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MEMORANDUM

To: Harry Bronozian, MS; Chemical/Environmental Engineer
From: Ann Maest, PhD; Buka Environmental
Date: 27 August 2019
Re: Review of the ELARD/TRC Independent Third-Party Review of the Amulsar ESIA: Geology and Water Resources Sections

Main Summary Points

- The ELARD/TRC Independent review ("The Review") of the Amulsar Environmental and Social Impact Assessment (ESIA) finds major errors, data gaps, and uncertainties with the geology and water resources sections of the Amulsar ESIA. In fact, it is difficult to find positive statements about these ESIA sections in the Review. Despite these shortcomings, Lydian has said the Review confirms that mining can go ahead without any impacts. The Armenian government has hired a well-qualified set of reviewers for these sections (TRC), and they need to read the Review carefully and ensure its recommendations are followed.
- The highest areas of concern are not limited to the Jermuk Springs and Lake Sevan but also include water supplies for communities, springs on and near the site, and the three rivers in the Project area – the Arpa, Darb, and Vorotan Rivers.
- It is unrealistic to assume that the Amulsar Project will not release any mine-influenced water to the environment. Water pollution will occur. A company that has never operated a mine proposes to extract, by large-scale open-pit mining, materials with high acid generation and contaminant leaching potential in the heart of Armenia's water supply system. Studies conducted on large-scale mines in the United States, most with seasoned operators, have shown that 75 to 93% of the mines have adversely affected water quality, and that mitigation measures failed at 64% of the mines. The Review concludes that mine contamination will reach groundwater.
- The Review shows that the ESIA has underestimated the acid rock drainage (ARD) and contaminant leaching potential of the Amulsar Project. It concludes that the "ARD resistance" of Amulsar rocks does not exist, and the acidic (pH 3.3) Site 27 leachate is a reasonable indicator of the potential for ARD development at the Amulsar Mine. Underestimating acid generation and contaminant leaching potential will underestimate the severity and extent of environmental impacts and result in inadequate mitigation measures, including water treatment approaches.

- The Review concludes that geologic, hydrogeologic (including the movement of contaminants along faults that the ESIA ignored), waste characterization, and water treatment studies need to be conducted before mining begins. These studies must form the basis for water quality predictions and the design of effective mitigation measures. Implementing The Review's recommended studies and mitigation measures represents substantial changes to Amulsar's mine plan and should require a Supplemental ESIA.
- Although Lydian has committed to implementing many of the recommended mitigation measures, no engineering details are provided, so outcomes are not assured. For one of the most important measures, active water treatment, Lydian proposes to skip the important characterization studies and start installing more minor mitigation measures only after water quality worsens. This approach will result in more severe environmental impacts.

Introduction

The comments contained herein address the geology and water resources sections of the independent third-party review of the Amulsar Environmental and Social Impact Assessment (ESIA; Wardell Armstrong, 2016) conducted by ELARD and TRC (2019). I have reviewed and submitted reports and memoranda on the Amulsar ESIA and many other Amulsar documents as part of the Bronozian Consultants in 2017 and 2018,[1] including the NI-43-101 document (Samuel Engineering, 2017), which The Review did not evaluate. I visited the Amulsar Project site in June 2018. My areas of specialty include geochemical characterization and the effects of hardrock mining on water quality, which relate respectively to the geology and water resources sections in The Review. I have worked for over 25 years as a researcher and consultant and hold a PhD from Princeton University in geochemistry and water resources. ELARD/TRC refer to some of my work on geochemical characterization in their review (Maest et al., 2005).

My comments on the Review focus on the potential for releases from the Amulsar Project during and after mining, acid rock drainage (ARD) and contaminant leaching potential, and the recommendations from the Review related to geology and water resources.

Technical Comments

Realistic Expectations

A company that has never operated a mine proposes to extract, by large-scale open-pit mining, materials with high acid generation and contaminant leaching potential and essentially no acid neutralizing ability in the geographic center of Armenia's water supply system. Regarding potential impacts from the Amulsar Project, the Chairman of the Investigative Committee and Prime Minister Pashinyan are applying a standard that "no contaminated water should enter the environment…not to reduce acidification, but to avoid any pollution at all" (Investigative

