m^2 per L/min.

The PTS contains multiple trains of BCRs, one train for nitrate removal and a second train for sulfate removal. To function properly, the MIW a BCR receives should be fully oxidized. If it is not, the cellulose-degrading bacteria will not degrade the organic matter component in the BCR substrate and the nitrate- and sulfate-reducing bacterial communities will suffer for lack of nutrients. Consequently, the nitrate BCR

is followed by an aerobic polishing wetland to pre-condition/aerate the MIW for the sulfate BCR. The APW following the sulfate BCR/sulfide scrubber provides pre-conditioning for manganese removal. Note: BCRs are known to release manganese if it is present in organic substrate (typically it is found in the woody fraction of the substrate).

5.1.4   Manganese

Manganese oxide is Mother Nature's version of activated carbon. Many metals adsorb to it and the technical literature abounds with references, some written over 20 years ago (e.g., Bender et al. 1994), that document how manganese is biologically removed in aerobic passive treatment systems. Robbins and Ziemkiewicz (1997) observed the presence of 12 different biological mechanisms removing manganese in a passive treatment system at the Shade coal mine which was constructed in the early 1990s. At this site, influent manganese concentrations were reported to be reduced from 12 to 25 mg/L down to less than 2 mg/L.   Manganese removal kinetics from MIW has been empirically measured in a way similar to iron as developed by Hedin (1994). Hedin observed typical manganese removal rates ranging from 0.5 to 1 g/d/m^2 but there may have been interfering conditions that were unrecognized at the time. More recent data suggest that higher values are possible.

However, as MIW becomes more dilute, manganese removal kinetics become less efficient. Fortunately, neither site elevation nor water temperature appears to affect the biologically-influenced manganese removal kinetics in an aerobic wetland environment.

Rose et al. 2003 discussed two manganese removal methods, a limestone bed where MIW passes through granular limestone in a plug-flow configuration and an open limestone channel configuration with a free-water surface above a bed of granular limestone. Key findings in the paper include:

> *Effective Mn removal [in both bed and channel configurations] requires oxidizing well-aerated water, as well as prior removal of essentially all dissolved Fe and Al, and pH above about 6.5.*

> *Another key requirement for Mn oxidation is a low concentration of ferrous iron (Fe(II)). …if Fe(II) is present in a solution…, the oxidation potential of such a solution is considerably below the level required for Mn oxidation to Mn(III) or Mn(IV), and Mn will not oxidize and precipitate.*

> *Several of the [bed] systems have failed because of plugging of the inlet area with silt, leaves, Fe and/or Al precipitate, grass and other materials.*

> *Most Mn removal rates [in limestone beds] range from 1.5 to 5 g/m^2/day, with the lower values from beds with influents containing appreciable Fe and Al.*

> *Three successful limestone-lined channels have been observed, one with a Mn removal rate of about 10 g/m^2/day. A shallow bed or channel, lined with limestone, and containing algae to enhance O$_2$, appears to be an improved design.*

Data reported by ITRC (2010) cite a Mn removal rate of 2.6 g/d/m² at an abandoned coal mine site in Alabama.

Sovereign used a conservative value of 0.01 gdm to estimate the surface area required for manganese removal. This was driven by the very low manganese discharge limit (0.012 mg/L) – as discussed earlier, manganese removal efficiency decreases as the influent concentration becomes more and more dilute. Bench studies which develop site-specific gdm factors for manganese are recommended.

5.1.5   Selected Metallic Constituents of Concern (Co, Zn, Pb, & Ni)

If upstream processes are not as efficient as expected in the Amulsar PTS, some of the metallic constituents of concern (COCs) in the MIW are likely to adsorb to manganese oxides that should form in the manganese removal beds installed in the final treatment zones of the PTS. Review of the technical literature on this topic verified that manganese oxide minerals should indeed be capable of removing the metallic COCs in the MIW. For example, the following direct citation from Tebo et al. (2004) is offered:

> *Mn oxide minerals can adsorb or incorporate substantial amounts of Cu, **Co**, Cd, **Zn**, **Ni**, Sn, **Pb**, Ca, Fe, Ra, Hg, U, Pu, Po, As, Se, and Th (see multiple references in Tebo et al. 2004). These interactions have been reported to decrease dissolved trace metal and radionuclide concentrations by orders of magnitude (see multiple references in Tebo et al. 2004) even when only small amounts of Mn oxides are present (see Jenne 1968 cited in Tebo et al. 2004).*

For emphasis, the metallic COCs present in the MIW are **bolded** in the citation above.

Removal kinetics for the metallic COCs in the manganese removal portion of the PTS are unknown. The BCR effluent will contain some biochemical oxygen demand (BOD) and will exhibit very low levels of dissolved oxygen (DO). The BOD will be managed and the DO increased in the aerobic polishing wetlands (see Figure 1).

5.2   Constituents of Concern Removal Kinetics in Anaerobic Zones of the PTS; i.e., Biochemical Reactors

Biochemical reactors are typically constructed by filling a geomembrane-lined excavation with a blended carbon/alkalinity source that is generally provided by a mixture of solid substrates (e.g., wood chips, straw, hay) to provide both short term and long term carbon sources. This blend insures a quick start up as well as long term treatment. BCR substrates also typically contain a crushed limestone component as the alkalinity source.

In order to maintain anaerobic conditions, BCRs are operated under saturated conditions and are generally fed from the top, operating in vertical down-flow configuration. (Figure 5).

Additional information on the use of biochemical reactors to treat mining influenced waters is available in the recent ITRC guidance; Biochemical Reactors for Treating Mining Influenced Water (ITRC, 2013).

