Evaluation of the Plan for Tailings Management and Electricity Generation in the Pre-Feasibility Study for the SolGold Gold-Silver-Copper Cascabel Project, Imbabura Province, Northern Ecuador

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ABSTRACT

The Australian company SolGold has released the Pre-Feasibility Study for the gold-silver-copper Cascabel Project in Imbabura Province of northern Ecuador. Although the measured and indicated resources for the Alpala deposit are substantial (3013 million metric tons), the deposit is very low-grade either in terms of gold (0.28 grams per metric ton), silver (0.94 grams per metric ton), or copper (0.35%). The preferred options for tailings management are the transport of the cleaner and rougher tailings through two separate pipelines, each with length of 57 kilometers, to one of two sites on the coastal plains. The preferred options were selected using a Multiple Account Analysis (MAA) that was based 20% upon financial considerations. By contrast, according to the Global Industry Standard on Tailings Management (GISTM) and other industry documents, cost should not even be one of the factors in choosing the tailings management plan. Even so, the Pre-Feasibility Study estimates the initial capital cost, operating cost and closure cost of the tailings storage facility as USD 0.50, USD 0.15, and USD 0.03 per dry metric ton of tailings, respectively, although typical costs are USD 0.75, USD 1.20, and USD 0.13 per dry metric ton of tailings, respectively, so that the costs of tailings management have been greatly underestimated.

The Pre-Feasibility Study does not discuss either the likelihood or the consequences of tailings pipeline failure, although the pipelines would need to cross numerous rivers, including Rio Mira, Rio Negro Chiquito, and Rio Cachavi, as well as their tributaries. Based on the failure rates of Mexican oil and gas pipelines, the annual probability of failure of a tailings pipeline would be 47%, so that failures of tailings pipelines with release of tailings should be expected to occur during each year of the 28 years of the project. Based on industry standards, the tailings management plan is not sufficiently advanced even for a Pre-Feasibility Study. In particular, there has been no geotechnical testing of tailings samples or of the site foundation, no stability or seepage analyses, and no analysis of the consequences of tailings dam failure. All of the tailings management options involve a permanent water cover over the tailings in order to minimize acid mine drainage, which is no longer consistent with industry standards because of the detrimental impact on long-term stability. The Pre-Feasibility Study does not estimate the electricity consumption of the Cascabel Project and states only that multiple hydroelectric projects are in the advanced planning stage. Based on typical industry unit rates, the electricity consumption would be 91 MW, which would equal the combined power output of the Miravalle and Arenal hydroelectric projects on the border of Carchi and Imbabura provinces. Even so, the Miravalle and Arenal projects are only at the stage of conceptual designs with economic and environmental analyses.

The recommendation of this report is that SolGold should abandon the proposed Cascabel gold-silver-copper project at the present time. As an alternative, investors should decline to invest in the project and regulatory agencies should decline to issue permits for the project.

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EXECUTIVE SUMMARY

The Australian company SolGold has released the Pre-Feasibility Study for the gold-silver-copper Cascabel Project in Imbabura Province of northern Ecuador. The Cascabel Property includes the Alpala deposit, which would be exploited using underground mining with block caving as the preferred method, and the Tandayama-America deposit, for which both open-pit mining and underground mining are still under consideration. Although the measured and indicated resources for the Alpala deposit are substantial (3013 million metric tons), the deposit is very low-grade either in terms of gold (0.28 grams per metric ton), silver (0.94 grams per metric ton), or copper (0.35%). The Tandayama-America deposit has only indicated resources (722 million metric tons) with even lower grades of gold (0.23 grams per metric ton) and copper (0.23%). For reference, average grades of existing mines are 0.8 grams per metric ton for gold, 10 grams per metric ton for silver, and 0.64% for copper. According to a corporate presentation, "Cascabel has one of the largest gold resources amongst primary gold mines and assets worldwide, the second largest not controlled by a major." The claim might be true, but for the comparison group of nine other deposits that is provided in the presentation, the Alpala and Tandayama-America deposits rank 9th and 11th, respectively, in terms of the grade of gold. According to the same corporate presentation, "Cascabel is the largest undeveloped copper resource in Latin America not controlled by a major." Again, the claim might be true, but for the comparison group of 10 other deposits that is provided in the presentation, the Alpala and Tandayama-America deposits rank 8th and 12th, respectively, in terms of the grade of copper.

The Pre-Feasibility Study includes a plan for exploitation of 539.7 million metric tons of proven and probable reserves from the Alpala deposit over a period of 28 years. No mineable reserves have yet been determined for the Tandayama-America deposit. Considering the low grade of the Alpala deposit and the very large quantity of tailings that would be generated (529 million metric tons), the plan for tailings management is critical. A multiple accounts analysis (MAA) was used to select the preferred options for tailings management as the transport of the cleaner and rougher tailings through two separate pipelines, each with length of 57 kilometers, to one of two sites on the coastal plains with permanent storage behind a tailings dam. Since the cleaner tailings will be potentially acid forming, a permanent water cover would be maintained on the tailings in order to minimize oxidation and acid generation. The Pre-Feasibility Study recognizes community concerns regarding the open pit and the tailings storage facility as significant risk factors. The proposed action is "Do not publish the location of any controversial infrastructure (e.g. Tailings, Open Pit)," although it is difficult to understand how such information could be kept secret.

