Evaluation of a Proposal for Cyanide Extraction of Gold and Silver from Mine Waste at the Leadville Mill, Lake County, West-Central Colorado

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Report prepared at the request of Concerned Citizens for Lake County, submitted July 23, 2024

ABSTRACT

Union Milling Company and CJK Milling have proposed a remining operation for cyanide extraction of gold and silver from mine waste at the Leadville Mill, southwest of the city of Leadville, in Lake County, west-central Colorado. The 533,000 tons of tailings remaining from the remining operation would be partially dewatered and permanently stored on-site in a filtered tailings deposit (FTD). The remining operation would be located only 474 feet from California Gulch, a tributary of the Arkansas River, and within 2 miles of 510 domestic wells. The objective of this report is to evaluate the potential of the proposed project for harm to neighboring residents and the environment. A significant challenge in evaluating the application is the large amount of contradictory information, including such basic information as the anticipated water consumption rate, the target water content for the filtered tailings, and even the locations of the permit boundary, the FTD, and the monitoring wells. The project proponents are not signatory companies to the International Cyanide Management Code, are not committed to the World Gold Council Responsible Gold Mining Principles, and have not proposed a cyanide management plan. In particular, there is no plan for safe disposal of the iron-cyanide sludge. The FTD will be unstable because even the lower bound for the target water content exceeds the flow moisture point (meaning that the structure will flow as it is constructed), the FTD will have no structural zone (equivalent to a dam), the particle size distribution of the tailings is within the range that is susceptible to liquefaction, saturated or near-saturated tailings will be emplaced into the deposit, and the FTD has not been designed to withstand any particular precipitation or seismic event. The best prediction for the runout of a slump from the FTD is 742 feet, so that failure of the FTD could result in fatalities of neighboring residents or mill workers, washing tailings into California Gulch, or damage to the polishing pond of the Leadville Sanitation District. There is no plan for maintenance of the FTD after the remining operation, so that failure of the FTD will remain as a permanent threat. The water consumption rate has assumed that no water will be lost to evaporation, even for dust control, and no water source has yet been identified. There has been no consideration of hydrogeology, so that the monitoring wells are very likely in the wrong locations and at the wrong depths. Although the stormwater infrastructure is designed to accommodate a 100-year event, the appropriate design precipitation event should depend upon the consequences of uncontrolled overflow, which have not been considered. The potential for acid mine drainage or metal leaching from the tailings has been underestimated, since only one tailings samples was analyzed. The baseline data are invalid because there are no data for surface water and the parameters measured for groundwater are inconsistent with Colorado regulations. Finally, the proposal is devoid of any contingency plans regarding responses to instability of the FTD, contamination of surface water or groundwater or any other aspect of the project. The recommendation of this report is that the application be completely reconsidered and rewritten to address the above concerns.

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EXECUTIVE SUMMARY

Union Milling Company and CJK Milling have submitted an application for the cyanide extraction of gold and silver from mine waste at the Leadville Mill, southwest of the city of Leadville in Lake County, west-central Colorado. The majority (99%) of the mine waste would be excavated from off-site and transported to the site of the Leadville Mill. Although the application is categorized as “reclamation,” the mining engineering term for this type of operation is “remining.” The application does not state the grade of the existing mine waste, but the concentration of precious metals is probably on the order of 0.001%, so that there would be negligible reduction in the quantity of mine waste. The 533,000 tons of tailings remaining from the remining would be partially dewatered and then permanently stored on-site in a filtered tailings deposit (FTD). The remining operation would be located only 474 feet from California Gulch, a tributary of the Arkansas River, and within 2 miles of 510 domestic wells. Primarily based upon the proposed use of cyanide in the vicinity of water sources, the application received 593 objection letters from neighboring residents, people and organizations along the Arkansas River, and concerned citizens from across the country during the public comment period.

This objective of this report is to answer the following questions regarding the proposed remining operation:

1) Is the proposed remining plan aligned with industry standards on cyanide management and gold mining?
2) Will the filtered tailings deposit be stable as designed?
3) Has there been adequate consideration of the consequences of failure of the filtered tailings deposit?
4) Is there an adequate plan for permanent safe closure of the filtered tailings deposit?
5) Has there been a correct estimation of the water consumption rate and is there an adequate source of water for the remining operation?
6) Is there an adequate network of monitoring wells for the detection of groundwater contamination?
7) Does the plan include adequate infrastructure for the management of stormwater?
8) Has the potential for acid mine drainage and metal leaching from the filtered tailings been adequately assessed?
9) Are there sufficient baseline data for quality of surface water and groundwater?
10) Are there adequate contingency plans for responding to instability of the filtered tailings deposit or to detection of surface water or groundwater contamination?

To facilitate reading by non-specialists, this report includes both a tutorial on remining, including the use of cyanide and filtered tailings technology, and a tutorial on hydrogeology.

A significant challenge in evaluating the application is the large amount of contradictory information, including such basic information as the anticipated water consumption rate, the target water content for the filtered tailings, the locations of the monitoring wells, which monitoring well is the point of compliance, and even the locations and shapes of the permit boundary and the FTD. For example, the location of monitoring well LM-MW-2 (probably the point of compliance) is shown on a map and the coordinates are also stated as two different sets of values. While the map shows the monitoring well outside of the permit boundary, the two sets of coordinates are within the permit boundary. The mismatch between the two sets of stated coordinates is 275 feet, while the mismatches between the coordinates as measured from the map and the first and second sets of stated coordinates are 86 feet and 340 feet, respectively. A second discrepancy is that CJK Milling claims that 1 million tons of mine waste would be excavated, but with the production of only 533,000 tons of tailings. Additional discrepancies will be mentioned as necessary, but no attempt was made in this report to document all contradictory information within the application. A related issue is that, in general, the application does not specify whether water content refers to geotechnical water content or process water content, or whether cyanide concentrations refer to free cyanide, WAD (Weak Acid Dissociable Cyanide), or total cyanide (which can be 100 times greater than free cyanide). An additional related issue is the numerous contradictions between the application itself and the summary of the application on the website of CJK Milling.

The application variously states that the International Cyanide Management Code will be taken into consideration, that the remining operation will fully comply with the International Cyanide Management Code, and that the cyanide management plan will be developed at a later time. Neither Union Milling Company nor CJK Milling are signatory companies of the International Cyanide Management Code. Full compliance cannot be achieved without becoming a signatory company because the International Cyanide Management Code requires third-party audits under the auspices of the International Cyanide Management Institute. A significant discrepancy between the application and the International Cyanide Management Code is that the remining plan does not include any provision for the safe disposal of the iron-cyanide sludge that will result from the partial removal of dissolved cyanide from the tailings. In a similar way, neither Union Milling Company nor CJK Milling have committed to adherence to the Responsible Gold Mining Principles of the World Gold Council. The Responsible Gold Mining Principles incorporate the International Cyanide Management Code and also require adherence to current best practices in tailings storage facilities, which could be either the Global Industry Standard for Tailings Management (GISTM) or the more protective Safety First: Guidelines for Responsible Mine Tailings Management.

The target process water content is stated as either the range of 20% to 30% or as less than 25%. The range seems to be based on the process water contents that were achieved through nine tests (17.8 % to 28.5%) without any consideration of the optimum water content for maximum compaction. Only a maximum water content (as opposed to a range) is not standard for filtered tailings technology because tailings could be too dry for appropriate compaction and excessive dryness could lead to dust generation and lack of trafficability. According to the application, the tailings will be subjected to a Paint Filter test as they leave the filter presses, which is an EPA lab test for the presence of free water (water that is outside of pore spaces). All tailings with free water will be re-run through the filter presses, while tailings without free water but with process water content in the range 25-30% will be allowed to drain under gravity before placement into the FTD. However, it is difficult to imagine how this lab test could be applied to the entire output of the filter presses. Moreover, drainage under gravity will reduce the water content only to saturation or slightly under saturation, and the placement of saturated or near-saturated tailings into the FTD partially defeats the purpose of filtration and increases the likelihood of liquefaction of the FTD. It is significant that the application never states the water content at which the tailings will be saturated.

Besides the placement of saturated or near-saturated tailings, there are five other reasons why the FTD will be unstable as designed. First, the application states that the flow moisture point of the tailings (process water content above which the tailings will flow) is 19.4% and the transportable moisture limit is 17.5%. Since the flow moisture point exceeds even the stated lower bound of the target range (20%), the FTD will flow as it is constructed, meaning that it cannot actually be constructed. Second, since not all tailings will leave the filter presses with the appropriate water content for maximum compaction, the standard practice is to place the tailings with the appropriate water content on the perimeter to form a structural zone. The tailings that are too wet for maximum compaction are placed in the center and are called the non-structural zone. The standard practice is to compact the tailings in the structural zone and non-structural zone to within 95% and 90% of the maximum dry density, respectively. The structural zone serves the same function as a dam and should follow dam safety guidelines. By contrast, the application states that all tailings would be compacted to within 90% of the maximum dry density with no mention of a structural zone. Third, although the particle size distribution of the tailings will be within the range that is susceptible to liquefaction, the application does not mention any plan for the prevention of liquefaction. Fourth, the target process water contents correspond to geotechnical water contents in the range of 25 to 42.9% or a maximum of 33.3% By contrast, a typical geotechnical water content for a filtered tailings storage facility is 16.7% with a known range of 12 to 20%. Thus, the proposed FTD at the Leadville Mill would be, by far, the wettest filtered tailings storage facility ever constructed. Finally, the application does not mention any design seismic or precipitation event that the FTD ought to be able to withstand. The application does not show any stability analyses, but states that the factors of safety exceed 2.0 for both static loading and seismic loading without stating the exact values, and without clarifying that the factor of safety for static loading ought to be far higher than for seismic loading.

The application does not even mention the possibility of failure of the FTD. By analogy with the failure of a similar filtered tailings facility at the Pau Branco mine in Brazil in January 2022, and based on the height of the FTD (started as either 38 feet or as 38-43 feet), the best prediction of the runout of a slump is 742 feet past the toe of the FTD. The slump could travel to the west, which could result in fatalities of neighboring residents, or to the southwest, which could lead to fatalities of mill workers. A travel of the slump to the south will not reach California Gulch, but subsequent normal precipitation events will wash the tailings into the stream. Finally, a travel of the slump to the southeast will result in mixing of the tailings with the pre-existing polishing pond of the Leadville Sanitation District, so that the mixture of tailings and water will become a fully fluidized mass that could travel for a considerable distance down California Gulch and into the Arkansas River. In addition, damage to or destruction of the polishing pond would likely result in significant sewage effluent contamination of the Arkansas River for an extended period while the District facilities were restored. Based upon the expected loss of life as a consequence of failure, according to federal regulatory and industry standards, the FTD should be designed to withstand both the Probable Maximum Precipitation (PMP) and the Maximum Credible Earthquake (MCE). Despite the risks to people and the environment, the application does not include any plan for safe closure of the FTD, aside from planting grasses. In particular, there is no plan for monitoring, inspection, maintenance, and review of the FTD after the cessation of the remining project.

The anticipated water consumption rate is estimated as either 27 gallons per minute or as 0.33 tons of water per ton of milled mine waste (equivalent to 82 gallons per minute). The application states that water loss will occur only as a result of the permanent incorporation of water into the stored tailings with no water lost by evaporation during any phase of the remining operation, including dust control. However, by analogy with mine projects in South Africa in a similar semi-arid climate, dust control on the haul road alone could consume 46 gallons per minute. Although CJK Milling states that the water source will be the Parkville Water District, the application states that there are three options and that no decision has been made about the water source. The three options are the Parkville Water District, the Leadville Sanitation District, and an on-site water-supply well, with no information provided about the location and depth of the well or the potential impact on other domestic wells. The application includes a letter from the Parkville Water District stating an intention to provide 35,000 gallons per day (24 gallons per minute) for the remining operation, which would not satisfy the needs of the project even at the lowest projected water consumption rate (27 gallons per minute) based on zero evaporation. The latter is dated January 14, 2021, with expiration of the commitment on January 14, 2023.

The application lists seven monitoring wells that are classified as either “Up Gradient” or “Down Gradient” either in a regional sense or with respect to the filtered tailings deposit (FTD) or the emergency containment sump (ECS). The classification assumes that all groundwater is flowing to the southwest without any justification. The application does not include any information about local and regional hydrogeology, including no information about groundwater flow directions, the potential pathways for contaminants resulting from the remining operation, or the characteristics, locations, and depths of aquifers, or the aquifers that are penetrated by the various monitoring wells. Based on a detailed stream map alone, the groundwater flow directions at the locations of the monitoring wells could be completely different (even perpendicular to) the assumed uniform flow to the southwest, especially for local, shallow groundwater flow. Although the application indicates monitoring well LM-MW-2 (southwest and outside of the permit boundary) as the point of compliance, a more appropriate point of compliance could be due south of and within the permit boundary. Without further information about the hydrogeology, it is impossible to determine the appropriate depth of the point of compliance or the aquifer over which the point-of-compliance well should be screened. The application also shows, without justification, a plume of contaminated groundwater moving to the southwest (at an unspecified depth and in an unspecified aquifer), but does not discuss any means for distinguishing between future groundwater contamination by the remining operation and the pre-existing contaminant plume. Additional evidence that the current groundwater monitoring network is inadequate is that monitoring wells LM-MW-2 (the point of compliance) and LM-MW-3 were persistently dry during the period of collection of baseline data, so that groundwater samples could not be collected.

The stormwater management plan is quite difficult to follow in light of the contradictions regarding the locations and shapes of the permit boundary and the filtered tailings deposit (FTD). For example, while the permit boundary covers 42.93 acres and the affected land covers 42.60 acres, less than 20 acres is accounted for in the stormwater management plan. In a general sense, all stormwater would flow either to a pre-existing emergency containment sump (ECS), to a sediment trap at the southwest corner of the ECS, or directly to California Gulch. Stormwater would be diverted around the FTD to an FTD collection pond that is within the watershed of the sediment trap. The stormwater infrastructure would be designed to withstand a 100-year storm, which is described as a worst-case condition. However, the worst-case condition is the Probable Maximum Precipitation (PMP), which is significantly rarer than even a 10,000-year storm. The design precipitation event should depend upon the consequences of uncontrolled overflow from the stormwater infrastructure, which are not considered in the application. The most important consequences are the uncontrolled overflow of stormwater from the diversion channels onto the FTD, which could potentially lead to failure of the FTD, or the uncontrolled overflow into California Gulch. Moreover, the stormwater management plan does not take climate change into account, which is now standard practice in the mining industry.

Although mine waste would be excavated from multiple waste piles, which are likely to be quite heterogeneous in composition, the potential for acid mine drainage and metal leaching from the tailings was assessed based on only one sample. According to industry standards, based on the quantity of mine waste, at least 26 samples should have been tested, even if all of the waste piles had the same mineralogy. The conclusion in the application that the tailings would be non-acid-generating is surprising in view of the claim by CJK Milling that the problem that motivates the “reclamation” project is the acid mine drainage from the existing mine waste piles.

All of the baseline water-quality data in the application should be regarded as invalid. There are no baseline data for surface water quality in either California Gulch or the Arkansas River. Although there are five quarters of baseline groundwater data, the measured parameters are inconsistent with the parameters that are listed in Colorado regulations. In particular, the application reports only total concentrations, whereas most of the parameters that are regulated in Colorado refer only to dissolved concentrations. Even so, there is not yet sufficient knowledge of the hydrogeology to determine the proper locations and screen intervals for monitoring wells for the collection of baseline groundwater data. Although the application claims that a pre-existing groundwater contamination plume is migrating to the southwest beneath the Leadville Mill, there is no evidence for the contamination plume in the baseline data, which underscores the need for a credible baseline study.

Nearly all large-scale mining and other engineering projects are based on the Observational Method (also called Adaptive Management). For complex projects, not all actions can be planned in advance. Instead, a monitoring program is set up together with a set of pre-planned actions ready for execution (contingency plans) as a response to every possible adverse observation. By contrast, the application is devoid of any contingency plans to respond to indications of instability in the FTD or to groundwater contamination or surface water contamination (which, according to the application, would not even be monitored). In general, the application is devoid of any consideration as to the possibility that anything could go wrong.

The recommendation of this report is that the application for cyanide extraction of gold and silver from mine waste at the Leadville Mill should be completely reconsidered and rewritten with special attention to the following:

1) All information in the application should be correct and consistent. Cyanide values should indicate whether they refer to free, total or WAD cyanide. Water contents should indicate whether they refer to geotechnical water content or process water content.
2) Alternatives to the use of cyanide for gold and silver extraction should be fully considered and any final decision to use cyanide should be justified from both economic and environmental perspectives.
3) Both Union Milling Company and CJK Milling should become signatory companies of the International Cyanide Management Code. The application should include a complete cyanide management plan with explanation as to how the plan aligns with the International Cyanide Management Code.
4) Both Union Milling Company and CJK Milling should implement the Responsible Gold Mining Principles of the World Gold Council, including obtaining independent assurance. The application should explain how the proposed plan for remining aligns with the Responsible Gold Mining Principles.
5) At a minimum, both Union Milling Company and CJK Milling should either become Company Members of the International Council on Mining and Metals (ICMM) or should commit to full implementation of the Global Industry Standard on Tailings

Management (GISTM). Preferably, both Union Milling Company and CJK Milling should commit to full implementation of the more protective guidance document Safety First: Guidelines for Responsible Mine Tailings Management.

6) There should be a plan for safe disposal of the iron-cyanide sludge.
7) Target water contents should be chosen based on the optimum water content for maximum compaction.
8) The upper bound on the target water content should be significantly less than the flow moisture point.
9) Test results should be presented that confirm the ability of current filter press technology to consistently achieve the target water content.
10) The liquefaction potential of the tailings should be fully assessed and a plan should be presented to prevent the resaturation and liquefaction of the tailings.
11) There should be a plan to prevent the placement of saturated or near-saturated tailings onto the filtered tailings deposit.
12) The filtered tailings deposit should include a structural zone with compaction of tailings to 95% of the maximum dry density.
13) There should be a complete geotechnical characterization of the tailings and the foundation.
14) Stability analyses should be presented for both static and seismic loading and the exact values of the factors of safety should be stated.
15) The filtered tailings deposit should be designed so as to withstand both the Probable Maximum Precipitation (PMP) and the Maximum Credible Earthquake (MCE).
16) There should be a complete analysis of the consequences of failure of the filtered tailings deposit.
17) There should be a plan for monitoring, inspection, maintenance, and review of the filtered tailings deposit in perpetuity or until all credible failure modes have been eliminated.
18) The estimated water consumption rate should include realistic rates for dust control and for evaporation throughout all phases of the remining operation.
19) The application should identify a definitive water source. If the water source is an on-site supply well, the application should evaluate the impacts on neighboring domestic wells.
20) There should be a complete characterization of the local and regional hydrogeology, including aquifers, groundwater flow directions, and potential pathways for travel of contaminants from the remining operation.
21) The complete characterization of the local and regional hydrogeology should be used to determine the appropriate locations, depths, and screen intervals for monitoring wells and points of compliance.
22) Monitoring wells should be deep enough so that groundwater samples can be collected on a consistent basis.
23) Baseline groundwater quality data should be collected only after the determination of the appropriate locations, depths, and screen intervals for monitoring wells.
24) There should be a complete analysis of the consequences of uncontrolled overflow of the stormwater and water storage infrastructure. The design precipitation event for stormwater and water storage infrastructure should depend upon the consequences of failure.

25) The design precipitation event for stormwater and water storage infrastructure should take climate change into account.
26) There should be a complete geochemical characterization of all the mine waste piles that will be exploited for the remining operation. The geochemical characterization should determine the number of tailings samples that should be tested for potential for acid generation and metal leaching, but a minimum of 26 samples should be tested under any circumstances.
27) Baseline surface water quality data should be collected in California Gulch and the Arkansas River both upstream and downstream of the remining operation.
28) Both baseline groundwater and surface water quality data should be measured with regard to the parameters listed in Colorado Regulation 41.
29) Complete contingency plans should be developed for instability of the filtered tailings deposit and for observations of contamination in groundwater or surface water.

OVERVIEW

CJK Milling and Union Milling Company have submitted a proposal for the use of cyanide to extract gold and silver from mine waste at the Leadville Mill, 7400 feet southwest of the city of Leadville in Lake County, west-central Colorado (see Figs. 1-2). The 533,000 tons of tailings that would remain after the cessation of the project would be filtered and stacked as a permanent filtered tailings deposit (FTD) (Union Milling Company, 2024). The mass of tailings is not yet exactly known because the application also states that "the full capacity … of the FTD is approximately 500,000 tons, which provides approximately 3.5- to 4-years of storage assuming full plant production of 140,000 tons per year" (corresponding to 490,000 to 560,000 tons) and "the main objective of the construction plan was to optimize storage capacity (airspace) within the FTD to provide a minimum of 500,000 tons of stored capacity" (Union Milling Company, 2024). The formal application for the project permit was submitted by Union Milling Company (2024) to the Colorado Department of Reclamation, Mining and Safety (DRMS) on February 2, 2024. All assets of the Leadville Mill, including land, infrastructure, and equipment, are wholly owned by CJK Milling. Union Milling Company holds the current operating permit, which will be transferred to CJK Milling if the permit application is approved (CJK Milling, 2024a).

Although some of the mine waste is already present on the site of the Leadville Mill, the vast majority (99%) will be transported to the mill site from historic mine sites to the east of Leadville. According to Union Milling Company (2024), "The Leadville Mill is designed as a remedial reprocessing facility that will recover valuable metals from historic mine dump materials from the Penn Group, located east of Leadville that will be excavated and transported via truck to the plant site for processing … Existing ore stockpiles and tailings have been stored on site since approximately 1991. There are 3 historic stockpiles totalling approximately 1,500 tons which lie on unlined areas … There is also a tailings pile containing approximately 900 tons of tailings."

Mine waste can refer to either waste rock or tailings. Waste rock is the rock or overburden that was removed to reach the ore body and which was never processed to extract a commodity. Tailings refers to the crushed rock particles that remain after the commodity of value has been removed from the ore body. Whether a particular rock body is regarded as ore or waste rock depends upon the grade (concentration of the commodity), the price of the commodity and the available mining technology at the time of mining. The crushed rock particles that remain after the proposed cyanide extraction at the Leadville Mill would definitely be regarded as tailings.

It is important to note that the extraction of gold and silver from mine waste does not reduce the quantity of mine waste in any significant way. There is no available document that states the grade of either gold or silver in the mine waste that would be processed at the Leadville Mill. However, the average global grades of gold and silver are 0.00008% and 0.001% (Nassar et al., 2022a-b). For waste rock that was never processed or for tailings from which the commodities of value have already been removed using the technology available at the time, it should be assumed that the grade of precious metals is significantly less than 0.001%. Therefore, 533,000 tons of tailings should be the crushed rock particles that remain after processing no more than about 538,000 tons of mine waste (assuming a grade of 0.001%).

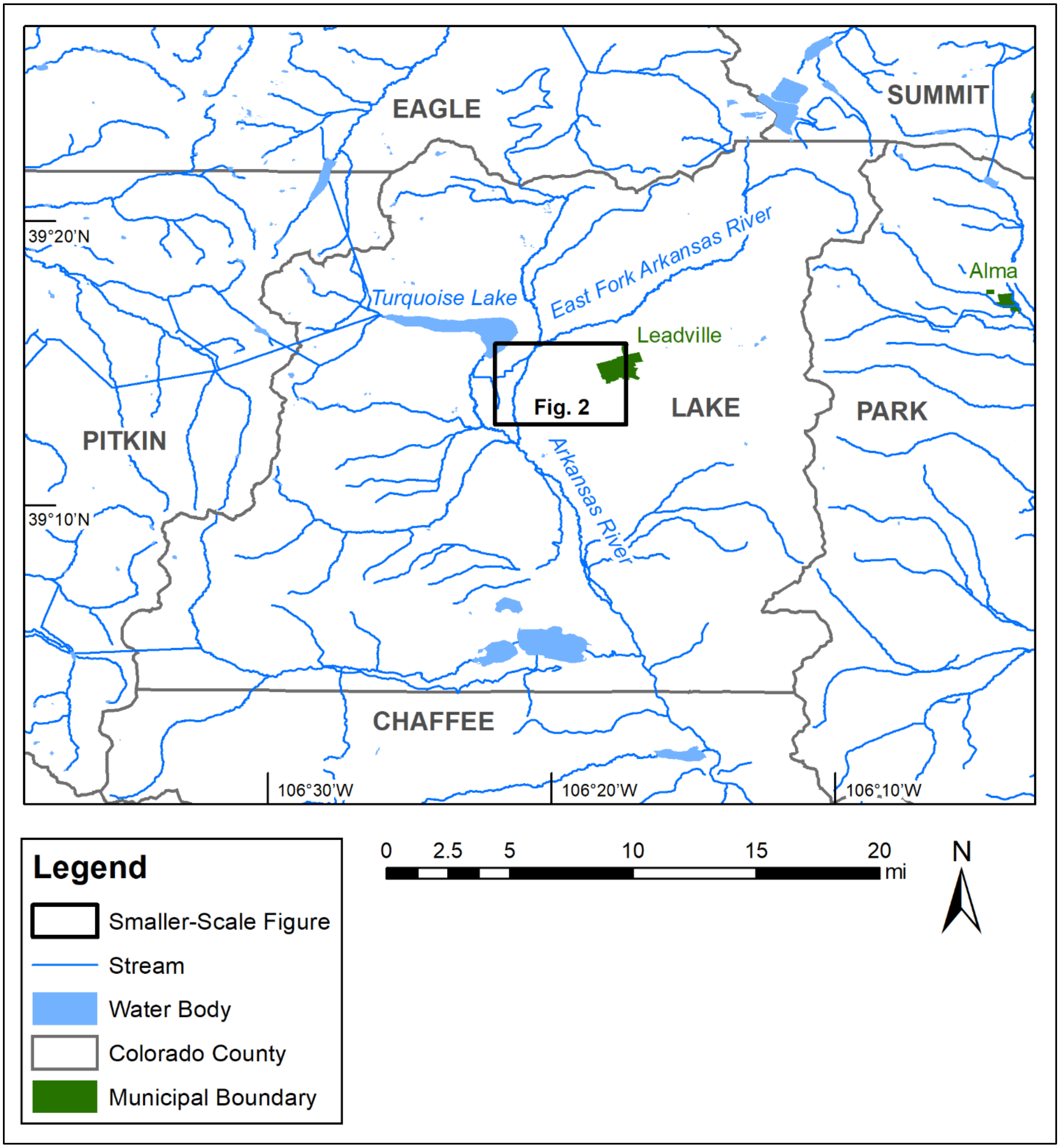


Figure 1. Union Milling Company and CJK Milling have proposed a remining project for the cyanide extraction of gold and silver from mine waste at the Leadville Mill, southwest of the city of Leadville in Lake County, west-central Colorado. See Fig. 2 for smaller-scale figure. Municipal boundaries from Colorado Geospatial Portal (2024) and streams from USGS (2024).

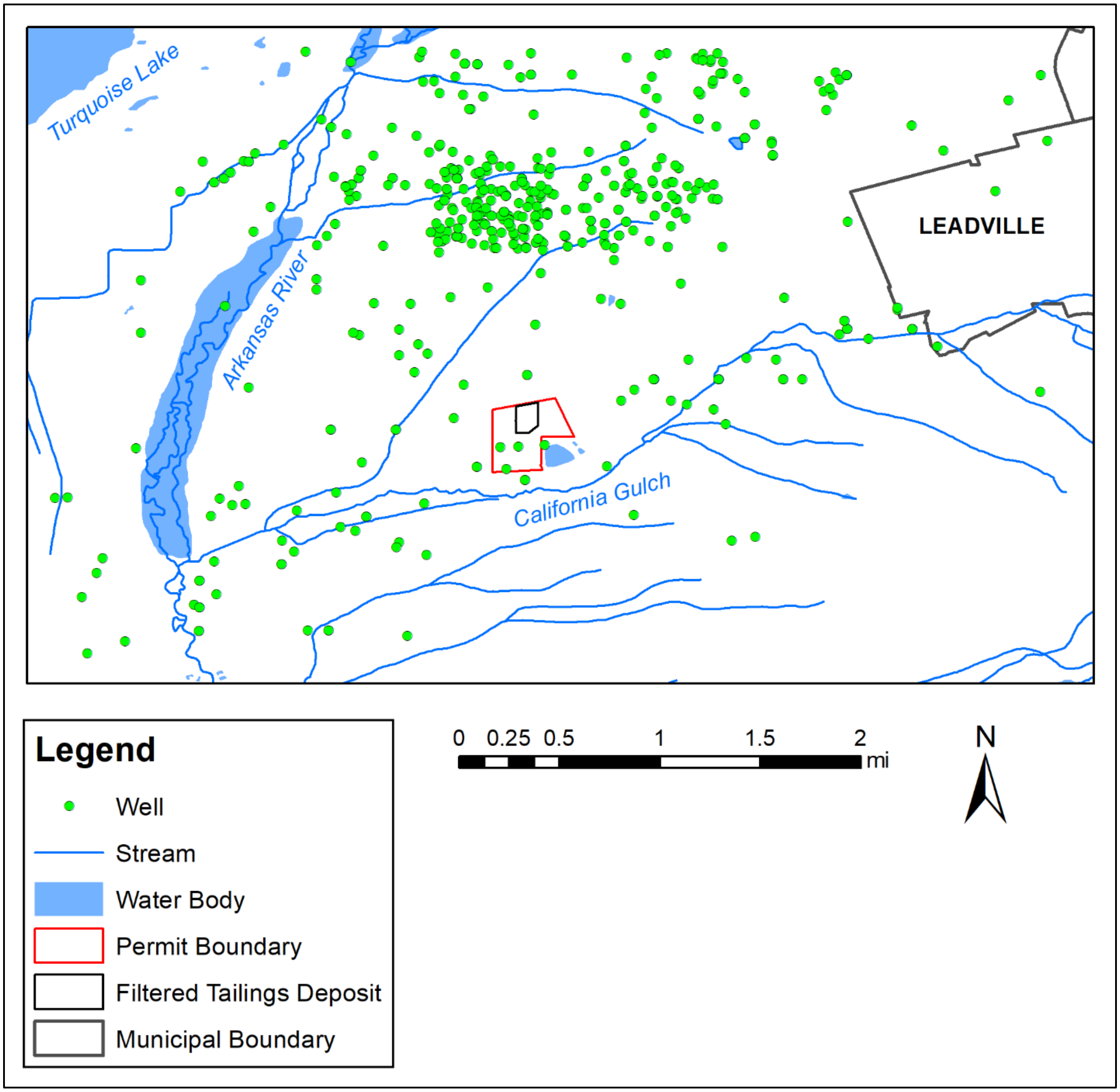


Figure 2. The proposed remining operation would be located only 474 feet from California Gulch, a tributary of the Arkansas River, and within 2 miles of 510 domestic wells. Permit boundary and perimeter of filtered tailings deposit (FTD) traced from maps in Union Milling Company (2024) (see Figs. 19a-b). Well locations from coordinate list in Union Milling Company (2024). Municipal boundaries from Colorado Geospatial Portal (2024) and streams from USGS (2024).

The permit application (Union Milling, 2024) is referred to as a "Reclamation Permit Application Package." While "reclamation" is probably the correct regulatory designation in Colorado, the proper mining engineering term for the proposed operation is "remining." According to a recent review by Maest (2024), "Remining can be defined as the use of mine waste, including solid and liquid waste, as the source material from which to extract metals or create other materials of economic value. The remining sources addressed in this review include wastes from abandoned hardrock mines, existing metal mines, coal mines, and byproduct and primary production. The wastes of greatest interest for remining at abandoned and existing metal mines are tailings … ” Although the application (Union Milling Company, 2024) devotes some discussion to the reclamation of the Leadville Mine site after the cessation of the proposed project, there is no discussion of “reclamation” of the sources of mine waste material from off the mill site (which would constitute 99% of the mine waste designated for processing). Therefore, the proposed project will be referred to as a “remining operation” throughout the remainder of this report.

According to CJK Milling (2024b), the company “is re-imagining mine waste cleanup.” CJK Milling (2024c) explains that “Historically, material that didn’t contain enough metal to mine economically was removed to the surface and placed in piles as waste.” CJK Milling (2024d) continues, “Physically removing acid-leaching historic mine waste from the environment is a unique approach to the centuries-old problem of cleaning up mine waste.” However, the proposal by CJK Milling and Union Milling Company essentially calls for transporting mine waste from east of Leadville to the Leadville Mill, removing a negligible quantity of commodity (in terms of mass, not necessarily in terms of value), and then re-stacking the re-processed mine waste as a permanent aboveground mine waste pile. Thus, the “unique approach” of CJK Milling is not essentially different from the historic approach.

A perplexing part of the promotion of the project is that, while the permit application by Union Milling Company (2024) states that approximately 500,000 tons of tailings will be left behind at the Leadville Mill site, CJK Milling repeatedly claims that they will excavate 1,000,000 tons of existing mine waste. For example, CJK Milling (2024b) states, “We will recover over 1 million tons of mine waste from the California Gulch Superfund site with a potential for recovering much more in a four-step process.” According to CJK Milling (2024e), “CJK Milling plans to remove over 1 million tons of acid-generating mine waste in and around California Gulch.” According to CJK Milling (2024c), “The company will remove approximately 1 million tons of acid-generating mine waste, with the potential of remediating another 500,000 tons, dumped by historic mine operations in and around California Gulch.” Finally, under the tab “Fiction vs. Fact,” in response to the question “How much mine waste will be removed and processed?,” CKJ Milling (2024d) responds, “Initially, CJK-owned material, totaling more than 1 million tons of low-grade vein dump material in the Breece Hill and Evans Gulch areas of the Historic California Gulch Mining District east of Leadville, will be removed and processed.” It should be clear that there is no possibility that CJK Milling can excavate 1,000,000 million tons of mine waste, remove any remaining gold and silver, and leave behind 500,000 tons of tailings, thus reducing the mass of mine waste by half. The numerous contradictions both within the permit application and between the permit application and the information provided by CKJ Milling (2024a-f) is a major theme of this report and will be developed more completely in the “Methodology” section.

The remining operation would be located only 474 feet from California Gulch, a tributary of the Arkansas River, and within 2 miles of 510 domestic wells (see Fig. 2). Primarily based upon the proposed use of cyanide in the vicinity of water sources, during the public comment period, the application received 593 objection letters from neighboring residents, people and organizations along the Arkansas River, and concerned citizens from across the country (Colorado DRMS, 2024a). Historically, there has been considerable opposition to the use of cyanide in mineral processing at the local and county levels in Colorado. Conejos, Costilla, Gilpin, Gunnison, and Summit counties in Colorado have all passed land-use ordinances prohibiting the use of cyanide in mineral processing (Rodríguez and Macías, 2009; Laitos, 2013). However, in response to a lawsuit by the Colorado Mining Association, in 2009, the

Colorado Supreme Court overturned all of the county ordinances on the basis that only the Colorado Mined Land Reclamation Board has the authority to regulate the use of cyanide in mineral processing (Rodríguez and Macías, 2009; Laitos, 2013).

Even aside from the use of cyanide, the placement of a tailings storage facility close to a river is generally regarded as problematic. The FTD would be only 1450 feet from California Gulch (see Fig. 2). According to Safety First: Guidelines for Responsible Mine Tailings Management, "Tailings facilities must not be constructed in a location where a failure would materially impact public water supplies or critical habitats, or near protected ecological resources" (Morrill et al., 2022). Some jurisdictions, such as the People's Republic of China, prohibit the construction of tailings storage facilities near rivers (Zhang and Daly, 2019; Zhang and Singh, 2020). According to Department of Basics for Production Safety (China) (2020), "It is strictly forbidden to build new (or modified or expanded) tailings facilities within three kilometers from the banks of the main streams of the Yangtze River and the Yellow River, and one kilometer from the banks of their important tributaries" (translation from Chinese by the author).

The objective of this report is to answer the following question; Does the permit application provide adequate protection to people and the environment? To facilitate reading by non-specialists, this report includes a tutorial on key concepts of remining, including the use of cyanide in ore processing and filtered tailings technology, and a tutorial on key concepts of hydrogeology. After a summary of the proposal for remining at the Leadville Mill, the objective will be refined into a series of ten questions in the "Methodology" section.

TUTORIAL ON KEY CONCEPTS OF REMINING

Use of Cyanide in Extraction of Gold and Silver

Cyanide was first used as an extractant for gold in 1889 at the Crown mine in New Zealand (Johnson, 2015). Cyanide is such an effective extractant (also called a lixiviant) that it can extract microscopic quantities of gold from a large body of gold ore, on the order of fractions of a gram of gold per metric ton of ore (fractions of a part per million). In this way, the gold mining industry has continued to be profitable, even while the grades of the remaining gold deposits have declined from 50 grams per metric ton in the mid-19th century to around 1 gram per metric ton at the present time (Mudd, 2010). According to Laitos (2013), "Nonetheless, by the 21st century, over 90% of gold extracted worldwide is the result of cyanide leaching techniques. Prior to the introduction of cyanide leaching operations, most low-grade ore deposits could not be profitably removed using traditional placer or lode mining techniques; to that end, the low capital costs associated with cyanide heap leaching have made profitability on low-grade ores a reality. By utilizing cyanide mineral leaching techniques in large-tonnage mine projects, operators were able to extract small, sometimes microscopic flecks of gold and other precious minerals from low-grade ore with 90% to 95% efficiency. As a result of the efficiency of heap leaching, mountains full of low-grade ore have been transformed into profitable mineral extraction operations."

Cyanide is highly toxic and can be lethal to birds, wildlife, aquatic organisms, livestock, and humans if it is accidentally released into the environment. The lethal effect of cyanide results from its tendency to attach to red blood cells, so that the blood cells can no longer release oxygen to tissues and organs, resulting in suffocation. Because of its high toxicity, alternatives to cyanide have been sought for over a century, or almost since the use of cyanide in gold ore processing was first introduced. Any alternative lixiviant to cyanide should have some combination of the following characteristics (Laitos, 2013):

1) It should be relatively inexpensive.
2) It should be relatively recyclable, meaning that after extracting gold from gold ore, the lixiviant can be recovered, so that it can be applied to more gold ore.
3) It should be selective, meaning that it preferentially extracts gold and not every other metal.
4) It should be relatively non-toxic.
5) It should be possible to destroy or recover the lixiviant from any water or waste that might be released into the environment.

After over a century of research, no lixiviant has emerged that satisfies a reasonable number of the above characteristics. Mercury is just as effective at extracting gold as cyanide, but it is much more toxic and is highly persistent in the environment. On that basis, the World Gold Council (2019a) does not recommend the use of mercury for gold processing under any circumstances. Thiosulfate is an effective lixiviant and less toxic than cyanide, but it is usually too expensive due to its high consumption rate during gold ore processing. Coal-gold agglomeration (CGA) is far less toxic than cyanide, but is effective only for extracting free gold particles (such as may be found in river or beach deposits), not in extracting gold from hardrock (Laitos, 2013). In summary, despite its toxicity, the modern gold mining industry could not exist in its present form without the use of cyanide.

Although over 90% of gold mining operations rely on the use of cyanide, there are still large-scale mines that do not use cyanide. For example, according to Laitos (2013), "In commercial practice, Newmont Gold and Consolidated Empire Gold Inc. have successfully used thiosulphate in heap leaching of gold ore … The bromine system has received increasing attention in the mining industry following a patent by the Great Lakes Corporation on its bromine-based gold leaching process." On that basis, the use of cyanide in a mineral processing operation should be justified for every operation from both economic and environmental perspectives. Thus, the statement by CJK Milling (2024b) that "cyanide is required to process gold and silver" is not literally true." Although CJK Milling (2024a) also states that "the test work determined that leaching using cyanide is the only viable technology to treat the waste material," this test work is not discussed in the permit application by Union Milling Company (2024), nor in any other available document. Along similar lines, under the tab "Fiction vs. Fact," CJK Milling (2024d) states, "Cyanide has been used safely and effectively for more than 125 years around the world for the extraction and recovery of gold and silver" and provides "Society for Mining, Metallurgy and Exploration [SME]" as a source. The author is not aware of any SME guidance document that states such a blanket generalization.

An excellent reference for the use of cyanide in mineral processing is the SME handbook Basic Cyanide Chemistry (Botz, 2024) (which does not state that the use of cyanide is always safe and effective). The process of gold ore processing using cyanide involves dissolving a cyanide salt (such as sodium cyanide) in water, so that it dissociates to form the cyanide ion (CN^-) and hydrogen cyanide (HCN). The gold ore is crushed and is either placed onto a heap leach pad, where cyanide solution is poured over it, or mixed with the cyanide solution in a vat. The cyanide ion extracts the gold from the ore to form a dissolved gold-cyanide complex. The solution with the gold-cyanide complex is called the pregnant solution.