A photo of a BCR is provided in Figure 6.
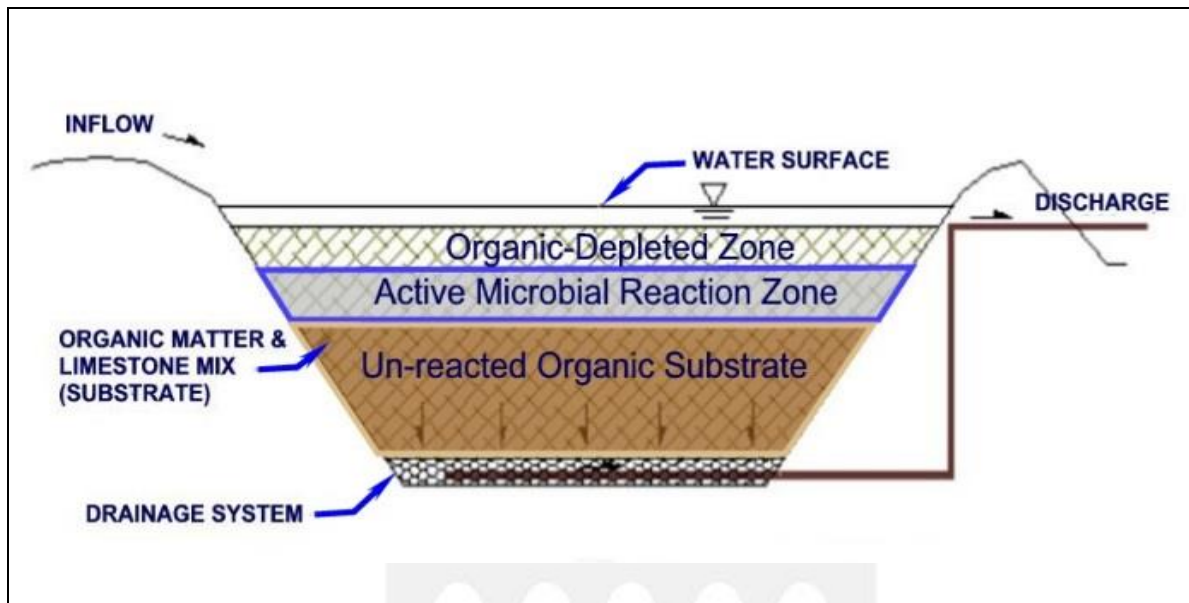
Figure 5 – BCR (NO$_3$ and SO$_4$) Schematic Cross Section View

Figure 6 – A Typical BCR in Pennsylvania, USA

5.2.1   *Nitrate Removal Kinetics in the NO$_3$ BCRs*

Nitrate derived from blasting agent residue is the first major COC that will be removed in the PTS. De-nitrification is the primary removal mechanism in BCRs. The chemical reactions are facilitated by natural bacteria including *Thiobacillus de-nitrificans* in nitrate BCRs. Nitrate is reduced to atmospheric nitrogen (N$_2$). Minor concentrations of metal, particularly dissolved aluminum, may be removed in a nitrate BCR.

A bench scale nitrate reduction rate at a mine site in California (unpublished data) was observed to be 0.8 moles (or 11.2 grams) of nitrate (as N) removal per day per cubic meter (moles N/d/m^3) of organic substrate. This value was observed for an MIW with an ambient temperature of about 15°C. For the Amulsar nitrate BCR, a much colder MIW is expected as a result of the extended exposure in the PD-8 pond. Consequently, a conservative value of 0.4 moles N/d/m^3 was assumed (5.6 grams N/d/m^3). At this rate, the hydraulic retention time (HRT) for the proposed nitrate BCR was about 4.2 days. This value would need to be validated with bench and/or pilot test data before this component would be sized in the final design.

5.2.2   Sulfate Removal Kinetics in the SO$_4$ Biochemical Reactor

Metals concentrations that elude removal in the nitrate BCR would be removed in the sulfate BCR. Sulfate reduction is the primary metal removal mechanism in BCRs. The chemical reactions are facilitated by the bacteria *Desulfovibrio* in sulfate-reducing BCRs.

The sulfate-reducing bacterial reactions (equation 1) involve the generation of:

Sulfide ion (S^{-2}), which combines with dissolved metals to precipitate sulfides (equation 2).

Bicarbonate (HCO$_3^-$), which has been shown to raise the pH of the effluent.

The sulfate reducing bacteria produce sulfide ion and bicarbonate in accordance with the following reaction (Wildeman, et al., 1993):

$$SO_4^{-2} + 2\ CH_2O \rightarrow S^{-2} + 2\ HCO_3^- + 2\ H^+ \hspace{3cm} 1)$$
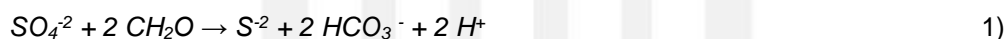
The dissolved sulfide ion precipitates metals (if present) as sulfides, essentially reversing the reactions that occurred to produce acidic or metal-bearing mine water. For example, the following reaction occurs for dissolved zinc, forming amorphous zinc sulfide (ZnS):

$$Zn^{+2} + S^{-2} \rightarrow ZnS \hspace{5cm} 2)$$

BCRs are typically sized based on the metals and sulfate mass loading, but only to a certain extent. As the influent becomes more dilute with respect to metals and/or sulfate, a minimum HRT design factor is adopted. This design decision was not necessary for sizing the BCR. Rather, a sulfate reduction rate observed in a demonstration BCR at a coal mine in Vancouver BC with a sulfate concentration of 600 mg/L was adopted. The "temperate" temperature sulfate reduction rate (observed at a number of sites, world-wide) is 0.3 moles (or 32 grams) of sulfate removal per day per cubic meter (moles/d/m^3) of organic substrate. For the Amulsar sulfate BCR, a conservative value of 0.1 moles/d/m^3 was assumed (9.6 grams SO$_4$/d/m^3). At this rate, the HRT for the proposed sulfate BCR was about 4.1 days. This value would need to be validated with bench and/or pilot test data before this PTS component would be sized in the final design.

The organic reactant in equation 1 above (CH_2O) is typically provided by cellulose-bearing materials such as wood chips, hay, and straw. It is expected that the wood chips would be obtained on or nearby (e.g. apricot orchards). To protect against acidity excursions in the BCR influent, a limestone sand component (no less than 10% by weight) is typically included in the substrate mixture. The microbial suite of *Desulfovibrio* and supporting bacterial strains of cellulose degraders and fermenting bacteria are provided in a relatively small amount of inoculum; it is typically composed of composted animal manure that is available from local farms.

