Evaluation of the Filtered Tailings Storage Facility in the Updated Proposal for the Savannah Lithium Barroso Mine, Northern Portugal

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LIGHTNING SUMMARY

The filtered tailings storage facility at the proposed Barroso lithium mine in northern Portugal would have a height of 140 meters, which is 97 meters taller than the current technological limit for the site precipitation. The toe of the facility would be 1000 meters from the Covas river, although by analogy with the failure of the filtered tailings storage facility at the Pau Branco mine in Brazil in January 2022, a slump of the filtered tailings will travel for 2415 meters. The filtered tailings storage facility would be excessively steep by industry standards and there is no consideration of dam safety standards, including safe construction methods.

EXECUTIVE SUMMARY

The Agência Portuguesa do Ambiente (APA) [Portuguese Environment Agency] released on March 23, 2023, an updated Environmental Impact Study (EIS) for the proposed Barroso lithium mine in northern Portugal, which was prepared by the British company Savannah Lithium. The chief difference is that the updated EIS replaces the previous mine waste storage facility that would have stored a homogeneous mixture of waste rock and tailings with a facility that would store only filtered tailings with impoundment by an embankment of waste rock. The filtered tailings storage facility would be 140 meters high and the toe of the facility would be 1000 meters from the Covas river. The objective of this report is to consider whether the concerns listed in the evaluation of the previous EIS have been adequately addressed.

Since filtered tailings can be re-saturated by precipitation, the mean annual precipitation is the chief constraint on the current technological limit on the height of a filtered tailings storage facility. The facility at the Barroso mine would be the second tallest ever constructed and, with a mean annual precipitation of 1649 mm, would be the third wettest site for any filtered tailings storage facility that has ever been constructed. The current technological limit is roughly constrained by a line connecting the La Coipa filtered tailings storage facility in Chile with a height of 200 meters and mean annual precipitation of 42.9 mm and the COMILOG filtered tailings storage facility in Gabon with a height of 30 meters and mean annual precipitation of 1779.1 mm. On that basis, the height of the filtered tailings storage facility at the Barroso mine would exceed the current technological limit by 97 meters.

The placement of a tailings storage facility so close to a river is not considered a best practice and is illegal in some jurisdictions, such as China. The updated EIS claims that a slump of the tailings would travel less than 1000 meters, but that claim is not supported by any model or calculation or empirical data. The failure of the filtered tailings storage facility at the Pau Branco mine in Brazil in January 2022 was considered in this report as a comparison. The filtered tailings storage facility was 48 meters high and the landslide traveled 828 meters past the

toe of the facility, resulting in the burial of a major highway. Based on a travel distance of 17.25 times the height, a landslide of the filtered tailings storage facility at the Barroso mine will extend for 2415 meters past the toe of the facility, or well into the Covas river, followed by transport to the Atlantic Ocean.

The walls of the filtered tailings storage facility at the Barroso mine would be unusually steep with slopes of 1V:2.5H (1 meter vertical for 2.5 meters horizontal) on slopes confined by waste rock and 1V:3H on unconfined slopes, as opposed to the industry standard of 1V:3.5H. As expected, on a global basis, the tailings storage volume of a filtered tailings storage facility is a strong predictor of the height. Due to the steep topography and the steepness of the slopes of the filtered tailings storage facility at the proposed Barroso mine, with a tailings storage volume of 7.1 million cubic meters, the facility would be 99 meters taller than would be predicted for its tailings storage volume, which is remarkably similar to the exceedance of the current technological limit based upon the mean annual precipitation.

Although the filtered tailings would be confined by an embankment of waste rock, which should be regarded as a dam by industry standards, the updated EIS never uses the word "dam" to describe the embankment of waste rock and there is no consideration of dam safety standards. The dam would be constructed using the upstream method in which the waste rock embankment would be emplaced on top of the confined filtered tailings, so that, if the tailings liquefied, the embankment will slide over or fall into the liquefied tailings. For that reason, the upstream construction method is illegal in Brazil, Chile, Ecuador and Peru, and has most recently been denounced in the SME (Society for Mining, Metallurgy and Exploration) Surface Mining Handbook. The danger is particularly acute for the proposed Barroso mine, since the updated EIS acknowledges that the tailings will be susceptible to liquefaction. In addition, there is no plan for what to do with the tailings that will be too wet for adequate compaction, either because they left the filter presses with excessive water content or because they were re-wetted by precipitation prior to compaction.

The previous EIS included some interesting and original ideas that had not been adequately tested, especially at the scale for which they were proposed. On that basis, the author identified the original EIS as an example of "Reckless Creativity." However, at this point, there is nothing creative about the proposal for an excessively tall facility in a wet climate with excessively steep slopes that would be constructed using an unsafe construction method close to a river, based on the unjustified claim that a landslide of tailings will not reach the river. Therefore, the updated EIS should be identified simply as "reckless." The recommendation of this report is that the updated EIS for the proposed Barroso lithium mine should be rejected without any further consideration.

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OVERVIEW

The Agência Portuguesa do Ambiente (APA) [Portuguese Environment Agency] released on March 23, 2023, an updated Environmental Impact Study (EIS) for the proposed Barroso lithium mine in northern Portugal, which was prepared by the British company Savannah Lithium (Savannah Lithium LDA, 2023a-b). The updated EIS was released for public consultation on March 22, 2023, with a deadline of April 4 for public comments. On April 3 the deadline was extended until April 19, at which point Associações Unidos em Defesa de Covas do Barroso and Povo e Natureza do Barroso engaged the author to evaluate the updated EIS. The objective of this report is to consider whether the concerns listed in the evaluation of the previous EIS (Emerman, 2021) have been adequately addressed. Due to the short deadline, only the most important aspects of the updated EIS are addressed in this report. The previous report (Emerman, 2021) includes detailed background information on liquefaction, filtered tailings technology, and design floods that is not repeated in this report.

The chief difference is that the updated EIS replaces the previous mine waste storage facility that would have stored a homogeneous mixture of waste rock and tailings with a facility that would store only filtered tailings with impoundment by an embankment of waste rock. Although Savannah Lithium LDA (2023b) variously states the height of the filtered tailings storage facility as 70, 85 or 103 meters, a table from Savannah Lithium (2023a) clarifies that the correct height would be 140 meters (see Fig. 1). The toe of the facility would be about 1000 meters from the Covas river, although the exact distance is never stated. The tailings production rate would be 1.5 million metric tons per year for a total tailings volume of 7.1 million cubic meters.