There are two important processes for removing the gold-cyanide complex from the pregnant solution. In the first process, the pregnant solution is mixed with or passed over activated carbon, so that the gold-cyanide complex leaves the solution and attaches to the activated carbon, after which the solution is referred to as the barren solution. Further steps (called stripping or elution) remove the gold from the activated carbon and restore the cyanide to the barren solution. Any lost cyanide is replaced in the barren solution and the solution is then recycled to extract additional gold from more gold ore. The second important process is called zinc cementation or the Merrill-Crowe process. In this process, the addition of zinc dust to the pregnant solution creates a highly-reducing (low-oxygen) environment. The highly-reducing environment causes gold to be reduced to its elemental (metallic) state, so that it precipitates as solid particles of gold. As with the activated carbon process, any lost cyanide is replaced in the barren solution and the solution is then recycled to extract additional gold from more gold ore.

Cyanide can also be used to extract silver from crushed ore. However, there are other, safer methods for the processing of silver ore and cyanide is rarely used to extract silver, unless there is a desire to extract both gold and silver from the same ore body. The reaction of silver with free cyanide will form a dissolved silver-cyanide complex and both of the above processes can then be used to remove the silver-cyanide complex from the pregnant solution. The silver-cyanide complex will attach to activated carbon, although not as strongly as the gold-cyanide complex, so that gold can out-compete silver for adsorption sites. The addition of zinc dust will also cause the reduction of silver to its elemental state and its precipitation as solid particles of silver. Generally, the Merrill-Crowe process is preferred when there are higher concentrations of silver in the ore with the activated carbon process used for lower concentrations (Botz, 2024). The combined cyanide extraction of gold and silver results in a semi-pure gold-silver alloy called doré, after which further refining can be carried out to produce pure gold and pure silver.

It is often said that cyanide does not persist in the environment, since it rapidly breaks down into carbon dioxide and ammonia as a result of processes such as oxidation, volatilization, photo dissociation, and biodegradation. The statement is generally true, but requires three critical qualifications. The first qualification is that the processes of cyanide attenuation in surface water can require days to weeks, depending upon many factors, such as the extent of aeration or mixing of the water, the depth of the water, the intensity of sunlight, and the presence of the appropriate microbial community. During that time period of days to weeks, extensive destruction of aquatic life and impacts on municipal water supply are still possible. For example, the leakage of cyanide-enriched water from the Summitville gold mine in Rio Grande County, Colorado, destroyed nearly all aquatic life along a 23-mile reach of the Alamosa River (Laitos, 2013). In the case of the spill of cyanide-enriched water from the Aurul S.A. gold mine near Baia Mare, Romania, in 2000, the cyanide plume traveled over 2000 kilometers down the Danube River to the Black Sea. The significance of the Baia Mare disaster to the gold mining industry will be discussed further in the following subsection.

The second qualification is that dissolved cyanide can disappear from the water column as carbon dioxide and ammonia, which is true destruction of the cyanide. On the other hand, cyanide can also disappear from the water column as a result of the adsorption of cyanide onto solid particles or the precipitation of a solid cyanide salt, such as iron cyanide. In these cases, the cyanide has not been destroyed, but is only being stored in the solid form. This type of storage is referred to as the “chemical time bomb,” because a change in water chemistry or photo dissociation can cause the transfer of adsorbed cyanide back into the dissolved form or the dissolution of the precipitated cyanide salts. According to Johnson (2015), “Of these fates, dispersal to the atmosphere and chemical transformation amount to permanent elimination of the cyanide, whereas sequestration amounts to storage of cyanide. If physicochemical conditions change, stored cyanide can potentially be released to infiltrating waters by means of dissolution or desorption reactions." It is noteworthy that the proposal by Union Milling Company (2024) is not to truly destroy the leftover cyanide (in the sense discussed above), but to convert it into an iron-cyanide sludge. The possible fates of the iron-cyanide sludge will be discussed in the "Responses" section of this report.

The third and most important qualification is that most of the processes leading to destruction function only for surface water and can be absent for groundwater. In particular, groundwater can have low oxygen levels, be disconnected from the atmosphere or sunlight, or lack the microbial community that can biodegrade cyanide. According to Laitos (2013), "In contrast to surface waters, because groundwater lacks ultraviolet light and has less available oxygen, cyanide will persist for longer periods of time if it works its way underground." Johnson (2015) drew attention to the problematic aspects of both large-scale spills of cyanide into surface water and leakage into groundwater. According to Johnson (2015), "From an environmental perspective, the most significant cyanide releases from gold leach operations have involved catastrophic spills of process solutions or leakage of effluent from solid wastes to the unsaturated [soil water] or saturated zones [groundwater]. Key to the environmental significance of spills and leakage is that these release pathways are unfavorable for two important cyanide attenuation mechanisms that can occur naturally: catastrophic spills allow little time for offgassing of free cyanide to the atmosphere, and effluent leakage to the subsurface does not allow for photodissociation of strong cyanometallic complexes to give free cyanide that can offgas." The precise meaning of "free cyanide" will be discussed in the subsection "Free Cyanide, WAD Cyanide, and Total Cyanide."

Aside from the question of the persistence of cyanide in the environment, a considerable portion of the environmental toxicity that is a consequence of the use of cyanide in gold ore processing is not the cyanide itself, but the by-products of the use of cyanide. Cyanide is equally effective in extracting mercury from crushed ore, so that any mercury present in the gold ore also appears as a dissolved mercury-cyanide complex within the pregnant solution. There is a mercury-cyanide complex that could attach to activated carbon along with the gold-cyanide complex, but not the particular mercury-cyanide complex that forms under the alkaline conditions that are necessary for processing with cyanide. Some of the hydrogen cyanide that develops when sodium cyanide is dissolved to form the cyanide solution remains in the dissolved form, but most of it volatilizes to escape as hydrogen cyanide gas. Hydrogen cyanide gas would be lethal to the mineworkers and would be economically undesirable, even if it could be ventilated, because it represents a loss of cyanide from the processing circuit. In order to minimize the production of hydrogen cyanide and maximize the production of the cyanide ion, the cyanide solution is maintained in a very alkaline state, in the pH range of 10-11 (Botz, 2024). In such a high pH range, the mercury-cyanide complex remains in the barren solution. Thus, every passage of the cyanide solution through the processing circuit causes the solution to encounter more ore that may contain additional mercury. As a consequence, the cyanide solution becomes increasingly enriched in mercury, which can be far more toxic to the environment than cyanide.

Other contaminants can be mobilized into the cyanide solution solely as a result of the high pH. These contaminants include elements that form oxyanions (negatively-charged ions that include oxygen) in the dissolved form. Examples of such elements are arsenic, antimony, molybdenum, selenium, and uranium. As with mercury, since none of the preceding oxyanions will attach to activated carbon, they will remain in the barren solution. Thus, every passage of the cyanide solution through the processing circuit will cause the solution to become increasingly enriched in arsenic, antimony, molybdenum, selenium, and uranium, if those elements are present in the gold ore.

International Cyanide Management Code and Responsible Gold Mining Principles

In January 2000 a tailings dam failed at the Aurul S.A. gold mine near Baia Mare, Romania. The tailings dam failure released 100,000 cubic meters of cyanide-rich water into the Somes and Tisza Rivers, which then flowed into the Danube River and finally into the Black Sea, a distance of over 2000 kilometers. The cyanide spill resulted in massive fishkill and the destruction of aquatic species (ICOLD and UNEP, 2001). The Aurul S.A. gold mine was actually a remining operation, in which cyanide was being used to extract additional gold from old gold tailings (Maest, 2024). An earlier failure of the tailings dam at the Omai gold mine in Guyana in 1995 released 4.2 million cubic meters of cyanide-contaminated water into the Omai River, fortunately, with only minor fishkill (ICOLD and UNEP, 2001). The public and governmental response led to a concern in the gold mining industry that governments would begin banning the use of cyanide, which would effectively put an end to the gold mining industry in those jurisdictions.

In fact, following the tailings dam failure at Baia Mare, the use of cyanide in ore processing was banned in Costa Rica, Czech Republic, Germany, and Hungary (Laitos, 2013). Turkey had already banned the use of cyanide in 1997 (Laitos, 2012). In 2010 the European Parliament called for a ban on the use of cyanide in mineral processing throughout the European Union, stating that a ban "is the only safe way to protect our water resources and ecosystems against cyanide pollution from mining activities" (Environment and Natural Resources Law & Policy Program, 2010). In the United States, the state of Montana had already banned the use of cyanide at open-pit mines in 1998 (Laitos, 2013). The states of Wisconsin and Virginia banned the use of cyanide in 2001 and 2024, respectively (Wisconsin State Legislature, 2001; Virginia's Legislative Information System, 2024). It has already been mentioned that Conejos, Costilla, Gilpin, Gunnison, and Summit counties in Colorado prohibited the use of cyanide in mineral processing, but the prohibitions were overturned after a lawsuit by the Colorado Mining Association (Rodríguez and Macías, 2009; Laitos, 2013). Eight provinces of Argentina have prohibited the use of cyanide in mineral processing, although there is no nationwide prohibition (Laitos, 2013). Some countries (for example, Burkina Faso, Cameroon, Ghana, Kenya, Mongolia, South Africa, Tanzania) prohibit the use of cyanide by artisanal and small-scale gold miners, that is, by gold mining operations that lack the capital and technical capacity to carry out cyanide processing safely (IGF, 2024).

CJK Milling (2024d) writes "FICTION: The use of cyanide cannot be done safely or in an environmentally responsible way" followed by "FACT: If this claim were true, cyanide would be banned and it is not." CJK Milling (2024a) further states, "The safe use of cyanide, followed by the destruction of this compound once used, is a proven technology and is in use worldwide, including Colorado." The claims by CJK Milling (2024a, 2024d) are somewhat disingenuous in that they leave out the information that cyanide is not literally in use worldwide because it is not in use in the five countries and three states of the USA where its use in mineral processing has been banned. The claims also leave out the information that five counties in Colorado did ban the use of cyanide in mineral processing and that the Colorado mining industry played a critical role in overturning those bans through judicial action. Finally, as discussed in the previous subsection, the permit application (Union Milling Company, 2024) is not proposing the literal "destruction" of cyanide, but the permanent storage of cyanide as an iron-cyanide sludge. The significance of the lack of cyanide destruction will be addressed further in the "Responses" section.

In an effort to forestall such governmental bans and their existential threat to the industry, the gold mining industry created the International Cyanide Management Code for the Manufacture, Transport, and Use of Cyanide in the Production of Gold (called the International Cyanide Management Code in this report) (The Cyanide Code, 2024a). The International Cyanide Management Code is a voluntary commitment that includes third-party audits for full certification. Thus far, over 200 companies are signatory to the International Cyanide Management Code, including mining companies, cyanide producers, and cyanide transporters. The Responsible Gold Mining Principles, which were developed by the World Gold Council are even broader than the International Cyanide Management Code because they incorporate the International Cyanide Management Code, in addition to other requirements. According to the Responsible Gold Mining Principles, "Where our operations use cyanide, we will ensure that our arrangements for the transport, storage, use and disposal of cyanide are in line with the standards of practice set out in the International Cyanide Management Code" (World Gold Council, 2019a).

It should be noted at the outset that the International Cyanide Management Code is not a guidance document, but a certification program. Thus, a company cannot commit to the requirements of the International Cyanide Management Code without engaging in the certification process. The Introduction to the International Cyanide Management Code begins, "The 'International Cyanide Management Code For the Manufacture, Transport, and Use of Cyanide In the Production of Gold' (Cyanide Code) is a voluntary, performance driven, certification program of best practices for gold and silver mining companies and the companies producing and transporting cyanide used in gold and silver mining … The objective of the Cyanide Code is to improve the management of cyanide used in gold and silver mining and to improve the protection of human health and the reduction of environmental impacts, while assuring stakeholders of the safe handling of cyanide through the disclosure of results from periodic audits by independent professional auditors. Implementation of the Cyanide Code is verified through triennial audits conducted by independent third-party auditors. Companies that adopt the Cyanide Code must have their operations that use, transport, or produce cyanide audited to determine the status of Cyanide Code implementation. Those operations that meet the Cyanide Code requirements are certified" (International Cyanide Management Institute, 2021a). The detailed procedures for carrying out audits are described in International Cyanide Management Institute (2021b-c).

A signatory company does not need to have an operating facility to obtain certification, so that a regulatory agency could reasonably require certification for proposals alone. According to the International Cyanide Management Institute (2021c), "The Code allows for pre-operational certification of a mining operation that is not yet active but that is sufficiently advanced in its planning, design, or construction that its plans and proposed operating procedures can be audited for conformance with the Code … Since mines that are not yet active cannot be audited for their actual operation, pre-operational certification is based on their commitments to design, construct and operate the mine in full compliance with the Cyanide Code's Principles and Standards of Practice. Auditors of mines seeking pre-operational certification must determine if the operation can reasonably be expected to be in full compliance with the Code's Principles and

Standards of Practices once its plans are implemented and it becomes active … A preoperational facility found in full compliance is conditionally certified, subject to an on-site audit to confirm that the operation has been constructed and is being operated in compliance with the Code."

In a similar way, a company cannot implement the Responsible Gold Mining Principles of the World Gold Council without providing third-party assurance. According to World Gold Council (2019a), "The Principles require implementing companies to:

1. Make a public commitment to align with the Responsible Gold Mining Principles
2. Develop internal systems, processes and performance that conform with the Principles
3. Report publicly on the status of their conformance with the Principles
4. Obtain independent assurance on their conformance with the Principles."

World Gold Council (2019a) continues, "Two public reports are associated with the assurance:

1. An annual report on implementation of the Responsible Gold Mining Principles produced by the implementing company
2. An Independent Assurance Report produced annually by the assurance provider."

World Gold Council (2019b) describes the detailed procedures for implementation and assurance of the Responsible Gold Mining Principles.

This review of the International Cyanide Management Code and Responsible Gold Mining Principles will focus on the aspects of gold and silver ore processing most relevant to this report, which are the safe disposal of cyanide waste, the proper construction and operation of tailings storage facilities, the emergency response plan for accidental releases of cyanide, the proper monitoring of surface water and groundwater, and the requirements for public disclosure of information concerning the use of cyanide. It should be kept in mind that the International Cyanide Code, as well as Responsible Gold Mining Principles, were developed almost entirely by the mining industry with little to no input by other stakeholders, such as civil society organizations, mining-affected communities or mineworkers. In other words, the industry guidance documents should be regarded as guidelines that balance protecting the environment with guaranteeing the profits of gold mining companies, not as guidelines that are intended to maximize the protection of the environment and downstream communities. On that basis, adherence to the International Cyanide Management Code and Responsible Gold Mining Principles should be regarded as the minimum expectations of gold mining companies, not as an aspirational utopia.

In terms of the International Cyanide Management Code, an important consideration is that the infrastructure for storing cyanide and for mixing cyanide with mine waste would not be the only cyanide facilities. Since some cyanide would be retained within the pore spaces of the filtered tailings, the proposed filtered tailings deposit (FTD) at the Leadville Mill would also be regarded as a cyanide facility. According to the International Cyanide Management Institute (2021c), "The term 'cyanide facilities' is defined in the Definitions and Acronyms document on the Cyanide Code website as: '(1) A storage, production, waste management or regeneration unit for managing cyanide or Process Solution' … Since the Code defines Process Solution as any solution with a concentration of 0.5 mg/l WAD cyanide or greater, the following would likely be cyanide facilities at most operations: … Tailings storage facilities." The precise meaning of WAD (Weak Acid Dissociable) cyanide will be explained in the following subsection "Free Cyanide, WAD Cyanide, and Total Cyanide." In summary, a collapse of the FTD or seepage from the FTD at the Leadville Mill would constitute an accidental release of cyanide into the environment from a cyanide facility.

The International Cyanide Management Code is made up of nine Mining Principles, five Production Principles, and three Transportation Principles, each of which is subdivided into multiple Standards of Practice. Mining Principle 4 (Operations) states "Manage cyanide process solutions and waste streams to protect human health and the environment" (International Cyanide Management Institute, 2021a). Some relevant Standards of Practice are the following (International Cyanide Management Institute, 2021a):

- Mining Standard of Practice 4.1: "Implement management and operating systems designed to protect human health and the environment including contingency planning and inspection and preventive maintenance procedures."
- Mining Standard of Practice 4.3: "Implement a comprehensive water management program to protect against unintentional releases."
- Mining Standard of Practice 4.5: "Implement measures to protect fish and wildlife from direct and indirect discharges of cyanide process solutions to surface water."
- Mining Standard of Practice 4.6: "Implement measures designed to manage seepage from cyanide facilities to protect the beneficial uses of ground water."
- Mining Standard of Practice 4.9: "Implement monitoring programs to evaluate the effects of cyanide use on wildlife, and surface and groundwater quality."

With regard to the requirement for management of the cyanide waste stream, of particular interest is the proposal by Union Milling Company (2024) to use ferrous sulfate to immobilize the cyanide waste. According to the International Cyanide Management Institute (2021c), "Ferrous sulfate binds cyanide in an insoluble complex but does not chemically convert it to a less toxic substance. The complex formed is susceptible to photodecomposition and can release cyanide back to the environment if it is not properly managed." The preceding quote is exactly the point made in the previous subsection that there is a distinction between the destruction of cyanide (release into the atmosphere) and the storage of cyanide. This discrepancy between the proposal by Union Milling Company (2024) and the International Cyanide Management Code will be further developed in the "Responses" section.

Mining Principle 5 (Decommissioning) states "Protect communities and the environment from cyanide through development and implementation of decommissioning plans for cyanide facilities" (International Cyanide Management Institute, 2021a). The two Standards of Practice for Mining Principle 5 are the following (International Cyanide Management Institute, 2021a):

- Mining Standard of Practice 5.1: "Plan and implement procedures for effective decommissioning of cyanide facilities to protect human health, wildlife, livestock, and the environment."
- Mining Standard of Practice 5.2: "Establish a financial assurance mechanism capable of fully funding cyanide-related decommissioning activities."

According to the International Cyanide Management Institute (2021c), "Decommissioning is that aspect of closure that addresses the cyanide remaining on site upon cessation of production activities and prepares the site for its closure and post closure period. The term is defined in the Code's Definitions and Acronyms document, and generally refers to 'treating, neutralizing or otherwise managing cyanide and cyanide containing process solutions remaining in storage and production facilities in preparation for closure so that they do not present a risk to people, wildlife or the environment due to their cyanide content.'" It should be noted that, according to the International Cyanide Management Code, the FTD at the Leadville Mill would be a cyanide facility that would require full decommissioning at the conclusion of the remining project. In a similar way, all cyanide waste remaining on-site, such as the iron-cyanide sludge remaining from the remining operation, would require full decommissioning.

Mining Principle 7 (Emergency Response) states "Protect communities and the environment through the development of emergency response strategies and capabilities" (International Cyanide Management Institute, 2021a). Mining Standard of Practice 7.1 then states, "Prepare detailed emergency response plans for potential cyanide releases" (International Cyanide Management Institute, 2021a). It should again be noted that the FTD at the Leadville Mill would be a cyanide facility and that its potential collapse would be equivalent to a potential cyanide release, for which an emergency response plan would be necessary. In fact, the following auditing question is provided with respect to Mining Standard of Practice 7.1 (International Cyanide Management Institute, 2021c): "Does the Plan consider the potential cyanide failure scenarios appropriate for its site-specific environmental and operating circumstances, including the following, as applicable: … j) Failure of tailings impoundments, heap leach facilities and other cyanide facilities?"

Mining Principle 9 (Dialogue and Disclosure) states "Engage in public consultation and disclosure" (International Cyanide Management Institute, 2021a). The two Standards of Practice for Mining Principle 9 are the following (International Cyanide Management Institute, 2021a):

- Mining Standard of Practice 9.1: "Promote dialogue with stakeholders regarding cyanide management and responsibly address identified concerns."
- Mining Standard of Practice 9.2: "Make appropriate operational and environmental information regarding cyanide available to stakeholders."

It hardly needs to be stated that Mining Standard of Practice 9.2 requires that the information provided to stakeholders be accurate and consistent.

In addition to the requirement that gold mining companies commit to the entirety of the International Cyanide Management Code, which necessarily includes certification through third-party audits, the Responsible Gold Mining Principles require adherence to best practices in the design and operation of tailings storage facilities. Principle 8 of Responsible Gold Mining Principles is entitled "Environmental stewardship: we will ensure that environmental responsibility is at the core of how we work" (World Gold Council, 2019a). Requirement 8.2 then states, "We will design, build, manage and decommission tailings storage and heap-leaching facilities and large-scale water infrastructure using ongoing management and governance practices in line with widely supported good practice guidelines" (World Gold Council, 2019a). The World Gold Council (2019b) then clarifies that Requirement 8.2 means that gold mining companies should "Ensure management and governance practices are in place for existing facilities, and provide evidence of how these align with good practice guidance … For new facilities, develop design, build and management specifications with explicit references to widely recognised good practice guidelines … Discuss and review how widely recognised good practice guidelines have been taken into account in the design, build and management of facilities."

Although not stated in the Responsible Gold Mining Principles, current best practice guidelines for tailings storage facilities include the Global Industry Standard for Tailings Management (GISTM) (ICMM-UNEP-PRI, 2020) and Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022). The GISTM was released by the International Council on Mining & Metals (ICMM), United Nations Environment Programme (UNEP), and Principles for Responsible Investment (PRI) in August 2020 (ICMM-UNEP-PRI, 2020). Company Members of ICMM were obligated to fully comply with the GISTM by August 5, 2023 (ICMM, 2020, 2021). Neither CJK Milling nor Union Milling Company are Company

Members of ICMM nor, to the knowledge of the author, has either company made its own commitment to comply with the GISTM. However, it is noteworthy that Association Members of ICMM include the US-based National Mining Association (NMA), the US-based Society for Mining, Metallurgy and Exploration (SME), and the World Gold Council (ICMM, 2024). In nearly all respects, Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022) is more protective of people and the environment than the GISTM.

Free Cyanide, WAD Cyanide, and Total Cyanide

Environmental standards for cyanide may refer either to free cyanide or total cyanide, and sometimes to WAD (Weak Acid Dissociable) cyanide. Free cyanide refers to cyanide in the form of the cyanide ion plus hydrogen cyanide. Total cyanide refers to all forms of cyanide, including free cyanide and a wide variety of metal-cyanide complexes. WAD cyanide refers to free cyanide plus those metal-cyanide complexes that will dissociate into free cyanide upon application of a weak acid, including complexes of cyanide with cadmium, chromium, copper, manganese, mercury, nickel, silver, and zinc. WAD cyanide does not include the strong metal-cyanide complexes, such as gold cyanide, cobalt cyanide or iron cyanide that require the application of strong acids for the dissociation of the metal-cyanide complexes into free cyanide (Johnson, 2015; Botz, 2024). Thus, total cyanide is always greater than or equal to WAD cyanide, which is always greater than or equal to free cyanide.

The environmental significance of the three measures of cyanide relate to their different levels of toxicity. Thus, free cyanide has high toxicity, the weak metal-cyanide complexes have intermediate toxicity, and the strong metal-cyanide complexes have low toxicity (Johnson, 2015). Because free cyanide is the highly toxic form of cyanide, only free cyanide is regulated in some countries, such the USA (EPA, 2024a). Colorado regulations set a maximum free cyanide concentration of 0.2 mg/L for domestic water supply (Code of Colorado Regulations, 2016), which is the same as the National Primary Drinking Water Regulation (EPA, 2024a). Due to the extreme sensitivity of aquatic life to cyanide, the EPA aquatic standard for chronic exposure in freshwater is 0.0052 mg/L (EPA, 2024b). The International Cyanide Management Code is even more protective in setting a free cyanide limit of 0.022 mg/L in waterways downstream from cyanide-processing operations (International Cyanide Management Institute, 2021b). On the other hand, because the weak acids in animal and human stomachs will convert weak metal-cyanide complexes into free cyanide (Laitos, 2013), some regulations and guidance documents are based on WAD cyanide. It has been mentioned that mine infrastructure is assigned to the category of "cyanide facility" in the International Cyanide Management Code if the concentration of WAD cyanide in the facility is at least 0.5 mg/L (International Cyanide Management Institute, 2021c). Finally, because all forms of cyanide, including the strong metal-cyanide complexes, can be converted into free cyanide under certain circumstances, such as exposure to sunlight (Johnson et al., 2001, 2002, 2008), only total cyanide is regulated in some countries.

It is critical that concentrations of free cyanide, WAD cyanide and total cyanide not be used interchangeably in comparing measured concentrations with regulatory limits or guidance documents. Under some circumstances, free cyanide can be only slightly less than WAD cyanide, while WAD cyanide can be only slightly less than total cyanide. On the other hand, there are many examples of data throughout the geochemical literature in which total cyanide in mine wastewater was 10-100 times greater than either WAD cyanide or free cyanide (Smith and

Mudder, 1999; Johnson et al., 2000, 2001, 2002, 2008; Johnson, 2015). As a general rule, as processes of attenuation, such as volatilization, oxidation, photo dissociation or biodegradation, are given time and opportunity to operate, the proportion of free cyanide will decrease since it will be much more readily attenuated than the more resistant forms of cyanide. However, by the same logic, as the strong metal-cyanide complexes, such as iron cyanide, are exposed to sunlight, the proportion of free cyanide will increase as the strong metal-cyanide complexes are converted into free cyanide (Johnson, 2015).

Water Use and Water Consumption in Remining

Typically, mines recycle some amount of water with recycling ranging from 0-96% (Mudd et al., 2017), so that there is a distinction between water use and water consumption. The rate at which water circulates or is recycled through the mining operation is called "water use," while "water consumption" refers to the rate at which mine water must be replaced by withdrawals from groundwater or surface water resources. Water consumption is also called the "blue water footprint" and results from water lost by evaporation, water that is incorporated into the product (such as a gold concentrate) and shipped off-site, water that is permanently entrained within mine tailings, and water that is not returned to the same watershed from which it was withdrawn (Northey and Haque, 2013). In addition to the evaporation due to any exposure of water or wet material to the atmosphere, major sources of evaporative loss are the spraying of water for dust control and evaporation from open tailings ponds or water storage ponds.

Nearly all studies on water consumption for gold production have looked at virgin gold mines, not remining operations. Table 1 compares four studies on water consumption per metric ton of ore and eight studies on water consumption per metric ton of gold. Averaging the results of the studies yields global averages of 1.40 cubic meters of water per metric ton of ore and 390,908 cubic meters of water per metric ton of gold (see Table 1), equivalent to 336 gallons of water per ton of ore and 103.267 million gallons of water per ton of gold, respectively. At the present time, according to Maest (2024), "Little information is available on water use in remining operations, and best practice and regulations should include a careful accounting of water use." There is no obvious reason as to why water consumption should change due to milling operations or tailings production when comparing virgin mining and remining operations. The chief source of savings in water consumption for remining operations should be the general reduction in surfaces that require spraying of water for dust control through the elimination of an open pit or underground mine. On the other hand, the flow of groundwater into open pits or underground galleries often provides the water that is needed for the mining operation and that pumping of groundwater may or may not be counted as water consumption, depending upon the regulations or industry standards that are followed.

Based on the above discussion, the water consumption from remining gold tailings is probably less than the water consumption from mining a virgin gold ore, but probably not less by an order of magnitude. Therefore, a reasonable starting point for water consumption for remining would be one-half the water consumption for virgin mining, or 0.70 cubic meters of water per metric ton of ore and 195,454 cubic meters of water per metric ton of gold, equivalent to 168 gallons of water per ton of ore and 51.6335 million gallons of water per ton of gold. Continuing with the above reasoning, the production of 533,000 tons of tailings at the Leadville Mill (only slightly less than the quantity of ore) would involve the consumption of 89.544 million gallons of water. If the duration of the operation is 3.75 years, then the average rate of water consumption would be 45 gallons per minute. The preceding estimate will be compared with estimates in the permit application and on the website of CJK Milling in the "Responses" section.

Table 1. Average water consumption by gold mining

Study	**Based on Ore Production (m^3 water / metric ton ore)**	**Based on Gold Production (m^3 water / metric ton gold)**
Mudd (2007a)	1.42	691,000
Mudd (2007b)	0.88	325,000
Mudd (2010)	—	634,900
Norgate and Haque (2012)	—	259,290
Norgate and Haque (2012)[1]	—	288,140
Gunson (2013)	0.745	400,000
Northey and Haque (2013)	—	244,701
Northey and Haque (2013)[2]	—	284,235
DWS (2016)[3]	2.56	—
Average	1.40	390,908 12.16 (m^3 water / oz gold)

[1]Norgate and Haque (2012) used two different methods.
[2]Northey and Haque (2013) used two different methods.
[3]Department of Water and Sanitation (South Africa)

Mine Tailings and Liquefaction

A mass of mine tailings consists of solid rock particles in which the pores between the particles are filled with a combination of air and water. From an engineering perspective, a mass of mine tailings is a type of soil. Of course, from an agricultural perspective, a soil should include organic matter and organisms and be able to support the growth of higher plants. However, these biological properties are not relevant for engineering purposes. An excellent reference for more complete information on the engineering properties of soils is Holtz et al. (2011). The phrases "soil" and "mass of tailings" will be used interchangeably in this subsection, which largely follows the presentation in Holtz et al. (2011).

A normal stress means any stress that is acting perpendicular to a surface (see Fig. 3). A normal stress acting on a soil can be partially counterbalanced by the water pressure within the pores. The effective stress is defined as the normal stress minus the pore water pressure. The effective stress is a measure of the extent to which the solid particles are interacting with or "touching" each other (see Fig. 3). The normal stress without subtracting the pore water pressure is also called the total stress.

Terzaghi's Principle states that the response of a soil mass to a change in stress is due exclusively to the change in effective stress (Holtz et al., 2011). For example, suppose that sediments are deposited on a river floodplain or tailings are hydraulically discharged into a tailings reservoir without compaction. The weight of the solid particles creates a normal stress, so that the particles will consolidate under their own weight. The amount and rate of consolidation is determined by the effective stress, that is, the extent to which the particles are interacting with one another. Sufficient water pressure can offset the normal stress, so that little consolidation could occur and at a slow rate.

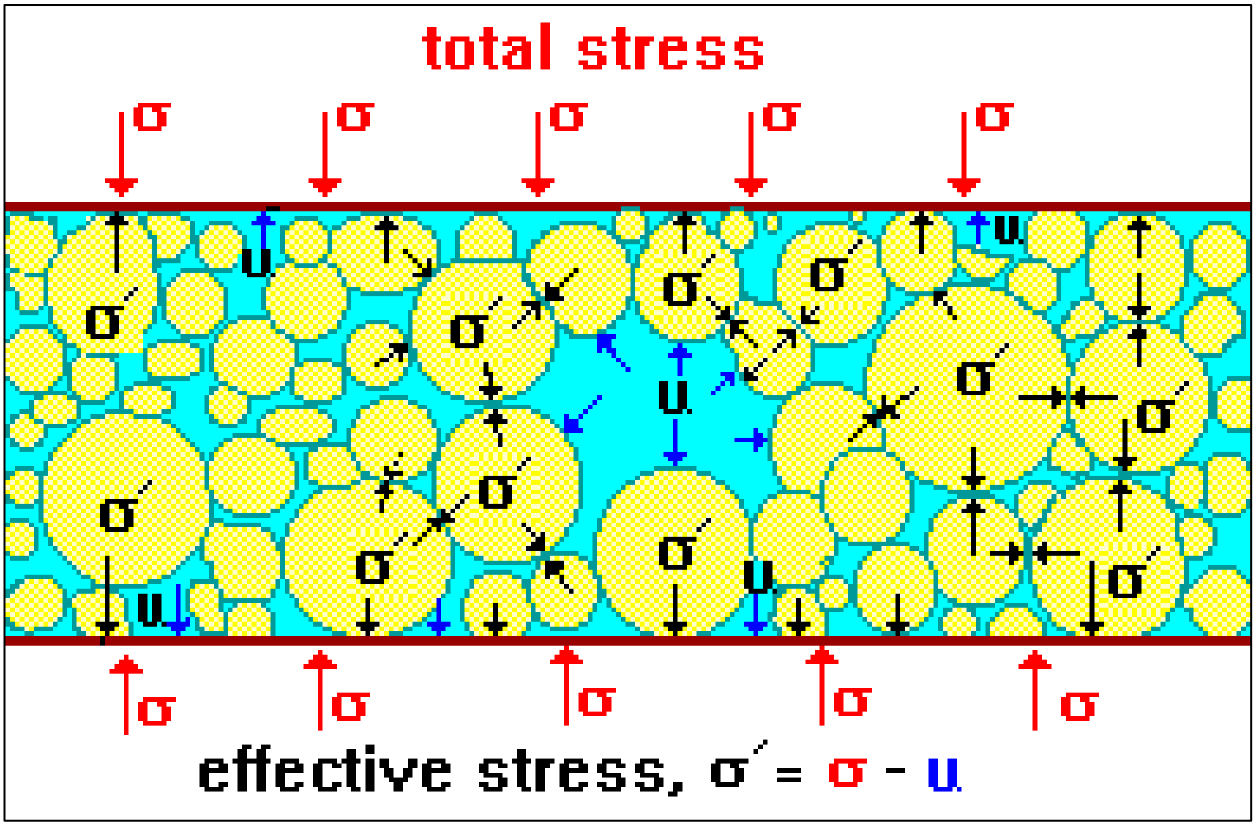


Figure 3. The effective stress in soil is equal to the total stress minus the pore water pressure. The effective stress is a measure of the extent to which the solid particles are interacting with or "touching" each other. Terzaghi's Principle states that the response of a soil mass to a change in stress is due exclusively to the change in effective stress. Figure from GeotechniCAL (2024).

The phenomenon of liquefaction, in which a soil loses its strength and behaves like a liquid, can be explained through an application of Terzaghi's Principle (see Fig. 4). In the diagram on the left-hand side of Fig. 4, although the solid particles are loosely packed and the pores are saturated with water, the particles touch each other. Because there is contact between the particles, the load (the weight of particles or other materials above the particles shown on the left-hand side of Fig. 4), is carried by the solid particles. The load is also partially borne by the water due to the water pressure. The term permeability refers to the ability of water to flow through the pores. A mix of coarse and fine particles will have low permeability because the finer particles will fill in the pores between the coarser particles and, thus, restrict the pore space for water flow.

Loose-packing means that the soil is in a contractive (or contractile) state, so that the solid particles will tend to compact to a more densely packed state following an increase in load or a disturbance (such as an earthquake). If the water cannot escape (due to low permeability or the speed of the disturbance), the solids cannot compact so that the additional stress is converted into an increase in pore water pressure (see right-hand side of Fig. 4). The increased water pressure can decrease the effective stress almost to zero or to the point where the particles no longer "touch" each other (see Fig. 3). At this point, the soil mass has undergone liquefaction in which the water supports the entire load and the mass of particles and water behaves like a liquid.

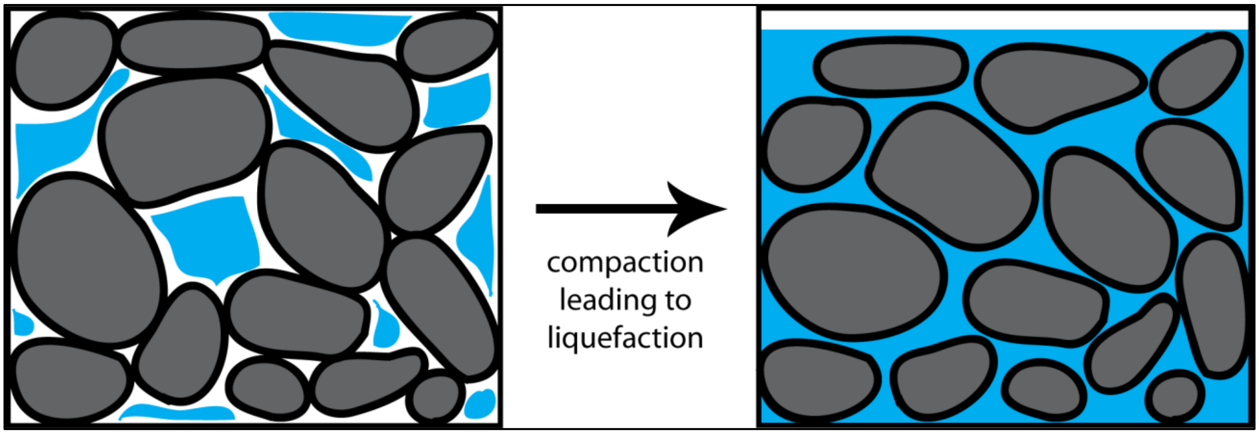


Figure 4. In the diagram on the left, although the solid particles are loosely packed and the pores are saturated with water, the particles touch each other, so that the load is supported by the particles (and partially by the water). Loose-packing means that the soil is in a contractive state, so that the solid particles will tend to compact to a more densely packed state following an increase in load or a disturbance (such as an earthquake). If the water cannot escape (due to low permeability or the speed of the disturbance), the solids cannot compact so that the additional stress is converted into an increase in pore water pressure (see the diagram on the right). The increased water pressure can decrease the effective stress almost to zero or to the point where the particles no longer "touch" each other (see Fig. 3). At this point, the soil mass has undergone liquefaction in which the water supports the entire load and the mass of particles and water behaves like a liquid. This phenomenon of liquefaction is promoted by saturated pores and loosely packed particles. Tailing deposits are especially susceptible to liquefaction because the tailings are very loosely packed due to the hydraulic discharge into the reservoir without compaction. If the pores are unsaturated prior to the disturbance, some compaction can occur (decreasing the size of the pores), so that the pores become saturated. Any further contractive behavior will then convert the additional stress into increased pore water pressure. On that basis, liquefaction is possible even if the pores are only 80% saturated. Figure from DoITPoMS (2024).

The phenomenon of liquefaction is promoted by saturated pores and loosely packed particles. Conventional tailings storage facilities are especially susceptible to liquefaction because the tailings are very loosely packed due to the hydraulic discharge into the tailings storage facility without compaction. If the pores are unsaturated prior to the disturbance, some compaction can occur (decreasing the size of the pores), so that the pores become saturated. Any further contractive behavior will then convert the additional stress into increased pore water pressure. On that basis, liquefaction is possible even if the pores are only 80% saturated. There is a considerable literature on methods for evaluating the susceptibility of soil or tailings to liquefaction (Fell et al., 2015). For example, incomplete gravity separation during hydraulic discharge could lead to a mix of coarse and fine tailings, which could make the tailings more susceptible to liquefaction by reducing their permeability.

Soil that is already in a densely packed state is said to be in a dilative (or dilatant) state, so that the solid particles will tend to expand following a disturbance. In this case, disturbance causes a strengthening, rather than a weakening of the soil, due to the resulting decrease in pore water pressure. A soil in which the particles will neither compact nor expand following a disturbance is said to be in the critical state. The basis of Critical State Soil Mechanics is the principle that, following a disturbance, all soils will tend to approach the critical state of packing, in which the critical void ratio (ratio of volume of pore space to volume of solid particles) depends upon the effective vertical stress.

Geotechnical Water Content and Process Water Content

The expression "water content" has two different meanings that cannot be used interchangeably. The geotechnical water content *w* of a mixture of solids, water and air is defined as

$$w\ (\%) = 100 \times \frac{M_W}{M_S} \tag{1}$$

where M_W is the mass of water and M_S is the mass of solids, while the process water content m_C of the mixture is defined as

$$m_C\ (\%) = 100 \times \frac{M_W}{M_W + M_S} \tag{2}$$

In other words, the geotechnical water content is defined on a "dry" basis, while the process water content is defined on a "wet" basis. Typically, the mass of air is not considered in mass-based calculations, since it is much less than the masses of water or solids. Combining Eqs. (1)-(2) yields the relationship between geotechnical water content and process water content

$$w = 100\left(\frac{m_C}{100 - m_C}\right) \tag{3}$$

The geotechnical water content is always greater than the process water content. For example, if the process water content is 25%, then the geotechnical water content is 33.3%.

