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Evaluation of Hydrogeochemical Issues Related to Development of the Amulsar Gold Project, Armenia: Key Assumptions and Facts

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Key Assumptions and Facts about the Amulsar Project, Armenia

The Amulsar Gold Project is slated to become the largest mine in Armenia, with at least two open pits over 200 meters deep, 302 million tons (Mt) of waste rock, and a 112-hectare cyanide heap leach facility (HLF). The acid-generating, waste rock storage facility would be in the same watershed as the Kechut Reservoir, which is hydrologically connected to Lake Sevan by the Spandaryan-Kechut (SK) tunnel, and the facility is proposed to be in the buffer zone of the tunnel, where the placement of processing facilities and the use of hazardous chemicals are prohibited (ESIA, 2015, p. 3.26; Lydian, 2017, p. 26). The project area includes key biodiversity areas for birds, three protected state sanctuaries, and critical habitat for a rare plant (*P. porphyrantha*) and brown bear. Yet this acid-generating, cyanide-consuming, large-scale project of high environmental consequence is proposed to be managed by a company that has never operated a mine. On a recent tour of the site with Armenia's Minister of Economic Development and Investments, Lydian's Managing Director emphasized their commitment to build and operate an exemplary project, in line with international standards.[1] The company has put an independent advisory council in place and produced an Environmental and Social Impact Assessment (ESIA) and numerous management plans. However, missing baseline information and management methods that fall below a state-of-the-art approach raise questions about the environmental performance of the project. Numerous shortcomings need to be remedied before project approval should be considered. The following discussion highlights six key assumptions promoted by the company and the technical basis for public concern.

The report focuses on hydrogeochemical issues related to the proposed Amulsar Project, especially the results of geochemical characterization and testing. The 2015 ESIA contained an appendix in Chapter 4, Appendix 4.6.2: Geochemical Characterization and Prediction Report – Update, that contained numeric results of many of the geochemical tests. This appendix is missing from the 2016 ESIA, as is the fully updated ARD characterization report by GRE, which is supposed to be in Appendix 15 in the 2016 ESIA. Best or leading practice in mining dictates that data should not be excluded from public review, and transparency of information should be promoted. Results from the 2015 ESIA's Appendix 4.6.2 are used throughout this report. The documents reviewed are listed at the end of the report.

1. The mine will never require active treatment.

Acid mine drainage (AMD) is the most environmentally damaging water quality problem associated with metal mining,[2] and it can require management and treatment in perpetuity. AMD is still being generated from mining of the Amulsar deposit 60 years ago (ESIA, Appendix 4.6.2, p. 41). Mines that operated during the Bronze Age in Spain and 500 years ago in Bolivia are still producing acid drainage.[3] The potential effects of AMD from mining of the Amulsar Project include: acidic, metal-laden pit lakes that will attract terrestrial wildlife and birds after closure; contaminated rivers, springs, and groundwater; and leachate from the barren rock storage facility (BRSF) that could reach Lake Sevan through the S-K tunnel. The first project risk listed in Lydian (2017, Table 25.5) is potentially acid-generating (PAG) rock;

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[1] https://www.lydianarmenia.am/en/news/view/minister-visit.html

[2] See, e.g., U.S. Department of Agriculture, Forest Service, 1993. Acid Mine Drainage from Impact of Hardrock Mining on the National Forests: A Management Challenge. https://archive.org/details/CAT31108485

[3] See, e.g., Davis et al., 2000. Rio Tinto estuary (Spain): 5000 years of pollution. Environmental Geology 39, (10) 1107-1116. http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1157&context=gly_facpub. Strosnider et al., 2007. A legacy of nearly 500 years of mining in Potosi, Bolivia: Acid mine drainage source identification and characterization. Proceedings America Society of Mining and Reclamation, 2007 pp 788-803. http://www.asmr.us/Portals/0/Documents/Conference-Proceedings/2007/0788-Strosnider.pdf

this table is a compilation of economic risks, and it demonstrates that this issue could negatively impact the viability of the project. The risk mitigation listed in Table 25.5 misses the most important and uncalculated cost related to PAG rock: the need to design and build an active treatment plant.

The Amulsar Project has all the elements of a mine that will adversely affect water quality:

- The acid-base accounting (ABA) test results show that the rock is PAG with little to no neutralizing ability.
- The short-term leach and kinetic testing results show that acid is produced quickly and metals and other contaminants are leached rapidly and under variable pH values, including under neutral pH conditions.
- The proposed mine and its planned facilities are close to water resources – both surface water and groundwater – and the waters provide drinking water for the country.

According to a study by James Kuipers and myself that compared water quality predictions in Environmental Impact Statements (EISs) with actual water quality resulting from mining,[4] approximately 75% of large-scale metal mines in the United States caused exceedences of water quality standards. The vast majority of these mines stated in their EISs that exceedences would not occur. For mines with moderate to high acid drainage and contaminant leaching potential and close proximity to water, 85% of mines exceeded water quality standards in surface water and 93% exceeded standards in groundwater. The primary reason for failure to protect water quality was the failure of mitigation measures. These mines did use mitigation measures to prevent water quality impacts, including liners, treatment, and encapsulation of PAG rock, but they failed in 64% of the cases. The study found that the use of multiple mitigation measures was most effective at preventing water quality impacts. The Amulsar Project is not proposing the use of multiple mitigation measures under the waste rock facility; instead, for example, a simple clay liner is proposed rather than a synthetic liner with an underdrain system.[5] No active water treatment is proposed during operations or closure.

Spent ore is a potential source of acid drainage during and after closure, but Lydian (2017) states that it has a low risk to produce acid based on the generally low sulfide content, the fact that it will be UV rock, and that there will be alkalinity added to the heap during operations (p. 354). This statement is based on only 13 ABA and short-term leach tests for 142 Mt of ore. No mineralogy or kinetic testing was reported (Lydian, 2017, Table 24.1). Samples with low sulfide content can and do produce acid drainage, especially when the neutralization potential (NP) is low. For example, Lapakko and Antonson (1994) observed that samples from the Duluth Complex with %S values from 0.41 - 0.71% produced pH values from 4.8 to 5.3, and samples with %S values from 1.12 - 1.64% produced pH values of 4.3 to 4.9 after 150 weeks.[6] Tables 24.5 and 24.6 in Lydian (2017) show that the acid-generation potential (AP) exceeds the NP in all but one spent ore sample, often by over 10 times, including for three of the seven Erato samples. Although the samples generally have low sulfide content (<0.01 to 1.13% sulfide sulfur), the

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[4] Kuipers, J.R. and A.S. Maest, 2006. Comparison of Predicted and Actual Water Quality at Hardrock Mines: The Reliability of Predictions in Environmental Impact Statements. Prepared for Earthworks, Washington, DC. https://www.earthworksaction.org/library/detail/comparison_of_predicted_and_actual_water_quality_at_hardrock_mines/#.WTWhSevyupp

[5] ESIA, Appendix 8.19, Acid Rock Drainage Management Plan, does propose a clay liner under the BRSF but no synthetic liner and no leachate collection system.

[6] Lapakko, K.A. and Antonson, D.A., 1994. Oxidation of sulfide minerals present in Duluth Complex Rock: A laboratory study. In: Environmental Geochemistry of Sulfide Oxidation, C.N. Alpers and D.W. Blowes, eds. American Chemical Society Symposium Series 550, 593-607.

NP:AP ratios for the samples (not shown in Tables 24.5 and 24.6), are all well below 1 in 12 of the 13 samples. Therefore, by their own measure, the spent ore is PAG. In addition, the limited results from short-term and kinetic leach tests and bulk chemistry of UV rock show a potential to leach metals and metalloids that poses a threat to groundwater and nearby surface water. More testing is clearly needed, but the limited results so far indicate that the spent ore does have the potential to generate acid after mining stops, and only passive treatment is proposed during closure.