Although the EIS refers to "*empilhamento a seco de rejeitados*" [dry stack tailings] (Savannah Lithium LDA, 2023a) the tailings are not literally dry, but have a water content that is variously stated as either less than 15% (Savannah Lithium LDA, 2023a-b) or less than 20% (Savannah Lithium LDA, 2023b). The standard terminology is "filtered tailings." 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). On their website, the consulting company Knight-Piésold, which has consulted for Savannah Lithium regarding the Barroso mine, 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).

The objective of filtered tailings technology is to desaturate the tailings, so that they can be compacted in the tailings storage facility, thus reducing the likelihood of liquefaction and catastrophic failure of the facility. At this point, the majority of filtered tailings storage facilities are in arid climates. The challenge with the construction of filtered tailings storage facilities in wet climates is that the tailings can be rewetted by precipitation prior to compaction, which can make the tailings too wet for proper compaction. In addition, the precipitation onto the filtered tailings storage facility can result in the resaturation of the tailings, thus increasing the likelihood of liquefaction. In any climate, based on the current technology, a significant portion of the tailings will leave the filter presses with too much water for optimum compaction and these wet tailings cannot be relied upon for structural support and must be managed in some way so as not to compromise the stability of the filtered tailings storage facility.

With a height of 140 meters, the filtered tailings storage facility at the Barroso mine would be the second tallest filtered tailings storage facility ever constructed. The only taller filtered tailings storage facility would be the facility at the La Coipa mine in Chile at a site with a mean annual precipitation of 42.9 mm (Franks et al., 2021; GRID-Arendal, 2023). The problem is that, with a mean annual precipitation of 1649 mm (Savannah Lithium LDA, 2023b), the site of the Barroso mine would be the third wettest site for any filtered tailings storage facility that has ever been constructed. The only wetter sites with filtered tailings storage facilities would be the Greens Creek mine in Alaska (USA) with mean annual precipitation of 1760.2 mm and the COMILOG mine in Gabon with mean annual precipitation of 1779.1 mm (Franks et al., 2021; GRID-Arendal, 2023).

The placement of a tailings storage facility close to a river is not generally regarded as best practice. 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 China, prohibit the construction of tailings storage facilities near rivers. According to Department of Basics for Production Safety (China) (2020), "严禁在距离长江和黄河干流岸线 3 公里、重要支流岸线 1 公里范围内新（改、扩）建尾矿库" [It is strictly forbidden to build new (or modified or expanded) tailings ponds within 3 kilometers from the banks of the main streams of the Yangtze River and the Yellow River, and 1 kilometer from the banks of their important tributaries].

Table 3.1 – Comparison of characteristics of waste facilities (EIS and Updated Design)

Name of Facility	Storage Capacity	Origin and quantity of waste		Dimensions of infrastructure				Status
	Mt	Origin	Mt	Area (ha)	Minimum elevation (m)	Maximum elevation (m)	Elevation difference (m)	Temporary or permanent
EIS Design								
South Waste Dump	40,8	Pinheiro	11,2	44,6	499	648	148	Permanent
		Grandão	15,6					
		Mill (Tailings)	14,0					
West Waste Dump	25	Reservatório	22,2	54,4	650	735	60	Permanent
		Noa	2,8					
North Waste Dump	6,3	Grandão	6,3	16,7	427	653	226	Permanent
East Lobe Waste Dump	25,7	Grandão	25,7	29,8	427	653	226	Permanent
Total area of permanent waste dumps (ha)	EIS Design	145,5 ha						
Updated Design								
Tailings Facility (TSF)	20,1	Mill	13,8	28,5	560	700	140	Permanent
Waste Dump 1	9,4	Pinheiro	7,6	19,1	570	700	130	Permanent
		Grandão	5,1					
Waste Dump 2	4,9	Grandão	5,8	18,7	530	630	100	Permanent
Waste Dump 3	28,6	Noa	19,3	15,7	665	710	45	Permanent
		Reservatório	2,7	19,0	665	745	80	Temporary
Waste Dump T	21,0	Grandão	21,3	37,0	560	665	105	Temporary
Total area of permanent waste dumps (ha)	Updated Design	53.5 (Waste Dumps) + 28.5 (TSF) = 82 ha						

Figure 1. The height of the filtered tailings storage facility (TSF) at the proposed Barroso mine would be 140 meters, which would be the second tallest filtered tailings storage facility in the world. Although Savannah Lithium LDA (2023b) variously states the height as 70, 85 or 103 meters, the above table from Savannah Lithium (2023a) clarifies the correct height. Table from Savannah Lithium LDA (2023a) with overlay of English labels.

According to the updated EIS, "*Considerando que a instalação de resíduos se localiza a mais de 1 km do rio Covas, considera-se que a eventual rotura desta infraestrutura, dificilmente atingirá o rio Covas, e consequentemente a sua qualidade*" [Considering that the waste facility is located more than 1 km from the Covas river, it is considered that the eventual rupture of this infrastructure will hardly affect the Covas river, and consequently its quality] (Savannah Lithium LDA, 2023a-b). The updated EIS does not state an exact distance from the filtered tailings storage facility to the Covas river. The updated EIS also does not show the pathway that the spilled tailings will follow to reach the Covas river nor does it state the predicted distance that the spilled tailings will travel. The claim that a landslide of tailings will travel less than 1000 meters is not supported by any model or calculation or empirical database.

The plan in the updated EIS is to confine the filtered tailings using an embankment of waste rock. In addition, the plan allows for steeper slopes of 1V: 2.5H (1 meter vertical for 2.5 meters horizontal) in the portions of the filtered tailings storage facility that are confined by waste rock and slopes of 1V: 3H in the unconfined portions. According to the updated EIS, "*O talude da TSF será coberto por Estéril … Os taludes de rejeitados suportados por estéril não excederão 1V: 2,5H, enquanto os taludes de rejeitados não suportados não excederão 1V: 3H* [The slope of the TSF [Tailings Storage Facility] will be covered by waste rock … Tailings slopes supported by waste rock will not exceed 1V:2.5H, while unsupported tailings slopes will not exceed 1V:3H] (Savannah Lithium LDA, 2023b).