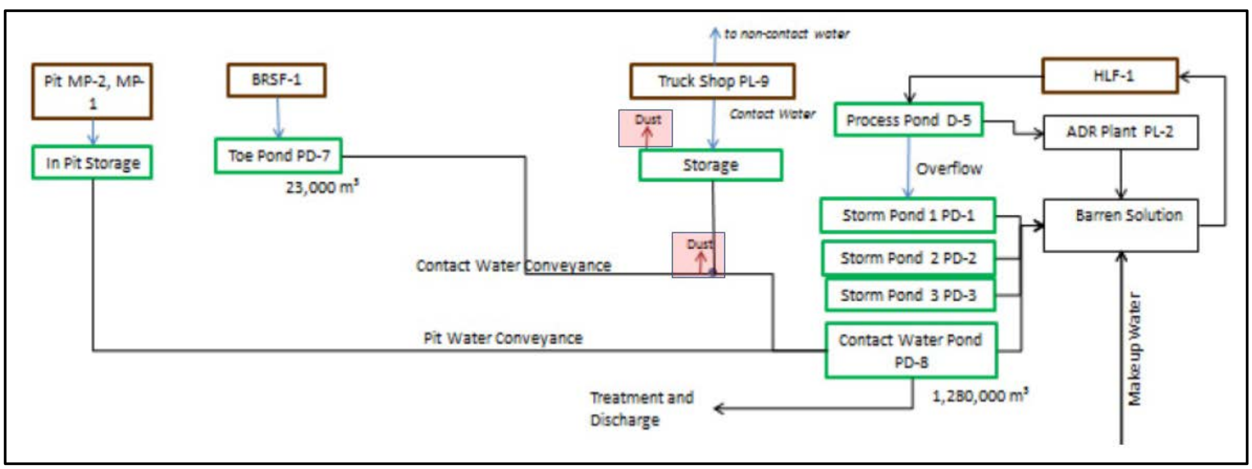
[1] See http://amulsar.com/pdfs/Bronozian-Consultants_Concerns-Consequences-Recommendations-Appendices_4Jan2017_Final.pdf for a list of reviewed documents, priority concerns, and recommendations.

Committee of the Republic of Armenia, 2019) The Review indicates that this is unlikely to happen. Armenia needs to adjust its expectations about the potential environmental outcomes of the Project. While the governmental oversight of Amulsar is an improvement over that of the existing mines in the country, it is unrealistic to assume that no pollution will enter the environment.

The Review (p. 110) states that "the ESIA/EIA incorrectly concludes that no contaminated water will reach the groundwater." Contamination of groundwater and movement into springs and surface water is one pathway for mine pollutants to reach the environment.

Lydian has committed "not to discharge any untreated contact water from the site to the environment" (Lydian Armenia CJSC, 2019). Contact water is water impacted by mining operations. Note that Lydian's wording is "discharge" rather than release. The use of the word discharge by Lydian refers to contact water they have captured, whereas release refers to uncontrolled discharges. Regarding captured contact water, Lydian's operational water balance flow chart shows that they plan to discharge untreated contact water for dust suppression (Figure 1). This constitutes a release of contact water to the environment and contravenes Prime Minister Pashinyan's condition. If Lydian no longer intends to conduct this practice, they need to indicate how they will manage the water in a supplemental EISA.

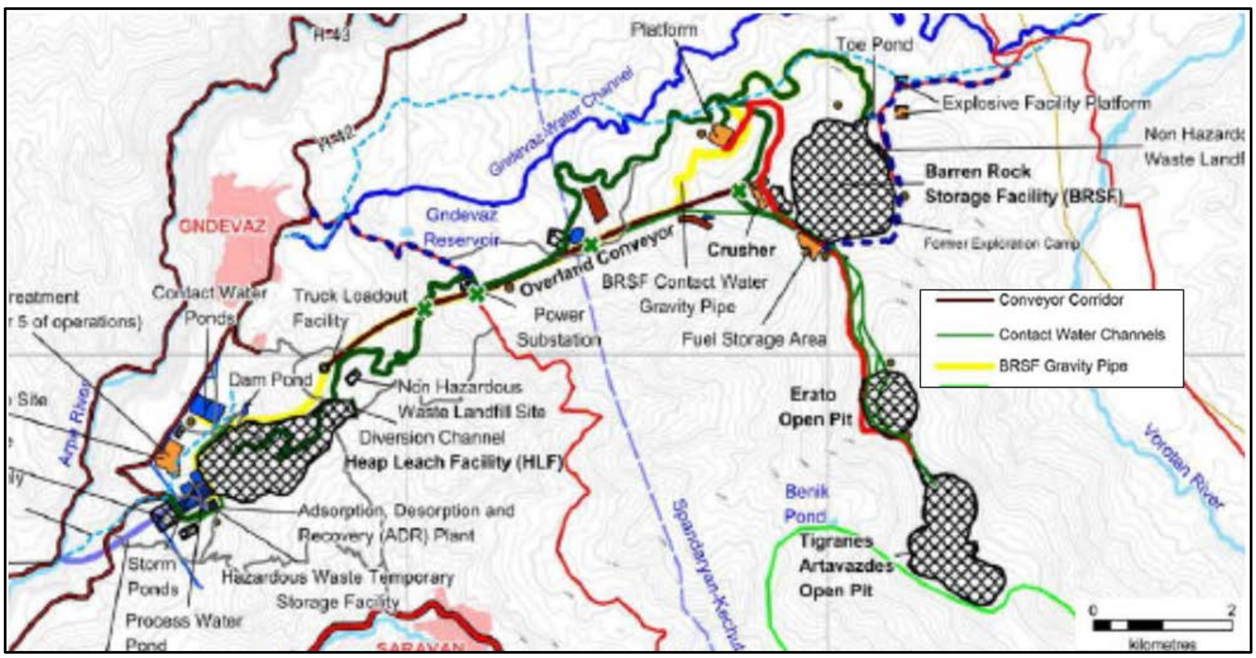
Figure 1. Operations phase water balance flow chart showing contact water planned to be used for dust suppression. Contact water ponds are shown in green outline. Contact water planned to be used for dust suppression without treatment is shown in the two pink highlighted areas (highlights added).