The geotechnical water content is typically used by geotechnical engineers, so that analyses of filtered tailings storage facilities usually refer to geotechnical water contents. On the other hand, the process water content is typically used by process or metallurgical engineers, so that analyses of ore processing plants usually refer to process water contents. A difficult aspect of interpreting the permit application by Union Milling Company (2024) is that, by and large, the application uses the expression "water content" without clarifying whether it refers to the geotechnical water content or the process water content. The only exception is the inclusion in the permit application of a 12-page consulting report by Paterson & Cooke entitled "Leadville Tailings Characterization," which explicitly states that "water content" refers to the process water content. In this report, it will be assumed that "water content" means process water content in the permit application, although some points of confusion will also be indicated. As appropriate, equivalent geotechnical water contents will also be stated for comparison with the literature on filtered tailings storage facilities.

Filtered Tailings Technology

Filtered tailings technology seeks to address two important problems in mining by partially dewatering the tailings before they are shipped to the tailings storage facility:

1) The water consumption can be reduced by recycling the water from the tailings back into the mining operation.

2) The likelihood of liquefaction of the tailings can be reduced by desaturating the tailings and then by compacting the tailings as they are stored in a filtered tailings storage facility.

In conventional tailings management, the tailings are shipped to the tailings storage facility from the ore processing plant with no dewatering, so that the geotechnical water content of the tailings is in the range 150-400%, although it can be as low as 67%. High-density thickened or paste tailings technology dewaters the tailings to geotechnical water contents in the range 33-67% prior to export to the tailings storage facility, while filtered tailings technology dewaters the tailings to geotechnical water contents less than about 20%. Conventional tailings behave like a wet slurry, while high-density thickened or paste tailings behave like a paste (as the name implies), and filtered tailings behave like a moist soil. The boundaries between the different tailings technologies depend upon the physical and chemical properties of the tailings, and is defined by physical behavior, not geotechnical water content. Other advantages of filtered tailings technology are reduction of the footprint of the tailings storage facility and facilitating the safe closure of the facility (Klohn Crippen Berger, 2017).

Although Union Milling Company (2024) and CJK Milling (2024f) repeatedly refer to the filtered tailings as "dry" and to the filtered tailings deposit as a "dry stack," this is non-standard terminology. The tailings are not literally dry and, if they were, it would be impossible to properly compact them for safe storage. For example, CJK Milling (2024f) states, "The resulting dry stack tailings system is more stable than the traditional wet tailings, further reducing the risk of contamination to water sources in the environment." Union Milling Company (2024) also states, "Solids in slurry form will be detoxified … and the detoxified process residue (tailings) will be dewatered to produce a dry filter cake." The non-standard usage of "detoxified" will also be addressed in the section "Summary of Proposal for Remining at Leadville Mill."

In contrast to the description of the tailings as "dry" by Union Milling Company (2024) and CKJ Milling (2024f), on their website, the consulting company Knight-Piésold includes a publication by employees of Knight-Piésold that states, "Regarding terminology, the rather misleading term dry stack is generally not a good engineering term since the target moisture content coming from the filter plant is typically desired to be somewhere around the optimum moisture content based on the Proctor compaction procedure … Geotechnical engineers associate the optimum moisture content with moisture levels just below full saturation after compaction, thus terming such a facility as a dry stack is a misnomer. The present authors would encourage practitioners to abandon the use of the term dry stacking in favor of the more straightforward term, 'filtered tailings.' It is not desirable to unintentionally mislead the public at large with an industry term that is noticeably misused" (Ulrich and Coffin, 2017). With regard to the proposed Twin Metals mine in Minnesota (USA), for which the mineral lease has since been canceled, the Minnesota Department of Natural Resources (2021) asked, "Is characterizing the tailings filter cake as being 'dry' a common terminology for a product exhibiting a 13% to 16% moisture content?" Finally, the SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook confirms that "The term dry stacking … is somewhat of a misnomer. Stacked tailings must be sufficiently dry to allow placement in stable and trafficable piles, but not so dry as to result in dust generation from prevailing wind" (Reemeyer, 2022). In this report, the tailings will be referred to as "filtered" rather than "dry," except to quote from the permit application or the website of CJK Milling.

A simple comparison of the preceding geotechnical water contents for the different categories of tailings overstates the reduction in water consumption that can be achieved by the transition from conventional to filtered tailings technology. The reason is that, within the tailings storage facility, the solid tailings will settle out of suspension so that the supernatant water can be recycled back into the mining operation. For example, a typical mill will export to the tailings storage facility 70 tons of water for every 30 tons of solid tailings (see Fig. 5). In a typical conventional tailings storage facility, of those 70 tons of water, 7 tons of water will remain entrained within the tailings for a geotechnical water content of 23.3%, while 63 tons of water will be released at the tailings facility and recycled back into the mining operation (see Fig. 5). The progression from conventional to thickened to high-density thickened to paste tailings technology increases the proportion of water that is recycled through dewatering of the tailings prior to shipment to the tailings storage facility ("reclaimed during processing") and decreases the proportion of water that is recycled out of the tailings storage facility ("released at tailings facility") (see Fig. 5). However, the end result from a water consumption standpoint does not change, namely that typically, for every 30 tons of solid tailings, 7 tons of water remain permanently entrained within the tailings (see Fig. 5). The step change occurs in the transition to filtered tailings technology, in which, typically, no water can be recycled from the filtered tailings storage facility, while 5 tons of water remain entrained within the tailings for every 30 tons of solid tailings, for a geotechnical water content of 16.7% (see Fig. 5). In summary, the typical reduction in water consumption through the use of filtered tailings technology is 2 tons of water for every 30 tons of solid tailings, in comparison to any other tailings management technology (Klohn Crippen Berger, 2017).

An additional source of reduction in water consumption through filtered tailings technology is the reduction in evaporation through the elimination of a free water surface on top of the tailings. The evaporation from the tailings pond is highly variable and depends upon solar radiation, water temperature, and atmospheric factors, such as air temperature, relative humidity and wind speed, as well as the technologies that can be used to reduce evaporation. According to Spiller and Dunne (2017), "The amount of evaporation of water from the TSF [Tailings Storage Facility] may range from about 5% to more than 60% of the total water lost at a TSF." On that basis, at the lower end of evaporation (5% of total water loss), for every 7 tons of water entrained within the tailings, another 0.4 tons of water will be lost to evaporation. At the higher end of evaporation (60% of total water loss), for every 7 tons of water entrained within the tailings, another 10.5 tons of water will be lost to evaporation. Thus, the reduction in water consumption through a conversion to filtered tailings technology could be as high as 12.5 tons of water for every 30 tons of tailings if the conversion occurred from an existing or planned facility with extremely high evaporation and no other technologies for reducing evaporation. On the other hand, the tailings pond can also be a source of water through the capture of precipitation and surface runoff (Klohn Crippen Berger, 2017). Most case studies regarding conversions to filtered tailings technology have not explicitly taken into account any reduction in water consumption through reduction in evaporation from the tailings pond (e.g., Gagnon and Lind, 2017; Moreno et al., 2018).

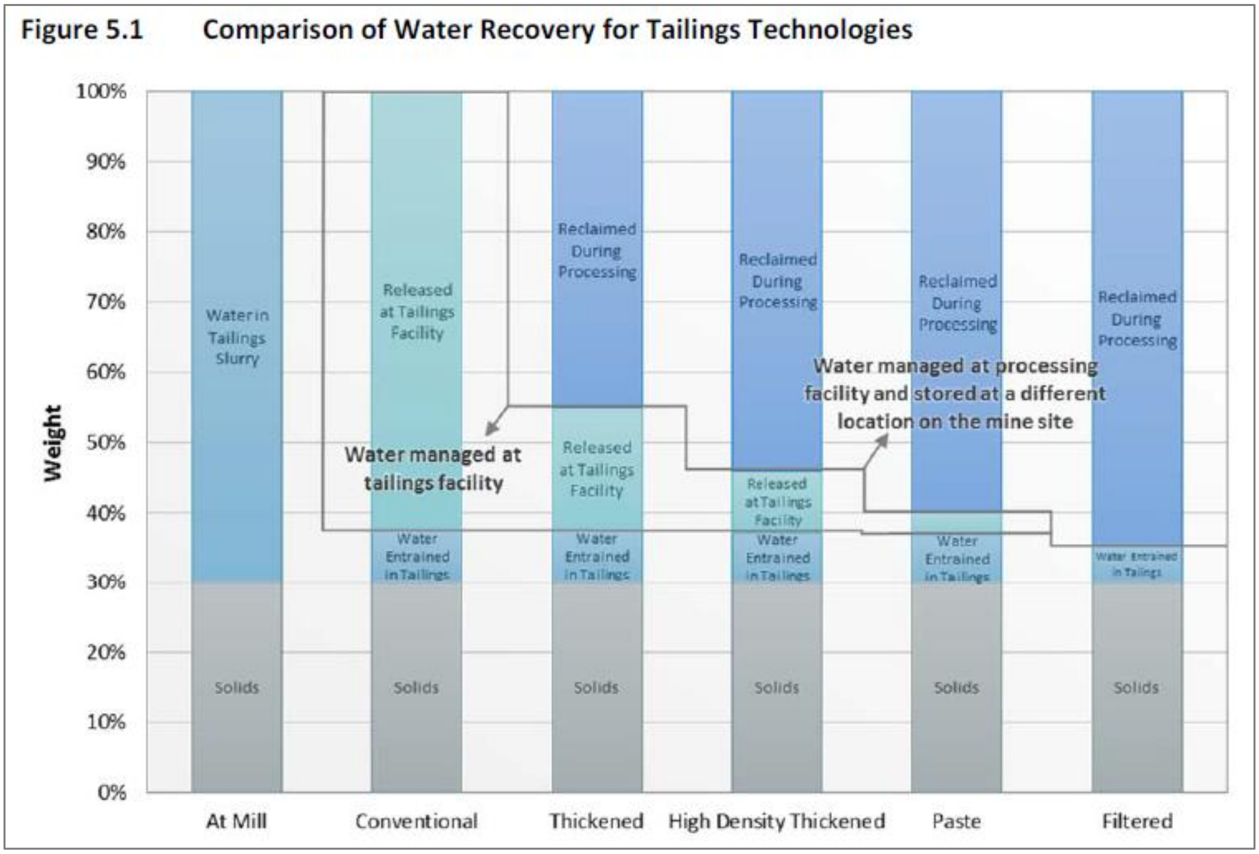


Figure 5. In conventional, thickened, high-density thickened, and paste tailings technology, for every 30 tons of solid tailings, the water entrained in the tailings has a mass of 7 tons. This entrained water is not released as the tailings settle out of suspension and is generally non-recoverable and, thus, a component of water consumption. In filtered tailings technology, for every 30 tons of solid tailings, the non-recoverable water entrained in the tailings has a mass of 5 tons. Therefore, the reduction in water consumption resulting from the use of filtered tailings technology is 2 tons of water for every 30 tons of tailings. Some additional reduction in water consumption could occur through reduction of evaporation at the tailings facility. Figure from Klohn Crippen Berger (2017).

Filtered tailings technology reduces the likelihood of liquefaction of the tailings stack through desaturating the pore spaces between the tailings, reducing the overall quantity of water in the tailings storage facility, and compacting the tailings within the tailings storage facility. This compaction reduces the likelihood of liquefaction by putting the tailings into a dilative (as opposed to contractive) state in which they will expand rather than consolidate when they are sheared or disturbed. Most typically, filtered tailings storage facilities are constructed with an outer shell of compacted tailings (sometimes called the “structural zone”) surrounding an inner core of uncompacted or lightly compacted tailings (see Fig. 6). Although some recent mining project plans have claimed that filtered tailings do not require a dam, the structural zone fulfills the exact same function as a dam, that is, it is an engineered structure that prevents the flow of water or waste materials containing water. For example, with regard to its proposal for a copper mine in Minnesota, Twin Metals Minnesota (2024) wrote, “Dry stacking filtered tailings means there is no need for a dam – dam failure is impossible.” The response from the Minnesota Department of Natural Resources (2021) was that a dam is a “structure that impounds water **and/or waste materials containing water**” (emphasis in the original). Klohn Crippen Berger (2017) has also emphasized that a filtered tailings facility “still requires ‘structural zones’ (which perform like dams), made of compacted tailings for confinement” and “if filtered tailings are placed in a stand-alone facility (pile/stack), the outer slopes must maintain structural stability (similar to a dam or a waste dump), particularly under seismic loading conditions.” Finally, according to Safety First: Guidelines for Responsible Mine Tailings Management, “Because they [filtered tailings facilities] still require a structural zone (which is a type of dam) for containment, they must be treated as an engineered tailings facility (i.e. tailings dam) from a regulatory standpoint … The structural zone of a filtered tailings facility serves the same function as a dam” (Morrill et al., 2022).

Figure 3.5 Schematic of a Filtered Tailings Facility

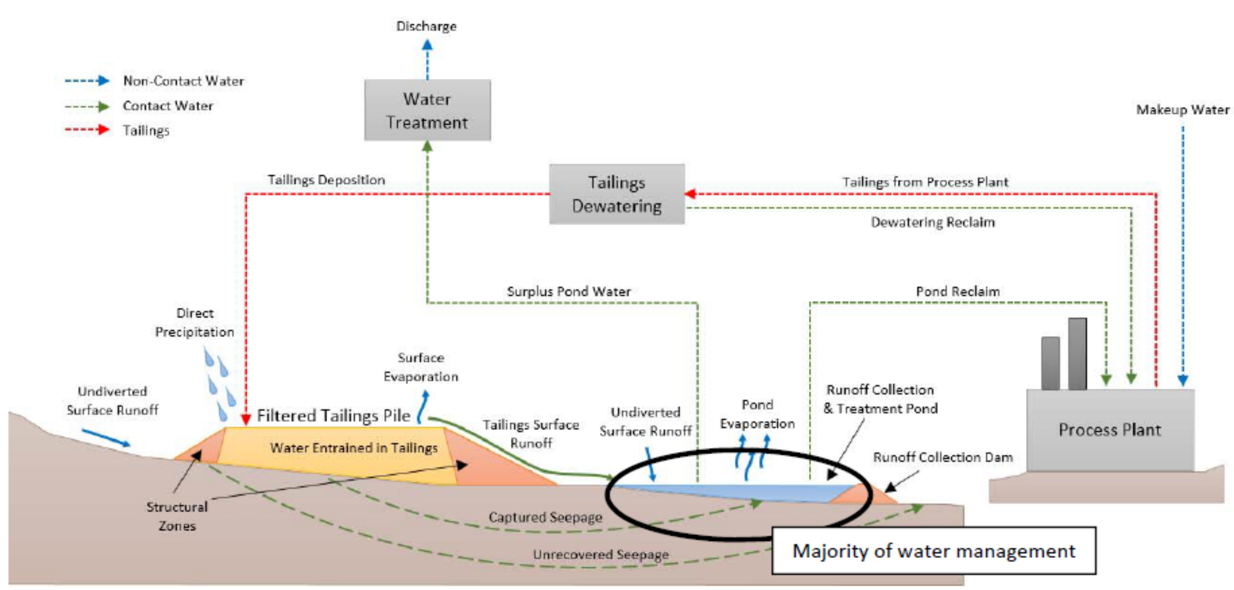


Figure 6. Current filter press technology does not consistently produce filtered tailings with the appropriate geotechnical water content for adequate compaction. Even if tailings do leave the filter presses with the appropriate water content, they can be rewetted by precipitation. The standard solution for filtered tailings stacks is to place the tailings that are too wet or too dry for adequate compaction in the center of the facility in a non-structural zone, in which the tailings are either uncompacted or lightly compacted. The tailings with the appropriate water content for adequate compaction are then placed on the periphery, where they can be compacted to form a structural zone. The structural zone serves the same function as a dam for the non-structural zone. Figure from Klohn Crippen Berger (2017).

The inner core of a filtered tailings storage facility is, in fact, a requirement for the storage of tailings that left the filter presses with too much water for adequate compaction. Crystal et al. (2018) have emphasized that target water contents for filtered tailings are rarely achieved. According to Crystal et al. (2018), “Commonly, projects are specifying (or promising) a target filter-cake moisture at the limit of the filter performance (including at the limit of the thickener’s ability to deliver feed at the required solids ratio). This has caused numerous examples where the operating performance does not consistently meet the target … Essentially, irrespective of site, ore body type, or filter press manufacturer, a 15% moisture content remains a typical target, while tracking of day-in and day-out moisture contents of filter cakes demonstrates that achievable moisture contents are often in the range of 17 to 18% when things are running smoothly and can be up to 20 to 23% when off-spec … ‘Targets’ may be cited or promised, but achievable filter cake moisture contents and the variability of the process are not generally within the tailings engineer’s control.” For example, Mexican gold and silver mines that use filtered tailings technology have achieved geotechnical water contents in the range 14-19% (Espinosa-Gomez et al., 2018). Cacciuttolo Vargas and Pérez Campomanes (2022) list 28 filtered tailings storage facilities with geotechnical water contents ranging from 12 to 20%, although without clarifying whether these are target or achieved water contents. Even if the tailings leave the filter presses with the target geotechnical water content, they can still be rewetted by precipitation. Thus far, these filtered tailings storage facilities have mostly been small and mostly constructed in areas with arid climates (Klohn Crippen Berger, 2017). The partial restriction to arid regions has partly been motivated by the greater need to recycle water in regions with high water scarcity. However, an additional factor has been the challenges in achieving the appropriate water content for adequate compaction in wet climates. At the present time, the standard solution in both arid and wet climates is to set aside an inner core (a region away from the outer slopes) for placement of tailings that cannot be adequately compacted. Crystal et al. (2018) continue, "The tailings engineer can, however, specify acceptable moisture contents for different areas of the dry stack, depending on stacking strategies. For example, external structural zones may have more stringent criteria than non-structural zones, for which reduced constraints may be allowed."

Because of its ability to reduce both the likelihood and the consequences of failure of tailings storage facilities, filtered tailings technology is currently regarded as the best available technology. According to the expert panel report on the failure of the tailings storage facility at the Mount Polley mine, "BAT [Best Available Technology] has three components that derive from first principles of soil mechanics: 1. Eliminate surface water from the impoundment. 2. Promote unsaturated conditions in the tailings with drainage provisions. 3. Achieve dilatant conditions throughout the tailings deposit by compaction … Filtered tailings technology embodies all three BAT components … There are no overriding technical impediments to more widespread adoption of filtered tailings technology." The document Safety First: Guidelines for Responsible Mine Tailings Management also mandates "the use of Best Available Technology for tailings, in particular filtered tailings" (Morrill et al., 2022).

At the same time, it goes without saying that the use of filtered tailings technology cannot be a license for ignoring other aspects of safety. Even though Twin Metals Minnesota (2024) writes, "Dry stacking filtered tailings means there is no need for a dam – dam failure is impossible," failure is never impossible. In fact, a filtered tailings storage facility collapsed at the Pau Branco iron-ore mine in Brazil on January 8, 2022 (Angelo, 2022; Morrill, 2022; Petley, 2022; see Fig. 7). In addition, the use of filtered tailings technology can lead to complacency from an illusion of safety. According to Oboni and Oboni (2020), "Dewatered tailings would tend to bring the probability of failure towards the bottom of the historical range, provided, of course the dewatering is effective, and does not generate excessive risk taking based on its promises." A related issue is the lack of guidance based on experience that always results from the adoption of a new technology. Again, according to Oboni and Oboni (2020), "The problem is that the possible alternatives to slurry deposition have not yet created the same body of knowledge that could support development of professional guidances and protocols of a quality equal to that for slurry deposition."

Figure 7. A 48-meter-high filtered tailings stack collapsed at the Pau Branco iron-ore mine in Brazil on January 8, 2022. Although filtered tailings are regarded as the Best Available Technology at the present time (Independent Expert Engineering Investigation and Review Panel, 2015; Morrill et al., 2022), the use of filtered tailings technology is not a license to ignore every other aspect of safety. Photo from Angelo (2022).

A key issue is that, although filtered tailings may be unsaturated when deposited in the tailings storage facility, it is still necessary to prevent resaturation of the tailings in order to prevent future liquefaction. The problem is particularly acute since the target geotechnical water content for maximum compaction is typically only a few percentage points less than the saturated geotechnical water content. The pore spaces between the tailing particles can become resaturated simply by consolidation under the weight of additional overlying tailings, which reduces the volume of pores so that they become filled with water (Klohn Crippen Berger, 2017). In fact, it is not unusual for the lower one-third to one-half of a filtered tailings stack to be saturated. Water can also enter the filtered tailings storage facility through surface runoff, upward groundwater seepage, and direct precipitation onto the tailings. The above water sources require diversion canals that isolate the tailings storage facility from the rest of the watershed and appropriate drainage infrastructure for conveying any excess water out of the tailings. The failure of the filtered tailings stack at the Par Branco mine (see Fig. 7) was probably caused by heavy rainfall that led to liquefaction (Morrill, 2022; Petley, 2022). According to Petley (2022), "[the failure of the filtered tailings stack at the Pau Branco mine] was probably a rotational landslide that fluidised into a flow." Note that the use of the word "fluidised" implies that liquefaction actually occurred.

It is important to point out that filtered tailings storage facilities have other possible failure mechanisms besides liquefaction. For example, surface runoff flowing over the structural zone could erode it away, thus exposing the uncompacted tailings that were behind the structural zone (see Fig. 6). Uneven settlement or failure of the foundation beneath the filtered tailings storage facility could cause failure of the entire structure. Finally, the structural zone (dam) could fail simply by sliding with no liquefaction or other flow behavior. According to Klohn Crippen

Berger (2017), due to the typical low water content of filtered tailings, "Failure, if it occurs, would likely be local slumping and consequences would be restricted to the local area (or the distance equivalent to roughly 10 times the height [of the tailings storage facility]) … " On the other hand, flow behavior of the tailings could develop if the tailings mixed with sufficient water after dam failure. The above quote continues, " … unless the material slumps into a water body … When large water ponds are located downstream of high-density thickened/paste facilities, cascading failures are possible and should be accounted for when developing the risk profile of tailings failure management" (Klohn Crippen Berger, 2017). On the above basis, drainage and runoff collection ponds should be located sufficiently far downstream from the tailings storage facility and excessive accumulation of water in these ponds should be avoided (Klohn Crippen Berger, 2017; see Fig. 6).

Limit Equilibrium Method and Factor of Safety

The limit equilibrium method evaluates the stability of a mass of rock or soil by assessing the tendency of a slope or structure to fail by one rigid block sliding over another (see Fig. 8). The output of the limit equilibrium method is the factor of safety, which is the ratio of the resistance to the load, or the ratio of the shear strength to the shear stress. Thus, a factor of safety equal to 1.0 indicates a slope on the cusp of failure, or more precisely, that the probability of failure is 50%. Higher factors of safety indicate slopes with increasing stability. The limitation of the limit equilibrium method is that not all failures involve the sliding of one rigid block over another. For example, the limit equilibrium method does not assess the tendency of a slope to fail by slow creep that could accelerate into more rapid motion, by rockfall, or by structurally-controlled failures along pre-existing joints or faults. In summary, the limit equilibrium method is a useful starting point, but should not be the totality of a slope stability analysis.

The input data for the limit equilibrium method are the topography (geometry), the unit weights (densities), shear stress parameters (cohesion and friction angle), and pore water pressures throughout the slope or structure and its foundation, as well as the position of the water table. The precise meanings of cohesion and friction angle are not necessary for this report, except that higher cohesion and higher friction angle correspond to greater shear strength. Materials that are saturated (below the water table) have lower shear strength and materials that are over-pressurized with water have even lower shear strengths. The limit equilibrium method considers all possible failure surfaces and calculates the factor of safety at each point along a possible failure surface (see Fig. 8). The factor of safety of a failure surface is the average of the factors of safety along every point of a surface. The failure surface with the lowest factor of safety is called the critical failure surface and the factor of safety of the critical failure surface is regarded as the factor of safety of the slope or structure (see Fig. 8).

It cannot be overemphasized that a factor of safety is not a measurement that is made, but the outcome of a model that depends upon a wide range of measurements, estimates and assumptions. There can be considerable uncertainty in the factor of safety as a result of uncertainty in the measurements of the input data and the incomplete sampling of structures for which the geotechnical parameters can have considerable spatial variability. There are also multiple computational methods for carrying out the limit equilibrium method for a given set of input data, each with its advantages and disadvantages, so that there is uncertainty as to whether the correct computational method has been used (Fell et al., 2015). As a consequence of the uncertainty in the data and the computational method, the calculated factor of safety cannot be assumed to be the same as the true factor of safety.

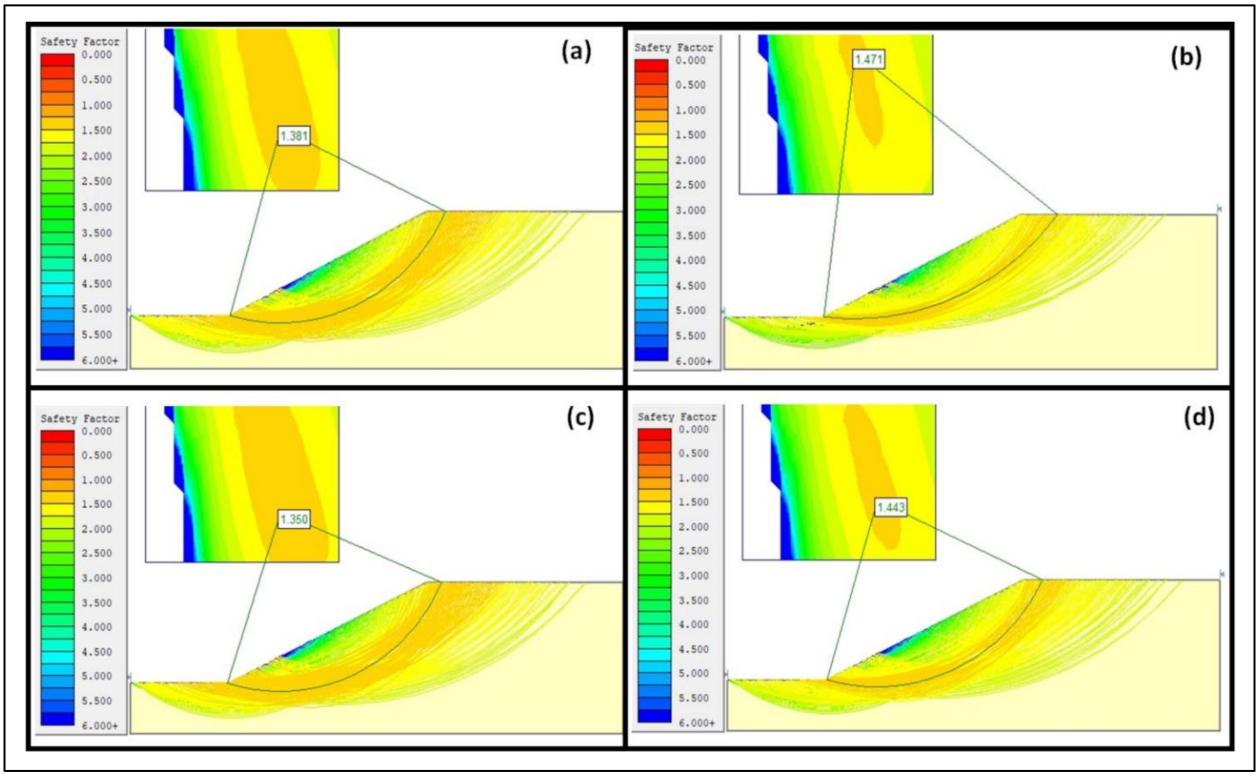


Figure 8. The factor of safety is the ratio of the shear strength to the shear stress (ratio of the resistance to the load) at some point within a slope, embankment or other type of earthen structure. The limit equilibrium method uses the unit weight, the shear strength parameters (cohesion and friction angle), pore water pressure, and position of the water table to calculate the factor of safety as averaged along every possible failure surface. The failure surface with the minimum factor of safety is called the critical failure surface. The factor of safety of the critical failure surface is regarded as the factor of safety of the structure. A factor of safety equal to 1.0 indicates that a structure is on the cusp of failure or, more precisely, that the probability of failure is 50%. Figure from Sengani and Allopi (2022).

A slope should be stable as long as the true factor of safety is greater than 1.0, although it should be kept in mind that the limit equilibrium method and its resulting factor of safety are evaluating only a narrow class of types of slope failures. However, because of the uncertainty in the calculated factor of safety, the engineering practice is to require a calculated factor of safety significantly greater than 1.0 in order to ensure that the true factor of safety (which could be less than the calculated factor of safety) is actually greater than 1.0. There are numerous publications, industry guidance documents, and regulations regarding the appropriate minimum factor of safety. These minimum factors of safety depend upon the application and the context, but a minimum factor of safety of 1.5 is common for many geotechnical applications (ANCOLD, 2012, 2019; Fell et al., 2015).

TUTORIAL ON KEY CONCEPTS OF HYDROGEOLOGY

Gaining and Losing Streams

The water table is the surface below which all pores between solid particles are filled with water (see Fig. 9). The region below the water table is the domain of groundwater and is called the saturated zone or the phreatic zone, while the water table is also called the phreatic surface. Between the surface of the Earth and the water table is the region in which pores are partly filled with water and partly with air, which is known as the unsaturated zone or the vadose zone. Surface water is free water (not confined within pores of solid particles) on the surface of the Earth. Typically, hydrology is the study of surface water, while hydrogeology is the study of groundwater, although the terms hydrology and hydrogeology are sometimes used interchangeably.

Although groundwater, surface water and vadose water can be regarded as distinct compartments, there is a continuous exchange of water among the compartments. In fact, a stream is simply a linear feature where the water table (groundwater) intersects the surface of the Earth (see Fig. 9). Other features of the landscape where the water table intersects the Earth's surface include springs, lakes, and fens. Many streams originate in springs and, thus, it is fairly arbitrary where a spring ends and a stream begins.

In a gaining stream, groundwater flows into the stream (see Fig. 9), while, in a losing stream, water flows out of the stream and into the groundwater system (see Fig. 9). The same stream could be gaining when the stream stage (elevation of the water surface) is low and losing when the stream stage is high (see Fig. 9). The streamflow that results from groundwater input, as opposed to precipitation or surface runoff, is referred to as baseflow. Evidence that a stream is gaining could be an increase in volumetric flow rate (also called discharge) in a downstream direction over reaches that have no tributaries.

Gaining streams are far more common than losing streams. Losing streams can occur in arid areas in which there is a low water table, but in which streams are fed by precipitation from mountainous regions and occasional overland flow. Losing streams could also occur when a stream draining a mountainous area with a fine-grained stream bed flows out onto a plain with coarse-grained alluvial sediment. Without further information, it should be assumed that any stream in the headwaters of the Arkansas River (see Fig. 2) is a gaining stream, except when the stream is at flood stage.

Based on the above discussion, it should be clear that surface water resources and groundwater resources are not separate resources. In particular, it cannot be proper to add the surface water resources and groundwater resources in a region to obtain the total water resources in the region. For example, groundwater that is pumped in a region with gaining streams is groundwater that would have flowed into a stream if it had not been pumped. Thus, the pumping of groundwater decreases the availability of surface water. In the same way, water that is taken from a losing stream decreases the availability of groundwater.

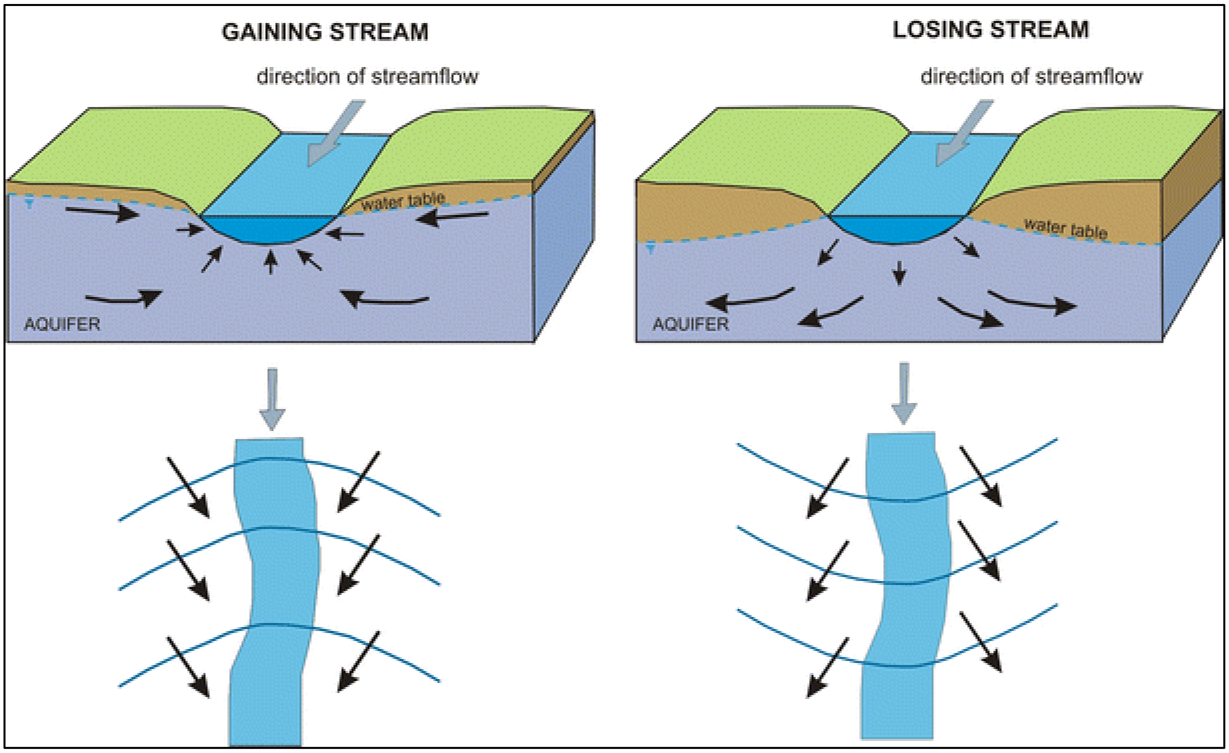


Figure 9. The water table is the boundary below which all pores are filled with water. The region below the water table is the domain of groundwater. An aquifer is a geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to wells. A stream is a linear feature at which the water table is at the surface. In a gaining stream, groundwater flows into the stream from the adjoining aquifer. In a losing stream, water flows out of the stream into the adjoining aquifer to become groundwater. The hydraulic head is the level to which water will rise in a well (see Figs. 10 and 11). For a stream, the hydraulic head is the water surface (the stream stage). Water flows from higher to lower hydraulic head. In the lower set of diagrams, the contours represent equal values of hydraulic head and show groundwater flowing from higher to lower hydraulic head for both gaining and losing streams. A map of hydraulic heads is also called a potentiometric surface. Because of the continuous exchange between surface water and groundwater, they should not be regarded as separate resources. Figure from Lasagna et al. (2016).

Confined and Unconfined Aquifers

An aquifer is an underground body of rock or sediment that is saturated with water and that has sufficient storage of water and sufficient hydraulic conductivity (pores that are sufficiently large and connected) that it can transmit economic quantities of water to water-supply wells or springs. An underground body of rock or sediment that is saturated, but which has hydraulic conductivity too low to effectively transmit groundwater to a water-supply well or spring, is called an aquitard or a confining layer or confining bed (see Fig. 10). Sometimes the term “aquiclude” is used to indicate a body of rock or sediment that is completely impermeable or which has zero hydraulic conductivity. Clearly, the identification of a body of rock or sediment as an aquifer depends upon the context. A rock layer that serves as an aquifer for a household well would not necessarily serve as an aquifer for a municipality. An aquifer is rarely a layer with a uniform thickness, composition, and hydraulic conductivity (as suggested by Fig. 10). The hydraulic conductivity of aquifers can easily vary over four orders of magnitude. There can be interbedding of layers with high and low hydraulic conductivity and the sections with high hydraulic conductivity can be poorly connected. For this reason, the phrase “aquifer complex" is often used instead of "aquifer." Along the same lines, the term "aquiclude" is also an idealization, since no earth material is literally impermeable.

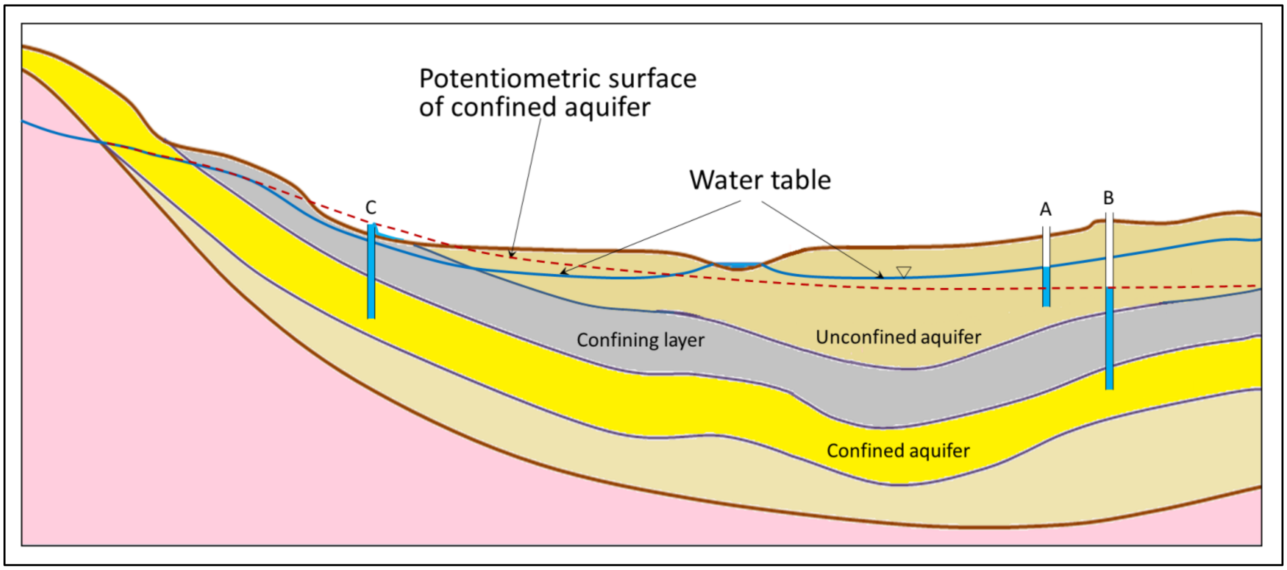


Figure 10. An unconfined aquifer has a vertical hydraulic connection with the surface. In a confined aquifer, the vertical hydraulic connection with the surface is blocked by a confining layer. The hydraulic head or potentiometric surface (see red dashed line and Wells B and C) is the level to which the groundwater would rise in a well if the confined aquifer were penetrated by a well. In an unconfined aquifer, groundwater is actually present at the potentiometric surface (even in the absence of a well), and the potentiometric surface is referred to as a water table (see blue line and Well A). Figure from BC Open Textbooks (2019).

Taking into account the above caution, aquifers or aquifer complexes can be regarded as either unconfined or confined (see Fig. 10). Unconfined aquifers have an unimpeded vertical hydraulic connection with the surface, so that these aquifers can be directly recharged by precipitation. When these aquifers are penetrated by wells, the groundwater rises in the well to the water table, the top of the region in which the pores are saturated with water (see Figs. 9-10). In the case of confined aquifers, the vertical hydraulic connection with the surface is blocked by a confining layer (see Fig. 10). The groundwater in these aquifers is under elevated pressure, so that the water rises above the top of the aquifer when the aquifer is penetrated by a well. In this respect, elevated pressure refers to pressure that exceeds the hydrostatic pressure. At a given depth below the surface, the hydrostatic pressure is the water pressure that would be present if the aquifer were a static pool that was hydraulically connected to the surface.

From a more general perspective, confined and unconfined aquifers should be regarded as end members in the characterization of aquifers. There are aquifers that are truly unconfined, but no real aquifer can be fully confined simply because, as mentioned previously, no earth material is literally impermeable. Even earth materials that typically have no measurable hydraulic conductivity in their intact state can still fail by cracking under some circumstances. Thus, between the end members of confined and unconfined aquifers is a wide range of aquifers that are called leaky confined aquifers. For wells that penetrate these aquifers, the water level in the well will be somewhere between the top of the aquifer and the level to which water would rise if the aquifer were fully confined.