The Environmental and Social Impact Assessment (ESIA)[7] contains a report in Appendix 4.6.2 that discusses geochemical issues related to the project.[8] The report underplays the importance of AMD by dividing it into different categories – mild, moderate, and severe – that they associate with different pH values (generally >4.5, <4.0, and <3.0, respectively). The implication is that mine drainage with a pH of 4.5 is acceptable. The GARD Guide uses a cut-off of pH 6 for acid drainage.[9] To estimate the acid drainage potential of Amulsar rocks, ABA and humidity cell testing were conducted. The ABA tests are static tests that measure the total possible acid-generation and acid-neutralization potential of a material, assuming that all acid-generating and -neutralizing minerals dissolve completely and are in contact with each other. Kinetic testing, including HCTs, is a better (but not perfect) estimation of whether a material will produce acid and leach other contaminants under field conditions. The appropriate length of an HCT depends on many factors, including the extent of weathering and the availability and ratio of acid-producing and neutralizing minerals. Lydian (2017) states that "It is generally accepted that a year of kinetic cell testing can prove beyond reasonable doubt that a rock sample will or will not generate acid." (p. 357). This strong statement is not supported by any information in the literature. For example, Lapakko (2003) demonstrated that a tailings sample with 1.3 wt % calcite and 6.6 w t% pyrite generated circumneutral drainage for 112 weeks before generating acidic drainage, and that a mixture of rotary kiln fines and rock with 2.1 wt% sulfur from the Duluth complex had a lag time of 581 weeks before it started producing acid.[10] In addition, only two of their eight HCTs lasted for one year or longer.

The Amulsar wastes from the 1950s and three of the Lower Volcanics (LV) humidity cell samples are described as having "ferric iron resistance," (SEIS, Appendix 4.6.2, p. 39 and 44)[11] or resistance to creating more severe AMD. Instead of showing resistance to severe acid production, the pH of leachate from one of the historic sites (Site 27), was 3.28 (SEIS, Appendix 4.6.2, Table 8-2). The ESIA later erroneously states that metal leaching only occurs at severely low pH values, which they say is "rare" at the site (Appendix 4.6.2, p. 45). The three LV HCTs that had pH values above 4.5 (at least for the duration of the relatively short HCTs) were the samples that had lower pyritic sulfur percentages, as did the historic wastes. This is not a magical quality called "ferric iron resistance." It is instead related to the relative amounts and availability of reactive sulfide and neutralizing material.

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[7] Amulsar Gold Mine Project Environmental and Social Impact Assessment, February 2015.

[8] Amulsar Project Geochemical Characterization and Prediction Report – Update. 31 August 2014.

[9] www.gardguide.com/index.php?title=Chapter_2

[10] Lapakko, K.A., 2003. Developments in Humidity-Cell Tests and Their Application. Chap 7 in Jambor, Blowes and Ritchie, eds., 2003. Environmental Aspects of Mine Wastes, MAC, Short Course vol. 31, p. 147-164.

[11] At pH values below 4, ferric iron (oxidized dissolved iron, Fe^{3+}) can oxidize pyrite and generate even more acidity than oxygen-oxidized pyrite, but oxygen still drives the AMD process and is needed to generate Fe^{3+} (see Nordstrom and Alpers, 1999. Geochemistry of acid mine waters. https://www.researchgate.net/publication/236246844_Geochemistry_of_acid_mine_waters)

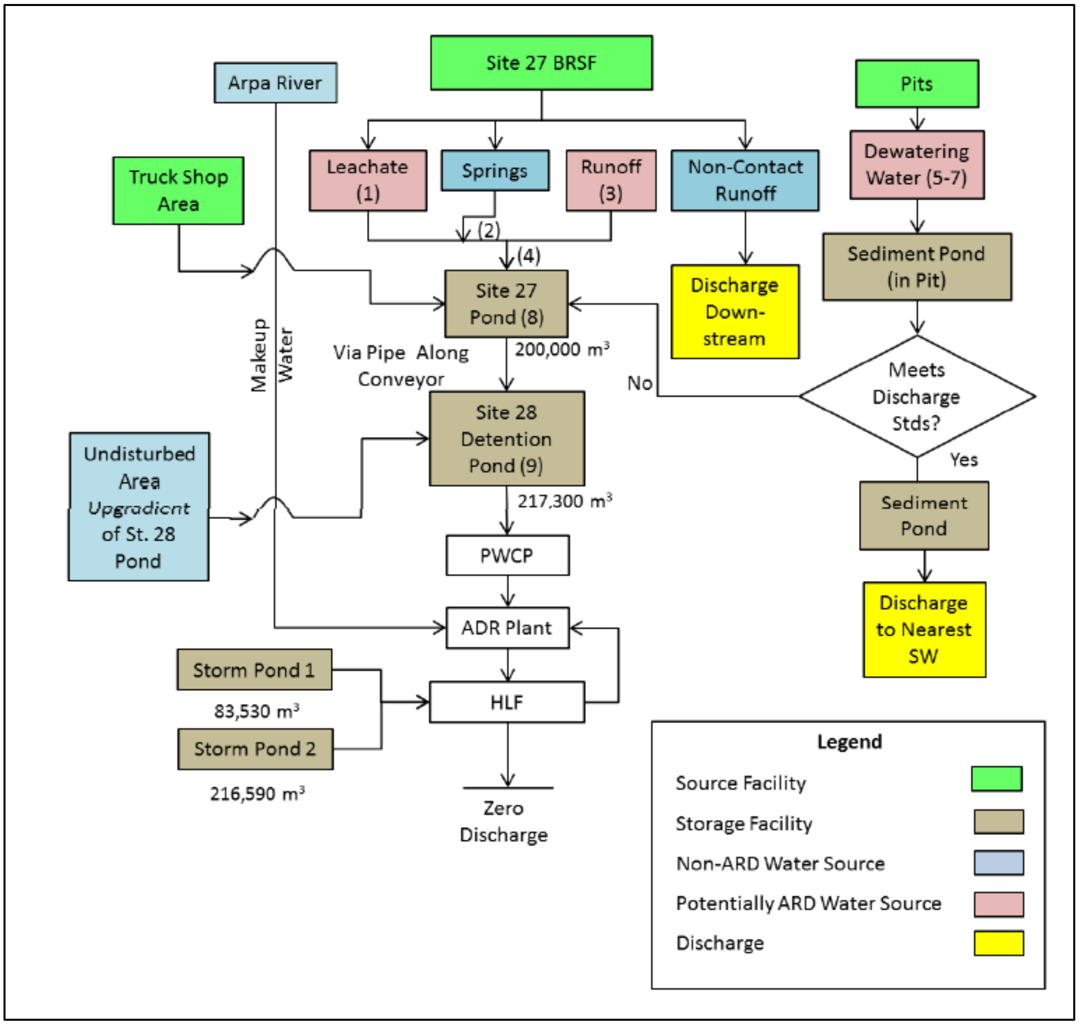

Figure 1. Acid drainage management plan schematic during operations. Note that no treatment is proposed during operations for acidic drainage generated by the mine. During mining, acidic drainage will be generated by the barren rock storage facility (waste rock dump; BRSF), the pit walls, and damaged rock affected by blasting of the pits. During closure/post-closure, the spent ore in the heap leach facility is also a potential source of acid drainage, but only passive treatment is proposed during closure, and no testing of water is proposed before discharging passively-treated water during closure.

ARD = acid rock drainage; BRSF = barren rock storage facility; PWCP = process water conditioning plant; ADR = adsorption desorption recovery plant; HLF = heap leach facility.
Source: Lydian, 2017, Figure 24.5.