The above components are included in the BCR substrate design which would also be validated in bench and pilot scale testing.

5.3   Sulfide Removal Kinetics in the Scrubber

As discussed earlier, in the absence of dissolved metals, sulfide (S^{-2}) produced by the SO_4-BCR is prone to re-oxidize back to sulfate (see equation 3). This reaction is prevented by sequestering the sulfide with a sacrificial metal such as iron. See equations 4 or 5 for expected reactions with zero valent iron [scrap iron] or magnetite, respectively.

$$S^{-2} + O_2 + Thiobacillus \rightarrow SO_4^{-2} \tag{3}$$

$$S^{-2} + Fe_0 \rightarrow FeS \tag{4}$$

$$3S^{-2} + Fe_3O_4 + 8H^+ \rightarrow 3FeS + 4H_2O \tag{5}$$

Equation 5 has the advantage of consuming hydrogen ion (H+), thus raising the pH of the MIW.

The kinetics of this reaction have been studied at bench and "demonstration" scales at a coal mine site on Vancouver Island, BC, Canada (unpublished data). Based on the demonstration scrubber data available to Sovereign, an HRT of about 13 hours was assumed for sulfide scrubber cell sizing. The sulfide scrubber media was assumed to be a mixture of 40% by weight magnetite (Fe_3O_4) and 60% by weight wood chips (to preserve the anoxic character of the SO_4-BCR effluent). The media was assumed to exhibit a void ratio of 60% for estimating HRT.

The sulfide scrubber will be fed from the bottom to preserve the temperature and anoxic conditions in the SO_4-BCR effluent.

6.0   CONCEPTUAL TREATMENT SYSTEM DESIGN

Step 1 – Identify Treatment System Components

The COCs present in the MIW suggests that at least four sequential process steps need to be included in the treatment system design. These process steps were shown schematically in Figure 1. To recap, they include:

- PD-8 pond for conversion of ammonia to nitrate

- NO_3-BCR for the removal of nitrate to meet effluent standards and pre-treat the MIW so that sulfate can subsequently be reduced. Based on Sovereign experience in bench tests at another site in the western USA (unpublished data), aluminum removal and some sulfate removal are likely to occur in the NO_3-BCR.

- Aerobic polishing wetland (APW) No. 1 to settle out biosolids that form due to residual BOD, and re-oxygenate and pre-condition the anoxic BCR effluent for introduction into the SO_4-BCR.

- SO_4-BCR for the removal of sulfate to meet effluent standards and remove cobalt, nickel, lead, and zinc as sulfides and residual aluminum as aluminum hydroxy-sulfate.

- Iron- and wood chip-filled scrubber for sequestering sulfide.

- Aerobic polishing wetland cell to re-oxygenate the anoxic SO_4-BCR effluent, settle out biosolids that form due to residual BOD, and

- Manganese removal beds to precipitate manganese oxide which is likely to be leached from the BCR organic substrates. MnO_2 has an affinity to adsorb other residual parameters.

To minimize both construction and operational costs, all flows are by gravity. The system is configured to operate unattended with little if any maintenance. However, low maintenance does not mean "no" maintenance. Lydian personnel should plan to visit the system monthly during the first few years of operation. Sampling and monitoring frequency might be relaxed once the performance of the PTS is consistent.

Step 2 – Develop Approximate Component Sizes

The sizes of the treatment units were based on assumptions shown in Table 5.

Table 5: Treatment Component Design Basis Summary

Component	Design Basis
PD-8	Originally designed to satisfy operational water balance requirements: capacity varies by date (see Golder 2015)
Nitrate Reducing Biochemical Reactor	4.2 days HRT in 60% void space; substrate comprised of wood chips (10% by weight), winery waste (60% by weight), crushed limestone 20%; hay (10%); bulk substrate density 0.32 kg/L; substrate thickness 2.0 m; total BCR depth 2.9m includes gravel & pipe layer on floor and side slopes of 3H:1V; 1.5mm geomembrane underlain and overlain with geotextile; BCR is covered (see Figures 8 and 9, Section 8.1).
Aerobic Polishing Wetland #1	BOD removal based on 5.28 m^2 of water surface area per liter per minute of flow; the aerobic polishing wetland is lined with 1.5 mm geomembrane underlain and overlain with geotextile; water depth 150mm; freeboard 460mm; organic matter in floor and sides 300mm thick; side slopes 3H:1V
Sulfate Reducing Biochemical Reactor	4.1 days HRT in 60% void space; substrate comprised of wood chips (10% by weight), winery waste (60% by weight), crushed limestone 20%; hay (10%); bulk substrate density 0.32 kg/L; substrate thickness 2.0 m; total BCR depth 2.2m includes gravel & pipe layer on floor and side slopes of 3H:1V; 1.5mm geomembrane underlain and overlain with geotextile; BCR is covered (see Figures 8 and 9, Section 8.1).
Sulfide Scrubber	13 hours HRT in 60% void space; substrate comprised of wood chips (60% by weight), magnetite sand (40% by weight); substrate thickness 2.0 m; total BCR depth 2.3m includes pipe layer on floor and side slopes of 3H:1V; 1.5mm geomembrane underlain and overlain with geotextile; fed from bottom.
Aerobic Polishing Wetland #2	BOD removal based on 5.28 m^2 of water surface area per liter per minute of flow; the aerobic polishing wetland is lined with 1.5 mm geomembrane underlain and overlain with geotextile; water depth 150mm; freeboard 460mm; organic matter in floor and sides 300mm thick; side slopes 3H:1V.
Manganese Removal Beds (2)	Two MRBs in series, fed from top; filled with 50% crushed limestone (<100mm dia.) and 50% silicate rock (<100mm dia.); media depth 820mm; Mn removal rate of 0.01 grams Mn/day/m^2 of water surface on top of MRBs.
Infiltration Trench	Coarse gravel-filled trench installed along the contour 10 to 20m uphill and parallel to G. Channel with imbedded perforated PVC pipe (150mm dia.); zone between trench and channel planted with sphagnum peat moss (local species).