Hydraulic Head

The most important concept in hydrogeology is the hydraulic head, also known as the potentiometric surface. The hydraulic head of an aquifer is the elevation above a fixed datum (such as sea level) to which the groundwater rises when the aquifer is penetrated by a well (see Fig. 10). The hydraulic head is not the depth below the ground surface of the water level in a well, but the depth below the ground surface can be used to calculate the hydraulic head if the surface elevation is precisely known. Note that, in the case of a confined aquifer, in the absence of a well, no groundwater from the aquifer is actually present at the potentiometric surface (see Fig. 10). In the case of an unconfined aquifer, groundwater is actually present at the potentiometric surface, even in the absence of a well, and the potentiometric surface is the same as the water table. Normally, the phrase “potentiometric surface” is used in conjunction with confined aquifers, while “water table” is used in conjunction with unconfined aquifers. The hydraulic head is exactly equal to the density of mechanical energy (energy per unit mass) of the water in an aquifer, as expressed as the height of a column of water above the entry point (the screen) of water into a well. In this respect, the mechanical energy is the gravitational potential energy (due to the elevation of the water) plus the elastic potential energy (due to the water pressure) plus the kinetic energy (due to the motion of the water). Since groundwater tends to flow relatively slowly, the hydraulic head is essentially the elevation of the screen plus the water pressure (expressed as the height of a column of water).

Besides determining how high water will rise in a well, the significance of the hydraulic head (or the potentiometric surface) of an aquifer is that it determines the direction of flow of groundwater. Groundwater flows from higher to lower hydraulic head, which is equivalent to flowing from higher to lower energy density. If the flow of groundwater is primarily vertical, hydraulic head increasing with depth indicates upward flow (see left-hand diagram in Fig. 11), hydraulic head decreasing with depth indicates downward flow (see middle diagram in Fig. 11), while hydraulic head independent of depth would indicate no vertical motion (see right-hand diagram in Fig. 11). When the flow of groundwater is primarily horizontal or has a horizontal component, a map of the potentiometric surface (a contour map of constant hydraulic heads) indicates the direction of groundwater flow in a horizontal sense (see Fig. 12).

A map of the potentiometric surface in the vicinity of a stream also indicates whether groundwater is flowing into a stream (a gaining stream) or out of a stream (a losing stream) (see Fig. 9). Additional evidence that a stream is gaining could be a higher hydraulic head both adjacent to and beneath the stream bed. Note that the water in a well that is placed on top of the stream bed or anywhere within a stream will rise to the stream stage (the water level of the stream surface). For a gaining stream, for a well that is driven below the stream bed, so that groundwater can enter from the subsurface sediments, the water in the well will rise higher than the stream stage, which is required by the upward flow of groundwater (see Figs. 9 and 11). Conversely, for a losing stream, in a well that is driven below the stream bed, the water in the well will rise lower than the stream stage, which is required by the downward flow of groundwater (see Figs. 9 and 11). Note that the stage of a stream and the hydraulic head of a stream are identical concepts.

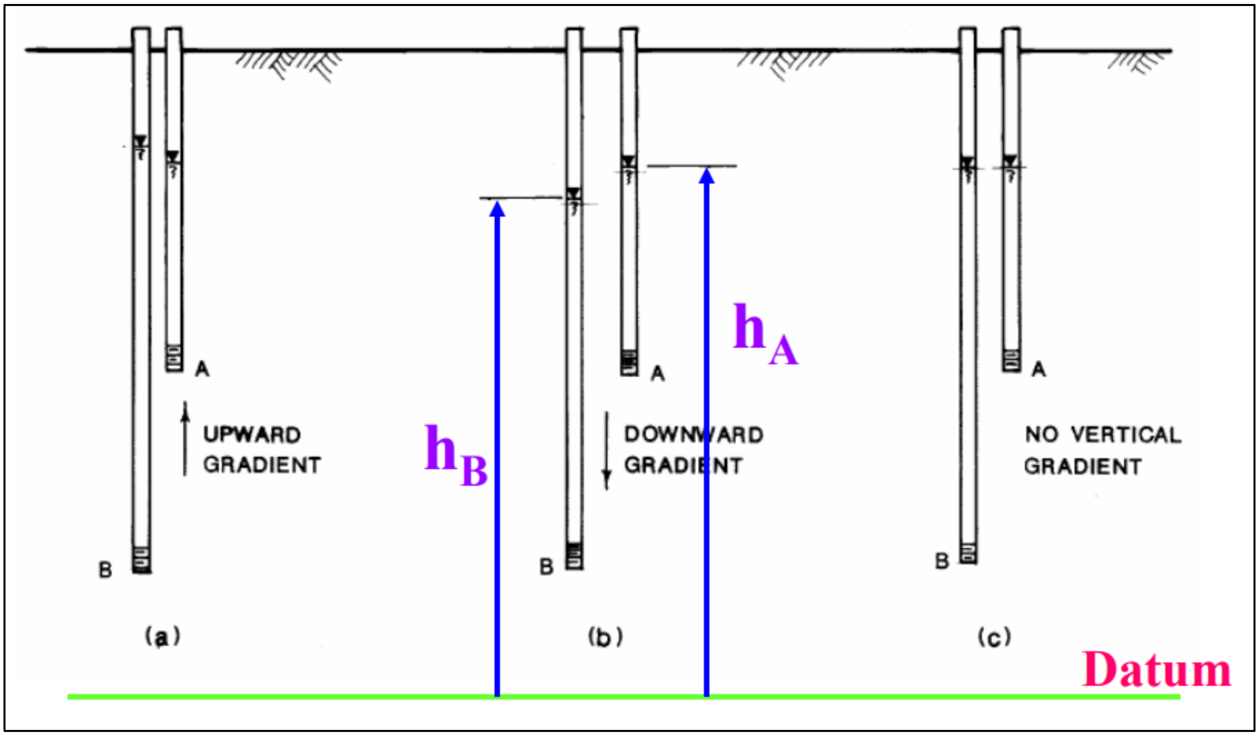


Figure 11. Groundwater flows from a layer with higher hydraulic head (higher potentiometric surface) to a layer with lower hydraulic head (lower potentiometric surface). Thus, groundwater flows upward in the left-hand diagram, and downward in the middle diagram, with no vertical movement in the right-hand diagram. Narrow, nonpumping wells with the function of indicating the elevation of the potentiometric surface (or hydraulic head) in an aquifer are called piezometers. Normally, piezometers have only short screens (visible at the bottoms of the wells in the diagrams) through which groundwater can enter so that they can measure the hydraulic head over a very short depth interval in an aquifer. The figure above shows dominant flow in the vertical direction, while Fig. 12 shows dominant flow in the horizontal direction. Figure from University of Alabama (2022).

Given the importance of the hydraulic head, the most important instrument in hydrogeology is the instrument that measures the hydraulic head, which is called a piezometer. A piezometer is a narrow, nonpumping well that is used to either automatically or manually log the level of water in the well. Normally, piezometers have only short screens through which groundwater can enter so that they can measure the hydraulic head over a very short depth interval in an aquifer (see Fig. 11). Thus, the hydraulic head or potentiometric surface is also known as the piezometric level.

Local and Regional Groundwater Flow

A watershed is the region over which all precipitation and surface water flow downstream toward the mouth of the watershed, unless it leaves the surface by evaporation or by infiltration into soil water or groundwater. For example, all surface water on the California Gulch watershed is flowing toward the mouth of the watershed at the confluence with the Arkansas River (see Fig. 2). Surface water on the California Gulch watershed cannot flow into neighboring watersheds, such as the watersheds of the unnamed streams to the north and south (see Fig. 2) because it would involve flowing uphill over the watershed boundary. Although there is a continuous exchange of water between the domains of surface water and groundwater, an important distinction is that the flow of groundwater is not restricted to the overlying surface watershed. As explained in the previous subsection, groundwater flows from higher to lower hydraulic head and not necessarily in the direction of decreasing surface topography.

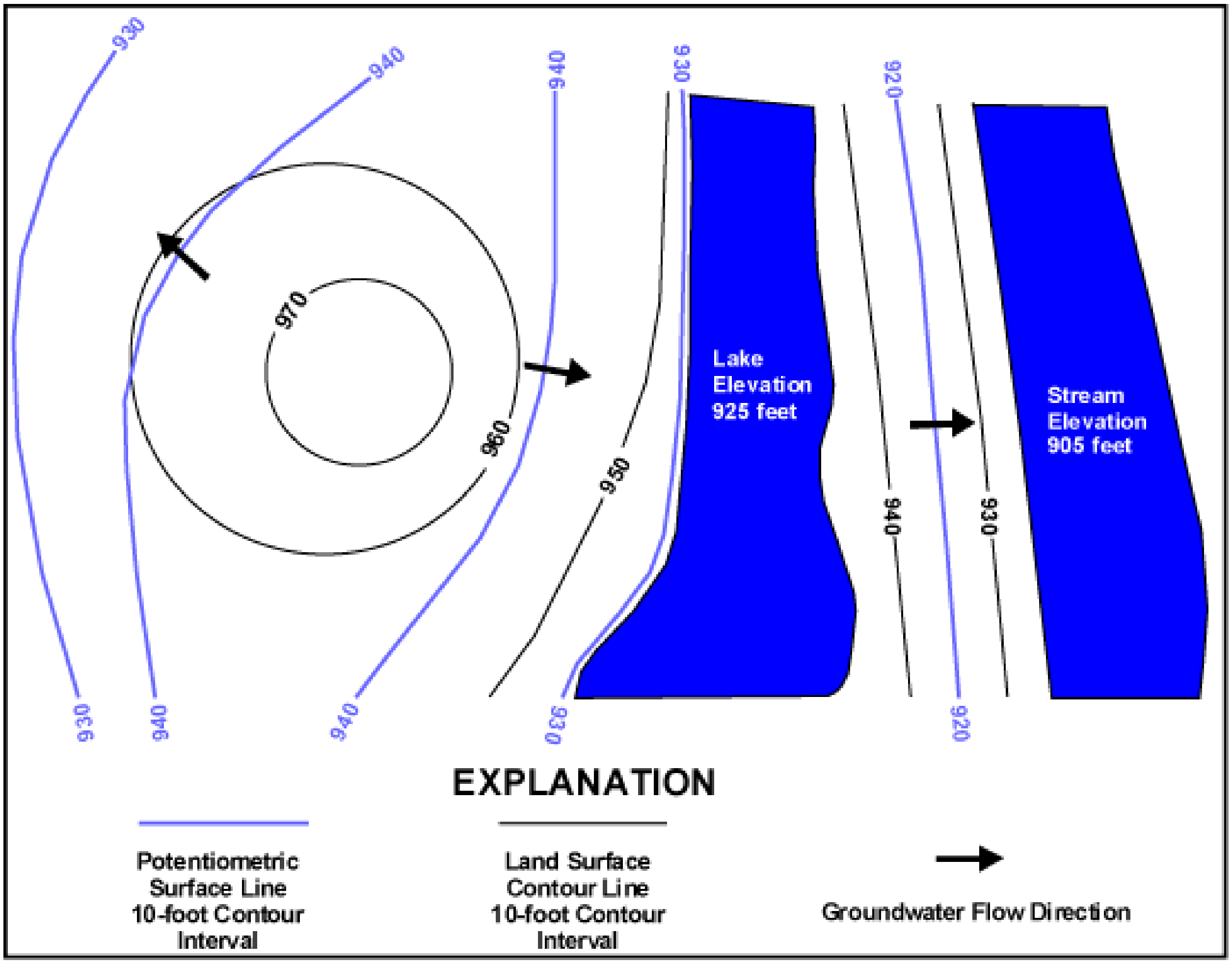


Figure 12. Groundwater flows from higher to lower hydraulic head. A map of hydraulic heads is also called a potentiometric surface. The figure above shows dominant flow in the horizontal direction, while Fig. 11 shows dominant flow in the vertical direction. Figure from Indiana Department of Natural Resources (2024).

Groundwater that flows toward the nearest stream is called local flow and is flowing within a single surface watershed (see Fig. 13). Groundwater that flows deeper than the local flow and which crosses surface watersheds is called regional flow (see Fig. 13). There is also an intermediate flow that does not flow as deep as the regional flow and which does not cross as many surface watersheds (see Fig. 13). Thus, groundwater could be flowing between California Gulch watershed and the neighboring watersheds to the north and south (see Fig. 2), depending upon the differences in hydraulic heads that are driving the flow. Because of the deeper and longer flow paths, groundwater in a regional flow system could be warmer and more mineralized than groundwater in a local flow system, depending upon many aspects of the aquifers and confining layers.

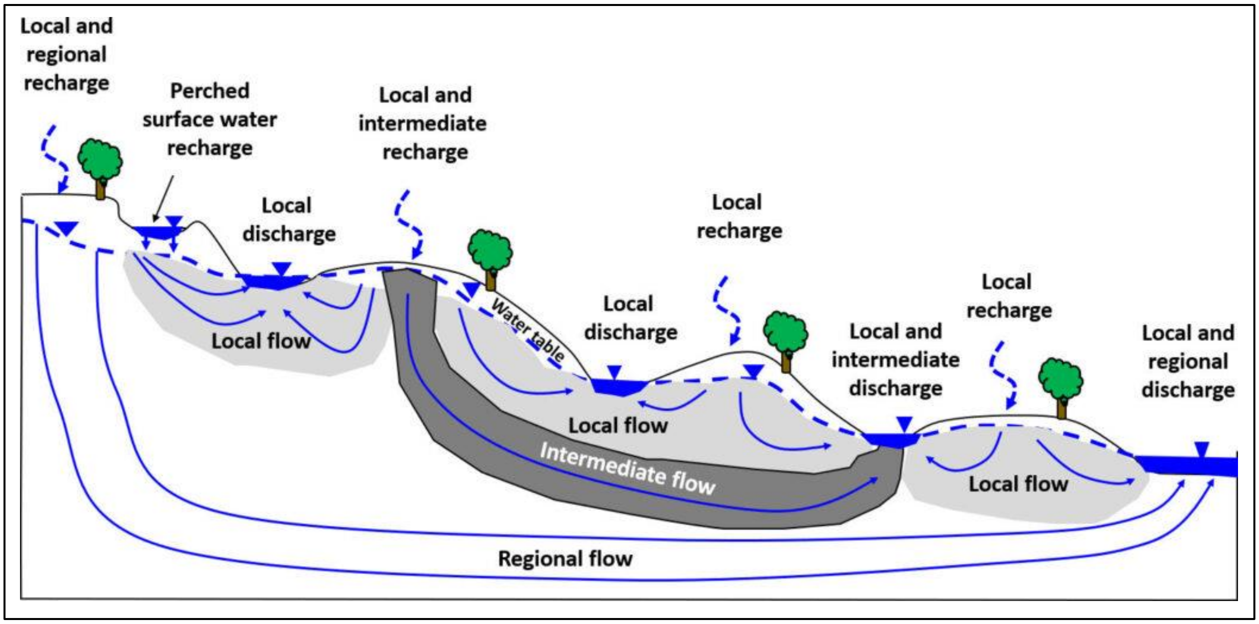


Figure 13. Groundwater flow toward the nearest stream is known as local flow. However, groundwater flow is not restricted to surface watersheds. Groundwater flow can also cross surface watersheds and flow to a non-neighboring stream, which is known as regional flow. Figure from The Groundwater Project (2024).

Acid Mine Drainage

Acid generation occurs when sulfide minerals from beneath the surface are excavated and exposed to oxygen and water on the surface, so that the reaction with oxygen and water (called oxidation) converts the sulfides into sulfuric acid. The conversion of sulfide minerals to sulfuric acid is promoted both by crushing the sulfide minerals, which increases the surface area that is exposed to oxygen and water, and by the permanent aboveground disposal, which allows for an extended time over which the acid-generating reactions can occur. Acid generation can result from the aboveground disposal of any mine waste, which can be referred to as either non-acid generating (NAG) or potentially acid generating (PAG), depending upon the concentrations of sulfide minerals, especially in comparison to other minerals, such as carbonate minerals, that could neutralize acid generation. Acid generation can even result from the exposure of the walls of open pits or underground workings if the host rock has a sufficient concentration of sulfide minerals.

The general acid-generating reaction can be written as a balanced chemical reaction as

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^+ \quad (4a)$$

or in words as

$$\text{pyrite + oxygen + water} \rightarrow \text{dissolved iron + sulfuric acid} \quad (4b)$$

Pyrite (iron sulfide) is the most common sulfide mineral, but many other metallic elements form sulfides, such as arsenopyrite (arsenic-iron sulfide or AsFeS), chalcopyrite (copper-iron sulfide or $CuFeS_2$), bornite (copper-iron sulfide or Cu_5FeS_4), galena (lead sulfide or PbS), and sphalerite (zinc sulfide or ZnS). Based on the above reaction, a by-product of acid generation is the mobilization of heavy metals into the dissolved form. The oxidation of pyrite results in the mobilization of dissolved iron. However, most sulfide minerals include a variety of other heavy metals that can substitute for the primary metal (such as substitutes for iron in the mineral pyrite), so that the oxidation of pyrite can result in the mobilization of a wide range of other heavy metals.

Acid mine drainage (AMD) results when the dissolved metals and sulfuric acid are introduced into surface water or groundwater, which can have detrimental impacts on public water supply and aquatic life. Acid mine drainage in streams is typically characterized by strong colors in the range of red, brown and yellow, which result from the oxidation of dissolved metals to form very fine-grained particles of metal oxides or metal oxyhydroxides that are transported with the streamflow. Under some circumstances, metal leaching (introduction of dissolved metals from mining by-products into surface water or groundwater) from sulfide minerals can also occur in the absence of acidity or even under alkaline conditions. Thus, streams affected by neutral (non-acidic) metal leaching can have the same colors as those affected by acid mine drainage. Of course, the determination of acid mine drainage requires that visual observations of color be supported by measurements of acidity and heavy metal concentrations. The literature on acid mine drainage and its impacts on human health and the environment is vast and good starting points are Maest et al. (2005) and the Global Acid Rock Drainage Guide (INAP, 2014).

Acid mine drainage can induce a positive feedback in that the downstream load of dissolved metals can greatly exceed the dissolved metals that result from the oxidation of the exposed sulfide minerals. Stream sediments typically include clay minerals, whose surfaces have negatively-charged sites that bind cations (positively-charged ions). Most dissolved metals are cations, although there are some exceptions, such as arsenic (actually a metalloid), molybdenum and uranium, which occur in dissolved form as oxyanions (polyatomic negatively-charged ions that include oxygen). When acidic water interacts with these stream sediments, the hydrogen cations in the water displace other cations (such as metallic cations) from the negatively-charged sites on stream sediments, so that metals are no longer fixed onto sediment, but are mobilized in the stream column as dissolved metals. Stream beds can also include tailings from previous episodes of mining that have heavy metals attached to surface sites. As above, these heavy metals can be mobilized by the introduction of new acid mine drainage into streams or by other anthropogenic increases in stream acidity. For this reason, mine tailings in stream beds are often referred to as a "chemical time bomb."

Tests for predicting the acid mine drainage and metal leaching that could result from a particular body of exposed mine waste fall into the general categories of static tests, short-term leach tests, and kinetic (long-term) tests. Static tests are used to screen for potential contaminants and to categorize mine waste as either potentially acid-generating (PAG) or non-acid-generating (NAG). Static tests do not take into account the reaction rates (either oxidation or neutralization) or the availability of minerals for chemical reactions. An assessment of the elemental composition of mine waste is a common static test for the possibility of metal leaching in terms of screening for any potential contaminants that are unusually abundant. A common static test for acid mine drainage is acid-base accounting, in which the sulfide (or sulfur) content of mine waste leads to the acidity potential (AP). In the same way, the carbonate content or the content that will react with acid leads to the neutralization potential (NP). Both AP and NP are expressed in units such as kilograms of calcium carbonate (CaCO3) equivalent per metric ton of mine waste. The net neutralization potential (NNP) is calculated as NP – AP, while the neutralization potential ratio (NPR) is the ratio NP/AP. There are no fixed thresholds for NNP or NPR for separation of PAG and NAG materials. Recommended thresholds for PAG materials range from NPR < 1 to NPR < 4 (Maest et al., 2005). By comparison with kinetic data on depletion rates of neutralizing minerals, Scharer et al. (2000) concluded that heterogeneous waste rock piles with NPR has high as 5.0 may still generate acid mine drainage in the long term. According to USEPA (1994), "If the difference between NP and AP is negative then the potential exists for the waste to form acid. If it is positive then there may be lower risk. Prediction of the acid potential when the NNP is between -20 and 20 [kg CaCO3 per metric ton] is more difficult."

A wide range of tools have been developed for the mitigation of acid mine drainage and metal leaching from mining that involves the excavation of sulfide minerals. For example, soil or clay covers on tailings storage facilities can minimize the contact of tailings with oxygen and rainfall, while stormwater diversion channels around the facilities can minimize the contact with surface water. Crushed limestone can be mixed with mine waste to neutralize any acidity that is generated. Impermeable liners can be placed beneath tailings storage facilities to prevent seepage into groundwater. Wells can be placed around tailings storage facilities for the capture and treatment of any acid mine drainage that escapes into groundwater. Water from tailings storage facilities can be treated for removal of acidity and dissolved metals prior to release into surface water. In fact, most of the above tools should be used at any mine site that carries out excavation of sulfide minerals and there should be no reliance on a single tool, such as a liner.

The website of CJK Milling repeatedly emphasizes that the mine waste piles east of Leadville that would be the source material for cyanide extraction at the Leadville Mill are potentially acid-generating (PAG) and are actively leaching contaminants into the Arkansas River. According to CJK Milling (2024b), "First, we remove the potentially acid generating mine waste dumps and transport them in covered trucks to the processing mill. This will remove the metals that leach into the ground and surface water contaminating the Arkansas River." CJK Milling (2024c) continues, "Historically, material that didn't contain enough metal to mine economically was removed to the surface and placed in piles as waste. While considered uneconomic by miners at the time, the material contains sulfur-bearing minerals with other metals including iron. Once brought to the surface these minerals oxidize, or rust, forming sulfuric acid. The metals bearing acid leach into the ground and streams flowing into the Arkansas River." The argument by Union Milling Company (2024) that, although the source material is acid-generating and is actively leaching metals, the tailings remaining after cyanide extraction would be non-acid-generating and non-metal-leaching will be evaluated in the "Responses" section.

Total and Dissolved Concentrations

In brief, dissolved concentrations refer to concentrations measured in water samples that were filtered prior to analysis, while total concentrations refer to water samples that were not filtered prior to analysis. The total concentration of a particular parameter is always equal to or greater than the dissolved concentration. Just as with free cyanide and total cyanide, and as with geotechnical water content and process water content, it is critical that dissolved and total concentrations not be used interchangeably, since the values can be very different. Whether water samples should or should not be filtered prior to analysis has been one of the most controversial issues in water sampling since the practice of sample filtering was introduced in the 1970s. Fortunately, some of the controversy has been settled since, due to the decrease in the cost of analytical instrumentation since about 2010, it has become standard practice to collect both filtered and unfiltered samples and, thus, to report both dissolved and total concentrations. Of course, the controversy as to whether the dissolved or total concentration is most relevant in a particular situation still remains. For simplicity, the controversy and the distinction between dissolved and total concentrations is explained below in terms of arsenic, although an equivalent explanation could be given for any other contaminant of concern.

Modern analytical instruments, such as the inductively coupled plasma spectrometer or the atomic absorption spectrometer, require that the water sample be free of solid particles that could become trapped within the instrument. For that reason, all analytical laboratories digest samples prior to analysis. Digestion refers to the dissolution of solid particles using various combinations of heat, acids, hydrogen peroxide, and other reagents. Because some solid particles may have resisted dissolution, the water samples are further forced through an ultrafine (0.45-μm) filter prior to their introduction into the analytical instrument. The arsenic that was already present in the sample in the dissolved phase will not be affected by digestion or filtering. However, since some of the arsenic in a water sample is in the solid phase, digestion of the sample will increase the arsenic concentration in the dissolved phase by moving arsenic from the solid to the dissolved phase. The various solid phases of arsenic include the following (listed in order from least to most resistant to digestion):

1) ionically bound arsenic
2) strongly adsorbed arsenic
3) arsenic coprecipitated with acid-volatile sulfides, carbonates, manganese oxides, and very amorphous iron oxyhydroxides
4) arsenic coprecipitated with amorphous iron oxyhydroxides
5) arsenic coprecipitated with crystalline iron oxyhydroxides
6) arsenic oxides and arsenic coprecipitated with silicates
7) arsenic coprecipitated with pyrite and amorphous orpiment As_2S_3 and remaining recalcitrant arsenic minerals
8) orpiment and remaining recalcitrant arsenic minerals (Keon et al., 2001).

If a sample was filtered through a 0.45-μm filter prior to digestion, then only the original dissolved component of arsenic would be measured, and the resulting arsenic concentration is referred to as "dissolved arsenic." If no pre-digestion filtering was done, and the digestion was carried out using hot concentrated nitric acid and 30% hydrogen peroxide so that all of the above solid phases were dissolved (EPA, 2024c), then all components of arsenic would be measured, and the resulting arsenic concentration is referred to as "total arsenic." It should be noted that water samples can contain colloidal particles smaller than 0.45 μm that will pass through the filter and then be dissolved during the digestion process. In that way, the arsenic adsorbed onto the dissolved formerly-solid particles will be measured as dissolved arsenic, even though the arsenic was not present in the dissolved form in the original water sample. Therefore, the dissolved arsenic concentration measured using the pre-filtered method is always greater than the true dissolved arsenic concentration (dissolved arsenic concentration in the original water sample). Moreover, the arsenic concentration measured using the non-pre-filtered method is always less than the true total arsenic concentration (total arsenic concentration in the original water sample) because not all of the solid particles will be fully digested (which is why water samples are always filtered even after digestion). For the above reasons, the phrases "dissolved arsenic" and "total arsenic" are often retained in quotes. Many studies have carried out sequential extractions, in which increasingly aggressive solvents are used to progressively extract arsenic from more resistant solid phases. For example, one hour of digestion using 1M HCl (hydrochloric acid) at 25°C will extract arsenic from the above Solid Phase 3, so that the measured arsenic concentration will be a sum of the dissolved arsenic, ionically bound arsenic, strongly adsorbed arsenic, and arsenic coprecipitated with acid-volatile sulfides, carbonates, manganese oxides, and very amorphous iron oxyhydroxides (Keon et al., 2001).

The important question is then: Should water samples be filtered prior to digestion or only after digestion? In other words, is it appropriate to measure “dissolved arsenic” or “total arsenic?” The answer is that it depends on the environmental and social context within which a water sample has been collected. Saar (1997) has written an excellent review of this subject and a briefer treatment can be found in Sanders (1998).

Four examples will help to illustrate this point. The first example is water sampled from a monitoring well that has been placed into a layer with low hydraulic conductivity, such as a clay or shale layer. The act of pumping or bailing this well can mobilize small particles that would not normally be moving with the flow of groundwater. These samples should be filtered prior to digestion, since the digestion of the particles would result in a measured arsenic concentration that was not representative of the pore water in the clay or shale layer. The second example is water drawn from a shallow, hand-dug well for domestic use that might be poorly constructed so that the water is slightly muddy. The well owners are not going to drink a glass of muddy water, nor are they going to force the water through an ultrafine filter. Any well owner would let the water sit until the solid particles settle and then pour off the clear water (which would still contain the particles that were too fine to settle). Therefore, the sampling procedure should involve following the same steps that would be followed by a well owner. That is, the samples should be allowed to sit for 24 hours, after which the relatively clear water on top (the supernatant) should be poured off into a separate sample bottle. The supernatant should then be digested without any pre-filtering. The third example is flowing water samples that are collected from a pipe that leads from a spring and empties into a cattle trough. Although these samples might be muddy, the particles were in motion with the water and would be consumed by the cattle. Therefore, not only should the samples not be filtered before digestion, but before removing an aliquot of sample for digestion, the sample bottle should be vigorously shaken to ensure that a representative quantity of solid particles would be digested with the rest of the water sample. In fact, it is difficult to think of circumstances under which water samples that were collected from flowing water should be filtered prior to digestion. Possible circumstances could occur when the concern is aquatic organisms that might be impacted by dissolved metals, but not by metals in the particulate form.

The fourth and most important example is the case of a water sample collected from a tap that is intended for human consumption. If the water is relatively clear, then the typical practice would be to drink the water as it comes from the tap. Certainly, no householder is using a pump or syringe to force the water through an ultrafine filter. Filtering the samples prior to analysis has the potential to significantly underestimate the arsenic load that is being delivered to the consumer. This point is emphasized by Saar (1997), “If direct ingestion from a drinking water source is involved, whole, unfiltered samples … are needed.” In the same way, national and international drinking-water guidelines typically refer to total concentrations, although that judgment depends upon the context of water collection and consumption. In some localities, there may be some typical pre-consumption practices. For example, consumers may boil the water or add bleach to the water or, as mentioned above, allow the water to settle. In those cases, the pre-digestion procedure should follow the same consumer practices. Additional case studies regarding the appropriateness of filtration are presented by Saar (1997). In some cases, both filtering and not-filtering can be shown to have shortcomings. As mentioned above, the contemporary practice is to collect both filtered and unfiltered water samples, and to publish results for both "dissolved arsenic" and "total arsenic," so that readers can decide for themselves which concentration is most appropriate for a given situation.

By and large, EPA (2024a-b,d) does not specify whether standards refer to dissolved or total concentrations, but leaves that judgment open depending upon the environmental and social context of water sampling. However, many state regulations specify whether they refer to dissolved or total concentrations. The State of Colorado is somewhat unusual in terms of the range of standards that refer only to dissolved concentrations. Even for standards that refer to dissolved concentrations, Code of Colorado Regulations (2016) states, "The total concentration (not filtered) may be required on a case-by-case basis if deemed necessary to characterize the pollution caused by the activity." For example, in terms of inorganic chemicals that could affect human health in domestic water supply from groundwater, all standards are based on dissolved concentrations, except for asbestos and free cyanide, which must be measured as total concentrations (Code of Colorado Regulations (2016). The expressions "total concentration" and "total cyanide" should not be confused, in that one could measure the total concentration of free cyanide or the dissolved concentration of total cyanide. In terms of chemical parameters that could affect the taste, color, odor or technical characteristics of domestic water supply from groundwater, all standards are based on dissolved concentrations, except for chlorophenol, color, corrosivity, odor, pH, and phenol, all of which must be measured from unfiltered samples (Code of Colorado Regulations, 2016). Finally, all standards for agricultural water supply from groundwater refer to dissolved concentrations (Code of Colorado Regulations, 2016). The author is not aware of any document that explains the emphasis on dissolved concentrations in Colorado regulations.

SUMMARY OF PROPOSAL FOR REMINING AT LEADVILLE MILL

The purpose of this section is to describe the essential features of the proposal for cyanide extraction of gold and silver from mine waste at the Leadville Mill. For the most part, this section will be only description with critique reserved for the "Responses" section. However, some critique is necessary in this section simply in terms of the difficulty of understanding the proposal. For this report, the essential features of the proposal are the method for extracting gold and silver from the pregnant solution, the method for removing excess cyanide from the tailings, the methods for construction of the filtered tailings deposit (FTD), and the methods for the management of stormwater on the mill site.

After the mixing of the crushed mine waste in vats with dissolved sodium cyanide, the Merrill-Crowe process would be used to precipitate gold and silver to produce gold-silver doré bars, which would be the final, marketable product of the Leadville Mill. After the recovery of the maximum amount of cyanide from the barren solution, the mix of tailings and water would be mixed with ferrous sulfate in "detoxification tanks" prior to the filtration of the tailings (Union Milling Company, 2024). The purpose of the ferrous sulfate is to maximize the precipitation of cyanide from the mix of tailings and water to form an iron-cyanide sludge. The word "sludge" is not used in the permit application (Union Milling Company, 2024). However, the word "sludge" is used in this report to emphasize both that the precipitate will be wet (saturated with water) and that the material will not be a pure iron cyanide, but will include any other dissolved substances that will precipitate upon mixing with ferrous sulfate. The application does not include any discussion of the anticipated composition of the iron-cyanide sludge, but does emphasize that many other metals are expected to precipitate into the sludge. According to Union Milling Company (2024), "During detoxification using ferrous sulfate, residual metals are complexed to form insoluble compounds in a similar fashion that might be expected for materials undergoing chemical stabilization, which is sometimes applied to certain hazardous materials to affect non-hazardous re-classification."

Union Milling Company (2024) predicts that the total cyanide concentration remaining in the water mixed with the tailings will be 1 mg/L (equivalent to 1 part per million) after precipitation of dissolved cyanide with ferrous sulfate. According to Union Milling Company (2024), "Historically, iron-cyanide precipitation was widely used to convert free and WAD cyanides to less toxic iron-cyanide compounds, but its present utility is primarily as a polishing process to reduce total cyanide concentrations in the order of ±1 mg/L." The plus-or-minus symbol (±) does not make sense because concentrations cannot be negative. Union Milling Company (2024) does not provide any evidence that a total cyanide concentration of 1 mg/L will actually be achieved. Moreover, the use of a total cyanide concentration makes it impossible to compare the expected cyanide concentration in the mix of tailings and water with the definition by the International Cyanide Management Institute (2021c) that any facility containing a solution with a concentration of WAD cyanide greater than 0.5 mg/L is a "cyanide facility." Without further information, it will be assumed that the proposed filtered tailings deposit (FTD) at the Leadville Mill would be a "cyanide facility," as defined in the International Cyanide Management Code.

However, the statement in the application that the total cyanide concentration in the mix of tailings and water will be less than 1 mg/L is contradicted by the additional statement that "Detoxification will reduce NaCN [sodium cyanide] to about 0.05 lb-NaCN/ton-slurry, or about 1 ppm" (Union Milling Company, 2024). The application clarifies that "slurry" refers to the mix of tailings and water after treatment with ferrous sulfate and that the slurry will be 50% water by mass. According to Union Milling Company (2024), "Slurry is pumped from the Detox Tank (Area 500) to the FTD Filter Plant by a double-walled 4" poly pipe at a rate of 110.2tph [tons per hour] at 50% solids - 20tph solids, and 20tph (80gpm) water." Recognizing that 1 ton of slurry would be 1000 pounds of water and converting all units to the metric system shows that 0.05 lb-NaCN/ton-slurry is exactly equal to a concentration of sodium cyanide dissolved within the water of 50 mg/L, which far exceeds a total cyanide concentration of 1 mg/L. Moreover, based upon the atomic weights, 1 milligram of sodium cyanide is equivalent to 0.5309 milligrams of cyanide ion or free cyanide (CN^-), so that the free cyanide concentration in the water would be 26.54 mg/L. There is no sense in which 0.05 lb-NaCN/ton-slurry is equivalent to 1 ppm (1 mg/L). Thus, the two versions of the cyanide concentration, both in terms of values and in terms of using total cyanide and free cyanide interchangeably, show a considerable discrepancy in the anticipated cyanide toxicity of the filtered tailings deposit.

Another problematic aspect of the description of the process of cyanide removal in the application is the statement that the purpose of adding ferrous sulfate to the mix of tailings and water is to "detoxify cyanide to a safe compound in an oxidation reaction using Iron-Cyanide Precipitation" (Union Milling Company, 2024). The preceding statement is contradicted by the statement within the International Cyanide Management Code that "Ferrous sulfate binds cyanide in an insoluble complex **but does not chemically convert it to a less toxic substance**. The complex formed is susceptible to photodecomposition and can release cyanide back to the environment if it is not properly managed" (emphasis added) (International Cyanide Management Institute, 2021c). The website of the International Cyanide Management Institute further clarifies, "However, both ferro- and ferricyanides [types of iron cyanides] decompose to release free cyanide when exposed to direct ultraviolet light in aqueous solutions. This decomposition process is reversed in the dark" (The Cyanide Code, 2024b). The point is that the addition of ferrous sulfate does not literally "detoxify" cyanide, but only stores it in a solid form from which the highly toxic free cyanide can be released upon changes in water chemistry, or especially upon exposure to sunlight. The website of CJK Milling states, "Any cyanide that's not recovered is detoxified using an industry-proven method" (CJK Milling, 2024f). The preceding sentence leaves out the critical information that industry standards do not regard the proposed method as a type of "detoxification."

After partial removal of the cyanide and its temporary storage as an iron-cyanide sludge, the remaining tailings would be filtered to partially remove the water, followed by compaction and permanent storage as a filtered tailings deposit (FTD) (see Fig. 14). Fig. 14 shows "final top elevation approximately 38 ft above natural preexisting ground surface" (Union Milling Company, 2024). Elsewhere, Union Milling Company (2024) describes the height of the FTD as "approximately 38-ft to 43-ft above existing natural ground surface." The target water content for tailings after filtration is stated as either the range 20 to 30% or as less than 25%. For example, Union Milling Company (2024) states "The design target water content of between 20% and 30% will yield physical properties that allow for mechanical handling and placement of the tailings in the FTD" and also states "Tailings are only to be delivered to the FTD transfer conveyor when the drum filter is producing filter cake within at or below the target lower limit of 75% solids (25% water content)."

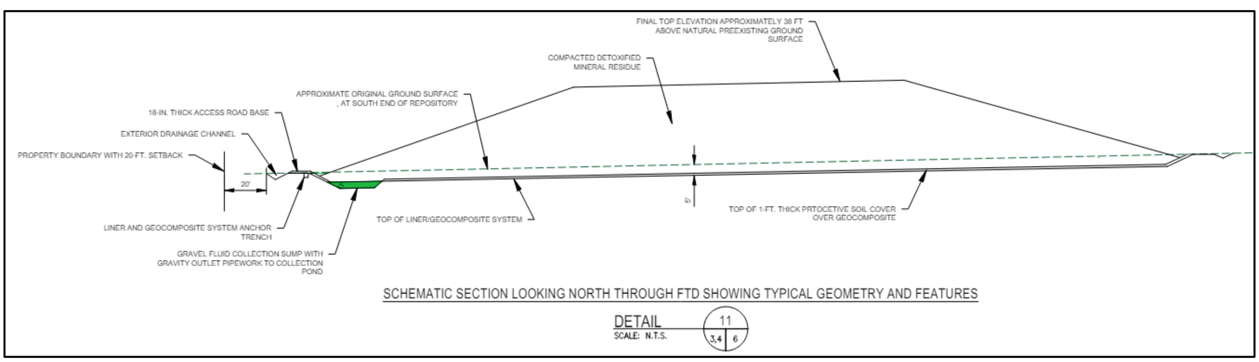


Figure 14. The filtered tailings deposit (FTD) would be constructed from partially dewatered tailings that had been compacted to within 90% of the maximum dry density. The industry standard is to construct a perimeter of tailings with the appropriate water content for maximum compaction (called the structural zone) and to place the tailings that are too wet for maximum compaction in the center (called the non-structural zone). The structural zone serves the same function as a dam. The industry standard is that the structural zone is compacted to within 95% of the maximum dry density, while the non-structural zone is compacted to within 90% of the maximum dry density. In other words, the FTD would be constructed with no structural zone, which is one of the factors that lead to the conclusion that the FTD will be unstable as designed. Although the diagram states that the approximate height will be 38 feet, elsewhere Union Milling Company states the approximate height as 38 to 43 feet. Portion of figure from Union Milling Company (2024).

The two variations on the target water content are not related to any measurements of the optimum water content for maximum compaction, which would be the standard procedure, but only to the water contents that currently have been achieved by filtration tests on tailings samples. Through a series of nine tests on filtration of tailings, Union Milling Company (2024) achieved process water contents in the range 17.8% to 28.6% (see Fig. 15), which is consistent with either a target range of 20 to 30% or a maximum of 25%, but which does not address the stability of the FTD that would result from these water contents. It is also non-standard to set a maximum water content (as opposed to a range with a minimum and maximum) because tailings can be too dry for adequate compaction. Moreover, overly dry tailings can lead to excessive dust generation from the filtered tailings deposit or a lack of trafficability.

TABLE 4-33: FILTRATION DATA

Sample Teat	Cake Thickness (mm)	Filter Cake (% Solids)	Filtration Rate (lbs_{dry}/ft^2-hr)
1 (Vacuum)	9.0	73.1%	97.0
2 (Vacuum)	20.0	71.4%	29.6
3 (Vacuum)	9.0	75.6%	56.9
4 (Vacuum)	19.0	75.2%	22.4
5 (Pressure)	8.0	80.6%	448.2
6 (Pressure)	8.0	82.2%	544.4
7 (Vacuum)	4.8	75.4%	91.7
8 (Vacuum)	22.0	71.5%	155.4
9 (Vacuum)	22.0	71.5%	421.5

Figure 15. Through a series of nine tests on filtration of tailings, Union Milling Company (2024) achieved water contents in the range 17.8% to 28.6%. Union Milling Company (2024) states the target water content for the filtered tailings deposit sometimes as the range of 20% to 30% and sometimes as less than 25%. There have been no reported measurements of the optimum water content for maximum compaction, so that the target water content range appears to be based on the water contents that have been obtained through testing, not on the water content needed for geotechnical stability of the filtered tailings deposit. It is assumed that the heading "Sample Teat" in the left-hand column should read "Sample Test." Although not stated, it is assumed that target water contents in Union Milling Company (2024) refer to the process water content, not the geotechnical water content. Table from Union Milling Company (2024).