The ESIA cautions against using the results of the 1950s waste piles to make inferences about the behavior of a developed Amulsar Mine (Appendix 4.6.2, p. 41-43). Clearly, a few samples from historic wastes should not be used to make inferences about a large-scale mine with an open pit and orders of magnitude larger waste rock piles. Nonetheless, this “resistance” is taken into account in the design of the AMD management plan (Figure 1), which may explain why the company felt it was unnecessary to include a treatment plant in its plans. As noted in Lydian (2017, p. 397), on-site kinetic testing is needed to evaluate whether the LV waste is “naturally-resistant to ferric iron oxidation ARD reactions.” Given that only five samples of LV wastes were subjected to kinetic testing, and two had pH values well below

4.5, it is incorrect to suggest that the LV wastes will not produce severe AMD and to base a treatment design on this belief. More geochemical testing of LV samples is needed to improve the characterization of the material and better evaluate its long-term environmental performance.

Instead of active treatment, passive treatment is proposed during closure when a mine is most likely to require extra care, show impacts, and have fewer personnel on site. Lydian (2017, p. 397) notes that no studies have been performed to evaluate the performance of a passive treatment system, and bench- and pilot-scale testing must be performed during final design. Instead, this testing should be conducted as soon as possible because if the passive approach fails, which I believe it will, a completely new and significantly more expensive active treatment plant must be designed, built, and tested well in advance of mine construction. No active metal mine in the United States with AMD that I am aware of uses only passive treatment – active management and treatment are needed certainly during operation and usually during closure. Some mines with AMD – such as the Golden Sunlight Mine in Montana, USA, and the Tyrone and Chino Mines in New Mexico, USA – are require by state governments to provide perpetual water collection and active treatment. The Amulsar Project needs an active treatment plant during mining and likely during closure, and given the mix of constituents, including metals, metalloids, sulfate, mercury, and nitrate/ammonia, a reverse osmosis plant should be required.

2. No groundwater pumping will be needed to keep the pits dry during mining, and no mine-influenced water will be released to the environment.

According to the results of groundwater modeling, no groundwater will flow into the pits during mining (ESIA, 2015, p. 3.67). However, a comparison of ground surface elevation on the sides of the pits vs. measured depth to groundwater shows that bedrock groundwater could easily flow into the pits during mining (Figure 2). As noted in the ESIA (p. 4.8.36), groundwater discharge occurs even at high elevations on Amulsar Mountain, and the water table is close to the surface near the ore bodies, which is where the pits would be located. Groundwater elevation varies seasonally, with up to 48 m of variability in unaltered LV rocks and in the HLF area (ESIA, Table 4.8.*7*). Hydraulic conductivity is also described as "highly variable," and numerous faults have been identified near the ore bodies (ESIA, Appendix 4.8.7, Drawing 4.8.4).

The Amulsar ARD management plan proposes to operate the mine as a zero-discharge facility (ESIA, Appendix 4.6.2, p. 2). A zero-discharge mine is one in which all water that comes in contact with mined materials, including dewatering water, is used in mine processes or stored on the site. In other words, no mine-influenced water is discharged to the environment during operations. The conclusion that a mine will be a zero-discharge facility (even for one part of the mine) must depend on a reliably conducted water balance that considers all possible water inputs, flows, and discharges; takes seasonal and interannual variability in groundwater elevations, precipitations, and streamflows into account; and accounts for engineering and other uncertainties. A thorough present-day water balance that does not consider mining inflows and uses is presented in the ESIA, Chapter 4.8, and a mine site water balance is presented in Appendix 6.10.1 of the ESIA. However, one of the assumptions about pit dewatering in the model is that all pit water comes from snow and rain running into the pits or falling onto the pits as direct precipitation. This water is assumed to be influenced by acid drainage. The approach further assumes that the only groundwater possibly entering the pits would be "perched" water rather than bedrock groundwater, and this "perched" water is not a significant long-term source of water (Appendix 6.10.1, p. 12). These assumptions ignore the possibility of groundwater entering the pit during the

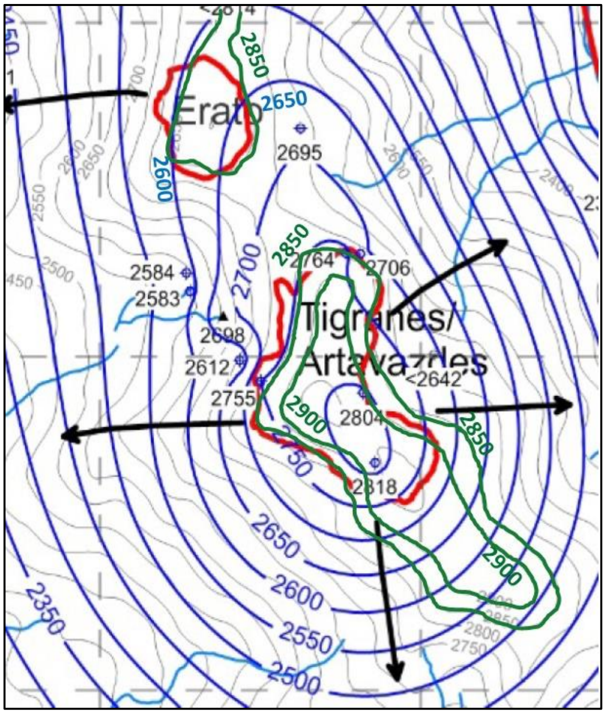

Figure 2. Average Groundwater elevations (in blue contours) and topography (in light gray contours, highlighted in dark green near the pits). The edges of the Tigranes/Artavazdes pit are close to 2850 m elevation. The maximum pit depth is expected to be 270 m, which would put the bottom of the pit at 2600 m (2850 – 270 = 2580 m). Two wells inside the pit had higher average groundwater elevations of 2804 and 2818 m, which indicates that groundwater could easily flow into the pit. The edges of the Erato pit are also at approximately 2850 m elevation. The anticipated maximum pit depth is 225 m, which would put the bottom of the pit at 2625 m (2850 – 225 = 2625 m). No wells are located in the pit, but a well just outside the pit had a higher average groundwater elevation of 2695 m, and the 2650 m average groundwater elevation contour, which is 25 m above the pit boundary, crosses the pit outline, indicating that groundwater could also flow into the Erato pit during mining. The figure shows average groundwater elevation, and levels would be substantially higher seasonally.

Source: Modified from Figure 4.8.13, ESIA, Chapter 4.

springtime, when water levels in many wells are much higher, and the movement of groundwater along faults. As noted in Lydian (2017; p. 397), “Site runoff, evaporation, seep and spring flow, surface water flow, and pit dewatering models all require additional model verification against field data.” Special attention is needed on pit dewatering, which is currently and erroneously assumed to only include pumping of pit runon and direct precipitation. Additional seasonal data and additional wells or piezometers are needed around the planned outline of the pits to evaluate the likelihood of bedrock groundwater inflow to the pit during mining. Such a water balance study will cost in excess of the $100,000 proposed in Lydian (2017, p. 397).

The ESIA states that no mine contact water will be discharged during mining (ESIA, Appendix 4.6.2, p. 2). Yet major uncertainties exist about water use, faults, preferential flow paths, groundwater inflows, and transport of mine-influenced water during operation. The only possible way the mine could not require active treatment, and even this is uncertain, is if no groundwater will need to be pumped (dewatered) from wells outside the pits to keep the pits dry during mining. In the likely event that groundwater will need to be pumped to keep the pits dry, a full-scale reverse-osmosis treatment plant will need to be constructed before mining begins. Neither the ESIA nor any other mine document contains a contingency plan for construction or use of a treatment plant during mining.