Source: Modified from ESIA, 2016. Figure 3.20.

A bigger concern is the *uncaptured* contact water that will leak from the pits, the BRSF, the HLF, and other mine facilities. Studies conducted on large-scale mines in the United States, which are operated by experienced miners, have been shown that 75 to 93% of the mines have adversely affected water quality from unintentional releases, and that mitigation measures failed at 64% of the mines (see, e.g., Kuipers and Maest, 2006; Gestring, 2012 and 2019). In addition to unintended leaks and spills from the pits, the BRSF, and the HLF, Spills and leaks can occur from pipelines and other conveyances. As shown in Figure 2, many tens of kilometers of contact water pipelines and the crushed ore conveyer belt are planned for the Project; the potential for spills and leaks along these conveyances has not been assessed. Appendix 8.9 of the ESIA contains response plans, but the potential for impacts from the spills and leaks and the extent of the impacts has not been estimated. The severity of the impacts should be assessed quantitatively by conducting additional site characterization and prediction studies and specific studies that would simulate spills and leaks, to address Prime Minister Pashinyan's condition that no contaminated water should enter the environment from the Amulsar Mine.

Figure 2. Location and extent of pipelines and conveyances carrying contact water and crushed ore during operations. The contact water channels are shown in thick green lines, and the BRSF gravity pipe (also carrying contact water) is shown in a thick yellow line. The conveyor planned to transport crushed ore for 5.6 km from the crusher to the crushed ore stockpile near the heap leach facility (HLF) is shown in a thick brown line. The potential for leaks and spills along these lines exists and has not been assessed.



Source: Modified from ESIA, 2016. Figure 3.1.

Where are the Concerns?

The Review's main water resources concerns are broader than those voiced by the Prime Minister[2] and include not only the Jermuk Springs and Lake Sevan but water supplies for

[2] Last year the Prime Minister Nikol Pashinyan stated that "If it turns out to be safe for Lake Sevan, Jermuk waters and water reservoir, we will allow the mine to be operated; if not we will choose a different way." https://www.globaldiasporanews.com/audit-report-confirms-serious-deficiencies-in-mining-companys-impact-assessment-and-monitoring-plan/