Assuming that the above water contents refer to process water contents, the corresponding geotechnical water contents would be a range of 25 to 42.9% or a maximum of 33.3% (see Eq. 3). By contrast, a typical geotechnical water content for filtered tailings storage facilities is 5 tons of water for every 30 tons of solid tailings or 16.7% (see Fig. 5) with a range of 12 to 20% (Espinosa-Gomez et al., 2018; Cacciuttolo Vargas and Pérez Campomanes, 2022). To the best knowledge of the author, the proposed filtered tailings deposit at the Leadville Mill would be the wettest filtered tailings storage facility ever constructed by far, even at the minimum geotechnical water content of 25%. The implications of the very wet tailings, even after filtration, for the stability of the proposed filtered tailings deposit will be reviewed in the "Responses" section.

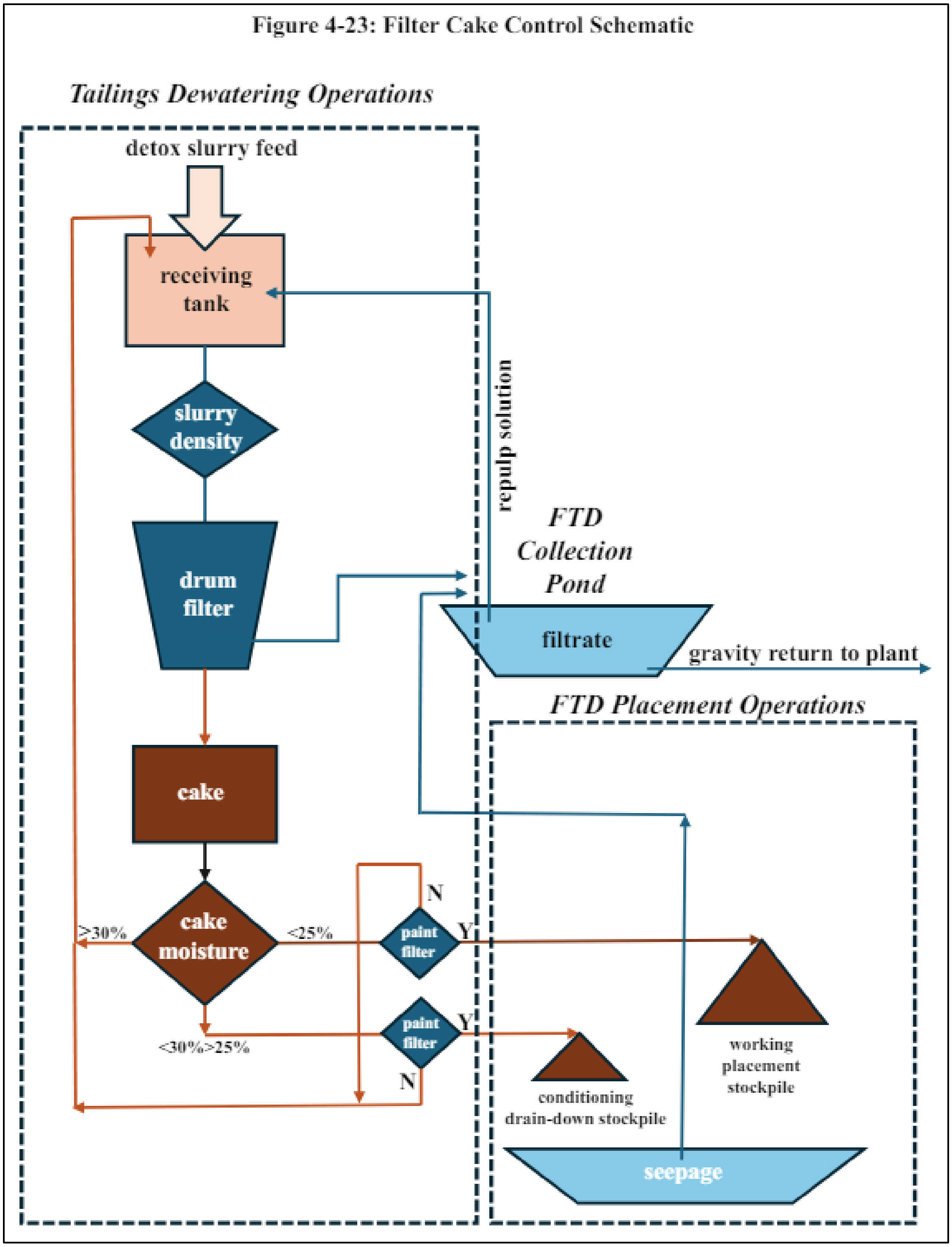


Figure 16. Although Union Milling Company (2024) sometimes states the target water content for the filtered tailings deposit as the range of 20% to 30%, the above diagram shows that filtered tailings will be sent to the filtered tailings deposit only if the water content is less than 25%. Only a maximum water content (as opposed to a range) is not standard for filtered tailings technology because tailings could be too dry for appropriate compaction and excessive dryness could lead to dust generation and lack of trafficability. The Paint Filter Test is an EPA lab test for the presence of free water. It is difficult to imagine how this lab test could be applied to all output from the filter presses. Although not stated, it is assumed that target water contents refer to the process water content, not the geotechnical water content. Figure from Union Milling Company (2024).

One version of the procedure for determining whether the filtered tailings are dry enough for compaction shows all tailings being subject to a Paint Filter test as the tailings leave the filter presses (see Fig. 16). The Paint Filter test is an EPA (2024c) lab test for determining whether a sample includes free water (water that is not confined to pore spaces). According to Union Milling Company (2024), "Tailings are only to be delivered to the FTD transfer conveyor when the drum filter is producing filter cake within at or below the target lower limit of 75% solids (25% water content). Filter cake that has water content above this limit (i.e. >25%) could be acceptable for placement if it passes the Paint Filter Test and may be placed in the stockpile on a system upset basis and allowed to drain down to water content that allows for effective spreading and compaction. Continuous testing of filter cake allows for warnings to trigger a response plan as illustrated on Figure 4-23 [Fig. 16 in this report]. The primary and ultimate acceptance criterion for filter cake into the FTD is passing the Paint Filter Test (no free water bleed)." It is difficult to imagine how the entire output of the drum filters could be subjected to such a lab test, although that is what is stated above and shown in Fig. 16. Even so, the tailings with a process water content in the range 25 to 30% and, which show no free water according to the Paint Filter test, would not be filtered any further, but only allowed to drain under gravity (see Fig. 16). This drainage under gravity would reduce the water content only to the saturated water content or slightly less than the saturated water content. The implications of placing saturated or near-saturated tailings in the filtered tailings deposit will be reviewed in the "Responses" section. It is noteworthy that the application by Union Milling Company (2024) never states the tailings water content that would constitute saturation for comparison with the various alternatives for target water contents.

The website of CJK Milling states that the Leadville Mill will be a zero-discharge facility, so that contaminated water from the mill site cannot impact nearby domestic wells (see Fig. 2). According to CJK Milling (2024f), "CJK Milling will operate a zero-discharge facility. Zero-discharge means all water used in the process is also recycled and no water is discharged into the environment." Under the "Fiction vs. Fact" tab, CJK Milling (2024d) continues, "The mill is a zero-discharge facility and will therefore not impact domestic water wells south and west of the mill." However, CJK Milling (2024b) clarifies, "We designed a zero-discharge facility. Zero discharge means all water is recycled on-site and no liquids are discharged from the mill into the environment." The clarification is that zero-discharge means only that there is no intentional discharge of contaminated water from the mill into the environment. There is still the possibility of accidental discharge and there is a flow of stormwater over the mill site and into California Gulch.

Figure 17a. The remining operation will include stormwater infrastructure to convey surface water around the filtered tailings deposit (FTD) to the FTD Collection Pond with other stormwater flowing to the emergency containment sump (ECS). All stormwater channels and water storage ponds are designed to contain the water from a 100-year precipitation event, which is described as a “worst-case condition.” However, the true worst case would be the Probable Maximum Precipitation (PMP), which is significantly rarer than even a 10,000-year event. The appropriate design precipitation event should reflect the consequences of uncontrolled overflow, which is never discussed in the proposal. Figure from Union Milling Company (2024).

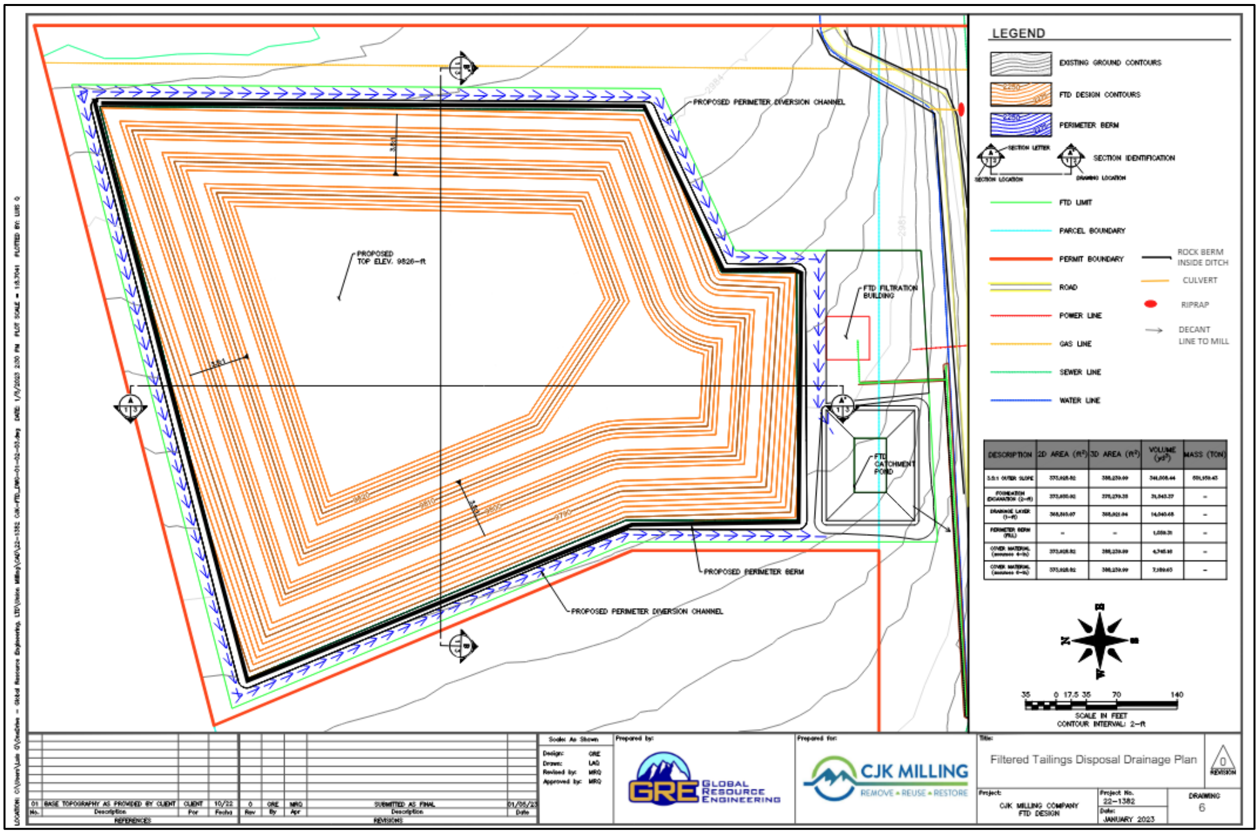


Figure 17b. The remining operation will include stormwater infrastructure to convey surface water around the filtered tailings deposit (FTD) to the FTD Collection Pond. All stormwater channels and water storage ponds are designed to contain the water from a 100-year precipitation event, which is described as a "worst-case condition." However, the true worst case would be the Probable Maximum Precipitation (PMP), which is significantly rarer than even a 10,000-year event. The appropriate design precipitation event should reflect the consequences of uncontrolled overflow, which is never discussed in the proposal. Note that the shape of the FTD contradicts the shape shown in Figs. 17a and 19a-b, but is similar to what is shown in Fig. 23. Figure from Union Milling Company (2024).

The proposed stormwater management plan for the Leadville Mill is shown in Figs. 17a-b and 18. Diversion channels would convey stormwater around the filtered tailings deposit and into an FTD Collection Pond at the downstream end of the FTD (see Figs. 17a-b). Fig. 18 shows the mill site divided into three drainage areas. Stormwater in Drainage Area 1 would flow into a pre-existing emergency containment sump (ECS) (see Fig. 18). Stormwater from Drainage Area 2 would flow around the ECS, into a sediment trap, and then into California Gulch, while stormwater from Drainage Area 3 would flow directly into California Gulch with no sediment capture (see Fig. 18). The FTD and the FTD Collection Pond would probably be in Drainage Area 2, so that any overflow from the FTD Collection Pond would probably flow into California Gulch after sediment capture. The stormwater management plan is difficult to interpret because, while the permit boundary covers 42.93 acres and the affected land covers 42.60 acres (Union Milling Company, 2024), less than 20 acres is accounted for in the stormwater management plan (see Fig. 18).

All stormwater infrastructure would be designed to accommodate a precipitation event with a return period of 100 years, that is, an event with an annual probability of exceedance of 1%. According to Union Milling Company (2024), "For representative purposes, 100-year storm events were modeled to provide base case design and estimates of anticipated flows for an extreme event … The FTD Collection Pond will retain the water from a 24-hour, 100-year discharge from the tailings disposal area under worst-case conditions of storm occurrence prior to the placement of any filtered tailings … The ECS pond will retain the water from a 24-hour, 100-year discharge." Further information about the proposal for remining at the Leadville Mill will be provided, as needed, in the "Responses" section.

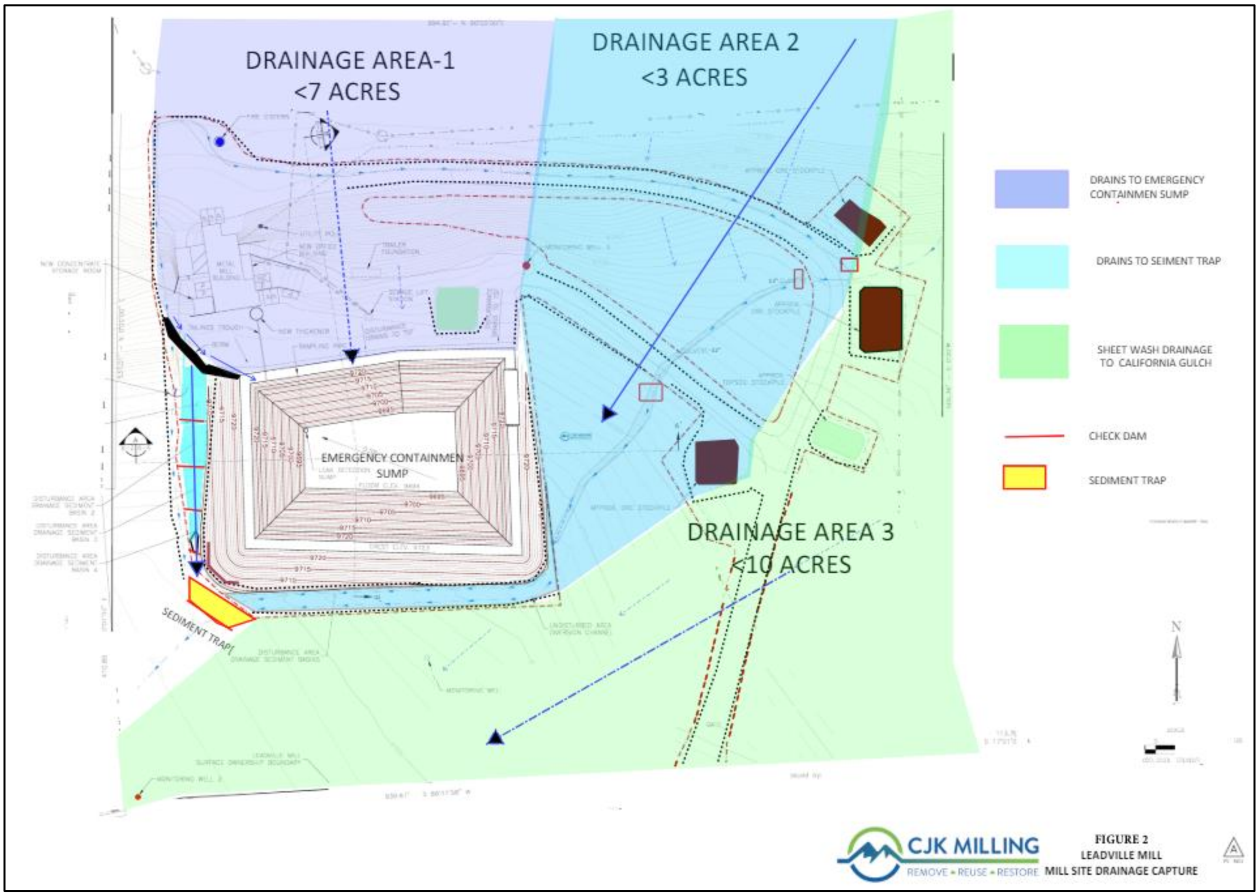


Figure 18. The remining operation will include stormwater infrastructure to convey surface water either to the emergency containment sump (ECS) or a sediment trap at the southwest corner of the ECS or directly to California Gulch. All stormwater channels and water storage ponds are designed to contain the water from a 100-year precipitation event, which is described as a "worst-case condition." However, the true worst case would be the Probable Maximum Precipitation (PMP), which is significantly rarer than even a 10,000-year event. The appropriate design precipitation event should reflect the consequences of uncontrolled overflow, which is never discussed in the proposal. The stormwater management plan is difficult to interpret because, while the permit boundary covers 42.93 acres and the affected land covers 42.60 acres, less than 20 acres is accounted for in the stormwater management plan. Figure from Union Milling Company (2024).

METHODOLOGY

Based upon the preceding sections, the objective of this report was subdivided into the following questions:

1) Is the proposed remining plan aligned with industry standards on cyanide management and gold mining?
2) Will the filtered tailings deposit be stable as designed?

3) Has there been adequate consideration of the consequences of failure of the filtered tailings deposit?
4) Is there an adequate plan for permanent safe closure of the filtered tailings deposit?
5) Has there been a correct estimation of the water consumption rate and is there an adequate source of water for the remining operation?
6) Is there an adequate network of monitoring wells for the detection of groundwater contamination?
7) Does the plan include adequate infrastructure for the management of stormwater?
8) Has the potential for acid mine drainage and metal leaching from the filtered tailings been adequately assessed?
9) Are there sufficient baseline data for quality of surface water and groundwater?
10) Are there adequate contingency plans for responding to instability of the filtered tailings deposit or to detection of surface water or groundwater contamination?

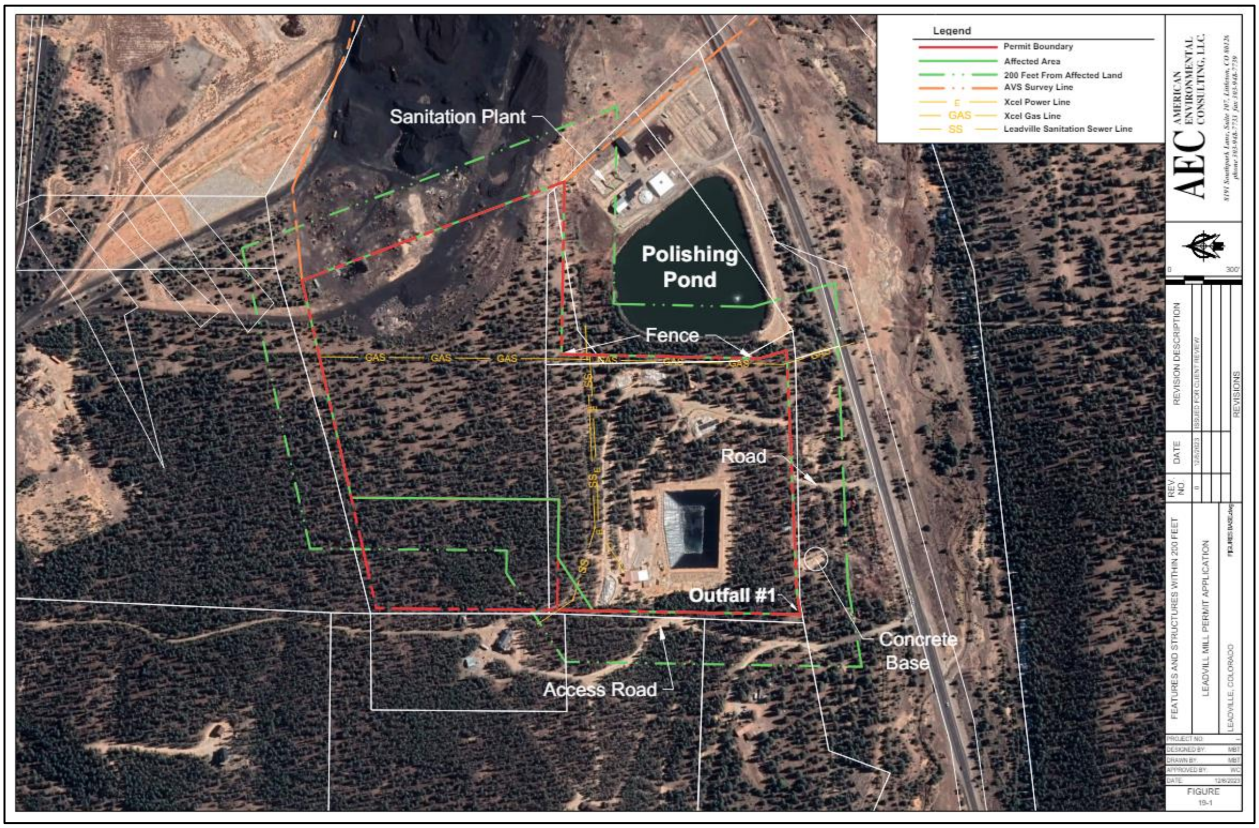


Figure 19a. The permit boundary for the maps in this report (see Figs. 2, 22, 28, 30, and 31) was constructed by comparing the above map from Union Milling Company (2024) with Google Earth imagery from October 2, 2019. The permit boundary is similar in some maps (see Figs. 17a) in Union Milling Company (2024), but completely different in other maps (see Figs. 17b, 21, and 23).

Figure 19b. The perimeter of the filtered tailings deposit (FTD) for the maps in this report (see Figs. 2, 22, 28, 30, and 31) was constructed by comparing the above map from Union Milling Company (2024) with Google Earth imagery from October 2, 2019. The perimeter is similar in some maps (see Figs. 17a) in Union Milling Company (2024), but completely different in other maps (see Figs. 17b, 21, and 23).

TABLE 7-1: MONITORING WELLS			
Well	Well Completion Depth (ft.)	Water Table Elevation (ft.)	Gradient Position
BMW-1	1,244	9979	Regional Up Gradient
PZ-4	137	9897	Regional Up Gradient
MA1TMW-4	85	9718	FTD Up Gradient
LM-MW-2	56	9651	ECS Down Gradient
LM-MW-3	71	9684	FTD Down Gradient ECS Up Gradient
MW13	100	9594	Regional Down Gradient
MW13A	25	9600	Regional Down Gradient

Figure 20. With the exception of LM-MW-2 and LM-MW-3, there is no information regarding the aquifers that are penetrated by the seven monitoring wells in the vicinity of the Leadville Mill. Since BMW-1 and PZ-4 (also called BMW-1A) are adjacent wells (see Fig. 21) with a hydraulic head difference of 82 feet, they must be screened in different aquifers. The heading "Water Table Elevation" is not correct, since not all of the aquifers are unconfined, especially not the deeper aquifer that is tapped by monitoring well BMW-1 (compare with Fig. 10). The classification of monitoring wells as "Up Gradient" or "Down Gradient" in a regional sense or with respect to the FTD (Filtered Tailings Deposit) or the ECS (Emergency Containment Sump") depends on unjustified assumptions regarding groundwater flow pathways (see Figs. 29-30). Table from Union Milling Company (2024).

All original maps for this report were constructed using ESRI ArcMap v. 8.2. Since the application does not include shapefiles or other digital spatial files for any mill site infrastructure, the permit boundary was traced from Fig. 19a (taken from Union Milling Company (2024)) by comparing the background with Google Earth imagery from October 2, 2019. The perimeter of the filtered tailings deposit (FTD) was traced from Fig. 19b (also taken from Union Milling Company (2024)) by comparing the background with the same Google Earth imagery. The coordinates of the seven monitoring wells (see Fig. 20) were also determined by comparing the background in Fig. 21 from the permit application (Union Milling Company, 2024) with the same Google Earth imagery. Union Milling Company (2024) does not state the coordinates for any monitoring wells, except for LM-MW-2 and LM-MW-3 (see Figs. 20 and 21). All relevant surface elevations were determined using Google Earth.

A significant challenge in reviewing the permit application by Union Milling Company (2024) was the large amount of contradictory information, even with regard to the most fundamental information for the proposed remining operation. For example, although Union Milling Company (2024) states the coordinates for monitoring wells LM-MW-2 and LM-MW-3, the coordinates are stated as two completely different sets of coordinates for each well (see Table 2). Moreover, the stated coordinates are different from the coordinates that can be measured from the map (see Figs. 21-22 and Table 2). In particular, for LM-MW-2, the mismatch between the two sets of stated coordinates is 275 feet (see Fig. 22 and Table 2). The mismatches between the measured coordinates and the first and second sets of stated coordinates are 86 feet and 340 feet, respectively (see Fig. 22 and Table 2). For LM-MW-3, the mismatch between the two sets of stated coordinates is 51 feet (see Fig. 22 and Table 2). The mismatches between the measured coordinates and the first and second sets of stated coordinates are 148 feet and 190 feet, respectively (see Fig. 22 and Table 2). The map in Union Milling Company (2024) (see Fig. 21) clearly shows that monitoring well LM-MW-2 is outside of the permit boundary, while the two sets of coordinates stated by Union Milling Company (2024) for LM-MW-2 would place the monitoring well inside of the permit boundary (see Fig. 22).

Figure 21. The mapped locations of the seven monitoring wells (see Fig. 20) were compared with Google Earth imagery from October 2, 2019, to determine the coordinates (see Table 2). In addition to the map, Union Milling Company (2024) stated two different sets of coordinates for LM-MW-2 and LM-MW-3 (see Table 2). For LM-MW-2, the mismatch between the two sets of stated coordinates is 275 feet. The mismatches between the measured coordinates and the first and second sets of stated coordinates are 86 feet and 340 feet, respectively. For LM-MW-3, the mismatch between the two sets of stated coordinates is 51 feet. The mismatches between the measured coordinates and the first and second sets of stated coordinates are 148 feet and 190 feet, respectively. The map above clearly shows that monitoring well LM-MW-2 is outside of the permit boundary, while the two sets of coordinates stated by Union Milling Company (2024) for LM-MW-2 would place the monitoring well inside of the permit boundary (see Fig. 22). Figure from Union Milling Company (2024).

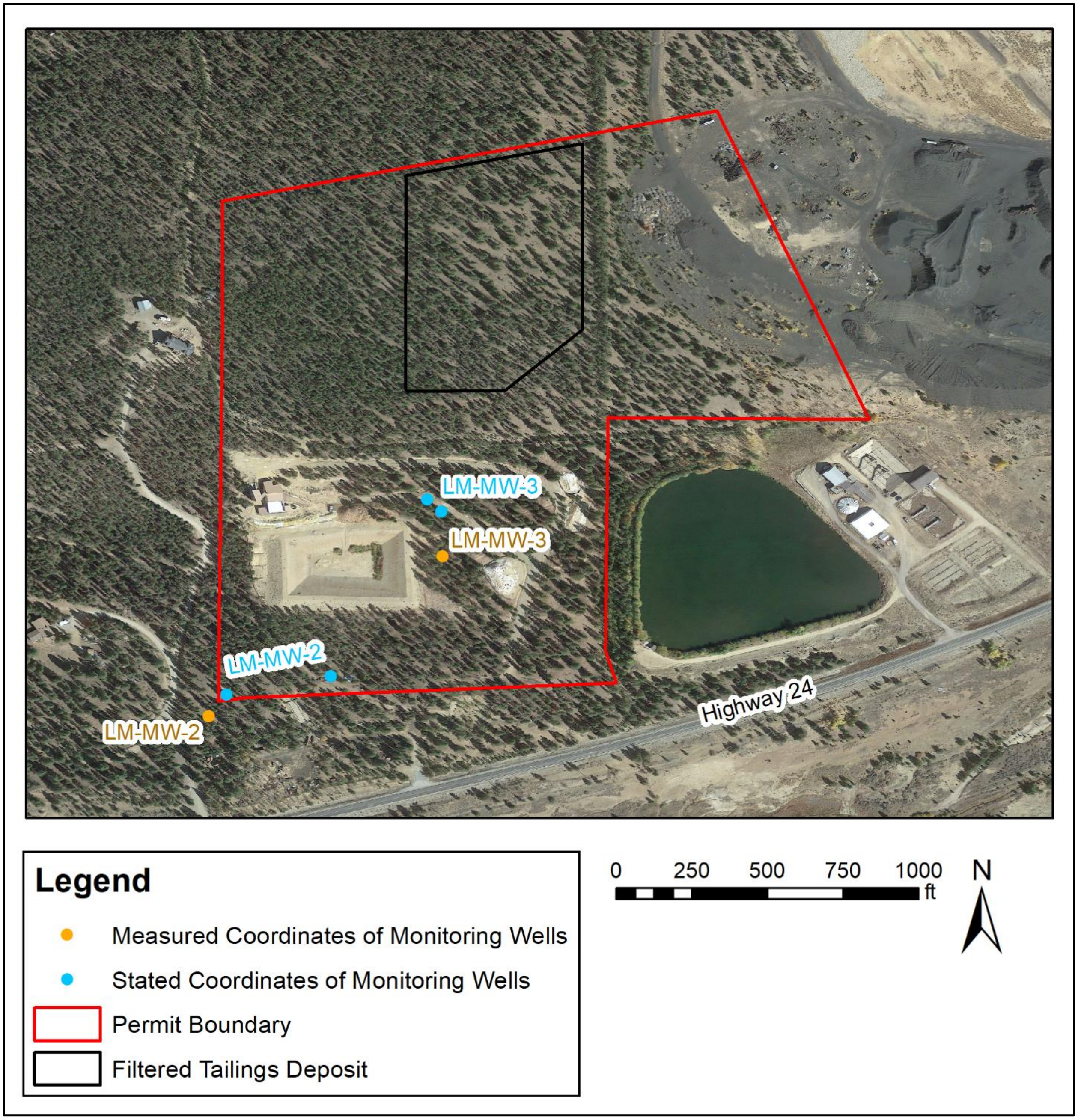


Figure 22. The mapped locations of the seven monitoring wells (see Fig. 21) were compared with Google Earth imagery from October 2, 2019, to determine the coordinates (see Table 2). In addition to the map, Union Milling Company (2024) stated two different sets of coordinates for LM-MW-2 and LM-MW-3 (see Table 2). For LM-MW-2, the mismatch between the two sets of stated coordinates is 275 feet. The mismatches between the measured coordinates and the first and second sets of stated coordinates are 86 feet and 340 feet, respectively. For LM-MW-3, the mismatch between the two sets of stated coordinates is 51 feet. The mismatches between the measured coordinates and the first and second sets of stated coordinates are 148 feet and 190 feet, respectively. The map in Union Milling Company (2024) (see Fig. 21) clearly shows that monitoring well LM-MW-2 is outside of the permit boundary, while the two sets of coordinates stated by Union Milling Company (2024) for LM-MW-2 would place the monitoring well inside of the permit boundary. Permit boundary traced from Fig. 19a and perimeter of filtered tailings deposit traced from Fig. 19b. Background is Google Earth imagery from October 2, 2019.

Table 2. Monitoring well locations[1]

Name	Latitude[2] (°N)	Longitude[2] (°W)	Easting[3,4] (m)	Northing[3,4] (m)
BMW-1	39.24496	106.30720	387198	4344774
PZ-4 (BMW-1A)	39.24496	106.30720	387198	4344774
MA1TMW-4	39.23561	106.33153	385083	4343767
LM-MW-2	39.22857	106.33361	384892[5]	4342988[5]
LM-MW-3	39.23002	106.33149	385077[6]	4343147[6]
MW13	39.22599	106.34210	384155	4342713
MW13A	39.22590	106.34218	384147	4342703

[1]Latitude and longitude were measured by comparing an unlabeled map on p. 315 of Union Milling Company (2024) with Google Earth imagery from October 2, 2019. See additional monitoring well information in Fig. 20 and map in Fig. 21.
[2]WGS84
[3]Latitude and longitude were converted to UTM coordinates using WVDEP Geographic Information Server (2024).
[4]Zone 13N, NAD83
[5]Union Milling Company (2024) states the UTM coordinates as (Easting: 384906, Northing: 4343010) in one place and as (Easting: 384988, Northing: 4343027) in a second place. The mismatch between the two sets of stated coordinates is 84 meters (275 feet). The mismatches between the measured coordinates and the first and second sets of stated coordinates are 26 meters (86 feet) and 104 meters (340 feet), respectively.
[6]Union Milling Company (2024) states the UTM coordinates as (Easting: 385077, Northing: 4343192) in one place and as (Easting: 385067, Northing: 4343204) in a second place. The mismatch between the two sets of stated coordinates is 16 meters (51 feet). The mismatches between the measured coordinates and the first and second sets of stated coordinates are 45 meters (148 feet) and 58 meters (190 feet), respectively.

It is not possible even to establish the correct permit boundary or the correct perimeter of the filtered tailings deposit (FTD). Although the permit boundary shown in Fig. 19a (taken from the permit application) was used to construct the maps for this report, Fig. 23 (taken from the same permit application) shows a completely different size and shape for the permit boundary. In the same way, although the perimeter of the FTD shown in Fig. 19b (taken from the permit application) was used to construct the maps for this report, Fig. 17b (taken from the same permit application) shows a completely different size and shape for the perimeter of the FTD. The permit boundary and FTD perimeter shown in Fig. 17a appear similar to what is shown in Figs. 19a-b, but that does not adequately resolve the question as to which information in the permit application is the correct information.

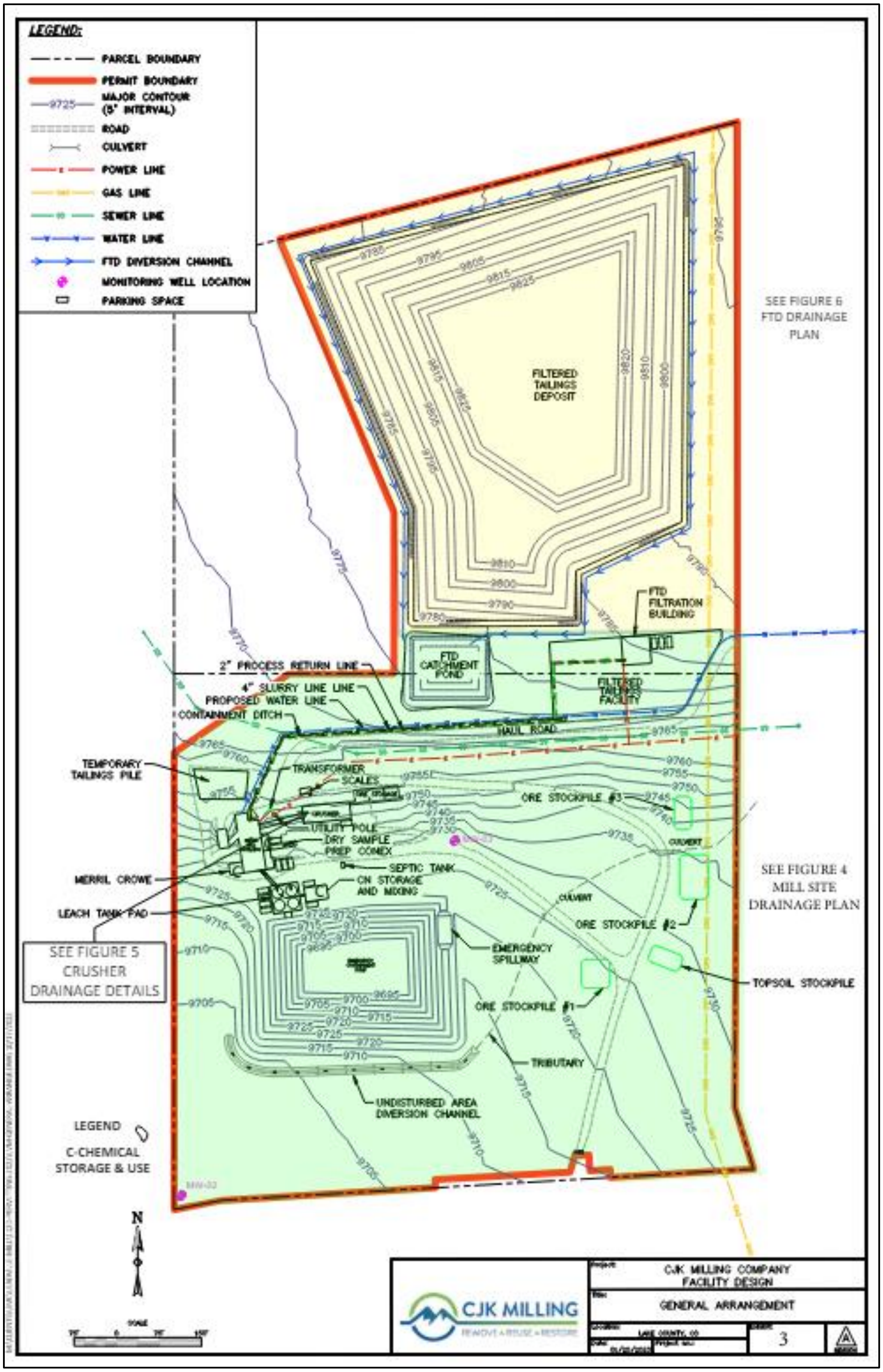


Figure 23. The application by Union Milling Company (2024) is filled with contradictory information. For example, the permit boundary and perimeter of the filtered tailings deposit in the above figure are inconsistent with the same information in other figures (compare with Figs. 17a and 19a-b). The perimeter of the filtered tailings deposit is, however, consistent with Fig. 17b. Figure from Union Milling Company (2024).

Aside from discrepancies in the permit boundary, the FTD perimeter, and the locations of the monitoring wells, a partial list of contradictory information within the application by Union Milling Company (2024) is given as follows:

1) The total cyanide concentration in the mix of tailings and water before filtration is stated as 1 mg/L, while the sodium cyanide concentration is stated as 0.05 lb-NaCN/ton-slurry (equivalent to a free cyanide concentration of 26.54 mg/L).
2) The height of the filtered tailings deposit is stated as approximately 38 feet and as approximately 38-43 feet.
3) The target water content for the filtered tailings is stated as the range 20 to 30% and as a maximum of 25%.
4) The rate of production of tailings is stated as 20 tons per hour and as 26.67 tons per hour.
5) The water consumption rate is stated as 27 gallons per minute and as 0.33 tons of water per ton of mine waste (equivalent to 82 gallons per minute for tailings production of 26.67 tons per hour with a process water content of 25%).
6) The capacity of the ECS is stated as 5.6 million gallons and as 6.2 million gallons.
7) Although the application denotes monitoring well LM-MW-3 as the point of compliance, the description of the point of compliance would apply to monitoring well LM-MW-2.

No attempt was made in this report to document all contradictory information in the permit application, nor to document all contradictions between the permit application itself and the representation of the application on the website of CJK Milling. As a single example of the latter, according to the "Fiction vs. Fact" tab of CKJ Milling (2024d), "Every effort will be made to recycle water, however any water needed will be supplied by Parkville Water District … The current plan calls for 20 gallons per minute (gpm)."