The updated EIS never refers to the embankment of waste rock as a "dam" and there is no consideration of dam safety standards, except for the dams that would confine the various mining and sedimentation ponds. However, the embankment of waste rock is repeatedly described as having the exact same function as a dam. According to Savannah Lithium LDA (2023a), " *O suporte da TSF será efetuado por resíduos estéreis, provenientes das cortas, que integrarão a escombreira ESC1, com o objetivo de melhorar a sua estabilidade à medida que o volume da instalação de rejeitados for aumentando*" [The support of the TSF will be accomplished by waste rock, coming from the open pits, which will constitute the waste dump ESC1, with the objective of improving its stability as the volume of the tailings facility increases]. In a similar way, Savannah Lithium LDA (2023b) states, "*Os rejeitados da lavaria serão depositados criando um declive de 3H:1V, estando circundado exteriormente por uma escombreira (Esc. 1) para estabilidade e controle de erosão … A Figura III.20 mostra a Esc.1 colocada no talude da TSF para melhorar a estabilidade, atuando como um contraforte* [The tailings from the mill will be deposited creating a slope of 3H:1V, being externally surrounded by a waste dump (Esc. 1) for stability and erosion control … Figure III.20 shows Esc.1 placed on the TSF slope to improve stability, acting as a buttress].

METHODOLOGY

Based on the previous section, the objective of this report can be subdivided into the following questions:

1) Is the proposed height for the filtered tailings storage facility consistent with the current technological limit for a given site precipitation?
2) Will the spilled tailings reach the Covas River in the event of a failure of the filtered tailings storage facility?
3) Is the steepness of the slopes of the proposed filtered tailings storage facility consistent with industry standards?

4) Is the proposed dam construction method consistent with dam safety standards, even though the EIS does not refer to the embankment of waste rock as a "dam?"

The first question was addressed by plotting the heights of existing filtered tailings storage facilities as a function of mean annual precipitation. The current technological limit was constrained by a straight line connecting the parameters at the lower and upper ends of mean annual precipitation. Heights and mean annual precipitation were obtained for 74 filtered tailings storage facilities in the Global Tailings Portal Project (Franks et al., 2021; GRID-Arendal, 2023).

The second question was addressed by comparing the filtered tailings storage facility at the proposed Barroso mine with the filtered tailings storage facility at the Pau Branco mine in Brazil, which failed on January 8, 2022 (Angelo, 2022; Morrill, 2022; Petley, 2022; see Fig. 2). The landslide did not cause any fatalities, but it buried Highway BR-40. The extent of the landslide was measured based on drone videos (Observatório da Mineração [Mining Observatory], 2022) and a highway width of 27 meters as measured from Google Earth. The height of the filtered tailings storage facility of 48 meters (ANM, 2022) was then used to predict the corresponding extent of a landslide from the filtered tailings storage facility at the proposed Barroso mine. The mean annual precipitation of 1597 mm at the site of the Pau Branco mine was determined from Fick and Hijmans (2017). The failure of the facility at the Pau Branco mine is particularly relevant, since the failure was caused by heavy rainfall (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."

The third question was addressed by comparison with industry standards for the steepness of slopes of filtered tailings storage facilities (Cacciuttolo Vargas and Pérez Campomanes, 2022). The question was further addressed by plotting the tailings storage volume against the height for the 74 filtered tailings storage facilities in the Global Tailings Portal Project (Franks et al., 2021; GRID-Arendal, 2023). Thus, the question was asked as to whether the projected height of the filtered tailings storage facility at the Barroso mine would be typical for the projected tailings storage volume. The fourth question was addressed by comparison with industry standards and with the mining legislation in the Latin American countries.

RESULTS

Current Technological Limit for Height of Filtered Tailings Storage Facilities

The current technological limit was roughly constrained by a line connecting the La Coipa filtered tailings storage facility in Chile with a height of 200 meters and mean annual precipitation of 42.9 mm and the Greens Creek filtered tailings storage facility in Alaska (USA) with a height of 109 meters and mean annual precipitation of 1760.2 mm (see Fig. 3a). On that basis, with a mean annual precipitation of 1649 mm and a planned height of 140 meters (see Fig. 1), the filtered tailings storage facility at the Barroso mine would be 25 meters taller than the current technological limit. Construction within the technological limit is not a guarantee of success, since the failed filtered tailings storage facility at the Pau Branco mine with a height of 48 meters and mean annual precipitation of 1597 mm, was well within the current technological limit (see Fig. 3a).

Figure 2. A 48-meter-high filtered tailings storage facility collapsed at the Pau Branco iron-ore mine in Brazil on January 8, 2022. Photo from Angelo (2022).

From another perspective, the height of the filtered tailings storage facility at the Greens Creek mine is not relevant since its tailings production rate had been only 750 metric tons per day (Klohn Crippen Berger, 2017), which increased to 1500 metric tons per day by 2022 (Cacciuttolo Vargas and Pérez Campomanes, 2022), as opposed to the planned tailings production rate of 4110 metric tons per day at the Barroso mine. On that basis, the current technological limit was reconstructed as a line connecting the La Coipa filtered tailings storage facility in Chile with a height of 200 meters and mean annual precipitation of 42.9 mm with the COMILOG filtered tailings storage facility in Gabon with a height of 30 meters and mean annual precipitation of 1779.1 mm (see Fig. 3b). Based on the reconstructed technological limit, the filtered tailings storage facility at the Barroso mine would be 97 meters taller than the current technological limit (see Fig. 3b). It is noteworthy that, with the deletion of the Greens Creek mine based on its low tailings production rate, the failed filtered tailings storage facility at the Pau Branco mine and the filtered tailings storage facility at the Pinos Altos mine (Mexico) with a history of stability concerns (Franks et al., 2021; GRID-Arendal, 2023) are right on the current technological limit (see Fig. 3b). In summary, based on the best available data, the projected height of the filtered tailings storage facility at the Barroso mine would be 97 meters above or about 230% of the current technological limit.