Step 3 – Develop Construction Footprints for Components

It is a well-accepted fact that passive treatment systems consume larger areas than active treatment systems with similar loading/treatment capacities. The dimensions of the conceptual PTS treatment units were plotted on the available land downhill from P-08 to determine if land requirements would become an engineering constraint. Table 6 provides the approximate areas required for each of the PTS components.

Table 6: PTS Treatment Component Footprint Summary

PTS Component	Approximate Total Footprint (Ha)
Nitrate BCR	1.14
Aerobic Polishing Wetland #1	0.39
Sulfate BCR	1.29

Sulfide Scrubber	0.12
Aerobic Polishing Wetland #2	0.39
Manganese Removal Bed	0.22
Total	**3.6**

The general conceptual layout of the PTS in relation to the HLF and P-08 is shown in Figure 7.

It appears that there is sufficient land area to construct the PTS as currently sized.
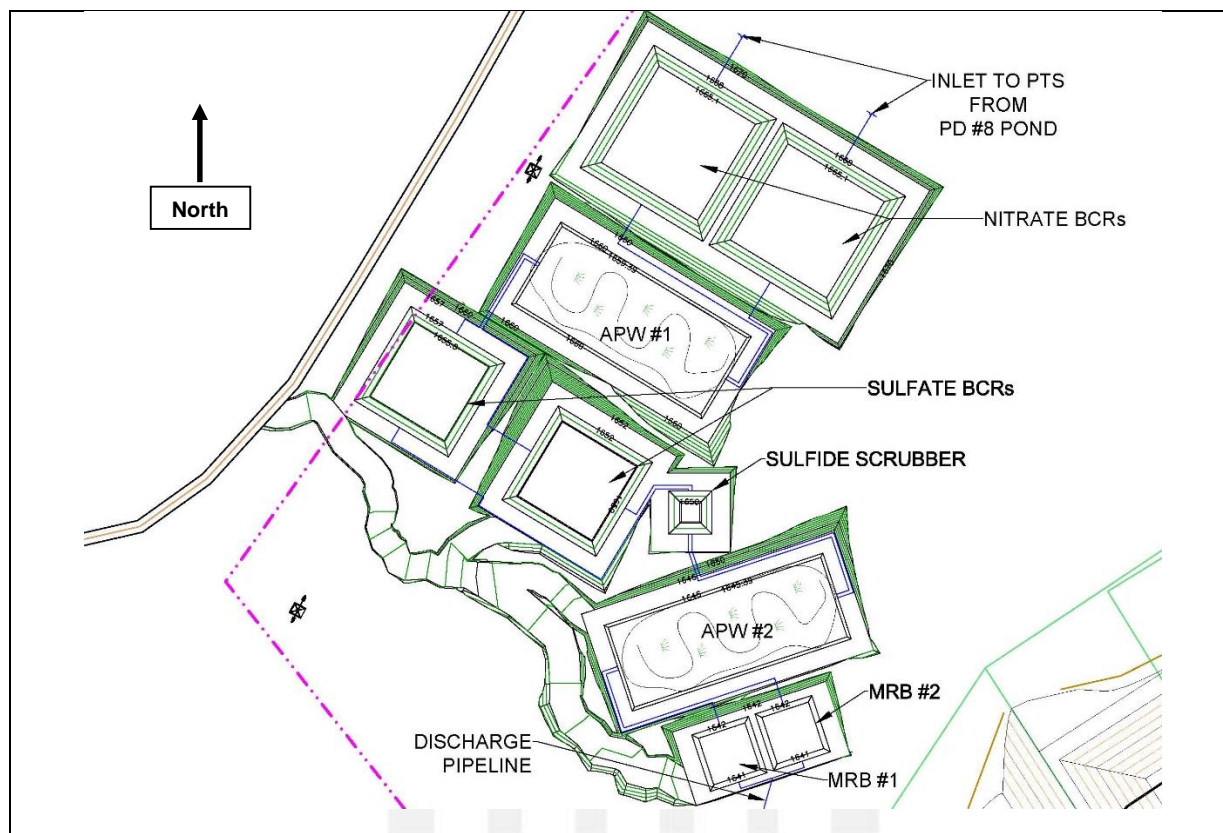
Figure 7 –Passive Treatment System General Layout, Plan View (Not to Scale)

7.0   PREDICTION OF POST-TREATMENT WATER QUALITY

The post-treatment MIW quality provided in Table 7 is based on Sovereign experience and in-house PTS component sizing models that assume nearly complete removal of the parameters of concern.

Table 7: Estimated PTS Discharge Quality

Parameter	Units	Category II Arpa River MAC Values	PD #8 Pond	Nitrate BCR	APW 1	Sulfate BCR	Sulfide Scrubber	APW 2	MRB 1	MRB 2
Conventional Parameters										
pH	s.u.	6.5 to 9.0	3.28	5.5	NC	6.5	NC	NC	7.5	7.5
Nitrate (as N)	mg/L	2.5	42	<2.5	NC	NC	NC	NC	NC	NC
Sulfate	mg/L	16.04	44	NC	NC	12.0	NC	NC	NC	NC
Sulfide (from SO_4-BCR)	mg/L	N.D.	N.D.	NC	NC	-	Low	NC	NC	NC
BOD (from BCRs)	mg/L	N.D.	N.D.	High	Low	High	High	Low	NC	NC
Total Metals										
Aluminum	mg/L	0.144	2.27	NC	NC	<0.144	NC	NC	NC	NC
Barium	mg/L	0.028	0.005	NC	NC	<0.028	NC	NC	NC	NC
Cobalt	mg/L	0.036	0.006	NC	NC	<0.036	NC	NC	NC	NC
Copper	mg/L	0.021	0.054	NC	NC	<0.021	NC	NC	NC	NC
Iron	mg/L	0.072	3.22	NC	NC	<0.072	NC	NC	NC	NC
Manganese	mg/L	0.012	0.015	NC	NC	NC	NC	NC	0.01	0.008
Zinc	mg/L	0.1	0.307	NC	NC	<0.1	NC	NC	NC	NC

Note: NC - No change

Modeling/design basis

Nitrate BCR	Nitrate removal Rate - 0.4 moles of nitrate /m3/day
APW 1	BOD loading factor = 5.28 m^2/L/min
Sulfate BCR	0.1 moles of sulfate/m^3/day
Sulfide Scrubber	HRT= 50% of Quinsam coal mine scrubber design HRT due to dilute sulfide levels
APW 2	BOD loading factor - 5.28 m^2/L/s
MRB 1	Mn removal - A (m^2) = -0.276QLog([Mn]/[Mno])/(k1SD)
MRB 2	Mn removal - A (m^2) = -0.276QLog([Mn]/[Mno])/(k1SD)

If proposed bench and pilot scale test results indicate additional process steps are required to meet Arpa River MAC standards, those processes would be amended to the treatment scheme rather than replace individual components. For example, such amended processes may include ion exchange media that is selective to the parameter of concern that is outside the Arpa River limits. As the amended process would be inserted at the end of the passive treatment process train, interferences from other MIW parameters is less likely.