3. The mine plan is firm and includes biodiversity set-asides.

When a government authority grants a mining permit and an environmental license, it should be based on a well-designed mine plan. If the mine plan changes substantially, the agency must review the changes and consider the revised mine plan and any additional social and environmental effects. The Project Description in the ESIA (Chapter 3) only mentions mining of the "Artavazdes and Tigranes areas" and the Erato open pit (ESIA, p. 3.3). It further states that the Arshak deposit, which is on the southeast side of the proposed Tigranes/Artavazdes (Tig/Art) pit, will not be mined because it is a biodiversity set-aside area (ESIA, p. 3.18). Appendix 4.6.2 of the ESIA, the updated Geochemical Characterization and Prediction Report, however, states that "more recent mine planning" has expanded the combined Tig/Art pit and added the Arshak pit area (Appendix 4.6.2, p. 4). The report further notes that the Arshak pit walls will remain exposed (not backfilled) during closure (Appendix 4.6.2, p. 45), that all pits will be dewatered during mining, including the Arshak "sub-pit" (p. 56); a schematic that shows how the Arshak Pit will be mined is shown in Appendix 4.6.2, Figure 10-7.

The discrepancies noted raise questions about what has been agreed to in the granting of a mining permit, how the mitigation measures and compensations have been calculated, and how potential impacts of the mining operations have been evaluated. It also demonstrates how mine plans can change over time, almost always as expansions. The company should clarify whether the mining of the Arshak deposit has been included in the mine application, and if it hasn't but it is proposed to be mined, a revised ESIA should be produced that evaluates all effects of the additional disturbance.

4. Mercury emissions will not be a concern during or after mining.

Mercury is present in the ore and waste rock and will be present in leach solutions (pregnant and barren), which could leak from the HLF to groundwater and affect surface water. Mercury vapor emissions from the cyanide heaps, especially operating heaps, are known to occur at other gold mines around the world but are ignored in this mine project.[12] In addition to heaps, carbon adsorption columns, carbon regeneration kilns, and mercury retorts are among the primary sources of mercury exposure at mines with mercury in gold ore.[13] Emissions could adversely affect surrounding streams and vegetation via aerial deposition and reach the lake and would affect employees, many of whom come from local communities and would work near the heaps and in the gold room. Because of the strong complexing of mercury with cyanide[14] and the relatively high concentrations of mercury in the ore, enough mercury is expected to be in the cyanide solution that a mercury retort is planned for removal of mercury (Lydian, 2017, p. 145). No viable market exists for mercury that does not send the substance to artisanal gold miners. Leading practice for mining companies is to manage any captured mercury in a

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[12] Eckley et al., 2011. Scaling Non-Point-Source Mercury Emissions from Two Active Industrial Gold Mines: Influential Variables and Annual Emission Estimates. Environmental Science and Technology, 45 (2), 392-399. Abstract: http://pubs.acs.org/doi/abs/10.1021/es101820q; Eckley et al., 2011. Measurement of surface mercury fluxes at active industrial gold mines in Nevada (USA). Science of the Total Environment 409 (3), 514-522. Abstract: http://www.sciencedirect.com/science/article/pii/S0048969710011095.

[13] U.S. Department of Labor, Mine Safety and Health Administration. Controlling mercury hazards in gold mining: A best practices toolbox. https://arlweb.msha.gov/s&hinfo/mercury/hgmain.htm

[14] Flynn and Haslam, 1995. Cyanide Chemistry - Precious Metals Processing and Waste Treatment. Information Circular 9429, U.S. Bureau of Mines, U.S. Dept. of Interior.

manner that protects human health and the environment along the entire supply chain, and this adds to the overall costs of the project.

Mercury was largely ignored in geochemical testing and water quality predictions. For example, mercury concentrations were not predicted for seepage water quality (ESIA, App. 4.6.2) from the following facilities: the BRSF (Tables 10-1 and 11-1), the Detention Pond during operations (Table 10-5), or the Tig/Art backfill or seepage from the Erato pit (Table 11-2 and 11-4). However, a mercury concentration of 28 μg/L was predicted in HLF drain-down water from the HLF after detoxification (Table 11-5); this value is over 10 times higher than the US drinking water standard and the World Bank discharge standard for mercury. The Lydian (2017) report also noted that trace levels of mercury were present in column leach studies, especially for the Erato ore samples, and that mercury and copper can be retained on the activated carbon in the gold recovery circuit (p. 145). The amount of mercury and other constituents loaded onto the column is shown in Table 1.

Table 1. Elements loaded onto activated carbon as part of the cyanide process

Sample	Ag ppm	Cu ppm	Fe %	Pb ppm	Zn ppm	Hg ppm	Se ppm
MC 068	1.73	200.0	8.92	27.7	15	1.9	5
MC 070	2.30	92.3	6.23	27.5	0	1.9	7
MC 070	2.19	142.5	4.38	36.9	5	1.2	4
MFP	1.41	166.5	5.86	21.9	14	3.0	9
Gossan	2.74	510.0	27.70	5,380.0	71	2.5	6
Fault Gouge	2.07	145.5	8.42	1,165.0	1	1.5	9
Siliceous Breccia	1.71	88.1	2.36	78.3	4	0.9	2

Source: Lydian, 2017, Table 13.45

To reactivate the carbon, it is heated in a kiln to between 550 to 700°C (Lydian, 2017, p. 259-260). The kiln converts mercury to elemental mercury, which is volatile, and purges the kiln discharge through a quench tank, which, unless it is captured, will allow the volatile mercury to escape from the water and be released to the atmosphere. Estimates should be made of the amount of mercury released to the atmosphere as part of the mining process, including from active heaps, carbon columns, carbon regeneration, and the mercury retort, and mercury capture methods should be proposed to limit mercury releases to workers and the environment.

5. The mine will only have a few contaminants of potential concern.

The ESIA discussed the contaminants of potential concern (COPC) for the mine and based them on short-term leach testing (SPLP, or synthetic precipitation leaching procedure) and NAG (net acid generation) testing, using undefined effluent discharge guidelines values (ESIA, Appendix 4.6.2, p. 27). The ESIA stated that it would be better to use long-term kinetic test leachate results, but the numeric values for the kinetic tests are not presented, and only limited analytes are included in Appendix E of ESIA Appendix 4.6.2. The COPCs listed varied for different sources, but the final list using this method appears to be limited to copper, manganese, and selenium, but iron, nickel, and sulfate are also mentioned, based on the results from SPLP tests (ESIA, Appendix 4.6.2, p. 39 and 28).

Additional approaches can and should be used to identify COPCs. The ESIA does compare average solid phase composition (i.e., total metals or whole rock chemistry) results to five times crustal averages, and arrives at a COPC list of antimony, arsenic, bismuth, lead, molybdenum, selenium, and silver (ESIA, Appendix 4.6.2, p. 24). In addition, results from metallurgical test work can be used to identify COPCs. As shown in Table 2, antimony, arsenic, copper, and zinc in barren leach solution (cyanide heap leach solution after gold is extracted) exceed the Arpa MAC standards by many times and often up to two to three orders of magnitude. The mercury concentration in leachate from the gossan (oxidized cap from supergene alteration most common in Upper Volcanics (UV) rocks) in Table 2 is almost 50% of the World Bank and US drinking water standard. As noted in #4 above, mercury concentrations in heap leach drain down water (which would occur upon closure) was 28 µg/L, which is over 10 times higher than international mercury water quality standards – and a mercury retort is planned for the operation, so mercury is clearly a COPC. The ESIA does not consider COPCs added by the use of blasting agents such as ammonium nitrate-fuel oil, which would add ammonia, nitrate, and oil & grease. The use of cyanide obviously adds cyanide to the list as well.