RESPONSES

The Company is not Committed to Following Industry Standards for Cyanide

The permit application by Union Milling Company (2024) variously states that the company is committed to following the International Cyanide Management Code, that the cyanide management plan will be developed at a later time, and that the International Cyanide Management Code will only be taken into consideration. Some key quotes from Union Milling Company (2024) are the following:

1) "Union Milling is committed to following the Cyanide Code Principles and implementing its Standards of Practice through all phases of the Leadville Mill Project."
2) "Prior to the start of operations, a comprehensive Cyanide Management Plan will be developed to ensure worker safety and to prevent release of cyanide to the environment."
3) "The Cyanide Management Plan will be developed in consideration of the principles and standards of practice of the International Cyanide Management Code (Cyanide Code)."

In contrast to the above quotes, the website of CJK Milling states that a comprehensive cyanide management plan already exists, but with no reference to the International Cyanide Management Code. According to CJK Milling (2024f), "As part of its commitment to safe and responsible operations, CJK Milling has developed a comprehensive cyanide management program protective of human health and the environment." Each of the three positions expressed by Union Milling Company (2024) are evaluated below.

The first position is that Union Milling Company is committed to following the International Cyanide Management Code. It has already been emphasized that the International Cyanide Management Code is a certification program, not a guidance document. Union Milling Company (2024) never states any intention to become a signatory company of the International Cyanide Management Code and to undergo the mandatory triennial third-party audits under the auspices of the International Cyanide Management Institute that would be required for certification. Therefore, it is difficult to understand what Union Milling Company means by making a commitment to a certification program without any intention of becoming certified. It is further unclear as to how the commitment by Union Milling Company could be binding on CJK Milling, which has made no such commitment. It should be recalled that all assets of the Leadville Mill are owned by CJK Milling. Union Milling Company is only the holder of the current operating permit that will be transferred to CJK Milling if the permit application is approved. The same caution would apply to any commitment that is expressed in the permit application by Union Milling Company (2024).

Despite the commitment by Union Milling Company (2024), the permit application significantly misrepresents what the International Cyanide Management Code actually says. For example, Union Milling Company (2024) includes a table with the heading "PRINCIPLES & STANDARDS OF PRACTICE AS DEFINED IN THE CYANIDE CODE." The table includes seven Principles and 21 Standards of Practice. However, the actual International Cyanide Management Code includes 17 Principles and 55 Standards of Practice (International Cyanide Management Institute, 2021a), so that the Principles and Standards of Practice are listed in quite a selective manner with no indication that Union Milling Company (2024) has not provided the complete list. It could be that Union Milling Company (2024) intended to list only the Mining Principles and Mining Standards of Practice, but there are still nine Mining Principles and 29 Mining Standards of Practice (International Cyanide Management Institute, 2021a).

The missing Mining Principles are the following (International Cyanide Management Institute, 2021a):

- Mining Principle 8 (Training): "Train workers and emergency response personnel to manage cyanide in a safe and environmentally protective manner."
- Mining Principle 9 (Dialogue and Disclosure): "Engage in public consultation and disclosure."

The missing Mining Standards of Practice are the following (International Cyanide Management Institute, 2021a):

- Mining Standard of Practice 5.2: "Establish a financial assurance mechanism capable of fully funding cyanide-related decommissioning activities."
- Mining Standard of Practice 7.4: "Develop procedures for internal and external emergency notification and reporting."
- Mining Standard of Practice 7.5: "Incorporate remediation measures and monitoring elements into response plans and account for the additional hazards of using cyanide treatment chemicals."
- Mining Standard of Practice 7.6: "Periodically evaluate response procedures and capabilities and revise them as needed."
- Mining Standard of Practice 8.1: "Train workers to understand the hazards associated with cyanide use."

- Mining Standard of Practice 8.2: “Train appropriate personnel to operate the facility according to systems and procedures that protect human health, the community and the environment.”
- Mining Standard of Practice 8.3: “Train appropriate workers and personnel to respond to worker exposures and environmental releases of cyanide.”
- Mining Standard of Practice 9.1: “Promote dialogue with stakeholders regarding cyanide management and responsibly address identified concerns.”
- Mining Standard of Practice 9.2: “Make appropriate operational and environmental information regarding cyanide available to stakeholders.”

Union Milling Company (2024) also selectively quotes from and misquotes from the International Cyanide Management Code, although it is clear from the context (a table with the heading “PRINCIPLES & STANDARDS OF PRACTICE AS DEFINED IN THE CYANIDE CODE’) that these are intended to be exact quotes. For example, the table in Union Milling Company (2024) states Mining Standard of Practice 2.1 as “Establish clear lines of responsibility for safety, security, release prevention, training and emergency response in written agreements with producers, distributors and transporters.” However, the correct version of Mining Standard of Practice 2.1 is “**Require that cyanide is safely managed through the entire transportation and delivery process from the production facility to the mine by use of certified transport** with clear lines of responsibility for safety, security, release prevention, training and emergency response” (emphasis added) (International Cyanide Management Institute, 2021a). Thus, the version stated by Union Milling Company (2024) seems to remove their responsibility for the entire cyanide transportation and delivery process. As a second example, the table in Union Milling Company (2024) states Mining Standard of Practice 5.1 as “Plan and implement procedures for effective decommissioning of cyanide facilities to protect human health, wildlife and livestock.” However, the correct version of Mining Standard of Practice 5.1 is “Plan and implement procedures for effective decommissioning of cyanide facilities to protect human health, wildlife, livestock, **and the environment**” (emphasis added) (International Cyanide Management Institute, 2021a). The omission of the expression “and the environment” seems disturbing. In general, the disturbing aspect is the implied claim by Union Milling Company (2024) that they will commit to their version of the International Cyanide Management Code, but not to the real International Cyanide Management Code.

The second position, which is that a comprehensive cyanide management plan will be developed at a later time, is also difficult to understand, especially in light of the claim by CJK Milling that a comprehensive cyanide management plan already exists. The purpose of the permit application is, presumably, to provide Colorado DRMS and the public with the information necessary to determine whether a proposed project will provide adequate protection to people and the environment. For a proposal to use cyanide for mineral processing, the comprehensive cyanide management plan should be the critical piece of information that is needed to assess the safety of a proposed remining operation. Since CJK Milling (2024f) claims that the comprehensive cyanide management plan already exists, it should be a simple matter for CJK Milling to provide the plan to Union Milling Company for inclusion in the permit application.

The remainder of this subsection will address the third position of Union Milling Company (2024), which is that the International Cyanide Management Code will not be literally followed, but will only be taken into consideration. For this purpose, the important consideration is the ways in which the cyanide management plan, as it is stated in the permit application, falls short of the expectations of the International Cyanide Management Code. The most significant shortcoming is that there is currently no plan of any kind for the safe disposal of the iron-cyanide sludge that will be produced by the partial removal of dissolved cyanide from the mix of water and tailings prior to filtration of the tailings. It has already been mentioned that solid iron cyanide is not inert and can convert to the highly toxic free cyanide upon exposure to sunlight or changes in the chemistry of the environment. Not only is there no plan for safe disposal of the iron-cyanide sludge, but Union Milling Company (2024) does not include any discussion of the anticipated composition of the sludge or the quantity of iron-cyanide sludge that will be produced. The lack of a plan for safe disposal of cyanide waste is inconsistent with Mining Principle 4 (Operations), which states "Manage cyanide process solutions and waste streams to protect human health and the environment" (International Cyanide Management Institute, 2021a).

The only hint as to a plan for the safe disposal of the iron-cyanide sludge is the statement that "The iron-cyanide precipitation process is suitable for detoxification since precipitation reactions can be controlled and the precipitated solids are properly disposed in the FTD" (Union Milling Company, 2024). It is not clear as to whether the preceding quote literally means that the iron-cyanide sludge will simply be added to the filtered tailings deposit (FTD). If so, it is difficult to understand the logic of removing cyanide from the tailings, filtering the water from the tailings, and then re-mixing the removed cyanide with the tailings in the filtered tailings deposit. If the plan is actually to add the iron-cyanide sludge to the filtered tailings deposit, then the following is a very partial list of the questions that have not yet been addressed:

1) How will the company prevent in perpetuity the conversion of the iron-cyanide sludge into free cyanide? In particular, how will the company prevent in perpetuity the erosion of the FTD and the exposure of the iron-cyanide sludge to sunlight?
2) How will the addition of the iron-cyanide sludge to the FTD affect metal leaching and acid mine drainage from the FTD? Answering this question would require knowledge of the anticipated quantity and composition of the iron-cyanide sludge, which will not be a pure iron cyanide, but will include all substances that will precipitate from the mix of water and tailings in response to the addition of ferrous sulfate.
3) How will the addition of the iron-cyanide sludge to the FTD affect the stability of the FTD? Answering this question would require knowledge of the anticipated quantity and geotechnical properties of the iron-cyanide sludge.
4) How will the addition of saturated material, such as the iron-cyanide sludge, to the FTD affect the stability of the FTD? It should be noted that there has been no discussion of the anticipated water content of the iron-cyanide sludge and there is no plan to filter or otherwise dewater the sludge.

Other shortcomings of the permit application (Union Milling Company, 2024) relate to the status of the filtered tailings deposit (FTD) as a "cyanide facility." A partial list of shortcomings is stated as follows:

1) There is no plan for the perpetual monitoring, inspection, maintenance and review of the FTD nor is there a plan for the elimination of all credible failure modes of the FTD. The lack of a plan is inconsistent with Mining Principle 5 (Decommissioning), which states "Protect communities and the environment from cyanide through development and implementation of decommissioning plans for cyanide facilities" (International Cyanide Management Institute, 2021a).

2) There is no analysis of the consequences of failure of the FTD and no emergency response plan in the event of failure. These deficiencies are inconsistent with Mining Principle 7 (Emergency Response), which states “Protect communities and the environment through the development of emergency response strategies and capabilities” (International Cyanide Management Institute, 2021a). In particular, these deficiencies are inconsistent with Mining Standard of Practice 7.1, which states, “Prepare detailed emergency response plans for potential cyanide releases” (International Cyanide Management Institute, 2021a). It has been mentioned that the corresponding auditing question asks: “Does the Plan consider the potential cyanide failure scenarios appropriate for its site-specific environmental and operating circumstances, including the following, as applicable: … j) Failure of tailings impoundments, heap leach facilities and other cyanide facilities?” (International Cyanide Management Institute, 2021b).
3) The contradictory information that has been provided to Colorado DRMS and the public is inconsistent with Mining Principle 9 (Dialogue and Disclosure), which states “Engage in public consultation and disclosure” (International Cyanide Management Institute, 2021a).

The first two shortcomings listed above will be developed more fully in the following subsections.

The Filtered Tailings Deposit will be Unstable

There are at least six reasons as to why the filtered tailings deposit (FTD) will be unstable based on its current design. The first reason is that, according to a 12-page consulting report by Paterson & Cooke that is included within Union Milling Company (2024), the flow moisture point and transportable moisture limit of the tailings will be 19.4% and 17.5%, respectively (see Figs. 24a-b), where the values refer to process water contents. The flow moisture point is the water content above which flow behavior occurs, while it is generally too dangerous to transport granular material with process water contents exceeding the transportable moisture limit because of the possibility of liquefaction setting up wave-like behavior within shipping containers. The preceding limits are much less than the target water content for the filtered tailings, which is stated as either the range 20 to 30% or less than 25%. Figs. 25a-b show the flow behavior that would be expected for process water contents in the range of 19.7 to 23.9%. Considerable flattening of the filter cake occurs at a process water content of 23.9% (see Fig. 25b), which would still be well within the range of acceptable water contents, as stated by Union Milling Company (2024) (compare with Fig. 16). As a consequence, the FTD will flow as it is constructed, meaning that it cannot actually be constructed.

The second reason as to why the filtered tailings deposit (FTD) will be unstable is that the tailings will be susceptible to liquefaction. It was mentioned previously that susceptibility to liquefaction depends upon the particle size distribution because a mixture of coarse and fine particles will prevent the escape of water in response to a disturbance (see Fig. 4). The particle size distribution also determines the compressibility of a mixture of solid particles or the tendency of the mixture to consolidate in response to disturbance (see Fig. 4). A tailings sample from the Leadville Mill was determined to be 41.8% sand, 38.4% silt, and 19.8 % clay (see Fig. 26a). For this report, the particle size distribution was digitized using PlotDigitizer and then superimposed onto a diagram (Hunter and Fell, 2003a-b; Fell et al., 2015) showing the ranges of particle-size distributions that are susceptible to liquefaction (see Fig. 26b). The superimposition shows that the particle size distribution of the tailings from the Leadville Mill will be within the range that is susceptible to liquefaction (see Fig. 26b). It should not be surprising that the Leadville Mill tailings will also be in the middle of the range that is typical for mine tailings (labeled as "3" in Fig. 26b).

Table I: Transportable Moisture Limit

Parameter	Leadville Tailings
Flow moisture point	19.4%m
Transportable moisture limit	17.5%m

Figure 24a. For the tailings that would be produced at the Leadville Mill, Union Milling Company (2024) determined the flow moisture point to 19.4% and the transportable moisture limit to be 17.5%, where the percentages refer to the process water content. The flow moisture point is the water content above which the material exhibits fluid-like behavior (see Figs. 25a-b). Since Union Milling Company (2024) has stated the target water content for the filtered tailings deposit sometimes as the range 20-30% and sometimes as less than 25% (see Fig. 16), the filtered tailings deposit will be unstable because it will flow as it is constructed. Table from Union Milling Company (2024).

There are more sophisticated methods for the assessment of susceptibility to liquefaction, but they require additional geotechnical properties, such as the plasticity index and the liquid limit (Fell et al., 2015). Besides the particle size distribution, the only geotechnical property of the tailings that is reported in Union Milling Company (2024) is that the specific gravity of the solid particles is 2.87 (see Fig. 26a). Even such fundamental information as the saturated water content and the optimum water content for maximum compaction are missing, although it should be quite important to compare those values with the target water contents and the flow moisture point. The permit application does not discuss any means for preventing liquefaction or even mention the phenomenon of liquefaction.

The third reason as to why the filtered tailings deposit (FTD) will be unstable is that the FTD will be constructed without any structural zone or dam for proper confinement of the tailings that will be too wet for adequate compaction (see Fig. 14). According to Union Milling Company (2024), "A series of field trials will be carried out to allow for a method specification for filtered tailings placement that produces densities at field scale that [are] compliant with a target 90% of maximum Proctor Density requirement [maximum dry density based upon a specific test]." The standard procedure is to construct a structural zone in which the tailings are compacted to 95% of their maximum dry density and a non-structural zone in which the tailings are compacted to 90% (sometimes as low as 85%) of their maximum dry density. As discussed previously, the structural zone is constructed out of the tailings with the appropriate water content for adequate compaction, while the non-structural zone is constructed out of the tailings that are too wet for adequate compaction. In essence, the plan for the FTD is to construct only a non-structural zone without any structural zone (see Fig. 14).

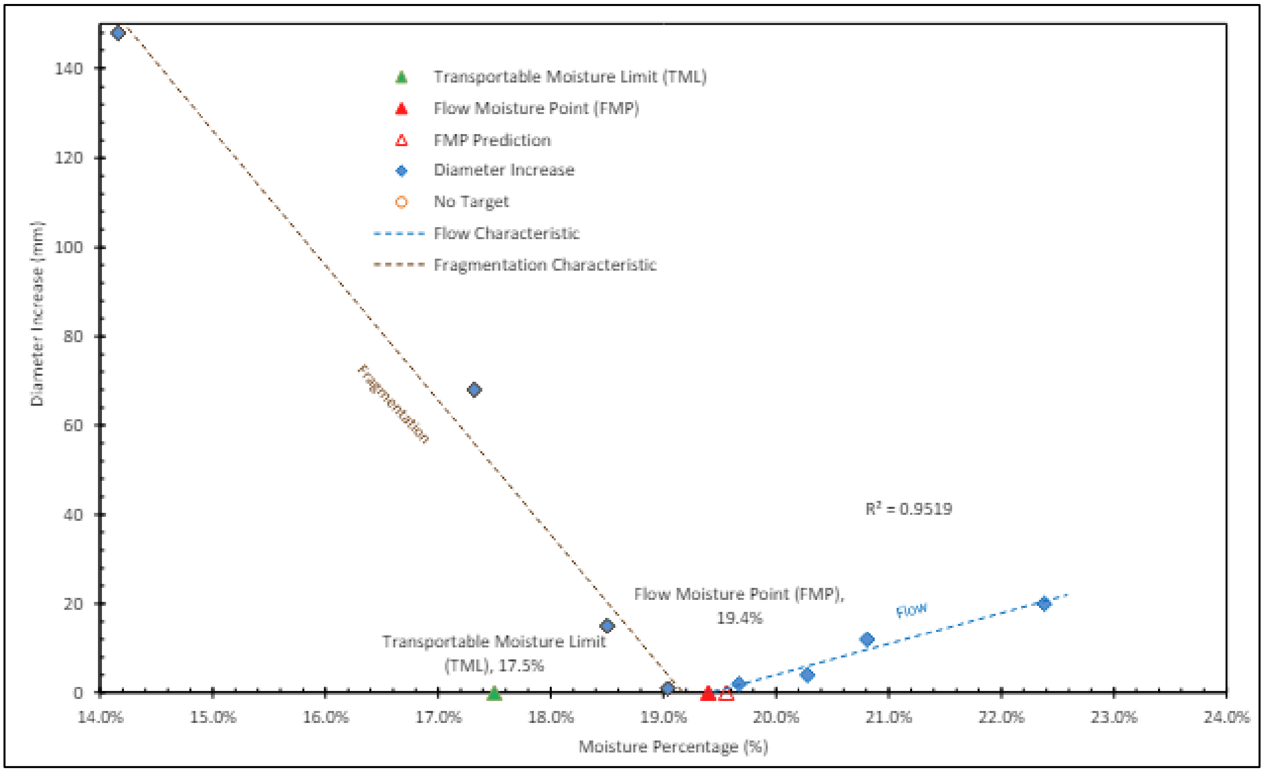


Figure 24b. For the tailings that would be produced at the Leadville Mill, Union Milling Company (2024) determined the flow moisture point to 19.4% and the transportable moisture limit to be 17.5%, where the percentages refer to the process water content. The flow moisture point is the water content above which the material exhibits fluid-like behavior (see Figs. 25a-b). The graph indicates that, for water contents greater than the flow moisture point, after disturbance (described only as "after 25 drops"), the filter cake increased in diameter due to flow. The pre-disturbance diameter was not stated. For water contents less than the flow moisture point, the filter cake fragmented (as opposed to flowed) after disturbance. Since Union Milling Company (2024) has stated the target water content for the filtered tailings deposit sometimes as the range 20-30% and sometimes as less than 25% (see Fig. 16), the filtered tailings deposit will be unstable because it will flow as it is constructed. Figure from Union Milling Company (2024).

The fourth reason as to why the filtered tailings deposit (FTD) will be unstable is that there has been no analysis of the impact of placing saturated materials within the FTD. The saturated materials could be the tailings with process water content in the range 25 to 30%, for which the only pre-treatment will be drainage under gravity prior to emplacement in the FTD. The other source of saturated materials could be the iron-cyanide sludge, for which there is no plan for dewatering or drainage or any kind of pre-treatment prior to emplacement in the FTD. It should be noted that it is still not clear as to whether the plan is to place the iron-cyanide sludge in the FTD (re-mixing the cyanide with the tailings from which the cyanide had been removed) or whether there is no plan whatsoever for the safe disposal of the iron-cyanide sludge.

Figure 4-16:

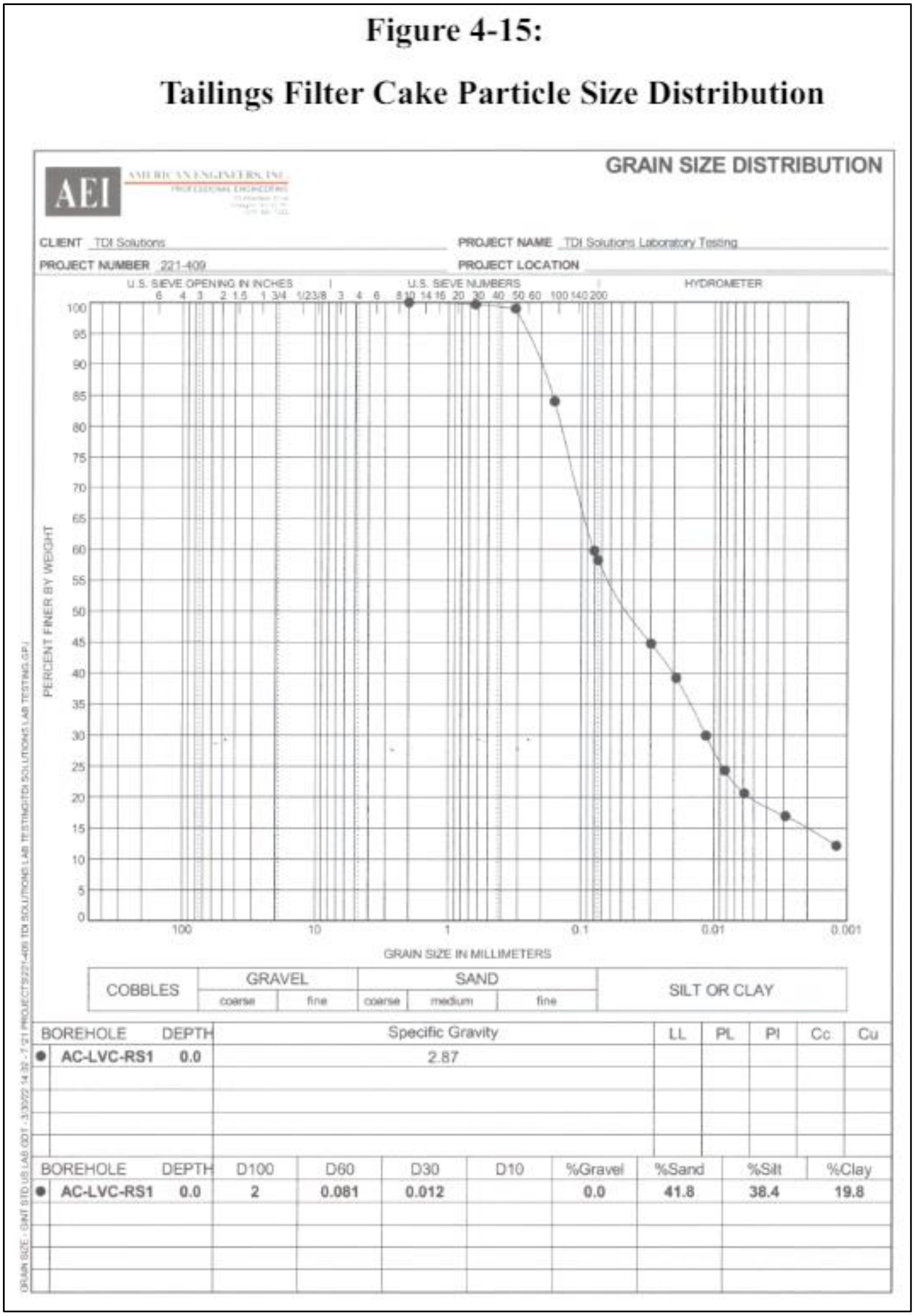
Tailings Filter Cake at Target Moisture Ranges

Figure 25a. For the tailings that would be produced at the Leadville Mill, Union Milling Company (2024) determined the flow moisture point to 19.4% and the transportable moisture limit to be 17.5%, where the percentages refer to the process water content. The flow moisture point is the water content above which the material exhibits fluid-like behavior. The above photos show the filter cake before (left-hand side) and after (right-hand side) disturbance at a range of water contents. The photos clearly indicate increasing flow behavior at water contents exceeding the flow moisture point. Since Union Milling Company (2024) has stated the target water content for the filtered tailings deposit sometimes as the range 20-30% and sometimes as less than 25% (see Fig. 16), the filtered tailings deposit will be unstable because it will flow as it is constructed. See higher water content (23.9%) in Fig. 25b. Photos from Union Milling Company (2024).

Figure 13: Leadville Tailings 23.9%m

Figure 25b. For the tailings that would be produced at the Leadville Mill, Union Milling Company (2024) determined the flow moisture point to 19.4% and the transportable moisture limit to be 17.5%, where the percentages refer to the process water content. The flow moisture point is the water content above which the material exhibits fluid-like behavior. The above photo shows the filter cake before (left-hand side) and after (right-hand side) disturbance at a water content of 23.9%. The photo clearly indicates extreme flow behavior at a water content exceeding the flow moisture point. Since Union Milling Company (2024) has stated the target water content for the filtered tailings deposit sometimes as the range 20-30% and sometimes as less than 25% (see Fig. 16), the filtered tailings deposit will be unstable because it will flow as it is constructed. See photos of lower water contents (19.7%, 20.3%, 20.8%, 22.4%) in Fig. 25a. Photos from Union Milling Company (2024).

The fifth reason as to why the filtered tailings deposit (FTD) will be unstable is that the target process water contents of a range of 20 to 30% or a maximum of 25% correspond to geotechnical water contents in the range of 25 to 42.9% or a maximum of 33.3%. By contrast, as discussed previously, a typical geotechnical water content for a filtered tailings storage facility is 16.7% with a known range of 12 to 20%. Thus, the proposed FTD at the Leadville Mill would be, by far, the wettest filtered tailings storage facility ever constructed. The sixth reason as to why the filtered tailings deposit (FTD) will be unstable is that the FTD has not been designed to accommodate any particular precipitation event or seismic event. The correct choice of the design precipitation event and design seismic event depends upon the consequences of failure and will be discussed in the following subsection.



BOREHOLE	DEPTH	Specific Gravity	LL	PL	PI	Cc	Cu
● AC-LVC-RS1	0.0	2.87					

BOREHOLE	DEPTH	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● AC-LVC-RS1	0.0	2	0.081	0.012		0.0	41.8	38.4	19.8

Figure 26a. Based on the particle size distribution of a tailings sample, Union Milling Company (2024) determined that the tailings would be 41.8% sand, 38.4% silt, and 19.8 % clay. See comparison with particle size distributions that are susceptible to liquefaction in Fig. 26b. Figure from Union Milling Company (2024).

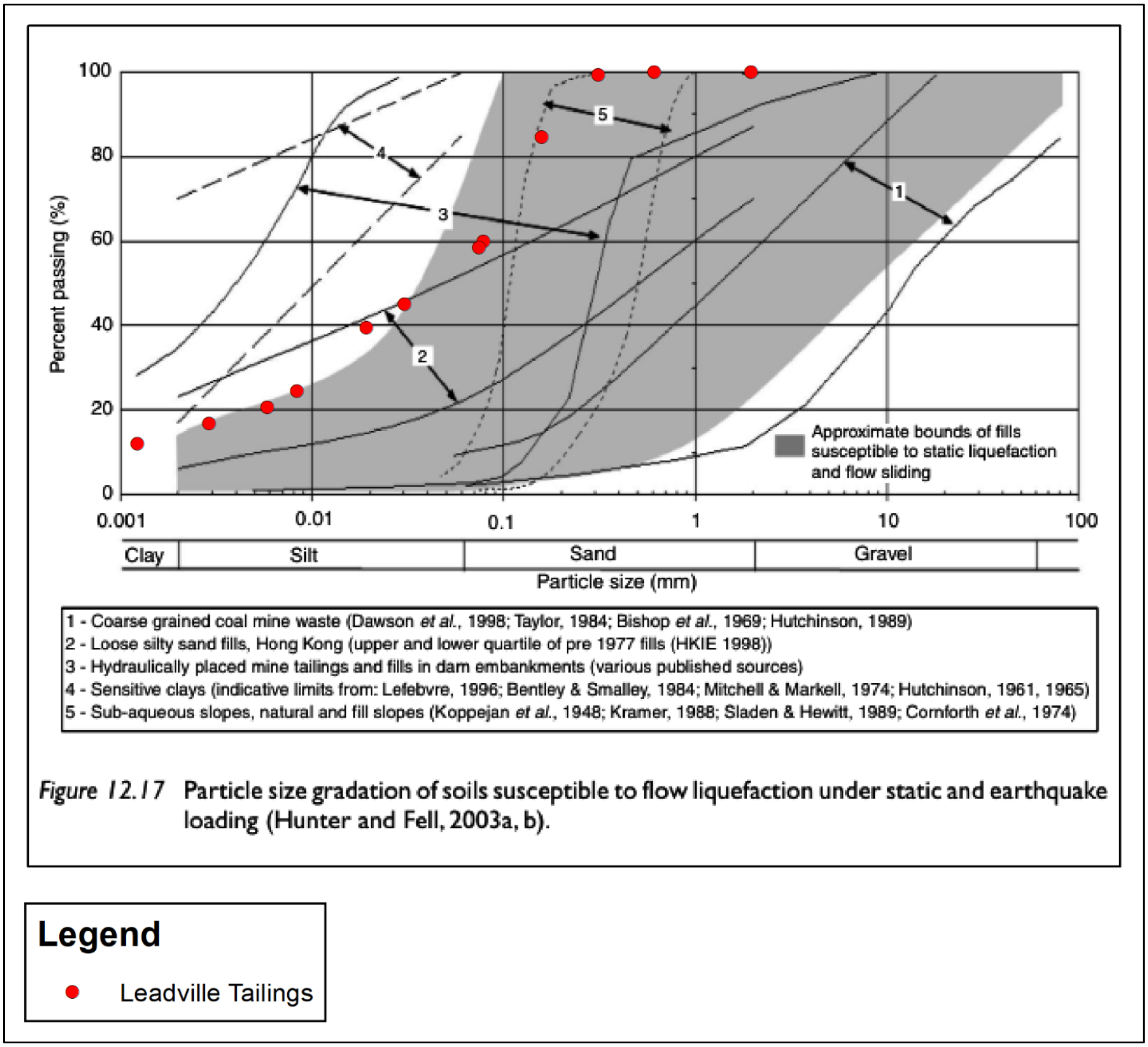


Figure 26b. Hunter and Fell (2003a-b) developed a diagram that shows the ranges of particle size distributions of granular materials that are susceptible to liquefaction. A superposition of the particle size distribution of the tailings from the Leadville Mill (see Fig. 26a) onto the above diagram shows that the tailings from the Leadville Mill will be susceptible to liquefaction. It should not be surprising that the tailings from the Leadville Mill fall in the mid-range for particle size distributions of mine tailings. Base figure from Fell et al. (2015).

Despite the preceding concerns, Union Milling Company (2024) indicates that they have already determined that the FTD will have a factor of safety of 2.0, that is, well above the typical minimum factor of safety of 1.5, but without providing any evidence for that determination. According to Union Milling Company (2024), “As a directional indication of anticipated stability, typical process tailings geotechnical properties from materials with similar particle size distributions [were] applied to a simple analysis using the ultimate FTD cross-sectional geometry and assuming target compaction and moisture contents. These results indicate factors of safety in excess of 2.0 for both static and pseudo-static [seismic] loading conditions.” The above statement is not accompanied by any stability analyses or the geotechnical parameters that would be required to carry out a stability analysis, such as the unit weight, friction angle, and cohesion of all of the materials that would make up the FTD and its foundation, as well as the anticipated height of the water table within the FTD. Union Milling Company (2024) continues, "The FTD design uses conservative parameters based on previous work related to the design and construction of the ECS [Emergency Containment Sump]." Of course, the ECS does not include any tailings and any geotechnical parameters that were required to design the ECS would be irrelevant for the FTD, except possibly for the foundation of the FTD. Finally, it is perplexing as to why Union Milling Company (2024) does not state the exact values for the static and seismic factor of safety, instead of just stating that they are greater than 2.0. The factor of safety for static loading ought to be considerably greater than for seismic loading (loading in response to the design earthquake).

The most surprising part of the geotechnical stability analysis of the FTD is the assertion that this work has not actually been done and will be carried out at a later date. According to Union Milling Company (2024), "Confirmatory geotechnical sampling and analysis of the FTD site is planned for spring 2024. Results of this analysis will be provided to CDRMS when this work is complete." The preceding assertion is found under the heading "RULE 6.5: GEOTECHNICAL STABILITY." The material under the heading consists only of the sentence "The FTD design uses conservative parameters based on previous work related to the design and construction of the ECS" followed by the two sentences above. The three-sentence response cannot possibly fulfill the requirements of Rule 6.5.

Rule 6.5 states in part, "On a site-specific basis, an Applicant shall be required to provide engineering stability analyses for proposed final reclaimed slopes, highwalls, waste piles and embankments. An Applicant may also be required to provide engineering stability analyses for certain slopes configuration as they will occur during operations, including, but not limited to embankments. Information for slope stability analyses may include, but would not be limited to, slope angles and configurations, compaction and density, physical characteristics of earthen materials, pore pressure information, slope height, post-placement use of site, and information on structures or facilities that could be adversely affected by slope failure" (Code of Colorado Regulations, 2014).

Rule 6.5 is particularly demanding for projects in which there is potential for impacts off the project site. Rule 6.5 continues, "Where there is the potential for off-site impacts due to failure of any geologic structure or constructed earthen facility, which may be caused by mining or reclamation activities, the Applicant shall demonstrate through appropriate geotechnical and stability analyses that off-site areas will be protected with appropriate factors of safety incorporated into the analysis. The minimum acceptable safety factors will be subject to approval by the Office, on a case-by-case basis, depending upon the degree of certainty of soil or rock strength determinations utilized in the stability analysis, depending upon the consequences associated with a potential failure, and depending upon the potential for seismic activity at each site." The potential for off-site impacts will be discussed in the following subsection.

The Failure of the Filtered Tailings Deposit could Cause Fatalities

The permit application by Union Milling Company (2024) is devoid of any analysis of the consequences of collapse of the proposed filtered tailings deposit (FTD), nor does the application even admit the possibility of collapse. By contrast, the application simply affirms that the FTD will be "stable." According to Union Milling Company (2024), "From that stockpile [of filtered tailings], the filter cake is spread and compacted in layers by mobile earthmoving equipment to form a stable, engineered fill." All the indications that the FTD will, in fact, be unstable were reviewed in the previous subsection. In contrast to the optimism expressed by Union Milling Company (2024), it is standard practice for any engineering project to consider the consequences of failure. The lack of such consideration would be an implicit assertion that failure is impossible, which should be a basis for rejecting a proposal for an engineering project. CJK Milling (2024f) is actually more realistic in stating that "the resulting dry stack tailings system is more stable than the traditional wet tailings." In other words, the website of CJK Milling simply asserts that dewatering the tailings increases the stability of the tailings storage facility, which is true in general, but not that dewatering creates "stability" in any absolute sense.

Along the same lines, Union Milling Company (2024) states, "The final deposit is considered as an engineered fill of very low risk classification from a geotechnical stability perspective." However, risk is a combination of the probability of failure and the consequences of failure. Therefore, nothing can be said about "risk" without some assessment of the consequences of failure. Moreover, the assessment of consequences is a socioeconomic and environmental question, and not a question of geotechnical stability.

In the absence of any analysis of the consequences of failure in the permit application, the purpose of this subsection is to carry out an approximate analysis. Although a full computational analysis is beyond the scope of this report, the consequences of failure of the FTD at the Leadville Mill can be estimated by analogy with the failure of the filtered tailings storage facility at the Pau Branco iron-ore mine in Brazil on January 8, 2022 (Angelo, 2022; Morrill, 2022; Observatório da Mineração [Mining Observatory], 2022; Petley, 2022; see Fig. 7). The estimation of the consequences of failure will then be used to determine the appropriate design precipitation event and design seismic event for the FTD. Another reason as to why analysis of the consequences of failure is necessary for any engineering project is that, without such an analysis, there is no rational basis for determining the design criteria.

By comparing drone videos (Observatório da Mineração [Mining Observatory], 2022) with Google Earth imagery, it was determined that the landslide from the filtered tailings storage facility at the Pau Branco mine extended for 828 meters (2717 feet) past the toe of the facility (see Figs. 27a-b). Since the height of the filtered tailings stack was 48 meters at the time of failure (ANM, 2024), the runout from the collapse was 17.25 times the height of the facility. The above result is reasonably close to the generalized statement by Klohn Crippen Berger (2017) that "Failure, if it occurs, would likely be local slumping and consequences would be restricted to the local area (or the distance equivalent to roughly 10 times the height [of the tailings storage facility]) … " Since the estimate by Klohn Crippen Berger (2017) was given without reference to any database and which was probably only a general impression, in the absence of a detailed calculation, a distance of 17.25 times the height will be used as the current best estimate for the runout of a slump from a filtered tailings storage facility. Based on the maximum height of 43 feet, the runout from a collapse of the FTD at the Leadville Mill will cover 742 feet.

Figure 27a. Based on the highway width of 27 meters, the slump at the filtered tailings storage facility at the Pau Branco mine in Brazil on January 8, 2022 (see Fig. 7), extended for 104 meters past Highway BR-40. Highway width was measured from Google Earth image from June 29, 2022 (see Fig. 27b). Still image at 0:38 of drone video (Observatório da Mineração [Mining Observatory], 2022).

A landslide from the FTD could potentially travel in multiple directions. A landslide directed to the west will result in the burial of multiple homes (see Fig. 28). As of the latest Google Earth imagery (October 2, 2019), the closest home was 485 feet from the intended perimeter of the FTD (see Fig. 28). In this case, fatalities should be expected because a failure of the FTD could occur with no warning or precursors (as happened at the Pau Branco mine) and the landslide will arrive in less than a minute. It should be noted that the maximum FTD elevation will be 71 feet higher than the homes to the west of the FTD. An alternative is that the landslide could travel to the southwest, resulting in burial of mine buildings that are 137 feet lower in elevation than the top of the FTD (see Fig. 28). In this case, fatalities of mill workers should be expected, again because a failure could occur with no warning or precursors and the landslide will arrive in less than a minute.

Other travel pathways will have considerable environmental and social consequences, but without expected fatalities. A landslide directed to the south would probably not reach California Gulch during the initial event (see Fig. 28). However, subsequent normal precipitation events will wash the tailings into California Gulch, from where they will flow into the Arkansas River (see Figs. 2 and 28). A landslide directed to the southeast will have more serious consequences because the spilled tailings will mix with the water in the polishing pond of the Leadville Sanitation District (see Fig. 28). The above quote from Klohn Crippen Berger (2017) continues, " … unless the material slumps into a water body … When large water ponds are located downstream of high-density thickened/paste facilities, cascading failures are possible and should be accounted for when developing the risk profile of tailings failure management." Thus, the mixing of the filtered tailings with the water in the polishing pond could result in a fully liquefied mass that could travel a considerable distance down California Gulch and the Arkansas River (see Figs. 2 and 28). From a socioeconomic standpoint, any damage or destruction of the polishing pond would likely result in the loss of sewage treatment for the city of Leadville and the surrounding area for an extended period. As an additional environmental consequence, significant sewage effluent contamination of the Arkansas River could occur while the District facilities were being restored.