The design criteria used to size each component of the PTS is described below:

7.1   BCR – Nitrate Removal

The primary design basis input for the BCR is the nitrate loading (flow times concentration). Metals concentrations and sulfate are inconsequential. While some incidental metals and sulfate reduction are expected in a nitrate-reducing BCR, their removal does not influence BCR sizing in this case. A design nitrate removal rate of 0.8 moles/day/m^3 was obtained from the bench scale testing performed at the Hayden Hill mine site (unpublished data). A 0.4 moles NO_3/day/m^3 removal rate was used to design the BCR due to the cold water temperature of the influent.

7.2   APW 1 and 2 – BOD Removal

The area required for BOD removal in the APWs was calculated based on 5.28 m^2 of water surface area per liter per minute of flow. This rate is four times more conservative than the BOD removal rate achieved from West Fork mine pilot scale testing (unpublished data). A full scale (4.5 m^3 per minute) PTS was designed based on these test results and it operated successfully for 19 years until it was intentionally decommissioned.

7.3   BCR – Sulfate & Metal Removal

Design basis input for the BCR was 0.1 moles of sulfate per cubic meter per day, based on the Quinsam Coal Mine bench testing during the winter months (unpublished data). Table 8 indicates the sulfate loading rate and the cumulative metal loading with the exception of manganese. Based on experience, the molar ratio for sulfate and metals removal is 1:1. Table 8 shows that all the metals would be removed from the MIW. The remaining sulfate would be removed as elemental sulfur and will be converted to sulfide.

Table 8: Total Metals Loading Rate

Parameter	Units	Detention Pond (mg/L)	Total Loading (mol/day)
Conventional Parameters			
pH	s.u.	3.28	-
Flow	L/day	950400	-
Nitrate (as N)	mg/L	2.35	
Sulfate	mg/L	105	**1,040**
Total Metals			
Aluminum	mg/L	2.27	120
Barium	mg/L	0.005	0.035
Cobalt	mg/L	0.006	0.10
Copper	mg/L	0.054	0.81
Iron	mg/L	3.22	54.84
Zinc	mg/L	0.307	4.5
Total			**180**

7.4   Sulfide Scrubber

The scrubber was designed based on half of the HRT from the Quinsam Coal Mine bench testing (unpublished data). This rate was assumed due to the relatively dilute expected sulfide levels from the Almulsar MIW compared to the Quinsam bench data.

7.5   MRB - Manganese Removal

Manganese will not be removed in the BCRs or the APWs. The following equation (Means and Rose, 2005) was used to design the MRBs:

$$A = -0.276 Q \operatorname{Log}([Mn]/[Mn_o])/(k1SD)$$

Where:

A = Bed area (m^2)

Q = Flow Rate (L/min)

Mn = Mn effluent concentration (mg/L)

Mn_0 = Mn influent concentration (mg/L)

k_1 = Rate Constant (hr^{-1} (m_s^2 /m_v^3)$^{-1}$

S = Specific surface of limestone (m^2)

D= Depth of water saturation in the bed (m)

Note: Means and Rose based their equation on manganese removal observations at 13 different PTS sites.

8.0   PTS MAINTENANCE AND COMPONENT LONGEVITY

The oldest BCR in operation was built in 1996 (Gusek, 2000) at a lead mine in Missouri, USA. Based on experience, the organic substrate in the BCR components (nitrate and sulfate units) in the PTS would need to be replaced every 20 years of operation.

The operation of the PTS should include the following activities:

- Periodic sampling of each PTS treatment unit, not just the PTS effluent, is recommended to avoid upset conditions.
- Post closure, two to three site visits per year to collect samples and inspect the site for functionality – assume two field personnel are required for this effort.
- Replacement of the BCR substrate every 20 years. This will involve:
  - o   purchasing fresh substrate materials and mixing them together;
  - o   removing the soil and infiltration chamber combination cover;

o   exhuming and disposing the spent substrate (probably on site); and

o   placing the fresh mixed substrate into the BCR and replacing the combination cover.

■ Replacement of the sulfide scrubber media every 15 years. With the exception of the removal and replacement of a cover, this work will involve activities similar to replacing the BCR substrates.

■ Checking for damage from animals and weather.

The aerobic polishing wetlands should be self-sustaining.

9.0   EXAMPLES OF THE TECHNOLOGY AT SIMILAR SITES

9.1   Examples of COC Removal

The technical literature is full of documented case studies where the COCs present in the MIW have been managed but no single MIW exhibits the same COCs at Amulsar. Table 8 provides a general perspective on the numerous sites where the passive treatment technology has been evaluated (bench or pilot scale testing) or implemented (full or demonstration scale). The reference column has two possible entries: U.D. or "unpublished data" or R.A. where a paper, presentation or technical publication is available in the public domain. Details of the unpublished data (which may be a confidential site) or the paper/ publication can be provided on request.

Clearly, the passive treatment technology is appropriate for a wide range of COCs. See the papers in Attachment A for a more detailed discussion.