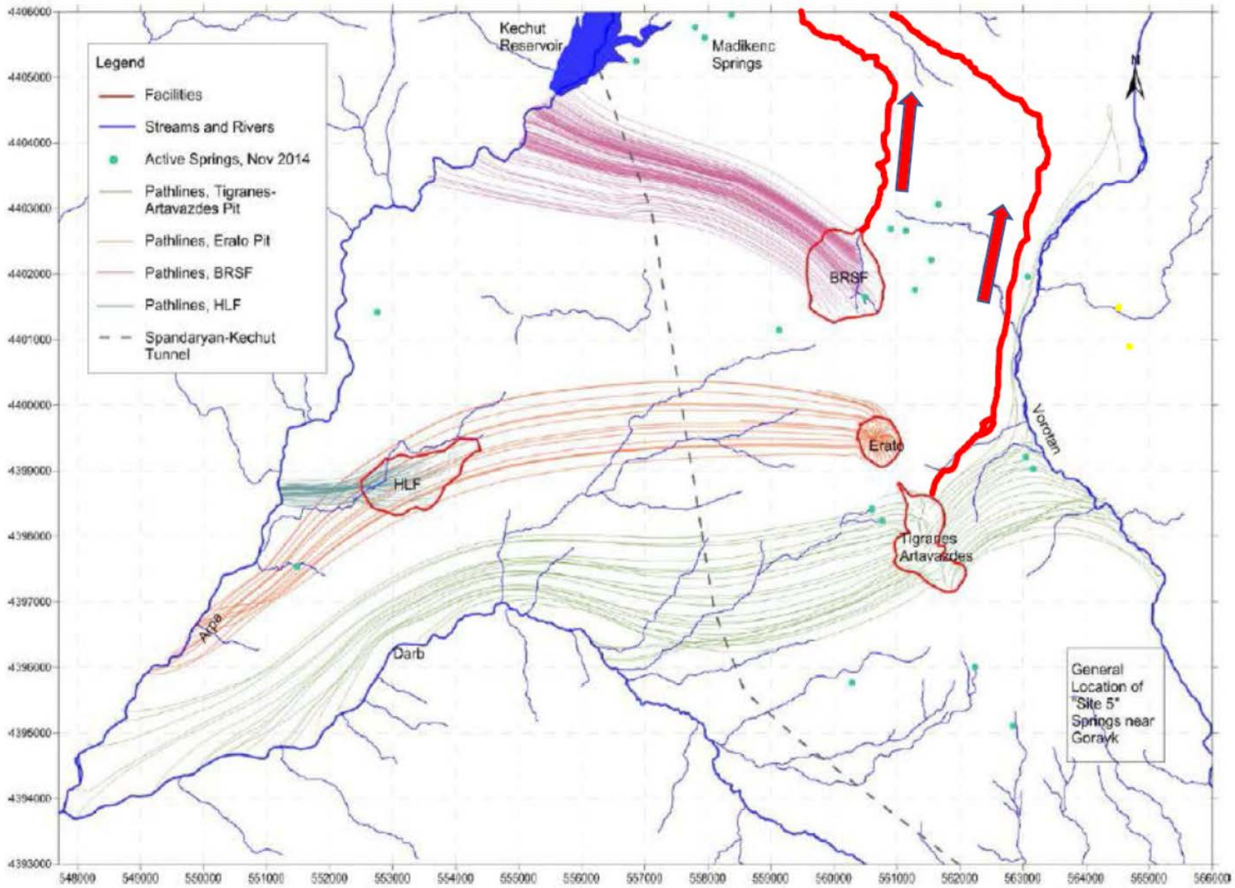
communities, springs on and near the site, and the three rivers in the Project area – the Arpa, Darb, and Vorotan Rivers. (The Review, p. 3). Limiting the government's concerns to Jermuk and Lake Sevan implies that water for communities and livelihoods closer to the Project site are not as important. In addition, impacts to the Kechut Reservoir and the Spandaryan Reservoirs will impact Armenia's current and future water supply system and Lake Sevan.

The Review states that mine water will not impact Jermuk springs "due to the hydraulic and physical setting" (The Review, p. 115). This conclusion reflects the current conditions without mining. However, the Review failed to evaluate the effects of mining on the transport of mine influenced water (MIW) to the Jermuk area. Mining will create and enhance preferential pathways that have not been evaluated in the ESIA or the Review. The lack of identification of faults and the interconnectedness of fractures and faults between the Project and Jermuk leads to uncertainty about potential effects of the mine on the Jermuk springs during mining.

Both the Kechut Reservoir and the Spandaryan Reservoir are part of the National Water Supply system (ESIA, 2016. Table 6.10.3; Chapter 6.10). The Kechut Reservoir is hydrologically connected to Lake Sevan by the Spandaryan-Kechut Tunnel (Figure 3), and the mine pits and the BRSF (waste rock facility) lie within the immediate impact zone of Lake Sevan, which is protected by Armenian law (The Review, p. 35, 115). The BRSF and the tributary draining the BRSF (see Figure 3) are in the Kechut Reservoir drainage (see ESIA Fig. 6.10.1). Discharge at the Kechut Reservoir indicates that groundwater at the site is entering the Kechut-Spandaryan Tunnel (The Review, p. 34). Mine-influenced groundwater could flow into the tunnel and Lake Sevan if mitigation measures do not perform as expected. Groundwater pathways from the mine pit area to the Kechut-Spandaryan Tunnel are shown in Figure 4. Contaminants flowing to the Vorotan River will be transported to the Spandaryan Reservoir located to the south of the Amulsar Project on the Vorotan River.