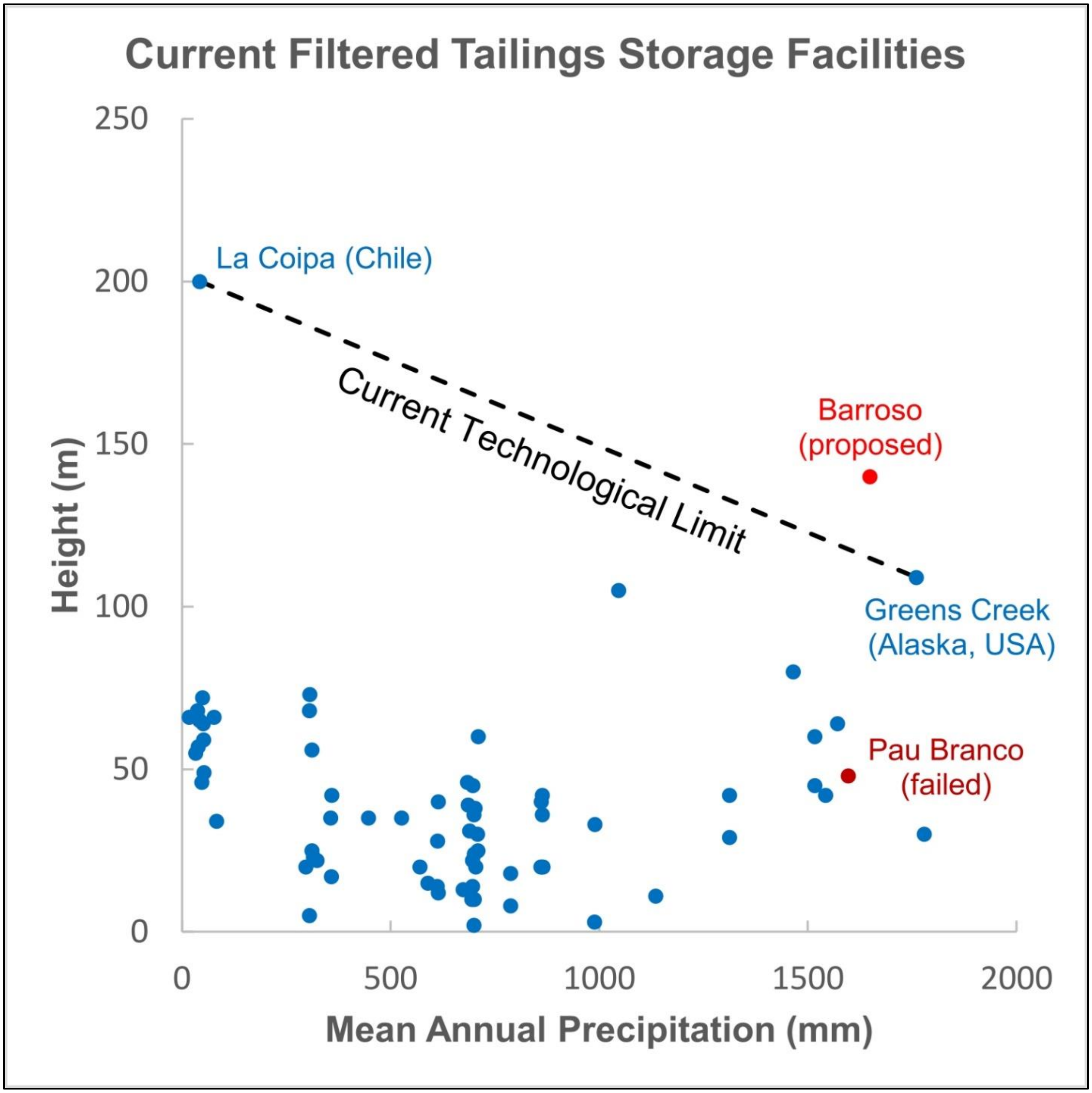

Figure 3a. At the present time, the chief limitation on the size of filtered tailings storage facilities is the impact of precipitation. Thus, the current technological limit is roughly constrained by a line connecting the La Coipa filtered tailings storage facility in Chile with a height of 200 meters and mean annual precipitation of 42.9 mm and the Greens Creek filtered tailings storage facility in Alaska (USA) with a height of 109 meters and mean annual precipitation of 1760.2 mm. On that basis, with a mean annual precipitation of 1649 mm and a planned height of 140 meters (see Fig. 1), the filtered tailings storage facility at the Barroso mine would be 25 meters taller than the current technological limit. Construction within the technological limit is not a guarantee of success, since the failed filtered tailings storage facility at the Pau Branco mine (see Fig. 2), with a height of 48 meters and mean annual precipitation of 1597 mm, was well within the current technological limit. From another perspective, the height of the filtered tailings storage facility at the Greens Creek mine is not relevant since its tailings production rate had been only 750 metric tons per day, which increased to 1500 metric tons per day by 2022, as opposed to the planned tailings production rate of 4110 metric tons per day at the Barroso mine (see Fig. 3b). Data on existing filtered tailings storage facilities from Klohn Crippen Berger (2017), Franks et al. (2021), and ANM (2022), and Cacciuttolo Vargas and Pérez Campomanes (2022). Mean annual precipitation from Fick and Hijmans (2017).