Table 8: Examples of PTS Technology Addressing Amulsar MIW COCs

Mine Site	pH	Al	Co	Ni	Pb	Zn	NO$_3$	Mn	SO$_4$	S^{-2}	Ref.	Cold Site?
Conf. Site, CA USA	7	•					•				U.D.	**Yes**
Quinsam Coal, BC Canada	7.5								•	•	R.A.	**Yes**
Ferris Haggarty Mine WY USA	7.5								•		R.A.	**Yes**
Buffalo Valley, NV USA	8						•				R.A.	**Yes**
Rocky Flats, CO USA	8						•				U.D.	**Yes**
Ore Hill Mine, VT USA	4				•	•					U.D.	**Yes**
Magenta Drain, CA USA	7							•			R.A.	No
Sudan Mine, MN USA	7		•						•		U.D.	**Yes**
Standard Mine, CO USA	3.3		•			•		•	•		R.A.	**Yes**

Mine Site	pH	Al	Co	Ni	Pb	Zn	NO_3	Mn	SO_4	S^{-2}	Ref.	Cold Site?
Golden Cross, NZ	7.5		•			•			•		U.D.	No
Iron King Mine, AZ USA	3 to 7	•				•		•	•		R.A.	No
Royal Mtn King, CA USA	7.8			•			•				U.D.	No
Elizabeth Mine VT, USA	4	•		•		•		•	•		U.D.	**Yes**
Stoller Site, SC USA	4.3	•		•		•		•	•		U.D.	No
Grouse Creek, ID USA	3.2	•				•		•	•		U.D.	**Yes**
Rosita Dump, Peru	2.7	•	•	•		•		•	•		U.D.	**Yes**
DeLamar Mine, ID USA	2.7	•	•	•		•		•	•		U.D.	**Yes**
Luttrell Site, MT USA	4	•				•		•	•		R.A.	**Yes**
Golinsky Mine, CA USA	3.4	•				•		•	•		R.A.	No
PJK, MT USA	7					•		•			R.A.	**Yes**
N. Potato CK, TN USA	2.5	•	•		•	•		•	•		R.A.	No
MSF Mine, Brazil	7			•				•	•		U.D.	No
Fran Mine, PA USA	2.2	•				•		•	•		R.A.	**Yes**
Richmond Hill Mine, SD USA	4.5	•	•	•		•		•			U.D.	**Yes**
West Fork Mine, MO USA	7.5				•	•		•	•		R.A.	**Yes**
Cadillac Mine, Quebec, Canada	2.7 to 3.4	•		•		•		•	•		R.A.	**Yes**

Notes:

U.D. – Unpublished data

R.A. – Reference/Paper/Presentation available on request

9.2　PTS Systems in Cold Climates

The wintry climate of the site is a design challenge. The far right column of Table 6 indicates whether the site location was wintry (i.e., sub-freezing conditions might be expected for more than a month). About 70 percent of the example sites satisfy this condition.

To ensure that the BCR substrate is maintained at an ambient temperature above freezing, Sovereign has assumed that the BCR would be buried. This is a typical design strategy in cold climates. To provide an insulating layer of air above the substrate, we have included a layer of off-the-shelf, lightweight infiltration chamber units typically used in domestic septic system leach fields. See Figures 8 & 9.
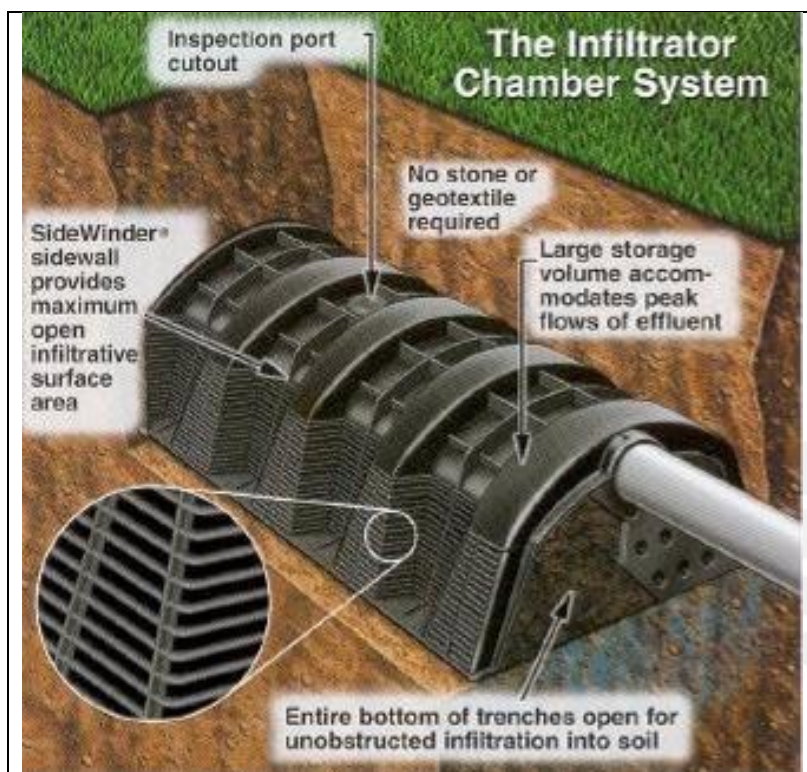
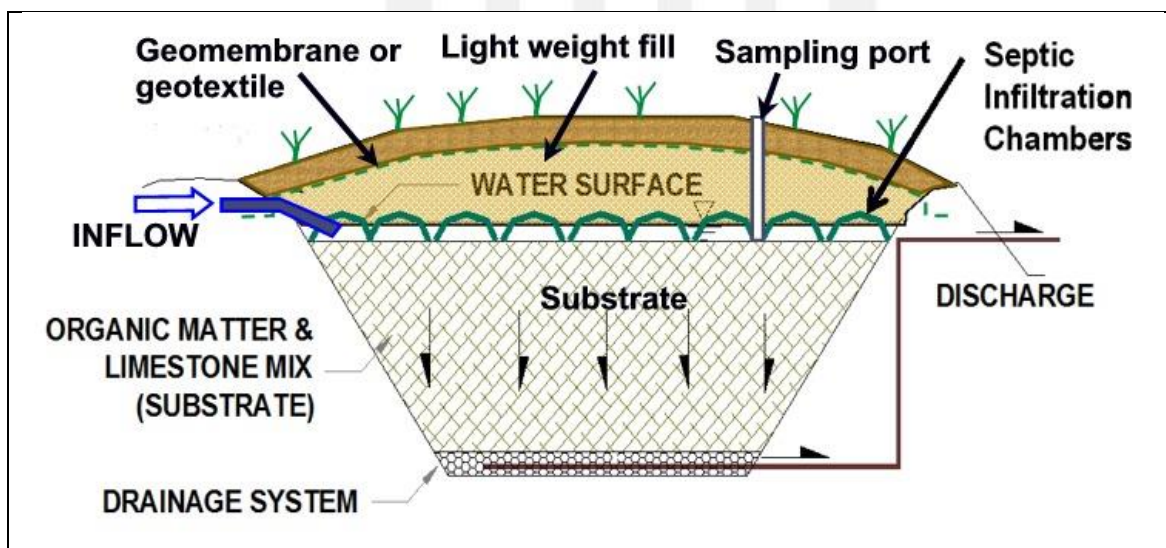**Figure 8 – Septic Infiltration Chamber**