One of the most important water quality concerns is uncaptured leachate from the BRSF. Predicted BRSF leachate concentrations during post-closure (Golder Associates, 2014a. Table 1) show high concentrations of nitrate (365 mg/L as N), zinc (2,300 μg/L), arsenic (105 μg/L), and selenium (52.8 mg/L), all of which exceed Armenian ARPA MAC standards by 2.6 to 146 times. High nitrate concentrations could contribute to eutrophication of the reservoir and Lake Sevan. Zinc is not adsorbed to the extent that other metals are, and it could potentially affect aquatic life in the Lake. Figure 3 shows groundwater flow paths leading from the BRSF directly to the Kechut Reservoir, but it does not show potential flow paths following the tributary on which the BRSF is located; the upper thicker red line shows this potential flow path. This tributary joins the Arpa River upstream of the Kechut Reservoir and will add contaminants to the upstream end of the reservoir if mitigation measures do not perform as planned. These contaminant inputs have not been considered as part of the water quality impact that could reach Lake Sevan.

Figure 3. Modeled groundwater flow paths from the mine facilities to the Arpa, Darb, and Vorotan Rivers and the Kechut Reservoir. Thicker red lines indicate a potential surface water flow path from the BRSF (waste rock pile) and a modeled groundwater flow paths from the Tigres Artavazdes Pit to the Arpa River upstream of the Kechut Reservoir (highlights added). The Kechut-Spandaryan Tunnel is shown as a long dashed line. During post-closure, modeling showed that groundwater would also flow from the Erato Pit to all three rivers, directly to the Kechut Reservoir, and the Arpa River upstream of the Kechut Reservoir. Contaminants entering the Vorotan River will flow to the Spandaryan Reservoir (see ESIA, 2016, Figure 6.9.3; Chapter 6.9).



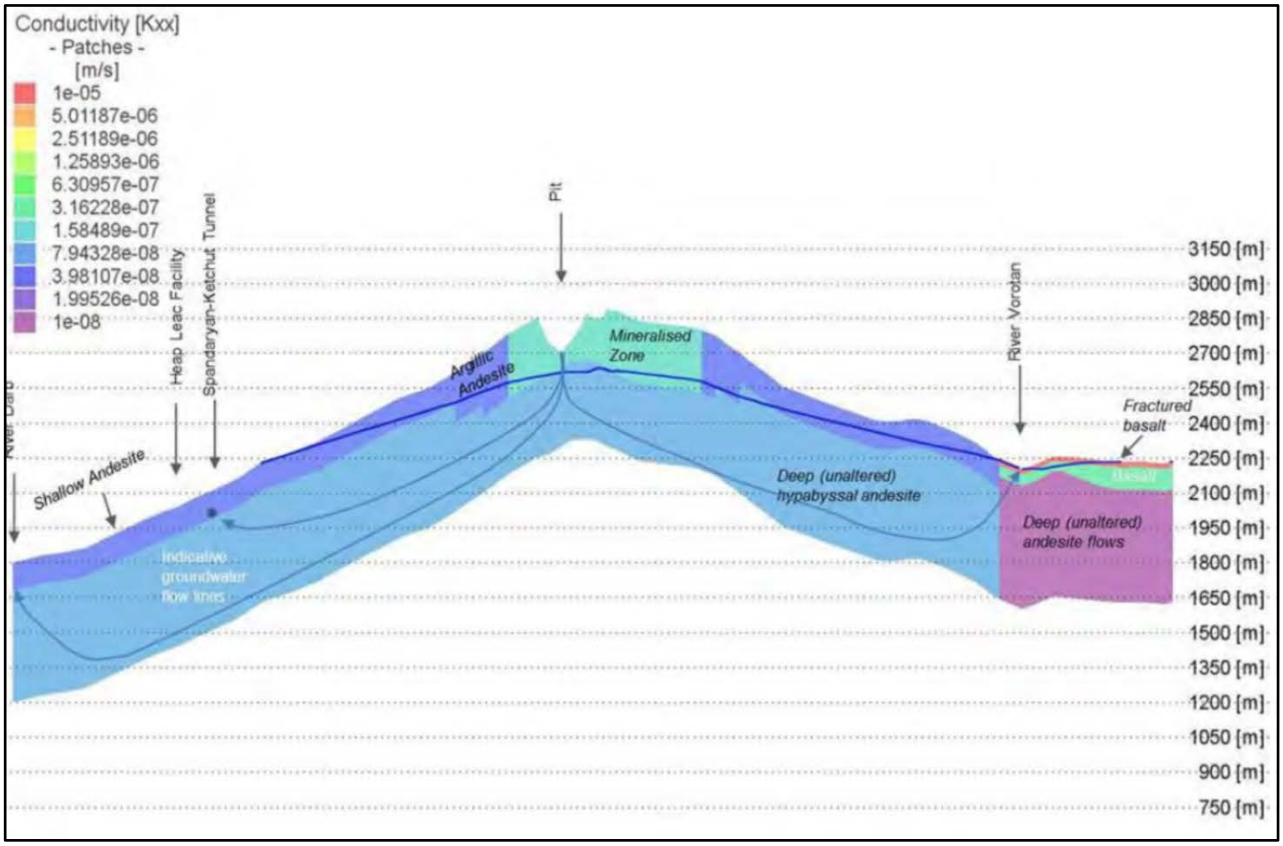
Source: ESIA, 2016. Figure 6.9.2, with modifications noted.