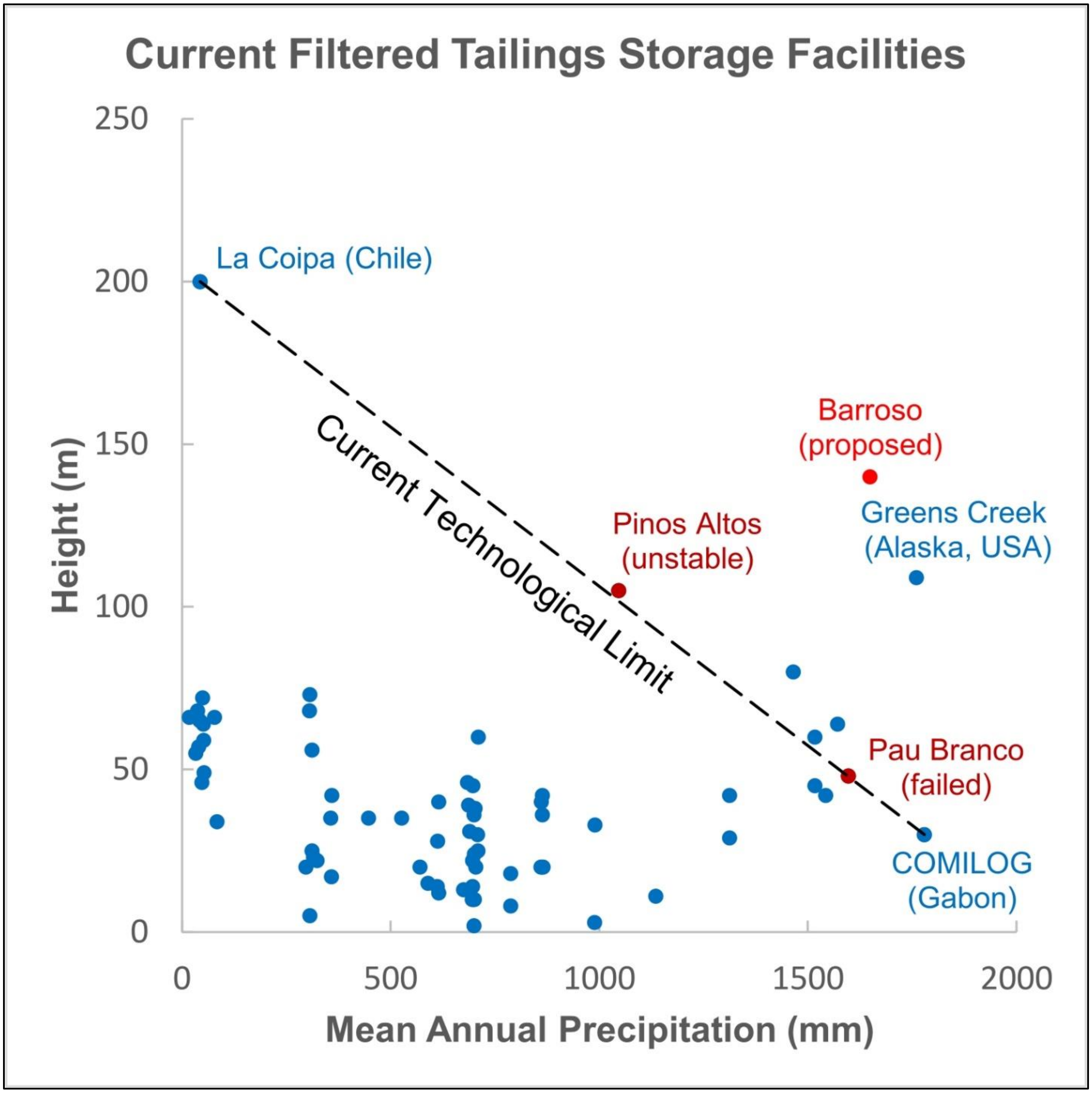

Figure 3b. At the present time, the chief limitation on the size of filtered tailings storage facilities is the impact of precipitation. Thus, the current technological limit is roughly constrained by a line connecting the La Coipa filtered tailings storage facility in Chile with a height of 200 meters and mean annual precipitation of 42.9 mm and the COMILOG filtered tailings storage facility in Gabon with a height of 30 meters and mean annual precipitation of 1779.1 mm. The height of the filtered tailings storage facility at the Greens Creek mine is not relevant since its tailings production rate had been only 750 metric tons per day, which increased to 1500 metric tons per day by 2022, as opposed to the planned tailings production rate of 4110 metric tons per day at the Barroso mine. Based on the preceding, with a mean annual precipitation of 1649 mm and a planned height of 140 meters (see Fig. 1), the filtered tailings storage facility at the Barroso mine would be 97 meters taller than the current technological limit. Note that the failed filtered tailings storage facility at the Pau Branco mine (see Fig. 2) and the filtered tailings storage facility at the Pinos Altos mine with a history of stability concerns are right on the current technological limit. Data on existing filtered tailings storage facilities from Klohn Crippen Berger (2017), Franks et al. (2021), ANM (2022), and Cacciuttolo Vargas and Pérez Campomanes (2022). Mean annual precipitation from Fick and Hijmans (2017).

Consequences of Failure of Filtered Tailings Storage Facility

Based on the highway width of 27 meters, the landslide from the filtered tailings storage facility at the Pau Branco mine extended for 104 meters past Highway BR-40 (see Fig. 4a). Thus, using the Google Earth image from June 29, 2022, the landslide 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 (see Fig. 4b). Considering the height of 140 meters of the filtered tailings storage facility at the proposed Barroso mine, the experience at the Pau Branco mine predicts that the landslide of the filtered tailings storage facility at the Barroso mine will extend for 2415 meters past the toe of the facility. Thus, it is not necessary to know the exact pathway of the spilled tailings or the exact distance to the Covas river to arrive at the conclusion that the landslide from the failure of the filtered tailings storage facility will extend well into the Covas river.

Figure 4a. 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. 3), extended for 104 meters past Highway BR-40. Highway width was measured from Google Earth image from June 29, 2022 (see Fig. 4b). Still image at 0:38 of drone video (Observatório da Mineração [Mining Observatory], 2022).

For comparison, according an industry guidance document, 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) unless the material slumps into a water body" (Klohn Crippen Berger (2017). Thus, Klohn Crippen Berger (2017) predicts a landslide distance of 1400 meters, which should still carry the spilled tailings into the Covas river. The above quote from Klohn Crippen Berger (2017) includes a footnote that states "Estimate of runout distance included for comparison purposes only." Thus, the estimate from the failure at the Pau Branco mine should be regarded as a more reliable predictor of the consequences of failure at the proposed Barroso mine.

It is important to consider the last part of the quote from Klohn Crippen Berger (2017), which ends with "unless the material slumps into a water body." Once the tailings mix with the water of the Covas river or any other waterways, they will constitute a fluidized mass that will continue flowing downstream, even if the initial failure of the filtered tailings storage facility did not involve liquefaction. The extent of downstream flow will depend upon the volume of spilled tailings. Emerman (2021) shows the downstream pathways for spilled tailings for a most-likely scenario based upon a database of past failures of tailings storage facilities and for a worst-case scenario that would involve the release of all of the stored tailings. Under the worst-case scenario, which would presumably occur in response to an extreme precipitation event, the tailings will flow all the way to the Atlantic Ocean (Emerman, 2021).