Table 2. Barren leach solution, multi-element assay results. Results in red exceed the Arpa MAC standard.

Analyte	Units	Arpa MAC Standards	MPF	FG	SB	GSN	MC 068	MC 070	MC 071
Antimony	mg/L	0.00028	0.053	0.03	0.202	0.088	0.022	0.024	0.017
Arsenic	mg/L	0.02	1.06	0.658	0.529	4.19	0.194	0.326	0.103
Copper	mg/L	0.021	0.667	0.901	0.765	1.52	0.551	0.507	0.384
Mercury*	µg/L	--	0.038	0.189	<0.010	0.93	0.017	0.042	0.044
Zinc	mg/L	0.1	0.969	1.34	0.815	2.17	0.713	0.854	0.538

Source: Lydian, 2017, Table 13.22.

**World Bank/IFC EHS Effluent Standard and the US Safe Drinking Water Act standard for mercury are 2 µg/L.*

Abbreviations: MPF=medium pervasive iron oxide; FG=fault gouge; SB=siliceous breccia; GSN=gossan; MC 068, MC070, and MC071 are composite samples from the Erato, Artavasdes, and Tigranes pits, respectively.

A re-evaluation of all the short-term leach data and humidity cell test (HCT) results in Appendices D and E of the ESIA's Appendix 4.6.2 shows that beryllium, cadmium, chromium, cobalt, and vanadium should be added to the list of COPCs. Those analytes with elevated "early flush" concentrations in HCT, such as beryllium, cadmium, copper, cobalt, and others, can easily be released from weathered barren rock or pit walls during and after operations.

No clear rules exist for identifying COPCs, but it is prudent to err on the side of identifying as many as is reasonable, based on the results of geochemical testing and knowledge about the mineralogy, alteration chemistry, baseline water quality, and chemicals used in the operation. COPCs are used to help design effective water treatment approaches, and it is important to design the method to cover contingencies in terms of potential flows and COPCs that could be encountered in operation expansions. The results can also be used to identify analytes that should have trigger levels for water quality monitoring. A more complete list of COPCs would include:

- Ammonia
- Antimony
- Arsenic
- Beryllium

- Bismuth
- Cadmium
- Copper
- Cyanide
- Lead
- Manganese
- Mercury
- Molybdenum
- Nickel
- Nitrate
- Selenium
- Silver
- Oil & grease
- Vanadium
- Zinc

Aluminum and iron are not included in this list because, although they will likely have high concentrations in mine-influenced waters, treatment plants must always consider these constituents, and they are not particularly toxic to humans or aquatic biota under most conditions.

The list of COPCs identified in the ESIA is too limited and should be expanded to include those bulleted above and should be considered in the design of treatment approaches and environmental monitoring.

6. The environmental testing was conducted on representative samples, and the results can be used to predict the environmental behavior of the operation.

The geochemical testing was not conducted on representative samples, and too few samples were subjected to testing. More detail of rock types and alteration effects is described in the metallurgical testing results, but the acid generation potential and leach tests were conducted only on two composite sample types: UV and LV. Only eight long-term kinetic tests (HCTs) were conducted, and all used only barren rock from the combined A/T pit. Additional testing should have been conducted on alteration units used in metallurgical testing (MPF, FG, SB, and GSN – see Table 2 and related discussion). Even the borrow material was divided into two test units: scoria and altered saprolitic andesite. HCTs testing was stopped before maximum or steady state contaminant concentrations were reached in samples that were known to produce acid, as shown in Figure 3. Without knowing these concentrations, reasonable estimates of the effects on nearby streams and groundwater cannot be made. Short-term leach testing was only performed on the same eight samples used for humidity-cell testing. The SPLP test produces leachate based on a high liquid:solid ratio (20:1) that may underestimate leaching potential.[15]

The amount of LV and UV rock expected to be extracted is not listed in the reports. The quantity of measured and indicated ore is estimated at 142,200,000 tonnes (Lydian, 2017, p. 37), and this material will become waste after it is leached. The amount of waste rock is estimated at 118,668,562 tonnes (SEIS, Chapter 3, p. 3.14), for a total of approximately 261 million tonnes of material extracted and placed on site. No firm numbers are used for the number of geochemical testing samples, but according to the GARD Guide, the number should depend on: (a) the amount of disturbance; (b) the compositional variability within a material type; and (c) the statistical degree of confidence that is required for the assessment.[16] As a rough example, and according to Price and Errington (1994),[17] the amount of material

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[15] Maest, A.S., J.R. Kuipers, C.L. Travers, and D.A. Atkins. 2005. Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State-of-the-Art. Earthworks, Washington, DC. Available: https://www.earthworksaction.org/library/detail/predicting_water_quality_at_hardrock_mines/#.WTWiCevyupo.

[16] GARD Guide, Chapter 4, 4.3.2.2 http://www.gardguide.com/index.php?title=Chapter_4

[17] Price, W. and Errington, J, 1994. ARD Policy for Mine Sites in British Columbia. Presented at International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of

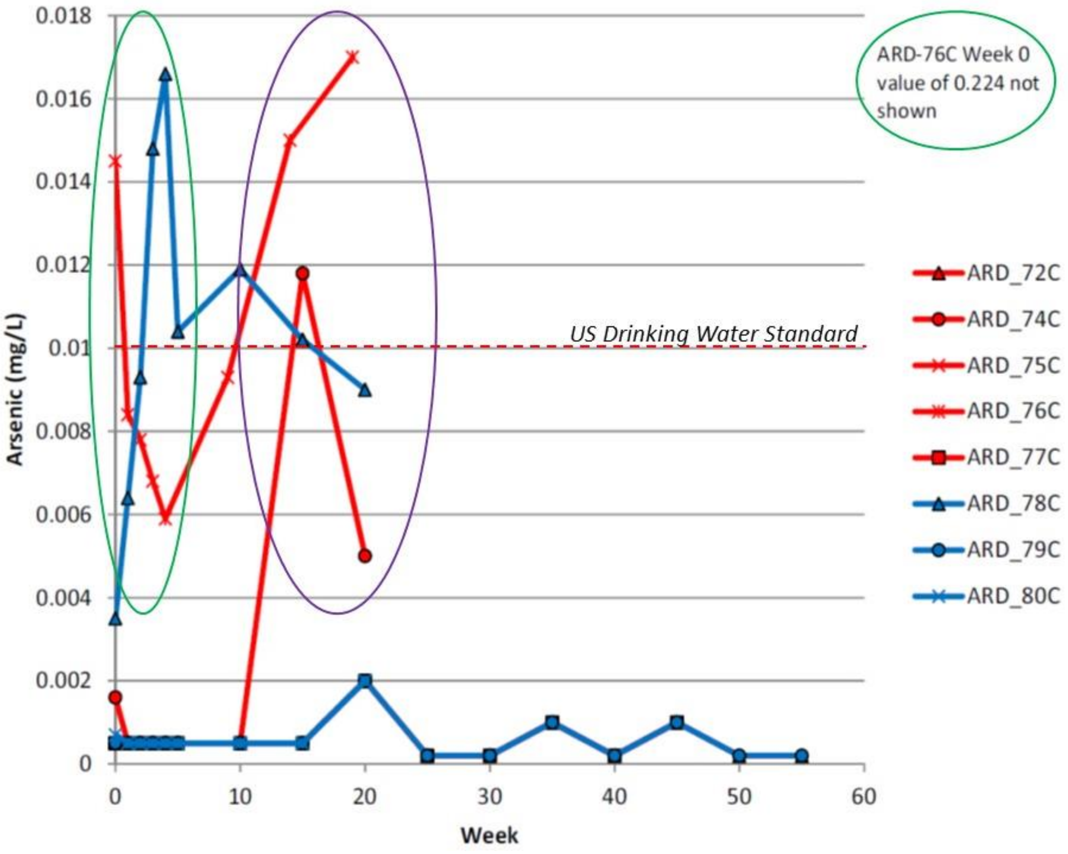

Figure 3. Humidity cell test leachate results for arsenic for barren rock from the A/T pit. Results in red are from the Lower Volcanics, and results in blue are from the Upper Volcanics. Results circled in green are "early flush" concentrations and show that weathered rocks can leach elevated concentrations of arsenic (and other contaminants) quickly. Results circled in purple show that the test was ended too early for two of the LV samples, and maximum concentrations of arsenic may not be known. See text for more detail.