Importance of Geology, Faults, and Hydrologic Properties to Contaminant Transport

The Review highlights the importance of faults in transporting contaminants from the Project to groundwater, surface water, and springs. The Review concludes that Lydian has major deficiencies in its understanding and characterization of faults in the Project area (p. 14). Without this information, the transport of contaminants from the pits and other mine facilities to water resources cannot be adequately modeled (The Review, p. 14):

Additionally, faults may be conduits of groundwater flow. Under such a setting, the

Figure 4. Groundwater flow paths from the mine pit area to the Kechut-Spandaryan Tunnel and the Darb and Vorotan Rivers. The blue lines with arrows indicate groundwater flow directions and potential transport pathways for mine-related contaminants.



Source: Golder Associates, 2014b. Figure 11.

> Agarakadzor fault could conduct contaminated groundwater to the Darb and Arpa Rivers. Similarly, the Zirak Fault could conduct contaminated groundwater, including potential seepage from the BRSF (elevation approximately 2,600 m), to the Kechut Reservoir (elevation approximately 1,950 m) and/or the Vorotan River (elevation approximately 2,200 m at the projected intersection of the Zirak Fault).

The groundwater model created by Golder Associates for the ESIA (Golder Associates, 2014c, Section 4.5.2) does not address groundwater flow through faults in any way; neither does the BRSF groundwater impact assessment (Golder Associates, 2014a). Golder Associates is known for its groundwater modeling, including the use of the code FEFLOW, which is the industry standard code for modeling groundwater flow through faults. The Review criticizes the ESIA for not delineating the geologic units or the structural geology of areas between the ridge (location of the proposed pits and economic focus) and the receptors (springs, rivers, downgradient groundwater). The ESIA model only calibrated the model using average groundwater elevation in Project Area monitoring wells (Golder Associates, 2014c, Section 4.6). The modeling results do not represent important groundwater flow paths or the variability in hydrologic or climatic conditions that can be expected at the site during operation and closure of the Project.

The Amulsar site and the surrounding areas have many identified faults – and of course many more that have not been identified. Faults present potential pathways for contaminated groundwater to enter the environment. Some of the larger identified faults are shown in Figures 4.6.4 (and the previous unnumbered figure), 4.6.7, and 4.6.8 in the 2016 ESIA (Chapter 4.6). A realistic site conceptual model and a representative groundwater flow and contaminant transport model cannot be created without this important information (The Review, p. 13):

> If geologic data are lacking for areas beyond the ridge or were obtained but not integrated into the conceptual model, this deficiency translates to poor understanding of the subsurface between sources and receptors of groundwater contaminants. For such an environmentally-sensitive area, the omission of illustrations of the structural and stratigraphic relationships across the Project Area is a serious shortcoming in the ESIA conceptual model.

The poor hydrogeologic characterization of the site is highlighted in the Review, along with its importance to understanding the transport of mine contaminants. The Review strongly states that the lack of pumping tests is "a serious omission in the characterization of hydraulic properties" (p. 31). Transport of ARD and other types of MIW will travel most rapidly through transmissive faults. According to the Review, faults have not been well characterized and no pumping tests were conducted to examine the interconnection of fractures and the potential for rapid groundwater to flow to rivers, for example. The Review considers the lack of pumping tests "a serious omission in the characterization of hydraulic properties" (p. 31). Without this information, the transport of MIW in the environment is not well understood.

The Review highlights major uncertainties in water flow and water quality modeling in the ESIA used to estimate downgradient and downstream impacts of the Project. It also emphasizes how fast MIW could migrate from areas highest on the Site (mountain ridges) to springs and rivers (e.g., less than three hours to reach the Vorotan River; p. 127). The mine facilities (pits, BRSF, HFL) are lower on the Site, and MIW could migrate even more rapidly from these contaminant sources to springs and rivers, especially if transported along faults.