Figure 9 – Covered BCR Cross Section

The following example sites in Table 6 included a BCR cover:

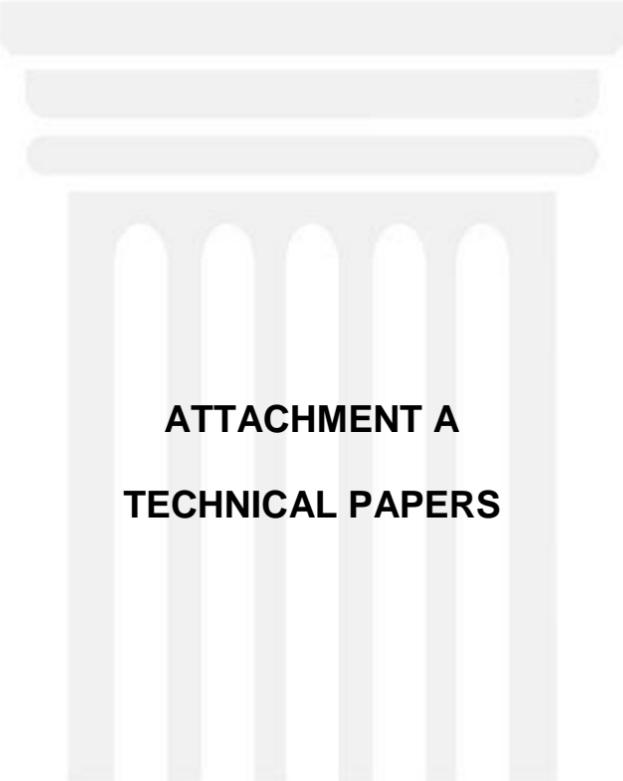- Ferris Haggarty Mine,
- Standard Mine

- Iron King Mine
- Fran Mine
- Cadillac Mine
- Confidential Site, CA (planned)

The septic infiltration chambers were used successfully at the Iron King Mine and they are included in the detailed design for the confidential site in California.

10.0   REFERENCES

Brant, D.L. and P.F. Ziemkiewicz, 1997. Passive removal of manganese from acid mine drainage. In: Proc. Amer. Soc. for Surface Mining and Reclamation, Austin, TX, May 1997, p. 741-744.

Eger, P., Lapakko, K. A., Otterson, P. 1980. Trace metal uptake by peat: Interaction of a white cedar bog and mining stockpile leachate. P. 542-547. In Proc. of the 6th International Peat Congress. Duluth, MN. Aug. 17-23, 1980.

Golder 2015. Amulsar Project Site Wide Water Balance, Golder Associates, Lakewood Colorado, October 2015.

Golder 2014a. Spring and Seep Interpretive Report. May 2014, Golder U.K.

Golder, 2014b. Nitrate Residue Technical Memorandum.

Gusek, J.J., T.R. Wildeman, C. Mann, and D. Murphy, 2000 "Operational Results of a 1,200-gpm Passive Bioreactor for Metal Mine Drainage, West Fork, Missouri", presented at the Fifth International Conference on Acid Rock Drainage - ICARD, Denver, CO May 21-24, 2000.

Gusek, J.J. and T.R. Wildeman, 2002. "A New Millennium of Passive Treatment of Acid Rock Drainage: Advances in Design and Construction Since 1988 presented at the 2002 National Meeting of the American Society of Mining and Reclamation, Lexington, KY, June 9-13.

Gusek, James J. 2008. Passive Treatment 101: An Overview of the Technologies. Presented at the 2008 U.S. EPA/National Groundwater Association's Remediation of Abandoned Mine Lands Conference, Denver, CO, October 2-3, 2008.

Gusek, J. and L. Figueroa (eds.) 2009. Mitigation of Metal Mining Influenced Water. Littleton, CO. Society for Mining, Metallurgy, and Exploration, Inc. for ADTI Metal Mining Sector. ISBN 978-0-87335-270-3.

Gusek, J., 2009. A Periodic Table of Passive Treatment for Mining Influenced Water. Paper was presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT, Revitalizing the Environment: Proven Solutions and Innovative Approaches May 30 – June 5, 2009.

Gusek, J. 2013. A Periodic Table of Passive Treatment for Mining Influenced Water - Revisited. Paper was presented at the IMWA 2013 Conference, August. Golden CO.

GRE 2014a. Geochemical Characterization and Geochemical Prediction Report -- update. September 2014.

GRE 2014b. Amulsar Project Site-Wide Water Balance. September 2014.

Hedin, Robert S., R.W. Nairn, and R.L.P. Kleinmann, 1994. Passive Treatment of Coal Mine Drainage, USDI, Bureau of Mines Information Circular IC 9389, Pittsburgh, PA.

Hedin, Robert, 2002. Personal communication.

Huntsman, B.E., J.G. Solch, and M.D. Porter, 1978. Utilization of Sphagnum Species Dominated Bog for Coal Acid Mine Drainage Abatement. GSA (91st Annual Meeting) Abstracts, Toronto, Ontario.