Source: ESIA, Appendix 4.6.2, Appendix E, pdf p. 150.

extracted for the Amulsar Project noted above should have over 2,000 geochemical characterization samples. The number of samples subjected to geochemical testing was closer to a couple hundred than a couple thousand (see SEIS, Appendix 4.6.2, appendices). The geology, mineralization, and alteration of the deposits is quite complex, yet very few geochemical test units were identified and carried through the geochemical testing methodology. Geochemical test units are rock types of distinctive lithology, mineralogy, and/or alteration that should be as homogeneous as possible, based on the lithology, mineralogy, alteration, and the availability of minerals to weathering.[18] The wide variety in results with the UV and LV rock samples, for example in percent sulfur, is a strong indication that geochemical test units were not properly identified or used in testing. Additional geochemical testing should be conducted, including more ABA, mineralogy, and HCTs on samples from all proposed pits, waste rock,

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Acid Drainage, Pittsburgh, PA, p. 287.

[18] Maest, A.S., J.R. Kuipers, C.L. Travers, and D.A. Atkins. 2005. Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State-of-the-Art. Earthworks, Washington, DC. Available: https://www.earthworksaction.org/library/detail/predicting_water_quality_at_hardrock_mines/#.WTWiCevyupo.

and ore. Additional geochemical testing units should be identified based on mineralogy and alteration and used for all testing.

The HCTs were conducted on a small subset of the types of rock and alteration types at the site. Kinetic testing such as HCTs provide the best indication of long-term leaching of the geochemical testing conducted for the Amulsar Project. Only eight HCTs were run: five from LV and three from UV rocks. Additional HCTs should be run for at least one year, or until concentrations peak and stabilize, even if the samples produce acid rapidly. The results from the additional HCTs can be used to evaluate the "ferric iron resistance" of LV rocks proposed in the ESIA and related documents. Table 3 shows that the HCT samples were not representative of the larger UV and LV rocks in terms of mercury, antimony, arsenic, and copper content. Mercury, antimony, arsenic, and copper concentrations in the samples selected for long-term kinetic testing were not representative of the mid and higher range of values in the larger set of UV and LV rocks. Results from the HCTs, which are used to predict contaminant concentrations during and after operations, will therefore likely underestimate leaching of mine wastes.

Figure 3 shows that initial concentrations of arsenic were high in samples from both UV and LV rocks; the week zero result for LV sample ARD-76C was 0.224 mg/L arsenic, which is over 20 times higher than the US, European Union, Australian, Canadian, and South African drinking water standards.[19] The UV sample with high arsenic concentrations, ARD-78C, had very low pyritic sulfur content (0.06 %; ESIA, Appendix 4.6.2, Appendix Table A-1) but high total arsenic concentrations (601 mg/kg; ESIA, Appendix 4.6.2, Appendix B-1). These results, and those for other analytes, imply that both UV and LV rocks have a high potential to leach contaminants, regardless of their sulfide content, and must be managed in a way to isolate them from water resources. The high "early flush" concentrations are an indication of the type of water quality that could be produced repeatedly - after snowmelt or a rainstorm – from weathered materials in the BRSF, the open pits, and the HFL.[20] In addition, Figure 3 shows that LV samples ARD-76C and ARD-74C and UV sample ARD-78C were stopped too early because arsenic concentrations had not leveled off and may not have reached maximum values. Because of the short test time, we don't know how high concentrations could become under acidified conditions, and this is important information for the design of effective treatment methods and mitigation measures. The UV sample ARD-78C leached elevated arsenic concentrations under neutral pH conditions (pH values had not dropped below 6 during the test). When total arsenic concentrations are high in UV rock samples, antimony concentrations are also elevated well above average crustal abundance values. Other metals such as copper, lead, and mercury are also elevated in UV rock samples that were not subjected to humidity-cell testing.

The elevated concentrations of leachable metals/metalloids in the UV rocks, especially arsenic and antimony, suggest that even if the pH of the UV leachate is neutral, elevated concentrations of contaminant will likely be released. In turn, the "encapsulation" of PAG LV rock in "a protective rind of non-acid-generating UV waste" (ESIA, Appendix 8.19, ARDMP, p. 4) does not increase confidence that the proposed acid drainage management plan will be successful. Based on the limited long-term leach testing conducted, the use of UV rock as construction material is similarly not advised because of its strong potential to leach arsenic, antimony, and other contaminants. Additional testing is needed.

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[19] Note that the Category II Arpa MAC standard for arsenic is twice as high at 0.020 mg/L.

[20] Maest and Nordstrom, 2017. A geochemical examination of humidity-cell tests. Applied Geochemistry 81, 109–131. http://www.sciencedirect.com/science/article/pii/S088329271730197X

Table 3. Total mercury, antimony, arsenic, and copper content (mg/kg) in humidity cell test (HCT) versus non-HCT waste rock samples from Lower and Upper Volcanic rocks. All LV and UV results in bold italics were higher than those in HCT samples. The HCTs were conducted on samples that did not reflect the average or upper concentration ranges of LV or UV rocks.

	Sample Type	**Mean**	**25th Percentile**	**75th Percentile**	**Maximum**	**Count**
Mercury	HCTs - LV	0.024	0.015	0.015	0.060	5
	HCTs - UV	0.030	0.015	0.038	0.060	3
	LV	***0.115***	0.010	***0.100***	***1.54***	51
	UV	***0.099***	0.010	***0.130***	***0.510***	34
Antimony	HCTs - LV	2.14	1.00	1.00	6.70	5
	HCTs - UV	20.3	12.0	25.0	37.0	3
	LV	***83.1***	***1.09***	***28.3***	***2460***	51
	UV	***75.6***	9.50	***81.5***	***463***	34
Arsenic	HCTs - LV	8.86	5.10	7.20	23.0	5
	HCTs - UV	217	25.1	321	601	3
	LV	***82.2***	***9.50***	***111***	***601***	51
	UV	159	10.8	215	***1020***	34
Copper	HCTs - LV	52.6	27.0	68.0	106	5
	HCTs - UV	36.8	22.2	51.5	66.0	3
	LV	***119***	***36.6***	***172***	***854***	51
	UV	***254***	20.9	***77.1***	***3460***	34

Data source: ESIA, 2015, Appendix 4.6.2, Appendix B-1; LV = Lower Volcanics, UV = Upper Volcanics.

The numeric results for the geochemical testing are not included in the current ESIA. This is a transparency issue and should be remedied by including the former Appendix 4.6.2 and the numeric HCT results in a subsequent draft of the ESIA.

Summary and Recommendations

Summary

What's at Stake: The proposed Amulsar Mine in Armenia would be the largest mine in the country, with impressive reserves of gold and lesser of silver in a complex structural, hydrothermally altered, and faulted geologic setting. The area also includes important biodiversity habitat for birds, the brown bear, and a rare plant. The deposits are located in the headwaters of two watersheds that feed the Arpa and Vorotan rivers, the Kechut Reservoir, and the highly prized and protected Lake Sevan.