Acid Rock Drainage and Contaminant Leaching Potential are Poorly Characterized and Underestimated

The Review strongly notes, as I did in my previous memos (Buka Environmental, 2017), that the ARD and contaminant leaching potential of the Project are not well understood and are likely underestimated. The most basic information needed to ensure that the samples are representative of the rocks that will be encountered during mining is lacking. Lydian has simply divided the rocks into two units: upper volcanics (VC) and lower volcanics (LV). As noted in the Review (p. 17), there are significant variations within each of these two very general categories that affect the potential for acid generation and contaminant leaching. Because more geochemical test units were not identified, the samples used for geochemical testing are not representative of the different kinds of mineralization that will be encountered. The lack of mineralogic information on colluvium and borrow materials at the site means that potentially acid-generating/contaminant leaching materials could be used for constructing the mine facility. Because of the lack of subcategories, misuse of acid-base accounting testing methods, and the lack of mineralogic information, the Review concludes (p. 21):

> The results of the entire characterization program should be viewed with caution. Although all the basic types of characterization were performed, there appears to be little planning and continuity in the approach.

The Review provides an excellent evaluation of the geochemical characterization program, and their interpretation is supported be a solid understanding of the mechanisms of formation of ARD and its effects, in which they correct several of the errors in the ARD management plan reports (Geoteam, 2016 and GRE, 2017).[3] They dismiss as nonsense, as I did, the notion that rocks at Amulsar are "resistant to ARD" (p. 25), as promoted by Lydian's consultants. This "resistance to ARD" is one of the foundations of Lydian's mitigation planning – that is, because Geoteam and GRE wrongly assume "strong" ARD will not form at Amulsar, they claim that strong ARD prevention and mitigation measures are not needed. Instead of assuming this "natural" resistance to developing low pH, the Review states (p. 19):

> The leachate from the Site 27 Soviet era waste pile has a pH of 3.3 and high acidity. These data are a reasonable indicator of the potential of the ARD from the Amulsar Mine.

Lydian's response to the Review (Lydian Armenia CJSC, 2019) proposes that certain measures will be instituted if contact water pH decreases below 3.5. None of these measures include installing an active treatment plant, rather than a passive treatment system. This response implies that contact water with a pH of 3.5 or lower is only a concern. The Review refutes this assumption (p. 21), stating:

> The ARD with pH in the range of 4 – 5 cannot be dismissed. Acid contributes to the rate of chemical weathering of rock, which can accelerate physical weathering. Accelerated weathering contributes to the rate of exposure of more pyrite in all rock types at Amulsar. With enough pyrite exposed, very low pH solutions develop that mobilize metals, as observed in the HC tests.

It is important to note that none of the post-ESIA documents, including GRE (2017) and Lydian Armenia SMSC (2019) can be considered part of the ESIA. Major changes regarding active vs.

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[3] See Section 2.1.1.2.3.3 of The Review. Note that GRE (2017) is not available on the Lydian Armenia website. In Lydian's Environmental and Social Management System (ESMS) Manual (Available: https://www.lydianarmenia.am/img/uploadFiles/632643d4e294bd91af8c0-00-MAN-ENV-82043ESMSManualRev8.pdf) it states on p. 38 that Revision 4, which is GRE (2017) is "awaiting approval from Tech Services."

passive treatment were made between the ESIA and GRE (2017), as noted in the Review (p. 63). The 2017 and 2019 documents noted above and other Amulsar documents represent major changes to Lydian's mine plan, and a new (Supplemental) ESIA should be required.

The Review calls the GRE (2017) assessment of ARD at Amulsar "misleading," because, among other reasons, it "underestimates the potential for ARD generation and the associated water quality, environmental impacts, and water treatment requirements" (p. 27). Underestimating acid generation and contaminant leaching potential will underestimate the severity and extent of environmental impacts and result in proposing inadequate mitigation measures, including water treatment approaches. Given that once ARD forms it can continue for centuries, such underestimates can have potentially grave, long-term consequences for Armenia.

Mitigation Measures and the Dependence on Good Site Characterization and Modeling

TRC clearly did the heavy lifting on the geology and water resources assessment in the Review, and they strongly assert that mitigation plans and measures are only as reliable as the underlying site characterization and assessment (TRC, 2019, p. 3):

> ELARD-TRC's independent assessment has identified key data gaps and deficiencies in the baseline, modeling, and impact assessment. The development of appropriate mitigation plans and supplemental mitigation measures necessitate addressing the data gaps and updating the models and assessment accordingly. The characterization, assumptions and bases of the models should be improved and corrected.