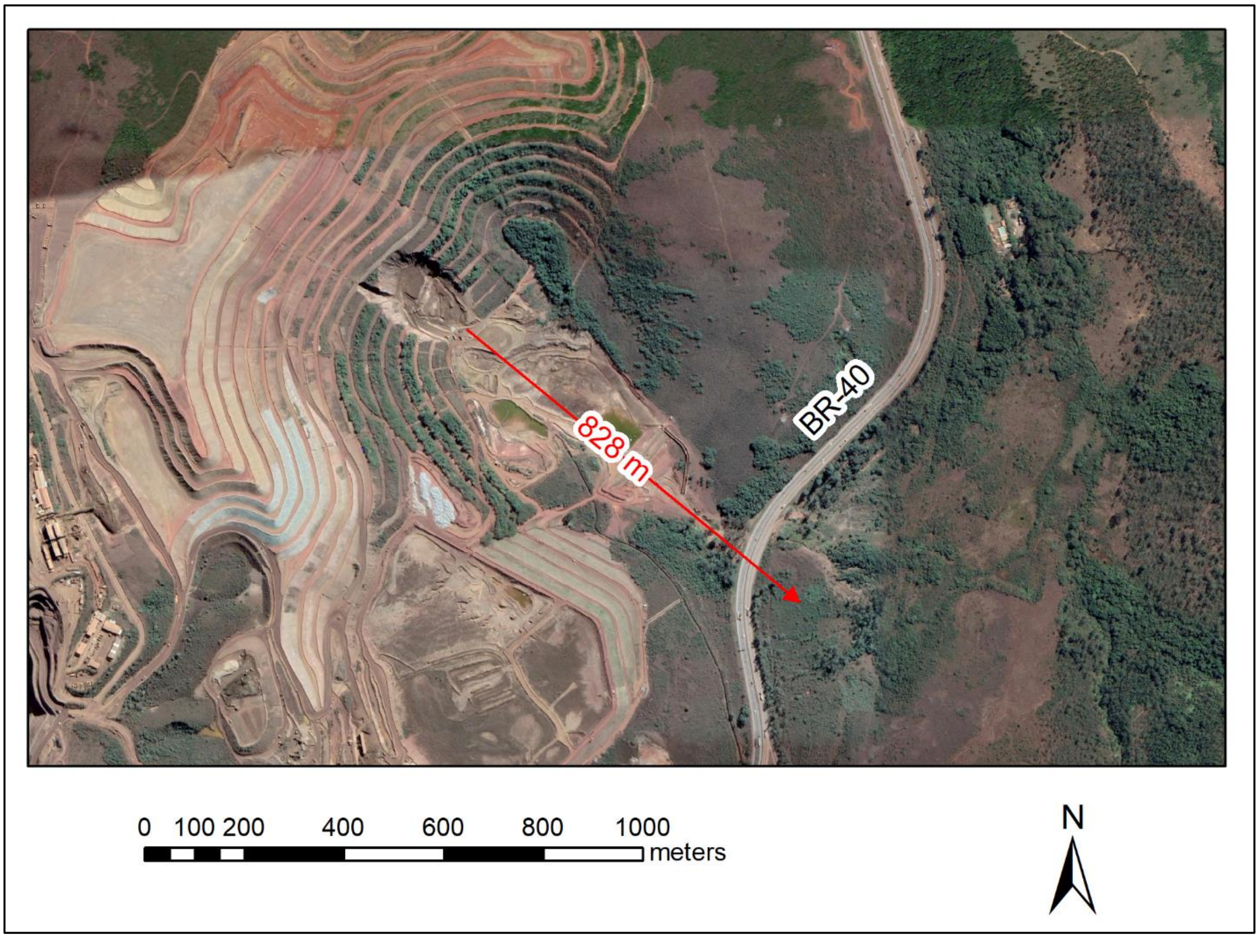


Figure 27b. The slump of the filtered tailings storage facility at the Pau Branco mine in Brazil on January 8, 2022 (see Fig. 7), extended for 828 meters past the toe of the facility or 17.25 times the height of the filtered tailings storage facility of 48 meters (ANM, 2022). The preceding observation is consistent with the statement in Klohn Crippen Berger (2017) that, for filtered tailings storage facilities, "Failure, if it occurs, would likely be local slumping and consequences would be restricted to the local area (or the distance equivalent to roughly 10 times the height)." Based upon the maximum height of 43 feet of the proposed filtered tailings storage facility at the Leadville Mill, the experience at the Pau Branco mine predicts that the slump of the filtered tailings deposit at the Leadville Mill will extend for 742 feet meters past the toe of the facility (see Fig. 28). Background is Google Earth image from June 29, 2022.

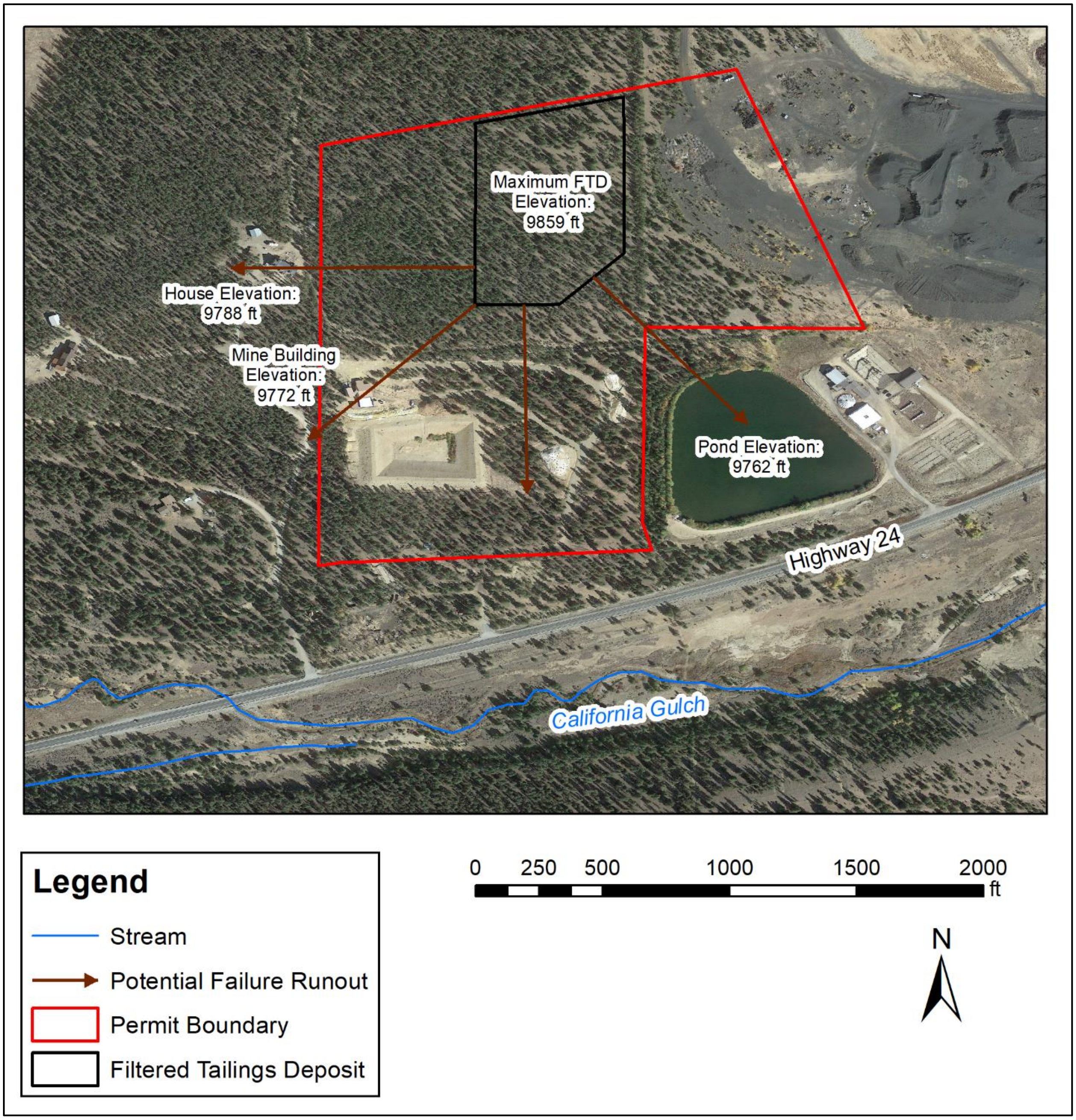


Figure 28. Based upon a maximum height of 43 feet and by analogy with the slump of the filtered tailings storage facility at the Pau Branco mine in Brazil (see Fig. 27b), the best prediction for the runout distance of a slump from the filtered tailings deposit (FTD) at the Leadville Mill is 742 feet. The slump could travel to the west and bury houses that are 71 feet below the FTD or travel to the southwest and bury mine buildings that are 87 feet below the FTD. The slump could travel to the south, after which normal rainfall will wash the spilled tailings into California Gulch. Finally, a travel of the slump to the southeast will result in mixing of the tailings with the pre-existing polishing pond of the Leadville Sanitation District, so that the mixture of tailings and water will become a fully fluidized mass that could travel for a considerable distance down California Gulch and into the Arkansas River (see Fig. 2). In addition, damage or destruction of the polishing pond would likely result in significant sewage effluent contamination of the Arkansas River for an extended period while the District facilities were restored. Streams from USGS (2024). Permit boundary traced from Fig. 19a and perimeter of filtered tailings deposit (FTD) traced from Fig. 19b. Background is Google Earth imagery from October 2, 2019.

In terms of the appropriate design precipitation event and design seismic event for the FTD, the key consideration is that the failure of the FTD will have expected fatalities. In this report, the appropriate design criteria for failures that will result in fatalities will be sought in dam safety guidelines. It is correct that the permit application (Union Milling Company, 2024) never uses the word "dam" nor the expression "structural zone" and that the diagram of the proposed FTD shows neither a dam nor a structural zone (see Fig. 14). However, the following statements are also correct:

1) A filtered tailings storage facility requires a structural zone.
2) A structural zone serves the exact same function as a dam.

The guidance document Safety First: Guidelines for Responsible Tailings Management has emphasized that companies must not be allowed to avoid compliance with dam safety guidelines simply by avoiding use of the word "dam." According to Safety First, "Operating companies may avoid using the word 'dam' in an attempt to skirt tailings dam safety requirements. However, it is important to note that these guidelines apply to any engineered structure that contains mine tailings, regardless of the terminology used by the operating company to describe the engineered structure. In particular, the guidelines in Safety First apply to: … 5. The structural zones (containment structures) of tailings disposal facilities, including the structural zones of filtered tailings facilities" (Morrill et al., 2022).

This review of the appropriate design criteria will start with the relevant federal regulatory agencies and then progress to dam safety regulations in Colorado. The Federal Emergency Management Agency classifies dams in three categories according to the hazard potential (FEMA, 2013). High Hazard Potential means "probable loss of life due to dam failure or misoperation." It is clarified that "probable loss of life" refers to "one or more expected fatalities" and that "economic loss, environmental damage or disruption of lifeline facilities may also be probable but are not necessary for this classification." Significant Hazard Potential means "no probable loss of human life but can cause economic loss, environmental damage, or disruption of lifeline facilities due to dam failure or misoperation." Low Hazard Potential means "no probable loss of human life and low economic and/or environmental losses due to dam failure or misoperation."

Each of the classifications of hazard potential corresponds to an inflow design flood (FEMA, 2013), which corresponds to a design precipitation event within the watershed of the dam. A dam with Low Hazard Potential must be designed for a 100-year precipitation event (event with a 1% exceedance probability in any given year) or "a smaller flood justified by rationale" (FEMA, 2013). A dam with Significant Hazard Potential should be designed for a 1,000-year precipitation event (event with an exceedance probability of 0.1% in any given year). However, a dam for which failure is expected to result in the loss of at least one life (High Hazard Potential) must be designed for the Probable Maximum Flood (PMF), which is defined as "the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin under study" (FEMA, 2013). The magnitude of the PMF is derived from the Probable Maximum Precipitation (PMP), which is defined as "the theoretical greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year" (FEMA, 2013). It is worth noting that, according to the U.S. Army Corps of Engineers, "the PMF does not incorporate a specific exceedance probability, but is generally thought to be well beyond the 10,000 year recurrence interval" (USACE-HCE, 2003).

In the same way, each of the hazard potentials corresponds to a design earthquake. According to the Federal Emergency Management Agency, the Maximum Credible Earthquake (MCE), is “the largest earthquake magnitude that could occur along a recognized fault or within a particular seismotectonic province or source area under the current tectonic framework” (FEMA, 2005). Furthermore, for dams with High Hazard Potential, “the MDE [Maximum Design Earthquake] usually is equated with the controlling MCE.” Just as with the design floods, “where the failure of the dam presents no hazard to life, a lesser earthquake may be justified, provided there are cost benefits and the risk of property damage is acceptable” (FEMA, 2005). Similar language is used by the U.S. Army Corps of Engineers in stating, “for critical features, the MDE is the same as the MCE” (USACE, 2016) and, just as with the PMF, has emphasized that “there is no return period for the MCE” (USACE, 2016). On the other hand, in the context of discussing criteria for determining the MCE at a particular location, FEMA (2005) states, “For high-hazard potential dams, movement of faults within the range of 35,000 to 100,000 years BP is considered recent enough to warrant an ‘active’ or ‘capable’ classification.” In other words, the MCE can be as rare as a 100,000-year earthquake, with a corresponding annual exceedance probability of 0.001%.

In terms of design precipitation events, the safety guidelines for dams designed by the U.S. Army Corps of Engineers are, in some cases, even stricter than those recommended by FEMA (2013). For all dams designed or maintained by the U.S. Army Corps of Engineers, “APF [Annual Probability of Failure] ≥ 1 in 10,000 (0.0001) Per Year. Annual probability of failure in this range is unacceptable except in extraordinary circumstances” (USACE, 2014). The U.S. Army Corps of Engineers has four categories of dam safety standards, similar to the three hazard potentials of the Federal Emergency Management Agency. The strictest “Standard 1 applies to the design of dams capable of placing human life at risk or causing a catastrophe, should they fail” (USACE, 1991). For this standard, “structural designs will be such that the dam will safely pass an IDF [Inflow Design Flood] computed from probable maximum precipitation (PMP) occurring over the watershed above the dam site.” For the third strictest Standard 3 dams, “the base safety standard will be met when a dam failure related to hydraulic capacity will result in no measurable increase in population at risk and a negligible increase in property damages over that which would have occurred if the dam had not failed” (USACE, 1991). For Standard 3 dams, “one-half of the PMF is the minimum acceptable IDF” (USACE, 1991).

To summarize the review thus far, if even a single fatality is “expected” (FEMA, 2013) or “at risk” (USACE, 1991) as a result of dam failure, then the dam should be designed so as to withstand the most extreme precipitation and seismic events that are theoretically possible at the dam location, which are the Probable Maximum Precipitation (PMP) and the Maximum Credible Earthquake (MCE). Of course, the dam safety legislation in Colorado is also relevant to a tailings storage facility in Colorado. The Office of the State Engineer Rules and Regulations for Dam Safety and Dam Construction (Code of Colorado Regulations, 2020) classifies dams into four categories, depending upon the consequences of dam failure. A High Hazard Dam is a dam “for which loss of human life is expected to result from failure of the dam. Designated recreational sites located downstream within the bounds of possible inundation should also be evaluated for potential loss of human life” (Code of Colorado Regulations, 2020). A Significant Hazard Dam is a dam “for which significant damage is expected to occur, but no loss of human life is expected from failure of the dam. Significant damage is defined as damage to structures where people generally live, work, or recreate, or public or private facilities” (Code of Colorado Regulations, 2020). A Low Hazard Dam is a dam “for which loss of human life is not expected, and significant damage to structures and public facilities … is not expected to result from failure of the dam.” Finally, a No Public Hazard (NPH) Dam is a dam “for which no loss of human life is expected, and which damage only to the dam owner's property will result from failure of the dam” (Code of Colorado Regulations, 2020).

The Colorado regulations classify dams as “large” if the height exceeds as 50 feet, as “small” if the height is between 20 feet and 50 feet, and as “minor” if the height is less than 20 feet (Code of Colorado Regulations, 2020). Thus, with a projected maximum height of 43 feet, the FTD at the Leadville Mill should be classified as a “small dam.” For large and small dams, the Colorado dam safety regulations require design for 90% of the Probable Maximum Precipitation (PMP) for a High Hazard Dam, 45% of the PMP for a Significant Hazard Dam, the 100-year precipitation event for a Low Hazard Dam, and even the 25-year precipitation event for a No Public Hazard Dam. The Colorado dam safety regulations allow alternative methods of computing the design precipitation event in the terms of the Extreme Storm Precipitation (ESP) or the Site-Specific Extreme Storm Precipitation (SSESP) (Code of Colorado Regulations, 2020). In terms of the design seismic event, the Colorado regulations state, “Dams classified as High Hazard and with a height greater than or equal to 30 feet, other than flood control structures, shall be designed for the maximum credible earthquake or for an earthquake with a minimum 5000-year return frequency [corresponding to an annual exceedance probability of 0.02%]” (Code of Colorado Regulations, 2020).

The relevance of Colorado dam safety regulations to tailings storage facilities is now considered more precisely. The Colorado dam safety regulations define a dam as “a man-made barrier, together with appurtenant structures, constructed above the natural surface of the ground for the purpose of impounding water. Flood control and storm runoff detention dams are included” (Code of Colorado Regulations, 2020). Not all states define dams in such a restrictive way. For example, as mentioned earlier, Minnesota includes man-made structures that impound wet waste as dams (Minnesota Department of Natural Resources, 2021). However, the dam safety regulations explicitly exclude tailings storage facilities by stating “Mill tailing impoundments which are permitted under the Colorado Mined Land Reclamation Act, sections 34-32-101 through 125, C.R.S. … are exempt from these Rules” (Code of Colorado Regulations, 2020). The rules for Hard Rock Metal Mining (2 CCR 407-1) include essentially no prescriptive requirements for how tailings storage facilities should be constructed and require only the submission of acceptable designs. According to Code of Colorado Regulations (2019), “If tailing ponds are part of the milling process, the mine plan description should address the following … Tailings: Describe the geochemical constituents of the tailing or leached ore, the chemistry of any leachate, anticipated impacts to ground or surface waters and design details such as liners, ponds and embankments, diversions or chemical treatment facilities to be used to control these impacts, and ground and surface water monitoring systems, to include proposed groundwater points of compliance.”

Based on the preceding discussion, Colorado dam safety regulations (Code of Colorado Regulations, 2020) are not strictly applicable to tailings storage facilities. On the other hand, nothing in the rules for Hard Rock Metal Mining (Code of Colorado Regulations, 2019) implies that any and all designs would be acceptable. Therefore, the standards for acceptable designs could be specific to particular sites or mining projects in Colorado, but should be grounded in state and national guidelines for both tailings storage facilities and water-retention dams. In summary, in light of the expected fatalities as a result of failure of the FTD, and in light of state (Code of Colorado Regulations, 2020) and federal (FEMA, 2005, 2013; USACE, 1991, 2014,

2016) dam safety regulations, the FTD at the Leadville Mill should be designed to withstand both the Probable Maximum Precipitation (PMP) and the Maximum Credible Earthquake (MCE).

A final caution is that, while the practice in the US has been to require very protective design criteria for tailings storage facilities for which failure would result in fatalities, the practice in other jurisdictions has been to prohibit the construction or the expansion of a tailings storage facility where there is a population residing downslope or downstream from the facility. The state of Minas Gerais in Brazil defines the concept of a "self-rescue zone" (which should be a chilling expression) and prohibits the construction or expansion of a tailings storage facility where there is a population residing in the self-rescue zone. According to Assembleia Legislativa de Minas Gerais [Legislative Assembly of Minas Gerais] (2019), "It is forbidden to grant an environmental license for the construction, installation, expansion or elevation of a dam for which studies of rupture scenarios identify a community in the self-rescue zone. § 1 – For the purposes of the provisions of this law, the portion of the valley downstream of the dam in which there is not enough time for intervention by the competent authority in an emergency situation is considered a self-rescue zone. § 2 – For the delimitation of the extent of the self-rescue zone, the greatest between the following two distances from the dam will be considered: I – 10 km (ten kilometers) along the course of the valley; II - the portion of the valley that can be reached by the flood wave within thirty minutes. § 3 - At the discretion of the competent body or entity of SISEMA, the distance referred to in item I of § 2 may be increased to up to 25 km (twenty-five kilometers), taking into account the density and location of the inhabited areas and the data on the region's natural and cultural heritage" (translation from Portuguese by the author).

The next year Ecuador adopted the same mandatory separation of 10 kilometers (6.2 miles) or the distance that the tailings could cover in 30 minutes, whichever is farther, but without the expression "self-rescue zone." According to Ministerio de Energía y Recursos Naturales No Renovables [Ministry of Energy and Non Renewable Natural Resources] (Ecuador) (2020), "The design and construction of tailings deposits is prohibited in cases where a populated area located downstream of the same is identified that could be affected by the flood wave, which is limited by the greater of the two distances: • Up to ten (10) kilometers downstream from the toe of the dam along the course of the valley, or; • The portion of territory that could be reached by the flood wave within 30 minutes" (translation from Spanish by the author).

Although the People's Republic of China is often assumed to be a country with weak environmental standards, it is prohibited to construct a tailings storage facility within 1000 meters (3281 feet) of a community. Department of Basics for Production Safety (China) (2020) defines "overhead tailings storage facilities" as "tailings storage facilities with residents or important facilities within 1 km from the toe of the embankment of the starter dam along the downstream tailings flow path." The Chinese regulations continue, "Starting in 2020, under the premise of ensuring the normal construction and development of mines for strategic minerals and minerals that are in short supply, the number of tailings storage facilities across the country will only decrease and not increase, and no new 'overhead tailings storage facilities' will be constructed … It is strictly forbidden to build new 'overhead tailings storage facilities'" (translation from Chinese by the author) (Department of Basics for Production Safety (China) (2020).

The point of the preceding three international examples is to suggest the possibility that, instead of requiring ultra-protective design criteria for tailings storage facilities for which failure could cause fatalities, an alternative could be to not construct new tailings storage facilities immediately upslope or upstream from communities or facilities where workers could be present. According to Safety First: Guidelines for Responsible Mine Tailings Management, "The most effective way to minimize risk to people is to prevent the construction of new tailings facilities where there is a population living or working in close proximity, downstream, or down gradient from the facility. Operating companies must not build infrastructure in which workers are likely to be present—offices, cafeterias, warehouses—in the zone of influence. The zone of influence is the 'area that would be significantly affected in case of a [tailings facility] failure and should be categorized as a risk zone.' New tailings facilities must not be constructed if the operating company cannot ensure the safe and timely assisted evacuation of any population that lives in the zone of influence" (Morrill et al., 2022). With regard to the requirements for minimum separation in Brazil, Ecuador, and China, Safety First states, "Although these geographic and temporal limits are better than no regulation, they do not necessarily ensure safe evacuation in every situation. Therefore, the minimum distance between communities and new dams must be defined on a case-by-case basis. This distance must be calculated based on the time it would take to evacuate the entire community with the support of a rescue team and the time it would take for a tailings flood to reach the community, with a safety buffer built into the calculation. The time it takes for a tailings flood to reach a community must be calculated based on a dam break study conducted for the specific tailings disposal facility." Of course, the State of Colorado does not require any minimum separation between tailings storage facilities and either communities or worker facilities. However, the fact that the proposed remining operation at the Leadville Mill would be illegal in the People's Republic of China should be sufficient motivation for pause and reflection.

There is no Plan for Safe Closure of the Filtered Tailings Deposit

The important point of this subsection is that, since the proposed filtered tailings deposit (FTD) is intended to be a permanent structure, the threat to neighboring residents, to California Gulch and the Arkansas River, and to the infrastructure of the Leadville Sanitation District will be permanent. However, there is little plan in the permit application (Union Milling Company, 2024) for the safe closure of the FTD, aside from the intention to plant grass on the FTD at the cessation of the remining operation. The lack of a plan for permanent maintenance of the FTD should stand in stark contrast to any other engineered structure, such as a dam or a highway or a bridge, that must be either maintained or demolished. For example, at the end of its useful life, or when it is no longer possible to inspect and maintain a dam, a water-retention dam is completely dismantled. A water-retention dam cannot simply be abandoned or it will eventually fail at an unpredictable time with consequences that are difficult to predict.

The need for perpetual maintenance of a tailings dam, as well as the realism of such a prospect, was discussed in the guidance document Safety First: Guidelines for Responsible Mine Tailings Management. According to Morrill et al. (2022), "It is imperative that the reclamation and closure of tailings facilities be a factor in their initial design and siting … A tailings facility is safely closed when deposition of tailings has ceased and all closure activities have been completed so that the facility requires only routine monitoring, inspection and maintenance in perpetuity or until there are no credible failure modes … Currently, there is no technology to ensure that an active tailings facility can be closed in such a way so as to withstand the PMF [Probable Maximum Flood] or MCE [Maximum Credible Earthquake] indefinitely without perpetual monitoring, inspection, and maintenance ... Given that operating companies will not exist long enough to accomplish perpetual monitoring, inspection, maintenance, and review, the operating company's ability to eventually eliminate all credible failure modes must be a key consideration during the permitting process. If a regulatory agency does not believe an operating company can carry out perpetual care and financial responsibility, or eliminate all credible failure modes, they must not approve the facility."

The phrase "credible failure mode" requires explanation. According to the Global Industry Standard on Tailings Management (GISTM), "The term 'credible failure mode' is not associated with a probability of this event occurring" (ICMM-UNEP-PRI, 2020). Thus, a credible failure mode is "a physically possible sequence of events that could potentially end in tailings dam failure" (Morrill et al., 2022), no matter how unlikely. There are not many ways to eliminate all physically possible failure modes from an aboveground facility, such as the proposed FTD, aside from moving the tailings to a belowground location, such as an exhausted open pit.

By way of connecting the concepts of safe closure and design criteria, the GISTM requires that closed tailings facilities be designed to withstand the 10,000-year precipitation event and the 10,000-year seismic event (events with an annual exceedance probability of 0.01%), regardless of the design criteria for the period of operation of the facility. The logic is that, while the socioeconomic and environmental consequences might be low during operation of the facility, the socioeconomic and environmental context of a tailings storage facility could change during the indefinite period of closure. Thus, even a tailings facility with Low consequences of failure during the operational phase, for which the design criteria are only 200-year events (events with an annual exceedance probability of 0.5%) must be able to withstand a 10,000-year event after closure of the facility (ICMM-UNEP-PRI, 2020). For reference, Low consequences means "Minimal short-term loss or deterioration of habitat or rare and endangered species. Minimal effects and disruption of business and livelihoods. No measurable effect on human health. No disruption of heritage, recreation, community or cultural assets" (ICMM-UNEP-PRI, 2020). As has already been mentioned, the permit application by Union Milling Company (2024) lacks any discussion of a design precipitation event or design seismic event neither during the operational phase nor during the closure phase.

In summary, the permit application by Union Milling Company (2024) is lacking in the following ways:

1) There is no recognition that a closed tailings facility requires monitoring, inspection, maintenance and review in perpetuity or until there are no credible failure modes.
2) There is no plan for perpetual monitoring, inspection, maintenance and review.
3) There is no plan for the elimination of all credible failure modes.
4) There is no recognition that the filtered tailings deposit even has credible failure modes.

From another perspective, the concept that a company would carry out a remining operation for a maximum of four years, followed by an eternity of maintenance of the tailings storage facility, is simply absurd. This perspective underscores the absurdity of the entire proposal for a remining operation at the Leadville Mill site and does not need to be pursued any further.

The Water Consumption Rate has been Underestimated

Union Milling Company (2024) states the water consumption rate as either 27 gallons per minute or as 0.33 tons of water per ton of mine waste. The rate of production of tailings is stated as either 20 tons per hour or as 26.67 tons per hour. Based on a rate of production of tailings of 20 tons per hour at a process water content of 25% (equivalent to production of 15 tons of dry tailings per hour), the water consumption rate would be 62 gallons per minute. Based on a rate of production of tailings of 26.67 tons per hour at a process water content of 25% (equivalent to production of 20 tons of dry tailings per hour), the water consumption rate would be 82 gallons per minute. The average rate of water consumption of 45 gallons per minute for a gold remining operation that was estimated in the subsection "Water Use and Water Consumption in Remining" is near the middle of the above estimates. By contrast, the "Fiction vs. Fact" tab of CKJ Milling (2024d) states, "The current plan calls for 20 gallons per minute (gpm)."

The factor that underlies all of the estimates of water consumption by Union Milling Company (2024) is the assumption that the only loss of water would be the water that is permanently entrained within the filtered tailings. According to Union Milling Company (2024), "The water balance shows a deficit of 27gpm (Stream B), which is made up from the Fresh Water tanks … The process plant-wide water balance, shown in Figure 4-2, operates at a 27gpm (0.06cfs) deficit. The deficit is solely due to water lost in the filtered tailings." In other words, the assumption is that no water will be lost by evaporation during any phase of the remining operation. In particular, there is no accounting for the water that will be sprayed for dust control, which is certainly lost to evaporation.

By contrast with the above assumption, there is considerable discussion throughout the permit application of the water that will be sprayed for dust control. According to Union Milling Company (2024), "Water will be used for dust suppression on the haul road. Consumption is weather dependent and it is anticipated will vary from approximately 0 to 500 gallons per day (gpd) … The MDM [Mine Dump Material] Bunker is a 3-compartment concrete structure with a total capacity of 200-tons. Water sprays will be available and will operate as required to control dust … Water is added at this step [the grinding circuit]. From this point the process facility treats wet material and no longer requires dust control measures … Where required during extended dry periods, organic surfactants, water, or other methods may be applied on higher-traffic access corridors or roadways within the FTD as deemed necessary by the operator or as mandated based on air-quality monitoring or operational needs to reduce dust generation." The website of CJK Milling continues the same theme of emphasizing the water that will be sprayed for dust control. Under the "Fiction vs. Facts" tab, CJK Milling (2024d) states, "Nevertheless, the material surface will often be dry and dust control measures as required will be implemented. Roads will also become dusty. Roads will be sprayed with dust surfactants and water … Material will be sprayed with water prior to loading in the crusher bin … Water sprays as well as contemporaneous reclamation of the FTD will control dust from the tailings."

As a lower bound on the water loss by evaporation, the water loss for dust control on the haul road alone was considered in this report. According to Union Milling Company (2024), "The haul road is approximately 4,500ft in length, and 25ft wide." The rate of water spraying for dust suppression on mine roads is difficult to predict in advance of a mining project and depends upon many factors, such as climate, road composition (especially silt content), vehicular and traffic characteristics, and the desired degree of dust suppression. For mine roads in South Africa (a semi-arid climate similar to Colorado), Thompson and Visser (2007) found water spray rates in the range of 0.3 to 0.5 liters per square meter with application frequencies ranging from 30 minutes to three hours, corresponding to a range of 2.4 to 24 liters per square meter per day. For field experiments in Chile, González et al. (2019) found a similar range of 5.55 to 8.83 liters per square meter per day. Applying the range of water application rates found by Thompson and

Visser (2007) to the area of the proposed haul road at the Leadville Mill yields a water consumption rate for dust suppression on the haul road alone in the range of 4.6 to 46 gallons per minute. Thus, for the upper end of the range, the water consumption rate for dust suppression on the haul road alone could be nearly twice the water consumption rate of 27 gallons per minute that was based only on the water that would be entrained within the tailings. The assumption by Union Milling Company (2024) that dust control on the haul road would consume 0 to 500 gallons of water per day (0 to 0.35 gallons per minute) was never justified and is very low in comparison to other mining projects in similar climates, unless the company is planning for a very low degree of dust control. In summary, it should be assumed that the rate of water consumption by the proposed remining operation at the Leadville Mill has been greatly underestimated.

According to the permit application, the source of water for the remining operation has not yet been determined. Union Milling Company (2024) states, "3 sourcing options for water supply are under consideration: • On-site water well; • Leadville Sanitation; • Parkville Water District, industrial user purchase. The selected water source will be provided prior to commencement of plant operation." The application does not include any information about the option of an on-site water well, such as the location of the well, the depth or screen interval of the well, the aquifer from which groundwater would be extracted, or the impacts of pumping on the neighboring domestic wells (see Fig. 2). The sense in which water might be provided by the Leadville Sanitation District is also not clear, in terms of whether this would be partially or fully treated wastewater or some other form of water.

The permit application by Union Milling Company (2024) includes a letter from the General Manager of the Parkville District dated January 14, 2021, stating the following: "Parkville Water District does intend to provide water to the CJK Milling Company LLC, for the operation of its mill West of Leadville Colorado. Parkville Water District will provide an estimated 35,000 gallons per day for continued operation of this mill. This commitment to provide water service will extend to January 14, 2023, at which time it will be subject to renewal at the discretion of the Parkville Board of Directors and Management." However, 35,000 gallons per day is only 24 gallons per minute, so that the offer by the Parkville District would not meet the minimum need by the Leadville Mill of 27 gallons per minute, which was based solely upon the water that would be entrained by the tailings (Union Milling Company, 2024) with no consideration of water loss by evaporation or dust control. The point of including a letter with an offer that had already expired (January 14, 2023) at the time of submission of the permit application (February 2, 2024) totally escapes the author of this report.

Although the permit application by Union Milling Company (2024) website states that a water source has not yet been determined, the website of CJK Milling states repeatedly that it is definite that all water will come from the Parkville Water District and that there will be no extraction of groundwater. For example, according to CJK Milling (2024f), "All water used at the mill will be obtained through Parkville Water District, and no water will be obtained from the aquifer used by residents. In addition, no aquifers, including the one used by residents, will be impacted from operations." The "Fiction vs. Fact" tab of the website states "FICTION: Mill water consumption could limit Parkville Water District serving new customers," followed by "FACT: The general manager of the Parkville Water District has confirmed the water district has more than an adequate supply of water and production capacity to provide the water needed for milling operations. The water supplied to the mill will not have any negative impact on their current or future water customers, or impact future development in any way" (CJK Milling, 2024d). The "Fiction vs. Fact" tab continues, "CJK prefers to access water from Parkville, as it is our understanding that Parkville welcomes us as a user, this water is available, and that an industrial client will result in an economic benefit to Parkville and the community" (CJK Milling, 2024d). The website of CJK Milling does not add the information, which is available in the permit application by Union Milling Company (2024), that the Parkville District has offered less than the minimum (and unrealistic) amount of water that would be required by the remining operation and that the offer by the Parkville Water District had expired over a year prior to submission of the application.

The Monitoring Wells are in the Wrong Locations

The permit application by Union Milling Company (2024) is nearly devoid of any information on the local and regional hydrogeology, including the locations and depths of aquifers and confining layers, the groundwater flow directions, and the likely groundwater pathways for contaminants from the remining operation. The application states that monitoring well LM-MW-2 (see Figs. 20-22) is 53 feet deep and penetrates only "glacial fill" (Union Milling Company, 2024). Groundwater was encountered at 45 feet below the surface, after which the water rose to 44 feet below the surface. Monitoring well LM-MW-3 is 73 feet deep and also penetrates only "glacial fill." Groundwater was encountered at 60 feet below the surface, after which the water rose to 57 feet beneath the surface. The well depths are also stated as 56 feet and 71 feet for monitoring wells LM-MW-2 and LM-MW-3, respectively (see Fig. 20). Since the hydraulic heads are slightly higher than the elevation of groundwater entry into the wells, the glacial fill should be regarded as a semi-leaky (slightly confined) aquifer.

There is no information about any other monitoring wells, except for the depths and the static water levels (see Fig. 20). Although Fig. 20 refers to the "Water Table Elevation" for each monitoring well, that expression probably refers to the hydraulic head (the elevation of the water within the well) and not the actual water table (compare with Fig. 10). In particular, there is no information about which aquifers are penetrated by each monitoring well. Monitoring wells BMW-1 and PZ-4 (BMW-1A) are at nearly identical locations (see Fig. 21 and Table 2), although the hydraulic head at the screen (intake interval) of BMW-1 is 82 feet higher than the hydraulic head of the screen of PZ-4, indicating that the two wells are receiving groundwater from different aquifers. Since BMW-1 is much deeper than PZ-4, groundwater is flowing upwards at this location (compare with Fig. 11). In the same way, monitoring wells MW13 and MW13A are at nearly identical locations (see Fig. 21 and Table 2). Since MW13 is deeper and shows a lower hydraulic head (see Fig. 20), groundwater is flowing downwards at this location (compare with Fig. 11).

In their "Groundwater and Surface Water Specific Adequacy Review" on April 11, 2024, Colorado DRMS (2024b) also drew attention to the dearth of hydrogeological information in the permit application. According to Colorado DRMS (2024b), "After reviewing the materials submitted, the Division has identified the following adequacy item(s) specifically related to groundwater and surface water that must be addressed to the Division's satisfaction:

1. Pursuant to Rules 6.4.21(8)(b) and Rule 6.4.7(2)(b) please identify all known aquifers and related subsurface water-bearing fracture systems within two (2) miles of the affected lands. Description of the aquifer shall include characteristics such as transmissivity, saturated thickness, stratigraphic units and other hydrologic characteristics.

2. Per Rule 6.4.21(8)(c) please describe all geologic media down to and including the uppermost aquifer under the proposed permit boundary. Description should be detailed enough to identify any impermeable layers in alluvium.
3. Per Rule 6.2.21(8)(d) please identify and locate on a map all known major fracture systems that affect rock formations under the permit boundary that have the potential to be impacted by proposed processes at the site.
4. Per Rule 6.4.21(8)(e) please provide an in-depth description and illustration of the groundwater hydrology within a two mile radius of the permit. The description and illustration should include at a minimum a hydrologic model (e.g. ModFlow) that clearly shows how groundwater flows through and around the proposed permit boundary and a prediction of where contamination would go should there be loss of containment at the site. Additionally, it should include maps and cross sections that depict geologic strata and fracture systems. The model shall be able to demonstrate the proposed point-of-compliance well, LW-MW-3, is suitable and meets all the requirements under Rule 3.1.7(6).
5. Please provide a discussion of how groundwater and surface water moving downgradient of the site will interact and potentially affect California Gulch which is approximately 600 feet from the permit boundary and Outfall #1.
6. In Section 21.9.1 the Applicant states there are 510 domestic wells within a 2-mile radius and 11 wells are within 0.5 miles of the Mill. For all domestic groundwater wells downgradient of the site please provide a summary of construction information identifying which aquifer each well is utilizing. Please highlight the wells which are screened in the same first aquifer found immediately under the proposed permit boundary.
7. Pursuant to Rule 6.4.21(9)(a) please clearly state what are the existing and reasonably potential future groundwater uses on and within two (2) miles down-gradient of the affected lands."

With regard to the fourth requirement above, the possibility that monitoring well LW-MW-2 is actually intended to be the point of compliance is discussed below.

The only hydrogeological information in the permit application is a map that shows groundwater flowing to the southwest in the vicinity of the Leadville Mill (see Fig. 29). The permit application does not provide any justification for the assumed flow to the southwest, nor does the application state the depths or aquifers in which the assumed flow is occurring or recognize the possibility that groundwater might be flowing in different directions in different aquifers or that the groundwater might be dominated by vertical flow at some locations. The map includes a light red shaded area that "denotes potentially contaminated groundwater as reported by the Colorado Department of Water Resources" (Union Milling Company, 2024). The permit application does not provide any information regarding the potential plume of contaminated groundwater or any source for the information from the Colorado Department of Water Resources. Union Milling Company (2024) also does not provide any information regarding how it could distinguish between the flow of an existing plume of contamination and any future contamination from the proposed remining operation. The same concern was expressed in the "Groundwater and Surface Water Specific Adequacy Review" by Colorado DRMS (2024b). The preceding list continues:

8. "Please provide additional information regarding the light red shaded background in Figure 21-1 [Fig. 29 in this report] indicating potentially contaminated groundwater and

how it impacts groundwater quality results at the site and down gradient from the site. Additionally, how does this impacted groundwater affect the Applicant's ability to detect, or not, if there is a release of toxic material or designated chemicals at the site."

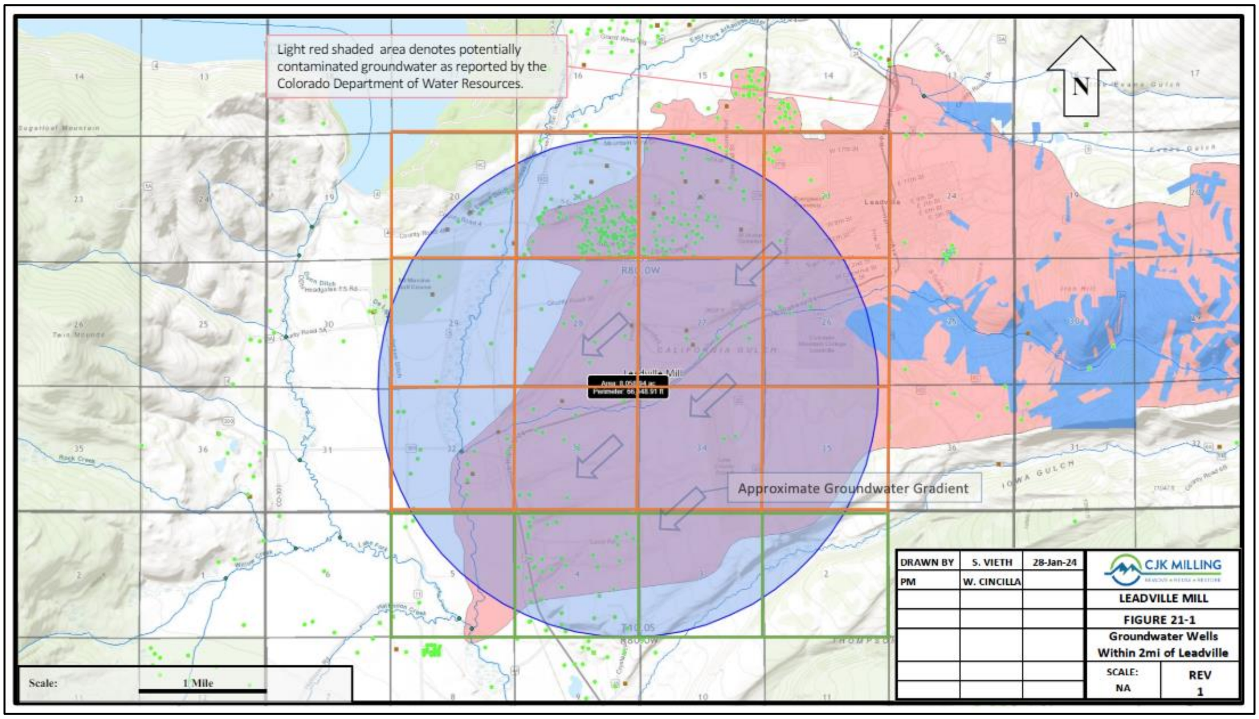


Figure 29. Union Milling Company (2024) claims that groundwater is flowing to the southwest in the vicinity of the Leadville Mill, but without providing any evidence. The possibility that the groundwater flow direction might be different in different aquifers was not considered. In addition, no evidence was provided for the existence of a plume of contaminated groundwater flowing to the southwest. Union Milling Company (2024) provided no information as to how it could distinguish between the flow of the existing plume of contamination and any future contamination from the proposed remining operation. See Fig. 30 for other possible directions for groundwater flow that would be consistent with the existing information. Figure from Union Milling Company (2024).