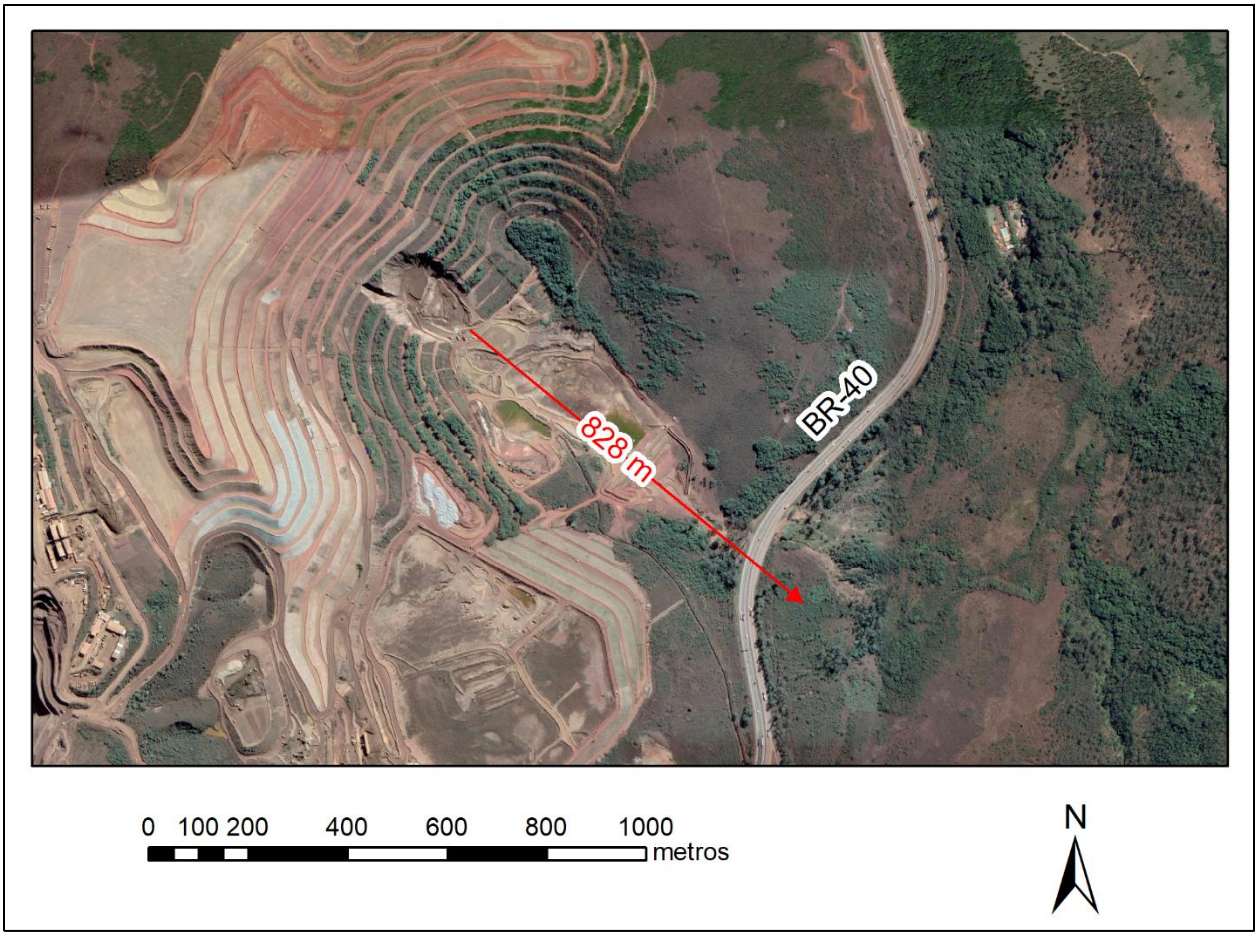

Figure 4b. The slump of the filtered tailings storage facility at the Pau Branco mine in Brazil on January 8, 2022 (see Fig. 3), extended for 828 meters past the toe of the facility or 17.25 times the height of the filtered tailings storage facility of 48 meters (ANM, 2022). The preceding observation 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 height of 140 meters of the filtered tailings storage facility at the proposed Barroso mine (see Fig. 1), the experience at the Pau Branco mine predicts that the slump of the filtered tailings storage facility at the Barroso mine will extend for 2415 meters past the toe of the facility, or well into the Covas river. Background is Google Earth image from June 29, 2022.