Another way to state this is: Lydian can agree to a list of mitigation measures that satisfy the Armenian government, but they must first fill the data gaps and deficiencies identified by the Review. Any mitigation measures agreed to must be provided with greater engineering detail than provided in TRC (2019). The TRC document was not intended to be a set of engineering plans, but it can provide the basis for the engineering designs. Without more engineering detail, the Armenian government would be allowing Lydian to proceed without sufficient assurance of success. And even with mitigation measures in place, unintended releases to the environmental still occur (Kuipers and Maest, 2006).

Management and Planning Sequencing

Lydian, and unfortunately the Government of Armenia, do not seem to understand the order in which studies, plans, and mitigation measures should be undertaken at a new mine site before mining begins.[4] These include:

- Geologic, hydrogeologic, and materials characterization studies need to be well planned and executed and conducted before mining begins and continued during operations.
- The results from the characterization studies form the basis for predicting potential impacts to receptors, including water and air resources, aquatic life, and humans. A Site

[4] See, e.g., Table 3-1, GARD Guide: http://www.gardguide.com/index.php?title=Chapter_3

Conceptual Model is created to help understand the fate and transport of contaminants of concern, and hydrogeologic and geochemical modeling can be conducted at this stage.

- The prediction and characterization results are used to design mitigation measures to minimize adverse effects. The measures will only be as effective as the characterization program: an incomplete program will produce ineffective mitigation measures. The mitigation measures are tested to provide at least an initial assessment of their site-specific effectiveness.
- A monitoring network is designed and installed, based on the characterization information and the Site Conceptual Model.
- An adaptive management plan is created before mining begins (and modified as mining progresses) to address predicted consequences and identify trigger levels and response actions.

Local communities should be engaged in these processes, including in the creation of an adaptive management plan (INAP, 2009. Chapters 3, 9, 10). To my knowledge, the communities have not been consulted or engaged meaningfully to date. Early meaningful and consistent engagement could have minimized conflicts.

Lydian (2019) states that if monitoring shows that concerns have been encountered, mitigation can then be planned and implemented. The prime example is the use of an active treatment system if the passive treatment system (PTS) fails. However, additional characterization studies, as recommended by the Review, could show that an active treatment system is needed before mining begins. In addition, Lydian does not have an adaptive management plan that would formalize what triggers would identify the failure of the PTS and what actions would be required to bring an active treatment system online.

TRC has created a list of recommended mitigation measures for Amulsar (TRC, 2019, p. 1):

> Below is a list of supplemental mitigation and contingent measures that can be used to enhance the mitigation of potential impacts to groundwater and water resources from the mine. Specific design details and augmentation of these measures will be based on the updated characterization, modeling, and assessment.

Because of the highly sensitive environmental setting and the high uncertainty and numerous data/information gaps, robust prevention, mitigation, and contingency plans are needed – yet none exist. TRC is clear that the studies should be conducted and completed before mining begins (TRC, 2019, p. 3-4; emphasis added):

> The construction (**not operation**) of mine structures and facilities (e.g., buildings, ponds, conveyer, belt, liners, etc.) may be resumed in parallel (concurrently)

while addressing the data gaps and the updating of the assessment, characterization, modeling, and mitigation measures.

The Review indicates that Lydian's characterization studies are inadequate and therefore cannot result in the design of effective mitigation measures. The Review states – strongly in some places and more subtlety in others – that the characterization of the site is wholly inadequate and must be improved and, in some cases, started again from the beginning. This takes time. But without greatly improved characterization, the predictions of environmental impact are too uncertain to proceed with mining. These measures need to be in place well in advance of mining, and the gaps need to be filled to increase certainty and protect natural resources and communities.

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Chapter 3. Project Description:
https://www.lydianarmenia.am/resources/mainFiles/pdf/bb14f43c96ec32f5840d4144b84554ae.pdf

Chapter 4.6. Geology and Seismicity:
https://www.lydianarmenia.am/resources/mainFiles/pdf/395751488fe62ea8133473e4d7b87e7e.pdf

Chapter 6.9. Groundwater Resources:
https://www.lydianarmenia.am/resources/mainFiles/pdf/a70da61db241d7c9c609ffb0ea842f91.pdf

Chapter 6.10: Surface Water Resources:
https://www.lydianarmenia.am/resources/mainFiles/pdf/0bccbb65ff30060b085e2d50682fa375.pdf