How Mine Contaminants Would Reach Water Resources: Mining would progress using cyanide heap leaching with ore extracted from over 200-meter deep open pits and would include a large waste rock pile and HLF. Leachate from historic mining of the deposit and the limited current-day geochemical testing results suggest that the waste rock and ore are highly acid-generating and would leach substantial amounts of metals and metalloids, including antimony, arsenic, copper, lead, nickel, selenium, manganese, and vanadium. The results to date for UV rock suggest that arsenic and antimony could be leached under neutral pH conditions. Blasting of the rock would add ammonia, nitrate, and diesel oil, and cyanide would be an additional contaminant of concern during operation and closure. The ore contains enough mercury that a mercury retort is planned for the operation, and metallurgical testing shows that water draining down from the heap leach pad after closure would contain mercury in concentrations over 20 times higher than international drinking water standards that could reach groundwater and nearby surface water. Data presented in the ESIA indicate that the spent heap materials, which are just upgradient of the Arpa River, will also be acid-generating after closure. Figure S-1 shows the groundwater flow paths that contaminants from the mine facilities would travel along after the mine is closed, which could reach the Arpa and Vorotan rivers, a tunnel that connects to Lake Seven (dashed line), and the Kechut Reservoir.

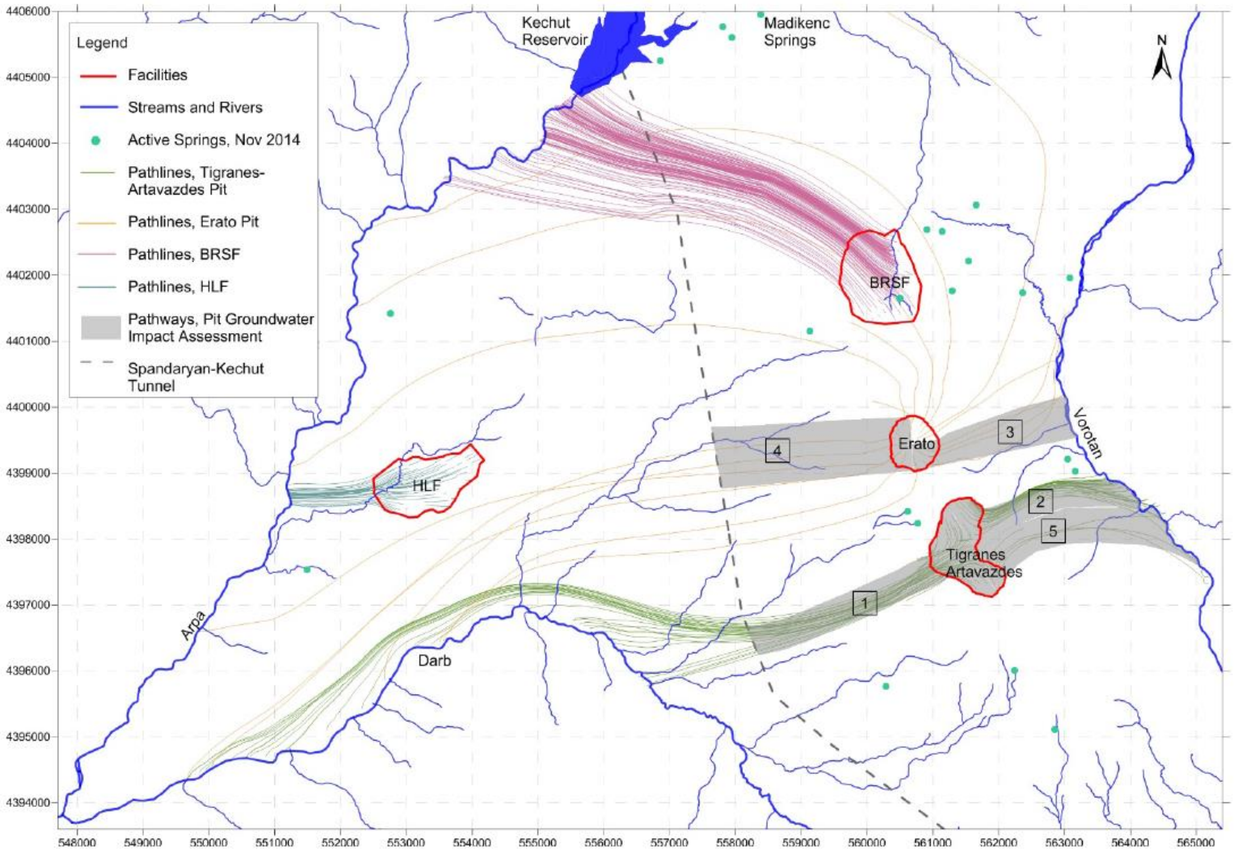

Figure S-1. Groundwater flow paths during closure.

Source: ESIA, Chapter 6, Figure 6.9.3.

<u>Inherent Characteristics and Likelihood of Affecting Water Quality</u>: The mine plan and the ESIA contain many questionable assumptions that require additional investigation before a mining permit should be considered. Although the exploitation will certainly create acid mine drainage and leach and generate contaminants of concern, no active treatment plant is proposed during operation or closure. Mines such as the Amulsar Project have a higher likelihood of adversely affecting water quality because of its high acid-generation and contaminant leaching potential and close proximity to water resources. Mines with these characteristics were found to exceed surface water and groundwater quality standards in 85% and 93% of the cases, respectively, even when using mitigation measures such as those proposed for the

Amulsar Project. The Amulsar Project falls short of leading practice in the industry because it does not propose additional mitigation measures to minimize the effects of acid drainage or treatment of any type during operations but instead assumes that the wastes will be “resistant” to the production of severe acid drainage and active treatment will not be needed.

No Mine-Related Discharges?: The mine plan and associated documents further assume that no groundwater pumping would be required to keep the pits dry during mining, even during expected extreme hydrologic and meteorologic events, and that no mine-influenced water will be discharged to the environment. The ESIA states that the only water entering the pits would be “perched” groundwater during limited times of the year, runoff, and direct precipitation falling on the pits. However, measured and interpreted average groundwater elevations are higher than the proposed bottom of the pits, and groundwater levels would be even higher following snowmelt and infiltration from large storms. It is therefore highly likely that bedrock groundwater will flow into the pits during mining and that a network of dewatering wells will need to be installed surrounding the pits. Groundwater pumped from these wells would far exceed planned capability for water use and storage capacity during operations and would need to be treated and discharged to the environment, which would make the mine a discharging project rather than a zero-discharge operation. Additional permits would be required for such discharge. In addition, major uncertainties exist about water use, faults, preferential flow paths, groundwater inflows, and transport of mine-influenced water during operation. In the likely event that groundwater will need to be pumped to keep the pits dry, a full-scale reverse-osmosis treatment plant will need to be constructed before mining begins. Neither the ESIA nor any other mine document contains a contingency plan for construction or use of a treatment plant during mining.

Mine Plan Expansion?: An expansion of proposed operations has already occurred, and more will likely occur in the near future. The Arshak deposit lies southeast of the Artavazdes and Tigranes areas, and the ESIA states in one place that it will not be mined because it will be a biodiversity set-aside area, yet in other sections of the ESIA the mining of an Arshak pit is described in some detail. Unlike the combined Tig/Art pit, the Arshak pit is not planned to be backfilled, and contaminated water would likely take the place of the biodiversity set-aside. Permits to mine must be based on a well-designed mine plan, not one with large uncertainties and internal contradictions.