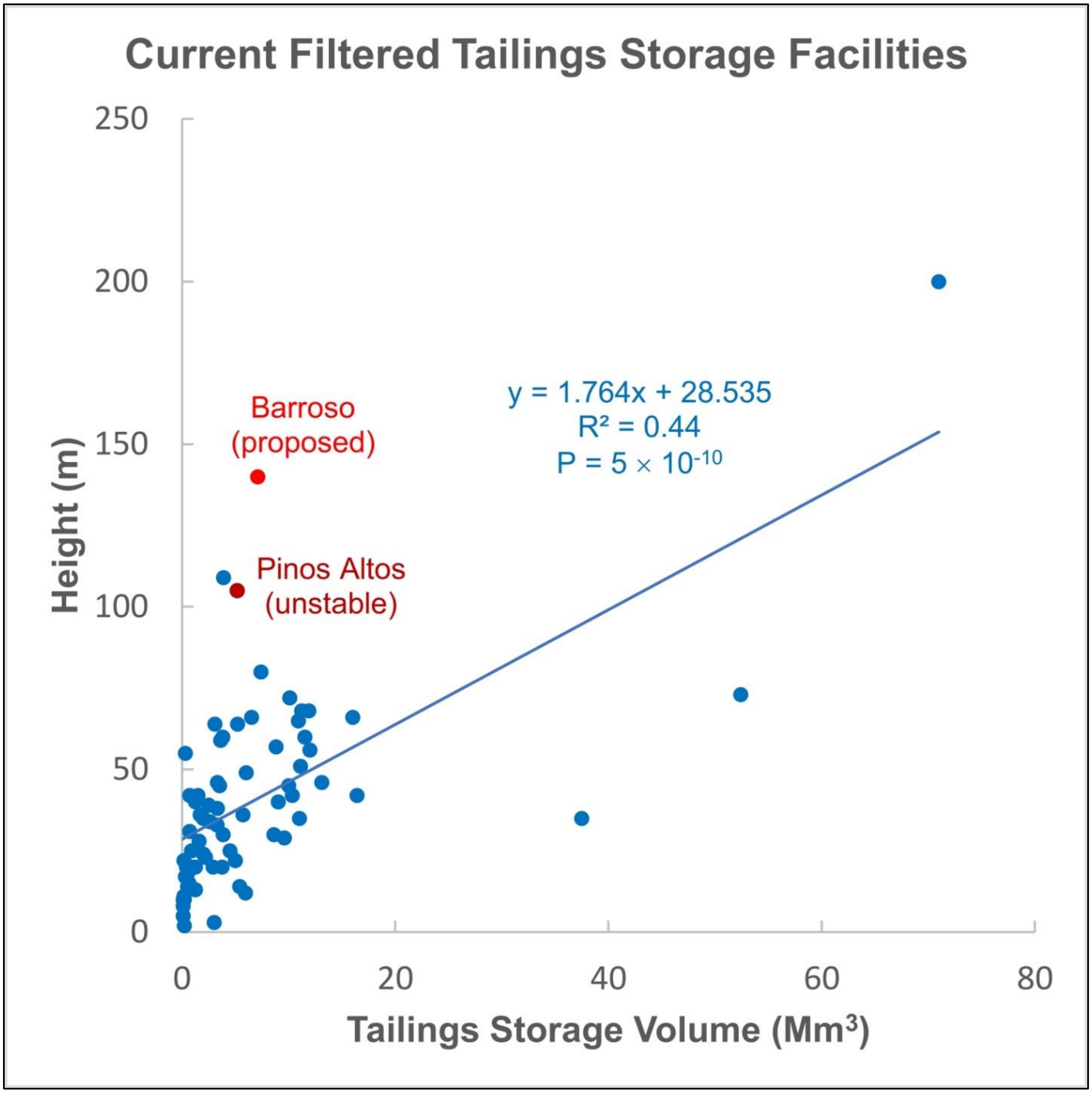

Figure 5. As expected the tailings storage volume of a filtered tailings storage facility is a strong predictor of the height ($R^2 = 0.44$, $P = 5 \times 10^{-10}$). Due to the steep topography and the steepness of the slopes of the filtered tailings storage facility at the proposed Barroso mine, with a height of 140 meters and storage volume of 7.1 million cubic meters, the facility would be unusually tall for the volume of tailings that would be stored. Based on the best-fit line for current filtered tailings storage facilities, the filtered tailings storage facility at the Barroso mine would be 99 meters taller than would be predicted for its tailings storage volume. The ratio of the height to the storage volume of the filtered tailings storage facility at the Barroso mine would be 19.7 meters per million cubic meters, which would be the second highest ratio for any filtered tailings storage facility with a tailings volume greater than 5.0 million cubic meters. The largest ratio of 20.4 corresponds to the filtered tailings storage facility at the Pinos Altos mine with a height of 105 meters and storage volume of 5.152 million cubic meters, which has a history of stability issues. Data on global filtered tailings storage facilities from Franks et al. (2021).

Excessive Steepness of Filtered Tailings Storage Facility

As expected, based on the global dataset, the tailings storage volume of a filtered tailings storage facility is a strong predictor of its height ($R^2 = 0.44$, $P = 5 \times 10^{-10}$; see Fig. 5). Due to the steep topography and the steepness of the slopes of the filtered tailings storage facility at the proposed Barroso mine, with a height of 140 meters and storage volume of 7.1 million cubic meters, the facility would be unusually tall for the volume of tailings that would be stored (see Fig. 5). The ratio of the height to the storage volume of the filtered tailings storage facility at the Barroso mine would be 19.7 meters per million cubic meters, which would be the second highest ratio for any filtered tailings storage facility with a tailings volume greater than 5.0 million cubic meters (see Fig. 5). The largest ratio of 20.4 corresponds to the filtered tailings storage facility at the Pinos Altos mine with a height of 105 meters and storage volume of 5.152 million cubic meters (see Fig. 5), which, as already mentioned, has a history of stability issues (Franks et al., 2021; GRID-Arendal, 2023). Based on the best-fit line for current filtered tailings storage facilities (see Fig. 5), the filtered tailings storage facility at the Barroso mine would be 99 meters taller than would be predicted for its tailings storage volume, which is remarkably similar to the exceedance of the current technological limit by 97 meters based upon the mean annual precipitation (see Fig. 3b).

The high ratio of height to tailings storage volume is connected with both the steep topography and the proposed steepness of the slopes of the filtered tailings storage facility. Although the proposal for the Barroso mine calls for slopes of 1V:2.5H where the tailings are confined by waste rock and 1V:3H on unconfined slopes, the industry standard is for slopes no steeper than 1V:3.5H (Cacciuttolo Vargas and Pérez Campomanes, 2022). According to Cacciuttolo Vargas and Pérez Campomanes (2022), "Steeper side slopes need a review of the filtered tailings geotechnical parameters to assure the stack stability."

Lack of Adherence to Dam Safety Standards

Although the embankment of waste rock would constitute a dam (see Fig. 6), the EIS includes no consideration of dam safety standards, either in terms of Portuguese dam regulations or industry guidance documents. In particular, there is no consideration of the precipitation event that the waste rock dam ought to be able to withstand. Although the waste rock dam is sometimes referred to as an "*escombreiro*" [waste rock dump] (see Fig. 6), that terminology does not guarantee stability. In fact, there are many failures of waste rock dumps described in Hawley and Cunning (2017), an industry guidance document that is included in the EIS.

A significant lack of adherence to dam safety standards is the use of the upstream construction method, meaning that the waste rock would be emplaced on top of the filtered tailings that are being confined (see Fig. 6). The consequence is that, if the tailings liquefied, the waste rock dam could fail by sliding over or falling into the liquefied tailings. For that reason, and because of the history of failures of mining dams constructed the upstream method, the upstream method of construction is prohibited in Brazil (ANM, 2019), Chile (Ministerio de Minería (Chile) [Ministry of Mining (Chile)], 2007), Ecuador (Ministerio de Energía y Recursos Naturales No Renovables [Ministry of Energy and Non Renewable Natural Resources] (Ecuador), 2020), and Peru (Sistema Nacional de Información Ambiental (Perú) [National System of Environmental Information (Peru)], 2014). The strongest industry denunciation of the upstream construction method comes in the SME Surface Mining Handbook. According to

Turek (2023), "Not mentioned in Table 4 [Tailings storage facility failures by decade from 1950 to December 16, 2020] is the fact that the upstream method of raising the level of the dams has been utilized in many of the most serious failures. This is in spite of the fact that the dangers of failure inherent with the upstream method have been recognized for many decades - see for example, Klohn (1972), who states that the 'history of this method of dam construction is plagued with failures, some of them catastrophic.'"

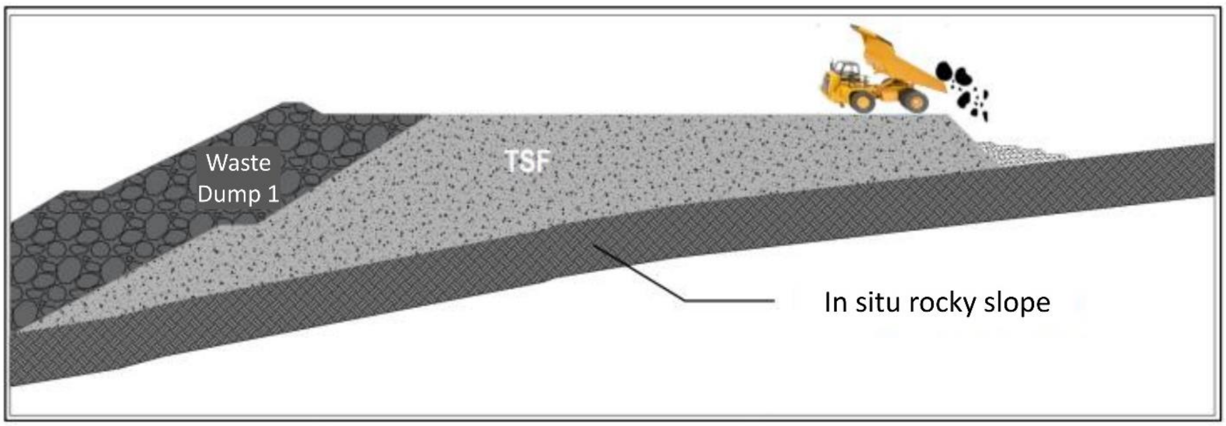

Figure 111.21 – Construction method for Waste Dump 1 and TSF

Figure 6. The filtered tailings at the Barroso mine would be confined by a dam of waste rock that would be on top of the tailings, which is known as the upstream construction method. If the tailings liquefied, the dam could fail by sliding over or falling into the liquefied tailings. As a consequence, the upstream construction method is prohibited in Brazil, Chile, Ecuador and Peru, and is strongly denounced in the SME (Society for Mining, Metallurgy and Exploration) Surface Mining Handbook. The problem is particularly acute for the Barroso mine since the EIS identifies the tailings as susceptible to liquefaction. The embankment of waste rock is never referred to as a "dam" and there is no consideration of dam safety standards. Figure from Savannah Lithium LDA (2023b) with overlay of English labels.