The connection that was not made by Colorado DRMS (2024b) was the concept that the locations of monitoring wells cannot be chosen without a minimal knowledge of the local and regional hydrogeology. In particular, the permit application classifies monitoring wells BMW-1 and PZ-4 (BMW-1A) as upgradient from the Leadville Mill and monitoring wells MW13 and MW13A as downgradient from the Leadville Mill (see Figs. 20-21 and 30). Monitoring well MA1TMW-4 is upgradient from the filtered tailings deposit (FTD), LM-MW-3 is downgradient from the FTD and upgradient from the emergency containment sump (ECS), while LM-MW-2 is downgradient from the ECS (see Figs. 20-22 and 30). According to Union Milling Company (2024), "LM-MW-3 is down-gradient of all process facilities and infrastructure making it the point of compliance [the location where groundwater standards should be met]. Although Union Milling Company (2024) explicitly states that monitoring well LM-MW-3 is the point of compliance, the description of the point of compliance as "down-gradient of all process facilities and infrastructure" (Union Milling Company, 2024) actually applies to monitoring well LM-MW-2 (see Figs. 20-22). In the absence of further information, it will be assumed throughout the rest of this report that the permit application intended for LM-MW-2 to be the point of compliance. The description of the locations of the monitoring wells in Fig. 20 and the designation of LM-MW-2 as the point of compliance would be generally consistent with the assumed groundwater flow to the southwest that is shown in Fig. 29, although the location of monitoring well LM-MW-2 outside of the permit boundary (see Figs. 21-22) is a matter of concern.

As opposed to the uniform groundwater flow to the southwest for all aquifers, as is shown in Fig. 29, the local flow in the uppermost aquifer tends to flow toward the closest stream (see Fig. 9). Thus, the shallow groundwater at the locations of monitoring wells BMW-1 and PZ-4 (BMW-1A) could be flowing to the south, directly toward California Gulch (see Fig. 30). In that case, monitoring wells BMW-1 and PZ-4 (BMW-1A) would not at all be upgradient of the Leadville Mill, but out of the groundwater capture area of the Leadville Mill. By the same logic, the shallow groundwater at the locations of monitoring wells MA1TMW-4, MW13 and MW13A could be flowing to the northwest toward either California Gulch or one of its tributaries (see Figs. 2 and 30), that is, perpendicular to the groundwater flow direction assumed in the permit application (see Fig. 29). In that case, MA1TMW-4 would not be upgradient from the FTD, while MW13 and MW13A would not be downgradient from the Leadville Mill (see Fig. 30). Finally, the groundwater at the location of monitoring well LM-MW-3 could be flowing south, directly toward California Gulch (see Figs. 30-31). In that case, LM-MW-2 would not be the appropriate point of compliance and an alternative point of compliance could be directly to the south of LM-MW-3, while still within the permit boundary (see Fig. 31).

The point of the preceding paragraph is not to argue that the groundwater flow directions shown in Fig. 30 are correct, while the uniform groundwater flow toward the southwest shown in Fig. 29 is incorrect. In fact, the groundwater flow shown in Fig. 30 might be correct for the shallow aquifer, while the groundwater flow shown in Fig. 29 might be correct for the deeper aquifers. The important point is that, based upon the available hydrogeological information, the groundwater flow directions are simply unknown. If the groundwater flow directions are unknown, then it cannot be determined whether the existing monitoring wells are upgradient or downgradient from the FTD or the ECS or the entire mill site, or simply out of the groundwater capture area of the mill site or out of the groundwater region that would have the mill site as a source of groundwater. In summary, the collection, compilation, and interpretation of hydrogeological data must precede the selection of locations and depths of monitoring wells, which, of course, must precede the collection of baseline groundwater data.

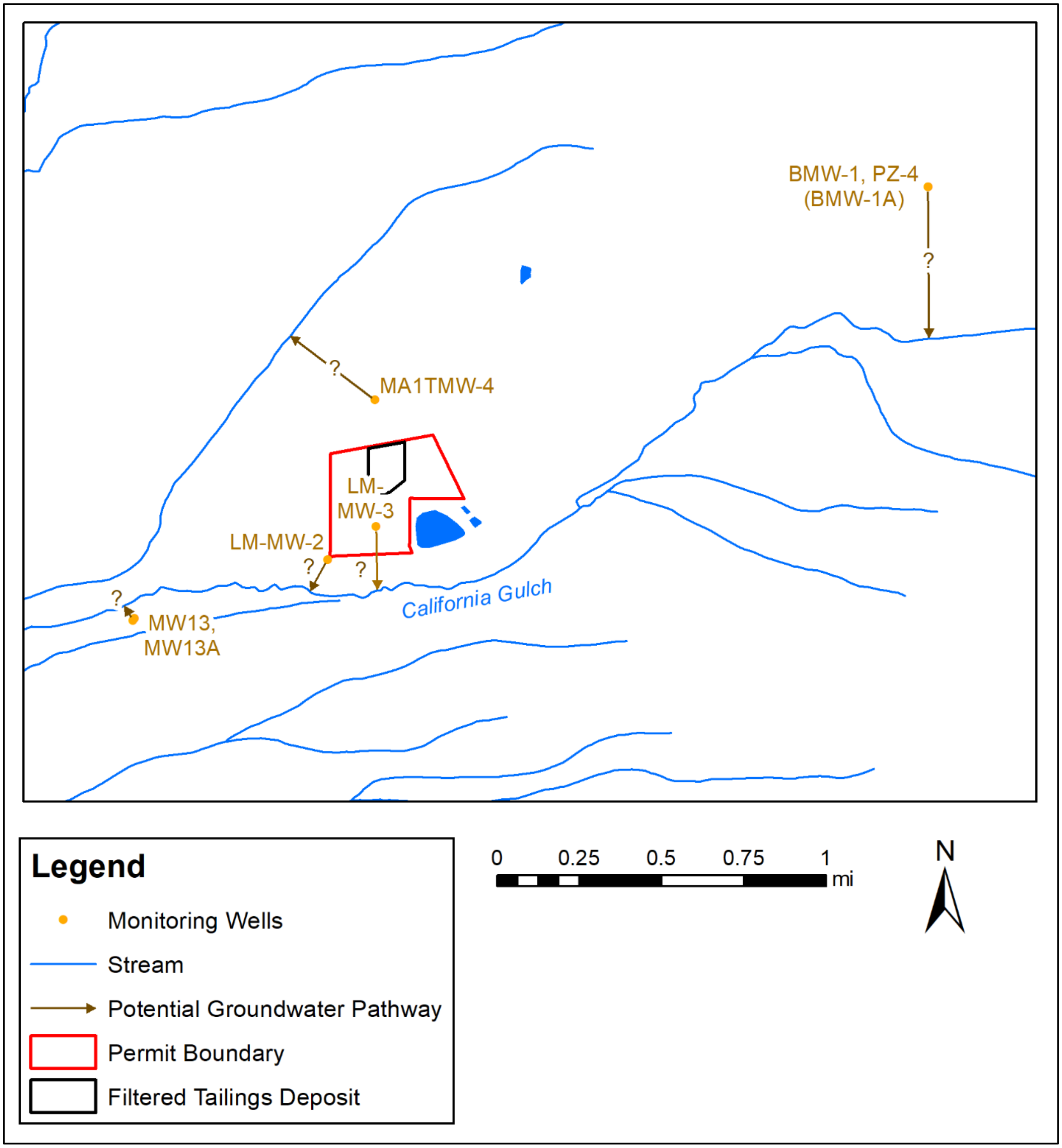


Figure 30. Without further information, it could be assumed that groundwater is flowing toward the nearest stream, especially for the local flow in shallow or unconfined aquifers (compare with Figs. 9 and 13). Thus, the actual groundwater flow directions could be very different from the flow direction to the southwest that was assumed by Union Milling Company (2024) (see Fig. 29). On that basis, the assumed classifications of the monitoring wells as "Up Gradient" or "Down Gradient" either in a regional sense or with respect to the FTD (Filtered Tailings Deposit) or ECS (Emergency Containment Sump) (see Fig. 20) could be completely irrelevant. The map indicates the need for a monitoring network that is sufficiently dense to delineate the groundwater flow directions and with due attention to the aquifers that are being monitored. Monitoring well locations from map in Union Milling Company (2024) (see Fig. 21). Streams from USGS (2024). Permit boundary traced from Fig. 19a and perimeter of filtered tailings deposit (FTD) traced from Fig. 19b.

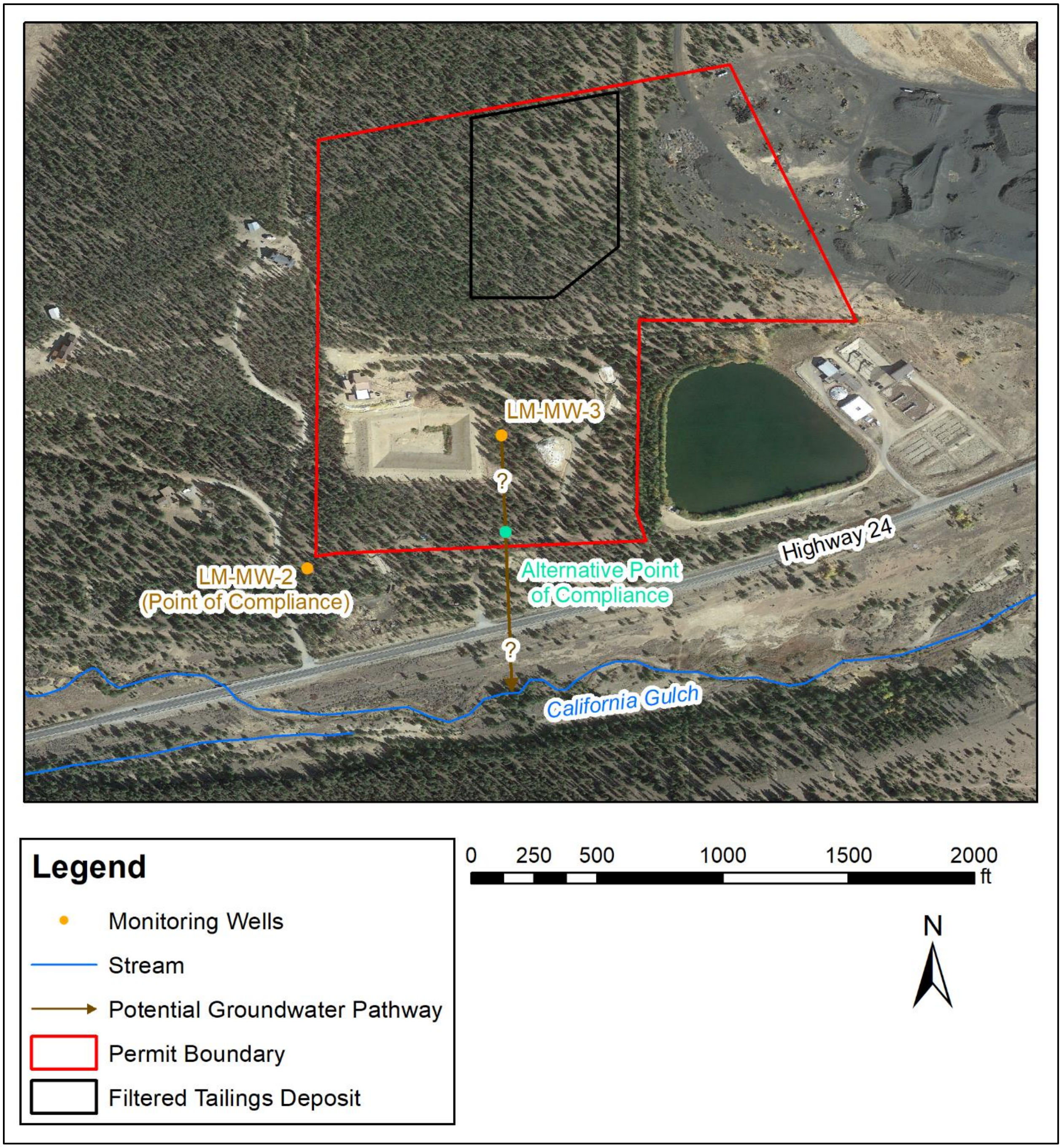


Figure 31. Since the groundwater flow could be to the south in the vicinity of the Leadville Map (see Fig. 30), an alternative point of compliance could be in the south-central portion of the permit boundary, as opposed to the current point of compliance (LM-MW-2) that is proposed by Union Milling Company (2024). It is assumed that the point of compliance ought to be within the permit boundary. Based on the current lack of knowledge of the hydrogeology, the appropriate depth and aquifer for the alternative point of compliance cannot be stated. The confusion regarding the appropriate point of compliance indicates the need for a monitoring network that is sufficiently dense to delineate the groundwater flow directions and with due attention to the aquifers that are being monitored. Monitoring well locations from map in Union Milling Company (2024) (see Fig. 21). Streams from USGS (2024). Permit boundary traced from Fig. 19a and perimeter of filtered tailings deposit (FTD) traced from Fig. 19b.

Additional evidence that the current network of monitoring wells is inadequate is the large number of failed attempts at obtaining groundwater samples from the wells. According to the permit application (Union Milling Company, 2024), attempts were made to collect groundwater samples on five occasions (December 29, 2022, January 16, 2023, June 8, 2023, September 29, 2023, December 27, 2023). Monitoring well LM-MW-2 was dry on the last four occasions, while monitoring well LM-MW-3 was dry on the last three occasions, so that no samples were collected (see Figs. 20-22). No samples were collected from monitoring well MA1TMW-4 (see Figs. 20-21) on the first four occasions with no explanation, so that it is not clear whether the well was dry or there was some other reason as to why samples were not collected. Of course, dry wells are worthless for groundwater monitoring. At a minimum, it appears as if the monitoring wells ought to be deeper even if the locations are appropriate. It should be recalled that Union Milling Company (2024) has denoted monitoring well LM-MW-2 as the "point of compliance" and that a persistently dry point of compliance will not accomplish any useful purpose. The confusion as to whether monitoring well LM-MW-2 or monitoring well LM-MW-3 is the intended point of compliance has already been discussed. That discrepancy does not matter here because both LM-MW-2 and LM-MW-3 were persistently dry during the period of collection of baseline data. A final note is that, while Union Milling Company (2024) states that groundwater samples have been collected quarterly, the first two sampling dates were only 18 days apart. Other issues regarding the current groundwater monitoring data will be discussed in the subsection "The Baseline Data are Invalid."

The Stormwater Management Infrastructure has been Underdesigned

As was discussed in the section "Summary of Proposal for Remining at Leadville Mill," the stormwater management plan is quite difficult to understand for the following reasons:

1) The permit application has multiple versions of the permit boundary and the perimeter of the filtered tailings deposit (FTD) (compare Figs. 17a-b, 19a-b and 23). For example, some components of the stormwater management plan are based on one version of the FTD perimeter, while other components are based upon a different version of the FTD perimeter (compare Figs. 17a and 17b).
2) While the permit boundary covers 42.93 acres and the affected land covers 42.60 acres, less than 20 acres is accounted for in the stormwater management plan (see Fig. 18).

In the absence of any ability to comment on the details of the stormwater management plan, this subsection will focus on the design criteria for the stormwater infrastructure, which is the 100-year precipitation event.

The permit application describes the 24-hour storm with a return period of 100 years (corresponding to an annual exceedance probability of 1%) as "worst-case conditions" (Union Milling Company, 2024). It should be clear from the subsection entitled "The Failure of the Filtered Tailings Deposit could Cause Fatalities" that the 100-year precipitation event is a long way from the worst-case scenario. The true worst-case scenario would be the Probable Maximum Precipitation (PMP), which has no defined return period, but which is significantly rarer than even a 10,000-year precipitation event (USACE-HEC, 2003). Although the rainfall from a 24-hour storm with a return period of 100 years is 2.48 inches at the Leadville weather station (Union Milling Company, 2024), the PMP for a 24-hour storm at the same location is in the range 6 to 8 inches (Applied Weather Associates, 2018).

As has been previously discussed, the design criteria should not be arbitrary, but should be based upon the consequences of failure. As with the filtered tailings deposit (FTD), the permit application does not include any discussion of the consequences of failure of the stormwater infrastructure. An obvious consequence is that the diversion channels that should convey stormwater around the FTD (see Figs. 17a-b) could overflow, thus spilling water onto the base of the FTD and potentially causing instability and failure of the FTD. Another obvious consequence is that an uncontrolled overflow from the stormwater infrastructure could spill water from the remining operation into California Gulch and the Arkansas River. Thus, a rational discussion of the appropriate design criteria must await an analysis of the consequences of failure.

Even if it were determined that design for the 100-year precipitation event was appropriate, the design for the 100-year storm (2.48 inches of rainfall in 24 hours) (Union Milling Company, 2024) is based only upon historical data and does not take climate change into account. At the present time, it is standard practice in the mining industry to take climate change into account for any hydrologic analysis, especially in relation to tailings management. According to the SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook, "When developing hydrotechnical designs, large-scale climate oscillations and climate change, which modify climate and hydrologic results, must be included … In the past, meteorologists and hydrologists assumed historical information was an accurate proxy to define future conditions. However, the increase in greenhouse gases (GHGs) in the latter part of the 20th century shaped worldwide meteorological and hydrologic changes in magnitude and frequency in ways beyond that seen in historical records, so stationarity assumptions are no longer valid … Climate change needs to be included as an uncertainty with respect to tailings management" (Muñoz and Hoekstra, 2022). According to Safety First: Guidelines for Responsible Mine Tailings Management, "All modeling and design for floods must take climate change into account — this applies for both closed and operating facilities … Maximum credible event calculations, such as the PMF [Probable Maximum Flood], cannot rely solely on historical data and must consider changes produced by climate change" (Morrill et al., 2022).

The Global Industry Standard on Tailings Management (GISTM) is the most explicit in describing how climate change ought to be taken into account. According to the GISTM, "Develop and document knowledge about the social, environmental and local economic context of the tailings facility, using approaches aligned with international best practices … This knowledge should capture uncertainties due to climate change … To enhance resilience to climate change, evaluate, regularly update and use climate change knowledge throughout the tailings facility lifecycle in accordance with the principles of Adaptive Management … For new tailings facilities, use the knowledge base, including uncertainties due to climate change, to assess the social, environmental and local economic impacts of the tailings facility and its potential failure throughout its lifecycle … If new data indicates that the impacts from the tailings facility have changed materially, including as a result of climate change knowledge or long-term impacts, the Operator shall update tailings facility management to reflect the new data using Adaptive Management best practices … Develop, implement and maintain a water balance model and associated water management plans for the tailings facility, taking into account the knowledge base including climate change, upstream and downstream hydrological and hydrogeological basins, the mine site, mine planning and overall operations and the integrity of the tailings facility throughout its lifecycle" (ICMM-UNEP-PRI, 2020).

It could be argued that climate will probably not change significantly over the anticipated 3.5 to 4 years of the remining operation. However, the important point is that the filtered tailings deposit (FTD) will be permanent, as was discussed in the subsection "There is no Plan for Safe Closure of the Filtered Tailings Deposit." Thus, the threat of an uncontrolled overflow of the stormwater diversion channels (see Figs. 17a-b) onto the FTD will be permanent. There is a conceivable future in which, due to climate change, the stormwater diversion channels will be significantly underdesigned. It must also be pointed out that there is no plan for long-term maintenance of the FTD, which should include such obvious tasks as cleaning the stormwater diversion channels.

The Potential for Acid Mine Drainage and Metal Leaching has been Underestimated

The permit application reports on the analysis of a single sample of tailings from the Leadville Mill and concludes that the tailings will be non-acid generating and non-metal leaching. According to Union Milling Company (2024), "Following an assessment of the initial Acid/Base Accounting (Neutralization Potential) test results, additional sulfur speciation testing was carried out to determine the percentage of pyritic sulfur present in the waste samples. According to accepted protocol, if the percentage of pyritic sulfur is less than 0.3% and the paste pH of process tailings is above 5.5, a final determination of non-acid-generation classification is validated, and therefore the need to conduct any further acid-generation testing using humidity cells is eliminated. Based on these results, the anticipated waste can be classified definitively as Non-Acid Generating (NAG) … The results indicate that the tailings generated via the current Leadville process meet all criteria as non-hazardous wastes under RCRA [Resource Conservation and Recovery Act], meet all acceptance criteria by Lake County, and pose minimal risk to the physical environment and local groundwater when applying best available management practices in concert with accepted industrial standards for sampling and performance monitoring."

The preceding conclusion is surprising because the website of CJK Milling repeatedly emphasizes that the motivation for the "reclamation project" (which is actually a remining operation) is that the existing mine waste piles are potentially acid-generating (PAG) and are actively leaching contaminants into the Arkansas River, as was discussed in the subsection "Acid Mine Drainage." The explanation by Union Milling Company (2024) for the apparent discrepancy is that the addition of ferrous sulfate, which causes the precipitation of an iron-cyanide sludge, also removes any constituents from the tailings that could cause acid generation or metal leaching. According to Union Milling Company (2024), "The stabilization of metals evidenced by the testing results occurs in part because of the specific cyanide detoxification process planned for application at the Leadville Mill. During detoxification using ferrous sulfate, residual metals are complexed to form insoluble compounds in a similar fashion that might be expected for materials undergoing chemical stabilization, which is sometimes applied to certain hazardous materials to affect non-hazardous re-classification." Any evidence that toxic materials are transferred from the tailings to the iron-cyanide sludge simply reinforces the need for a plan for safe disposal of the iron-cyanide sludge and the danger of adding the iron-cyanide sludge to the filtered tailings deposit (FTD).

The primary purpose of this subsection is to consider the adequacy of a single tailings sample, especially in light of the multiple, and probably highly heterogeneous, mine waste piles that will be the source material for cyanide extraction at the Leadville Mill. Nearly all guidance documents on acid mine drainage emphasize the importance of adequate sampling, not only of the mine source material as a whole, but of each mineralogy within the mine source material.

According to Maest et al. (2005), “The extent of sampling of mined materials is often inadequate for representing the range of potential environmental impacts at a mine site, especially for mines with variable geology and mineralogy … The principal reason that current methods rarely, if ever, provide a reliable result is the failure to test a representative number of samples in each geologic rock unit in the proposed mine … Samples must be representative of all geologic, lithologic, and alteration types and of the relative amounts and particle size of each type of material; the compositional range within mineral assemblages or rock types must be known.” According to the Global Acid Rock Drainage Guide, “Samples should represent each geological material that will be mined or exposed and each waste type. The number of samples should be based on the project phase but ultimately must be sufficient to adequately represent the variability within each geological unit and waste type … Individual samples selected for testing should be representative of a single material type (e.g., lithology, alteration type) … Sample selection should include all major material types and cover the range of pertinent characteristics for each material type (e.g., pH, carbonate, sulphur, and neutralizing potential content)” (INAP, 2014).

Maest et al. (2005) followed Price and Errington (1994) in recommending a minimum number of three, eight, and 26 samples for each material type for masses of material types less than 10,000 metric tons, less than 100,000 metric tons, and less than 1,000,000 metric tons, respectively. According to Maest et al. (2005), “The minimum number of samples suggested [by Price and Errington (1994)] should be applied to each different type of mineralogy (for example, addressing the range of hydrothermal and supergene alteration for each lithology), rather than to each rock type.” Thus, the adequate characterization of the potential for acid generation and metal leaching from 533,000 tons of source material (484,000 metric tons) should require a minimum of 26 samples even if the source material were homogeneous. On the other hand, if the source material consists of, say, 50 distinct types of material with on the order of 10,000 tons of each type of material, then a minimum of 150 samples would be required. It should be clear that any determination of the minimum number of samples and any sampling strategy must begin with a complete geochemical characterization of the multiple mine waste piles that would be the source material for the Leadville Mill.

The same guidance documents on acid mine drainage also draw an analogy between the number of samples required for assessment of the potential for acid generation and metal leaching in mine source material and the number of samples required for the assessment of the grade of a commodity of value in mine source material. According to Maest et al. (2005), “The extent of geologic and mineralogic sampling should be commensurate with the extent of sampling for ore characterization.” According to the Global Acid Rock Drainage Guide, “A classification suitable for mineral extraction may not be sufficient to identify the environmental characteristics and corresponding ore and waste management requirements of the various material types” (INAP, 2014). The permit application by Union Milling Company (2024) does not state the grade of gold and silver that is anticipated in the multiple mine waste piles, but it should be assumed that the grade was not determined from a single sample.

The Baseline Data are Invalid

CKJ Milling (2024f) states, “Ground and surface water quality will be extensively monitored.” However, to date, there has been no baseline study of surface water quality in California Gulch, the Arkansas River, or any of their tributaries. The permit application by

Union Milling Company (2024) does not even include any discussion of possible sites for surface water monitoring. The same deficiency was noted in the "Groundwater and Surface Water Specific Adequacy Review" by Colorado DRMS (2024b). According to Colorado DRMS (2024b), "The Applicant did not submit any surface water data for locations that may be affected by operations at the site. Upon acceptance of the SAP [Sampling and Analysis Plan] requested in Item 9 of this review, and pursuant to Rule 6.4.21(11)(b) the Applicant needs to submit surface water quality and flow data collected during a minimum of five (5) successive calendar quarters and such other additional data as may be necessary to adequately characterize baseline conditions."

The following deficiencies in the groundwater baseline data have already been noted:

1) There are three different versions of the locations of monitoring wells LM-MW-2 (the point of compliance) and LM-MW-3 (see Figs. 20-22 and Table 2).
2) The locations and depths of the monitoring wells were chosen without any knowledge of the local and regional hydrogeology.
3) Monitoring wells LM-MW-2 and LM-MW-3 (see Figs. 20-22) were persistently dry during the period of collection of baseline data, so that those wells did not serve any useful purpose.
4) Most of the data were missing for monitoring well MA1TMW-4 without any explanation.

It should be noted that, although the application claims that a pre-existing groundwater contamination plume is migrating to the southwest beneath the Leadville Mill (see Fig. 29), there is no evidence for the contamination plume in the baseline data, which underscores the need for a credible baseline study.

An additional deficiency is that the groundwater monitoring by Union Milling Company (2024) reported only total concentrations, whereas, as discussed previously, Colorado groundwater standards are based almost entirely on dissolved concentrations. On that basis, the baseline data should be regarded as completely invalid. The same deficiency was also noted by Colorado DRMS (2024b-c). According to Colorado DRMS (2024b), "In Appendix 21-4 the Applicant provides the sample results for wells sampled beginning in the fourth quarter 2022 through the fourth quarter 2023, five total quarters. However, the results reported are for the total recoverable portion of the sample … The Division … requires groundwater sample results to be directly comparable to the Water Quality Control Commission's Regulation 41 - The Basic Standards for Ground Water (Reg. 41), specifically the most stringent criteria of Tables 1 through 4. The analytes listed in those tables are both total and dissolved with all of the metal analytes being dissolved. The data, as provided in Appendix 21-4, is insufficient to adequately characterize baseline conditions at the site. In conjunction with Item 9 of this review please commit to providing groundwater quality data collected in accordance with the requested SAP." The memo "Adequacy Review, Proposed Water Monitoring Plan" continued, "Please note the Division only requires analysis for Total portion for some analytes while the majority of analytes are the Dissolved portion. If the Operator wants to sample for the Total portion in addition to the Dissolved portion that is at their own discretion" (Colorado DRMS, 2024c).

The Proposal is Devoid of Contingency Plans

At the present time, the Observational Method (also called Adaptive Management) is the approach used by nearly all large-scale mining and other engineering projects. For complex projects, it is not possible to determine all actions in advance because some later actions will depend on the unknown outcomes of earlier actions. Instead, a monitoring plan is created together with a set of preplanned actions ready for execution in response to every possible adverse observation. According to the Global Industry Standard on Tailings Management (GISTM), the Observational Method is "a continuous, managed, integrated, process of design, construction control, monitoring and review that enables previously defined modifications to be incorporated during or after construction as appropriate … The key element of the Observational Method is the proactive assessment at the design stage of every possible unfavourable situation that might be disclosed by the monitoring programme and the development of an action plan or mitigative measure to reduce risk in case the unfavourable situation is observed" (ICMM-UNEP-PRI, 2020). The GISTM continues, "Full implementation of the Observational Method shall be adopted for non-brittle failure modes" (ICMM-UNEP-PRI, 2020), referring to failure modes that occur with some warning or precursors, so that there is sufficient time for observations and pre-planned responses.

By contrast with the standard practice in the mining industry, the proposal for remining at the Leadville Mill is devoid of any contingency plans and is nearly devoid of any monitoring program. There is no plan to monitor either surface water or the stability of the filtered tailings deposit (FTD). There is a plan to monitor groundwater, although with multiple deficiencies, as discussed in the previous subsection. However, there is no plan to do anything in response to any detection of groundwater contamination. Colorado DRMS (2024c) also noted this deficiency in writing "Please commit to providing the Division a written report within five (5) working days when there is evidence of groundwater discharges exceeding applicable groundwater standards or permit conditions imposed to protect groundwater quality, in accordance with Rule 3.1.7(9). Please be advised, this notice requirement would apply to any exceedance of the groundwater monitoring standards set for monitoring wells. However, enforcement actions would only be pursued for exceedances at the approved point of compliance well." The above request by Colorado DRMS (2024c) scarcely counts as "an action plan or mitigative measure to reduce risk" (ICMM-UNEP-PRI, 2020).

The need for specific preplanned actions (as opposed to simply writing reports) cannot be overemphasized. According to the investigation report on the catastrophic failure of the tailings storage facility at the Mount Polley mine in British Columbia in 2014, "The Observational Method is useless without a way to respond to the observations" (Independent Expert Engineering Investigation and Review Panel, 2015). According to Safety First: Guidelines for Responsible Mine Tailings Management, "There must be a system in place to respond to the observations" (Morrill et al., 2022). Finally, the SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook warned, "The observational method, since its inception, has experienced definitional and applicational drift, gradually being misused and redefined in a transition from planned change management to a 'make it up as you go' process. This is the paradox. The observational method is intended to leave nothing to uncertainty" (Hatton and van Zyl, 2022). The same handbook reviewed the original formulation of the Observational Method by Peck (1969) with the critical step: "Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis" (Hatton and van Zyl, 2022).

SUMMARY CONCLUSIONS

The ten questions posed in the “Methodology” section are repeated below, followed by very brief responses. More complete responses can be found in the “Responses” section.

1) Is the proposed remining plan aligned with industry standards on cyanide management and gold mining?

No, Union Milling Company and CJK Milling are not signatory companies of the International Cyanide Management Code, nor have they committed to following the World Gold Council Responsible Gold Mining Principles. Companies cannot fully comply with the International Cyanide Management Code without becoming a signatory company, because compliance requires third-party audits under the supervision of the International Cyanide Management Institute. The lack of any plan for safe disposal of the iron-cyanide sludge is a particular example of non-compliance with the International Cyanide Management Code.

2) Will the filtered tailings deposit be stable as designed?

No, the filtered tailings deposit will not be stable because even the lower bound for the target water content exceeds the flow moisture point so that the deposit will flow as it is being constructed. In addition, the filtered tailings deposit will not include a structural zone (equivalent to a dam), the particle size distribution of the tailings will be in the range that is susceptible to liquefaction, saturated or near-saturated tailings will be emplaced into the deposit, the target water content will result in the wettest filtered tailings storage facility ever constructed, and the filtered tailings deposit has not been designed to withstand any particular precipitation or seismic event.

3) Has there been adequate consideration of the consequences of failure of the filtered tailings deposit?

No, the proposal does not even mention the possibility of failure of the filtered tailings deposit. By analogy with the failure of a similar facility in Brazil in 2022, a slump from the filtered tailings deposit will travel 742 feet, which could result in fatalities of neighboring residents or millworkers or in the deposition of tailings into California Gulch. If the slump traveled southeast, so that the tailings mixed with the polishing pond of the Leadville Sanitation District, the resulting fluidized mass could travel a considerable distance down California Gulch and the Arkansas River. In addition, damage to or destruction of the polishing pond would likely result in significant sewage effluent contamination of the Arkansas River for an extended period, while the District facilities were restored.

4) Is there an adequate plan for permanent safe closure of the filtered tailings deposit?

No, there is no plan for monitoring, inspection, maintenance and review of the filtered tailings deposit after the cessation of the remining project.

5) ***Has there been a correct estimation of the water consumption rate and is there an adequate source of water for the remining operation?***

No, the estimated water consumption rate of 27 gallons per minute assumes that no water will be lost by evaporation during any phase of the remining operation, including dust control. By analogy with other projects, the rate of water loss due to dust control on the haul road alone could be 46 gallons per minute. No definitive water source has yet been identified for the remining operation.

6) ***Is there an adequate network of monitoring wells for the detection of groundwater contamination?***

No, the monitoring wells were chosen with no regard for the local or regional hydrogeology and with no discussion of the aquifers over which the wells are screened. The actual groundwater flow directions could be completely different from the assumed directions, so that the monitoring wells might be entirely irrelevant. The fact that the key monitoring wells were persistently dry during the period of collection of baseline data also underscores the inadequacy of the monitoring network.

7) ***Does the plan include adequate infrastructure for the management of stormwater?***

No, the stormwater infrastructure is designed to withstand a 100-year storm, which is described as a worst-case scenario. The design precipitation event should depend upon the consequences of uncontrolled overflow of stormwater channels or ponds, which have not been considered. The true worst-case scenario is the Probable Maximum Precipitation (PMP), which is significantly rarer than even a 10,000-year storm.

8) ***Has the potential for acid mine drainage and metal leaching from the filtered tailings been adequately assessed?***

No, the proposal reports the analysis of only one tailings sample, even though mine waste will be obtained from multiple waste piles. Even if all the mine waste piles had the same mineralogy, a minimum of 26 samples would be required.

9) ***Are there sufficient baseline data for quality of surface water and groundwater?***

No, there are no baseline data for surface water and baseline data for groundwater did not measure the parameters that are specified in Colorado regulations. In addition, the appropriate locations, depths, and aquifers for monitoring wells have not yet been established.

10) ***Are there adequate contingency plans for responding to instability of the filtered tailings deposit or to detection of surface water or groundwater contamination?***

No, there are no contingency plans for responding to instability of the filtered tailings deposit or detection of surface water or groundwater contamination.

RECOMMENDATIONS

The recommendation of this report is that the application for cyanide extraction of gold and silver from mine waste at the Leadville Mill should be completely reconsidered and rewritten with special attention to the following:

1) All information in the application should be correct and consistent. Cyanide values should indicate whether they refer to free, total or WAD cyanide. Water contents should indicate whether they refer to geotechnical water content or process water content.
2) Alternatives to the use of cyanide for gold and silver extraction should be fully considered and any final decision to use cyanide should be justified from both economic and environmental perspectives.
3) Both Union Milling Company and CJK Milling should become signatory companies of the International Cyanide Management Code. The application should include a complete cyanide management plan with explanation as to how the plan aligns with the International Cyanide Management Code.
4) Both Union Milling Company and CJK Milling should implement the Responsible Gold Mining Principles of the World Gold Council, including obtaining independent assurance. The application should explain how the proposed plan for remining aligns with the Responsible Gold Mining Principles.
5) At a minimum, both Union Milling Company and CJK Milling should either become Company Members of the International Council on Mining and Metals (ICMM) or should commit to full implementation of the Global Industry Standard on Tailings Management (GISTM). Preferably, both Union Milling Company and CJK Milling should commit to full implementation of the more protective guidance document Safety First: Guidelines for Responsible Mine Tailings Management.
6) There should be a plan for safe disposal of the iron-cyanide sludge.
7) Target water contents should be chosen based on the optimum water content for maximum compaction.
8) The upper bound on the target water content should be significantly less than the flow moisture point.
9) Test results should be presented that confirm the ability of current filter press technology to consistently achieve the target water content.
10) The liquefaction potential of the tailings should be fully assessed and a plan should be presented to prevent the resaturation and liquefaction of the tailings.
11) There should be a plan to prevent the placement of saturated or near-saturated tailings onto the filtered tailings deposit.
12) The filtered tailings deposit should include a structural zone with compaction of tailings to 95% of the maximum dry density.
13) There should be a complete geotechnical characterization of the tailings and the foundation.
14) Stability analyses should be presented for both static and seismic loading and the factors of safety should be stated.
15) The filtered tailings deposit should be designed so as to withstand both the Probable Maximum Precipitation (PMP) and the Maximum Credible Earthquake (MCE).
16) There should be a complete analysis of the consequences of failure of the filtered tailings deposit.

17) There should be a plan for monitoring, inspection, maintenance, and review of the filtered tailings deposit in perpetuity or until all credible failure modes have been eliminated.
18) The estimated water consumption rate should include realistic rates for dust control and for evaporation throughout all phases of the remining operation.
19) The application should identify a definitive water source. If the water source is an on-site supply well, the application should evaluate the impacts on neighboring domestic wells.
20) There should be a complete characterization of the local and regional hydrogeology, including aquifers, groundwater flow directions, and potential pathways for travel of contaminants from the remining operation.
21) The complete characterization of the local and regional hydrogeology should be used to determine the appropriate locations, depths, and screen intervals for monitoring wells and points of compliance.
22) Monitoring wells should be deep enough so that groundwater samples can be collected on a consistent basis.
23) Baseline groundwater quality data should be collected only after the determination of the appropriate locations, depths, and screen intervals for monitoring wells.
24) There should be a complete analysis of the consequences of uncontrolled overflow of the stormwater and water storage infrastructure. The design precipitation event for stormwater and water storage infrastructure should depend upon the consequences of failure.
25) The design precipitation event for stormwater and water storage infrastructure should take climate change into account.
26) There should be a complete geochemical characterization of all the mine waste piles that will be exploited for the remining operation. The geochemical characterization should determine the number of tailings samples that should be tested for potential for acid generation and metal leaching, but a minimum of 26 samples should be tested under any circumstances.
27) Baseline surface water quality data should be collected in California Gulch and the Arkansas River both upstream and downstream of the remining operation.
28) Both baseline groundwater and surface water quality data should be measured with regard to the parameters listed in Colorado Regulation 41.
29) Complete contingency plans should be developed for instability of the filtered tailings deposit and for observations of contamination in groundwater or surface water.

ABOUT THE AUTHOR

Dr. Steven H. Emerman has a B.S. in Mathematics from The Ohio State University, M.A. in Geophysics from Princeton University, and Ph.D. in Geophysics from Cornell University. Dr. Emerman has 31 years of experience teaching hydrology and geophysics, including teaching as a Fulbright Professor in Ecuador and Nepal, and has over 70 peer-reviewed publications in these areas. Since 2018 Dr. Emerman has been the owner of Malach Consulting, which specializes in evaluating the environmental impacts of mining for mining companies, as well as governmental and nongovernmental organizations. Dr. Emerman has evaluated proposed and existing tailings storage facilities in North America, South America, Europe, Africa, Asia and Oceania, and has testified on tailings storage facilities before the U.S. House of Representatives Subcommittee on Indigenous Peoples of the United States, the European Parliament, the United Nations Permanent Forum on Indigenous Issues, the United Nations Environment Assembly, the Permanent Commission on Human Rights of the Chamber of Deputies of the Dominican Republic, and the Minnesota Senate Environment, Climate and Legacy Committee. Dr. Emerman is the former Chair of the Body of Knowledge Subcommittee of the U.S. Society on Dams and one of the authors of Safety First: Guidelines for Responsible Mine Tailings Management.

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