Results used to Predict Mine Environmental Behavior are not Representative: The contaminants of potential concern (COPCs) that could be released to the environment as a result of mining are based on geochemical testing of an inadequate number of samples that do not represent the complexity of the deposits and surrounding rocks. In addition, six of eight HCTs were not conducted for long enough, and the samples used were not representative of the mid- and higher ranges of concentrations in the larger set of LV and UV samples. Results from the HCTs, which are used to predict contaminant concentrations during and after operations, will therefore likely underestimate leaching of mine wastes. The high “early flush” concentrations in the HCT results are an indication of the type of water quality that could be produced repeatedly - after snowmelt or a rainstorm – from weathered materials in the BRSF, the open pits, and the HLF. Properly and conservatively identifying the COPCs is important for the design of effective water treatment methods and environmental monitoring programs. No firm rules exist for the number of samples in geochemical testing programs, but a rough estimate for the amount of ore and waste produced at the Amulsar Project would suggest that at least 2,000 samples should be examined rather than the couple of hundred or less that were reported.

Not all Potential Contaminants Identified: The ESIA and associated documents failed to identify all COPCs. Mercury, which occurs in the ore and wastes, was not identified as a COPC, and neither were chemicals used for blasting or cyanide leaching. Based on a review of the available geochemical testing results, the following COPCs are expected from mining of the Amulsar deposits: ammonia, antimony, arsenic, beryllium, bismuth, cadmium, copper, lead, manganese, mercury, molybdenum, nickel, nitrate, selenium, silver, oil & grease, vanadium, and zinc.

Using Upper Volcanic Rocks for Construction: The elevated concentrations of leachable metals/metalloids in the UV rocks, especially arsenic and antimony, suggest that even if the pH of the UV leachate is neutral, elevated concentrations of contaminant will likely be released. In turn, the "encapsulation" of PAG LV rock in "a protective rind of non-acid-generating UV waste" (ESIA, Appendix 8.19, ARDMP, p. 4.) does not increase confidence that the proposed acid drainage management plan will be successful. Based on the limited long-term leach testing conducted, the use of UV rock as construction material is similarly not advised because of its strong potential to leach arsenic, antimony, and other contaminants. Additional testing is needed.

Recommendations

- An active treatment plant should be designed and tested for use during operations and likely during closure. Given the mix of constituents, including metals, metalloids, sulfate, mercury, and nitrate/ammonia, a reverse osmosis plant should be required.
- The Armenian regulatory agency should ask Lydian to demonstrate that a large-scale acid-generating mine with a heap-leach facility such as the Amulsar Project can be successfully operated and closed without harming the environment using no active treatment during operations. Such a demonstration would include three similar mines around the world that meet these criteria and that have adequate environmental monitoring to substantiate a finding of no significant adverse environmental impact.
- Additional seasonal data and additional wells or piezometers are needed around the planned outline of the pits to evaluate the potential for bedrock groundwater to flow into the pits during mining. In the likely event that groundwater will need to be pumped to keep the pits dry, a full-scale reverse-osmosis treatment plant will need to be constructed before mining begins. Neither the ESIA nor any other mine document contains a contingency plan for construction or use of a treatment plant during mining.
- The company should clarify whether the mining of the Arshak deposit has been included in the mine application, and if it hasn't but it is proposed to be mined, or if excavation of any additional areas or depths are planned, a revised ESIA should be produced that evaluates all effects of the additional disturbance.
- Estimates should be made of the amount of mercury released to the atmosphere as part of the mining process, including from active heaps, carbon columns, carbon regeneration, and the mercury retort, and mercury capture methods should be proposed to limit mercury releases to workers and the environment.
- The list of COPCs identified in the ESIA is too limited and should be expanded to include those listed above. The full list should be considered in the design of additional geochemical testing, treatment approaches, and environmental monitoring.
- Additional geochemical testing should be conducted, including more acid-base accounting, mineralogy, and humidity-cell testing on samples from all proposed pits, waste rock, and ore. Additional geochemical testing units should be identified based on mineralogy and alteration

and used for all testing. The additional HCTs should be run for at least one year, or until concentrations peak and stabilize, even if the samples produce acid rapidly. The results from the additional HCTs can be used to evaluate the "ferric iron resistance" of LV rocks proposed in the ESIA and related documents and to determine if UV rocks should be used for construction materials or instead require special handling because of their contaminant leaching potential.

- The numeric results for the geochemical testing program are not included in the current ESIA; this is a transparency issue and should be remedied by including the numeric results of all geochemical testing in a subsequent draft of the ESIA.
- The amount of LV and UV rock, and the amounts of each geochemical testing unit identified and expected to be extracted, should be calculated and included in subsequent reports.

Documents Reviewed

To conduct my review, I have reviewed all or relevant portions of the following Amulsar documents:

Amulsar ESIA, 2015: Chapter 4.6 Geology and Seismicity, Appendix 4.6.2. Amulsar Project Geochemical Characterization and Prediction Report – Update, 31 August 2014[21]

Amulsar ESIA, 2016: Chapter 3. Project Description, Chapter 4.6. Geology and Seismicity, Chapter 4.8. Groundwater, Appendix 4.8.5. Groundwater Quality, Appendix 4.8.7. Drawings, Appendix 8.1.9. Acid Rock Drainage Management Plan Report.[22]

Lydian International Limited, 2017. NI 43-101 Technical Report, Amulsar Updated Resources and Reserves, Armenia. March. Prepared by Samuel Engineering for Lydian International.[23]

About the Author

Ann Maest is an aqueous geochemist with Buka Environmental in Boulder, Colorado, USA. She has over 25 years of research and professional experience and specializes in the environmental effects of hardrock mining, the fate and transport of natural and anthropogenic contaminants, and geochemical testing methods. She has evaluated more than 150 Environmental Impact Statements for large-scale mines in the United States, Latin America, Asia, and Africa and provided training to government agencies on EIS evaluation, the environmental effects of mining, and best practices. The results of her research have been published in peer-reviewed journals including *Applied Geochemistry*, *Canadian Journal of Fisheries and Aquatic Sciences*, *Chemical Geology*, *Applied and Environmental Microbiology*, and *Environmental Science and Technology*. After completing her PhD, Dr. Maest was a research geochemist in the U.S. Geological Survey's National Research Program, where she conducted research on metal-organic interactions, metal and metalloid speciation, and redox geochemistry in surface water and groundwater systems. She has served on several National Academy of Sciences committees and a Board related to earth resources and has been an invited speaker at universities and national and international fora, including presenting on technical challenges and solutions for the mining sector at the United Nations. Ann holds a PhD in geochemistry and water resources from Princeton University.

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[21] http://amulsar.com/pdfs/Amulsar_Chapter_4.6_Geology_and_Seismicity.pdf

[22] http://www.lydianarmenia.am/en/publications.html

[23] http://www.lydianinternational.co.uk/images/TechnicalReports-pdfs/2017/Lydian_43-101_March_30,_2017.pdf

Acronyms and Abbreviations

ADR	Adsorption desorption recovery plant
AMD	Acid mine drainage
ARD	Acid rock drainage
AP	Acid-generation or -production potential
BRSF	Barren rock storage facility
COPC	Contaminants of potential concern
EIS	Environmental Impact Statement
ESIA	Environmental and Social Impact Assessment
FG	Fault gouge
GSN	Gossan
HCT	Humidity cell test
HLF	Heap leach facility
LV	Lower Volcanics
MPF	Medium pervasive iron oxide
Mt	Million tonnes
NAG	Net acid generation
NP	Neutralization potential
PAG	Potentially acid-generating
PWCP	Process water conditioning plant
SB	Siliceous breccia
SK	Spandaryan-Kechut (tunnel)
SPLP	Synthetic precipitation leaching procedure
Tig/Art	Tigranes/Artavazdes (pit)
UV	Upper Volcanics