The problem of lack of confinement after liquefaction is particularly acute in the case of the filtered tailings storage facility at the Barroso mine because the EIS identifies the tailings as susceptible to liquefaction. According to Savannah Lithium LDA (2023b), "*A curva de classificação indica que a amostra ensaiada cai dentro do limite de solos potencialmente liquefeitos e, portanto, a liquefação da massa de rejeitados precisa ser considerada no projeto*" [The classification curve indicates that the tested sample falls within the limit of potentially liquefied soils and therefore the liquefaction of the tailings mass needs to be considered in the design]. However, the design does not further consider the potential for liquefaction. In particular, there is no plan as to what to do with the tailings that will be too wet for proper compaction, either because they left the filter presses with excessive water content or because they were re-wetted by precipitation prior to compaction.

It should be noted that only a single sample of tailings was tested, which is the identical single sample that was discussed in the previous EIS. Savannah Lithium LDA (2023c) confirms that tailings properties were measured for only a single sample by writing "One bag of tailings sample was … sent to the KP [Knight-Piésold] laboratory in Perth in November 2019." Savannah Lithium LDA (2023c) also confirms that shear strength parameters were not actually measured, but were only estimated from the grain size distribution. According to Savannah Lithium LDA (2023c), "The typical effective friction angle and cohesion has been estimated based on the limited classification testing completed to date and empirical relationships." Based on the above, it should be assumed that the geotechnical properties of the tailings are very poorly known. In this regard, the warning by Cacciuttolo Vargas and Pérez Campomanes (2022) should be recalled that excessively steep slopes require a careful review of the geotechnical properties of the filtered tailings.

DISCUSSION

The previous EIS included some interesting and original ideas that had not been adequately tested, especially at the scale for which they were proposed. On that basis, the author identified the original EIS as an example of "Reckless Creativity" (Emerman, 2021). A related concept is called "Design Euphoria," which has even been applied to the failure of the filtered tailings storage facility at the Pau Branco mine (Riskope, 2022). With regard to the plan for mine waste storage at the Pau Branco mine, Riskope (2022) wrote, "Technological innovation provoked generalized blindness. The mine even won the Brazilian Environmental Award in 2017. However, any slope, anywhere and in any material has potential stability and drainage issues that one should carefully consider."

The concept of Reckless Creativity will not be reviewed further here because there is nothing creative about the updated EIS. The updated EIS is only reckless. The following are examples of reckless behavior that do not involve any creativity:

1) construction of the second tallest filtered tailings storage facility ever constructed at the third wettest site for any filtered tailings storage facility that has ever been constructed
2) construction of a filtered tailings storage facility 97 meters taller than the current technological limit for the site precipitation
3) construction of any tailings storage facility 1000 meters from a river
4) lack of any calculation or model or reference to empirical data for a claim that the spilled tailings could not reach the adjacent river
5) lack of any consideration of the possible flow path for spilled tailings from the failed tailings storage facility to the adjacent river
6) construction of a filtered tailings storage facility with slopes steeper than industry standards, especially with poor knowledge of the geotechnical properties of the tailings
7) construction of a dam without any consideration of dam safety standards
8) construction of a tailings dam using the upstream construction method
9) recognition that the tailings are susceptible to liquefaction, but without any plan for management of tailings that will be too wet for compaction
10) stability analyses based upon a single tailings sample, but without actual measurements of the shear strength parameters of that sample

CONCLUSIONS

The chief conclusions of this report can be summarized as follows:

1) Based on the mean annual precipitation at the mine site of 1649 mm, the height of the filtered tailings storage facility at the Barroso mine (140 meters) would exceed the current technological limit by 97 meters.
2) By comparison with the failure of the filtered tailings storage facility at the Pau Branco mine in Brazil in January 2022, a landslide of the filtered tailings storage facility at the

Barroso mine will extend for 2415 meters past the toe of the facility, or well into the Covas river, followed by transport to the Atlantic Ocean.

3) The walls of the filtered tailings storage facility at the Barroso mine would be unusually steep with slopes of 1V:2.5H (1 meter vertical for 2.5 meters horizontal) on slopes confined by waste rock and 1V:3H on unconfined slopes, as opposed to the industry standard of 1V:3.5H.
4) Due to the steep topography and the steepness of the slopes of the filtered tailings storage facility at the proposed Barroso mine, with a tailings storage volume of 7.1 million cubic meters, the facility would be 99 meters taller than would be predicted for its tailings storage volume, which is remarkably similar to the exceedance of the current technological limit based upon the mean annual precipitation.
5) Although the filtered tailings would be confined by an embankment of waste rock, which should be regarded as a dam by industry standards, the updated EIS never uses the word "dam" to describe the embankment of waste rock and there is no consideration of dam safety standards.
6) The dam would be constructed using the upstream method in which the waste rock embankment would be emplaced on top of the confined filtered tailings, so that, if the tailings liquefied, the embankment will slide over or fall into the liquefied tailings. For that reason, the upstream construction method is illegal in Brazil, Chile, Ecuador and Peru, and has most recently been denounced in the SME (Society for Mining, Metallurgy and Exploration) Surface Mining Handbook.
7) The danger is particularly acute for the proposed Barroso mine, since the updated EIS acknowledges that the tailings will be susceptible to liquefaction. In addition, there is no plan for what to do with the tailings that will be too wet for adequate compaction, either because they left the filter presses with excessive water content or because they were re-wetted by precipitation prior to compaction.

RECOMMENDATIONS

The recommendation of this report is to reject the proposal for the Savannah Lithium for the Barroso mine without further consideration.

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 70 peer-reviewed publications in these areas. Dr. Emerman is the owner of Malach Consulting, which specializes in evaluating the environmental impacts of mining for mining companies, as well as governmental and non-governmental 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, and the United Nations Environment Assembly. Dr. Emerman is the 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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