ITRC (Interstate Technology & Regulatory Council). 2003. Technical and Regulatory Guidance Document for Constructed Treatment Wetlands. Interstate Technology & Regulatory Council, Wetland Team. www.itrcweb.org.

ITRC (Interstate Technology & Regulatory Council). 2010. Abandoned Coal Mine Site, Tennessee Valley Authority, Alabama. Mine Waste Treatment Technology Selection Website. Washington, D.C.: Interstate Technology & Regulatory Council, Mining Waste Team. www.itrcweb.org.

ITRC (Interstate Technology & Regulatory Council). 2013. Biochemical Reactors for Treating Mining Influence Water. Interstate Technology & Regulatory Council, Mining Waste Team. www.itrcweb.org.

Kadlec R.H. and R.L. Knight, 1996. Treatment Wetlands. CRC/Lewis Publishers, Boca Raton, FL, 1996.

Lang, Gerald, R. K. Wieder; A. E. Whitehouse, 1982. "Modification of Acid Mine Drainage in Freshwater Wetland", in Proceedings of the West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, WV. April.

Langmuir, D., Mahoney, J., MacDonald, A., and Rowson, J., 1999. Predicting Arsenic Concentrations in the Pore Waters of Buried Uranium Mill Tailings. In: Tailings and Mine Waste '99, Balkema, Rotterdam, ISBN 9058090256 pp. 503-514.

MacDonald, R. J., K. E. Hague, and J. E.Dutrizoc. 1976. Copper recovery from copper-bearing peat moss. Miner. Res. Program, Miner. Science Lab. Report No. MRPjmSC 76-275 (IR).

Means B., Rose A., (2005). "Rate of Manganese Removal in Limestone Bed Systems" Paper was presented at the 2005 National Meeting of the American Society of Mining and Reclamation, Breckenridge, CO, June 19-23, 2005. Published by ASMR, 3134 Montevesta Rd., Lexington, KY 40502.

Robbins, Eleanora I., D. L. Brant and P. F. Ziemkiewicz, 1999. "Microbial, Algal and Fungal Strategies for Manganese Oxidation at a Shade Township Coal Mine – Somerset County, Pennsylvania". In Proceedings of the 16th Annual Meeting, ASSMR, Scottsdale, AZ, August 13-19.

Rose, Arthur W., P.J. Shah and B. Means, 2003. Case Studies of Limestone-Bed Passive Systems for Manganese Removal from Acid Mine Drainage. Presented at the 2003 National Meeting of the American Society of Mining and Reclamation and the 9th Billings Land Reclamation Symposium, Billings MT, June 3-6, 2003. Published by ASMR, 3134 Montevesta Rd., Lexington, KY 40502.

Salmi, M., 1955, Prospecting for bog-covered ore by means of peat investigations. Geol. Surv. Finland Bull 168, 34 pp.

Salmi, M., 1959, On Peat-Chemical Prospecting in Finland. International Geological Congress, 20th, 1956, Sym.De Exploration Geoguimica, Torno 2, pp. 243-254.

Sobolewski, A., 1997. The Capacity of Natural Wetlands to Ameliorate Water Quality: A review of Case Studies. Presented at: Fourth International Conference on Acid Rock Drainage May 31-June6, 197, Vancouver, B.C., Canada.

Tebo, B.M. et al., 2004. Biogenic Manganese Oxides: Properties and Mechanisms of Formation. Annu. Rev. Earth Planet. Sci. 32, 287–328

Wildeman, Thomas R., G. A. Brodie, and J. J. Gusek, 1993. Wetland Design for Mining Operations. BiTech Publishing Co., Vancouver, B.C. Canada.

Wildeman Thomas R., and M. Pavlik, 2000. "Accumulation of Metals in a Natural Wetland that Receives Acid Mine Drainage" in Proceedings of the 5th International Conference on Acid Rock Drainage, Denver, CO. May 21-24.

ATTACHMENT A

TECHNICAL PAPERS

LEGEND

- EXISTING GROUND TOPOGRAPHY CONTOURS (REFS. 1 AND 2)
- GAS PIPELINE BUFFER ZONE – 200m ON EITHER SIDE OF ALIGNMENT (REF. 3)
- VOROTAN RIVER BUFFER ZONE – 200m ON EITHER SIDE OF ALIGNMENT (REF. 3)
- SPANDARYAN–KECHUT TUNNEL BUFFER ZONE – 3km ON EITHER SIDE OF TUNNEL ALIGNMENT (REF. 4)
- PROJECT LICENSE BOUNDARY (REF. 3)
- PROVINCIAL BOUNDARY (REF. 3)
- SETTLEMENT 1km BUFFER ZONE LIMIT (REF. 4)
- EXISTING GNDEVAZ CHANNEL (REF. 3)
- EXISTING OVERHEAD POWERLINE (REFS. 2 AND 3)
- EXISTING HIGHWAY/VILLAGE ROAD (REFS. 4 AND 5)
- EXISTING UNPAVED ROAD (REFS. 2 AND 3)
- EXISTING DRAINAGE (REFS. 2 AND 3)

NOTES

REFERENCES

1. 5m CONTOUR INTERVAL TOPOGRAPHY FOR THE AMULSAR PROPERTY RECEIVED FROM SGS ON 21 JAN. 2014.
2. 1m CONTOUR INTERVAL TOPOGRAPHY FOR THE SITE 28 AREA RECEIVED FROM LYDIAN ON 17 DEC. 2013. 5m CONTOUR INTERVAL TOPOGRAPHY SHOWN FOR CLARITY.
3. AMULSAR PROPERTY FEATURES RECEIVED FROM SGS ON 22 JAN. AND 5 FEB. 2014.
4. AMULSAR PROPERTY FEATURES RECEIVED FROM LYDIAN ON 30 JAN. AND 1 FEB. 2014.
5. HIGHWAY ALIGNMENTS RECEIVED FROM WAI ON 5 FEB. 2014.
6. SGS SITE PLAN RECEIVED ON 18 APR. 2014.
7. DATA FROM AMC RECEIVED ON 10 APR. 2014.

SCALE IN METERS
CONTOUR INTERVAL: 5m

750 0 750 1500 3000

DRAFT