The objective of this report is to answer the following questions regarding the Pre-Feasibility Study:

1) Does the selection process for the tailings management plan give appropriate emphasis to safety?
2) Has the cost of tailings management been appropriately estimated?
3) Has the risk of tailings pipeline failure been correctly stated?
4) Is the tailings management plan sufficiently advanced for the stage of the Pre-Feasibility Study?
5) Is the plan for a permanent water cover on the tailings consistent with industry standards?

6) Does the Pre-Feasibility Study correctly state the electricity consumption and is there an available source of electricity?

To facilitate reading by non-specialists, this report includes a tutorial on key mining concepts, including tailings and tailings dams, tailings pipelines, acid mine drainage and metal leaching, mineral resources and mineral reserves, multiple accounts analysis, and the stage-gate process for mine planning (with emphasis on the Pre-Feasibility Study). This report also includes a database of 61 tailings pipeline failures, which has not previously been published.

The multiple accounts analysis (MAA) was weighted as 40% technical/engineering considerations, 25% social considerations, 20% financial considerations, and 15% environmental considerations. No information has been provided regarding the subaccounts or how the accounts and subaccounts were scored for each tailings management option. By contrast with the weighting in the Pre-Feasibility Study, according to the Global Industry Standard on Tailings Management (GISTM) and other industry documents, cost should not even be one of the factors in choosing the tailings management plan. In fact, the only goals for the MAA should be the minimization of risk to people and the environment and the minimization of the volume of tailings and water stored in aboveground tailings facilities. Despite the excessive emphasis on cost in the selection of the tailings management plan, the Pre-Feasibility Study greatly underestimates the cost of tailings management. The Pre-Feasibility Study estimates the initial capital cost, operating cost, and closure cost of the tailings storage facility as USD 0.50, USD 0.15, and USD 0.03 per dry metric ton of tailings, respectively, although typical costs are USD 0.75, USD 1.20, and USD 0.13 per dry metric ton of tailings, respectively. There is no consideration of the additional costs of long-distance tailings pipelines, which are not typical components of tailing management plans.

The Pre-Feasibility Study does not discuss either the likelihood or the consequences of tailings pipeline failure, although the pipelines would need to cross numerous rivers, including Rio Mira, Rio Negro Chiquito, and Rio Cachavi, as well as their tributaries. Based on the failure rates of Mexican oil (0.52% per kilometer per year) and gas (0.3% per kilometer per year) pipelines, the annual probability of failure of a tailings pipeline would be 47%, so that failures of tailings pipelines with release of tailings should be expected to occur during each year of the 28 years of the project. Based on industry standards, the tailings management plan is not sufficiently advanced even for a Pre-Feasibility Study, for which 15-20% of the engineering should already be complete at the time of release of the study. In particular, there has been no geotechnical testing of tailings samples or of the foundation of the proposed sites for the tailings storage facility, no study of groundwater or surface water at the proposed sites, no baseline environmental studies at the proposed sites, no stability or seepage analyses of the proposed tailings storage facilities, and no analysis of the consequences of tailings dam failure. As an example, the determination that the rougher tailings would be non-acid forming was based upon only a single sample, which is inadequate even for a Pre-Feasibility Study. The selection of a permanent water cover over the tailings in order to minimize acid mine drainage is no longer consistent with industry standards because of the detrimental impact on long-term stability of the tailings storage facility.

The Pre-Feasibility Study does not estimate the electricity consumption of the Cascabel Project. The only discussion regarding the availability of electricity is the statement: “The site power will be supplied from new hydroelectric power projects near the site. Multiple hydroelectric projects are currently in the advanced planning stage, with a total capacity of 200 MW having been identified in the local area. The Project plans to participate in these projects and secure the supply of power from them." Based on typical industry unit rates, the electricity consumption of the Cascabel Project will be 91 MW. By comparison, there are two possible hydroelectric projects on the border between Carchi and Imbabura provinces, which are the Miravalle project (power of 50 MW at approximate cost of USD 133.17 million) and the Arenal project (power of 40 MW at approximate cost of USD 150.513 million). Thus, the Cascabel Project would consume the entire power output of the only two anticipated hydroelectric projects in the vicinity. In addition, the economic analysis in the Pre-Feasibility Study does not include any contribution to the costs of hydroelectric plant construction or operation. Finally, the Miravalle and Arenal projects are only at the stage of conceptual designs with economic and environmental analyses, and not in the "advanced planning stage."

The stage-gate process in mine planning is a sequence of stages (such as a Pre-Feasibility Study) at which critical decisions are made as to whether to proceed with a project. The stage-gate process is not simply a sequence of steps that are carried through that inevitably ends in the construction of a mine, regardless of the information that is provided in the stages. Based upon both the information and the lack of information in the Pre-Feasibility Study, the recommendation of this report is that SolGold should abandon the proposed Cascabel gold-silver-copper project at the present time. As an alternative, investors should decline to invest in the project and regulatory agencies should decline to issue permits for the project.

OVERVIEW

The Australian company SolGold has released the Pre-Feasibility Study for the gold-silver-copper Cascabel Project in Imbabura Province of northern Ecuador (SRK Consulting (Canada) Inc., 2024) (see Figs. 1-2). The completion of the Pre-Feasibility Study is a critical stage in mine planning, after which the company decides whether to advance the planning to the Feasibility Study, to re-do the Pre-Feasibility Study, or to abandon the project (Henderson and Morrison, 2022; Carter and Tolmer, 2023; Clark and Dağdelen, 2023; Turek, 2023). Companies that trade on the Toronto Stock Exchange, such as SolGold, are also required to publicly release the Pre-Feasibility Study in the format of an NI (National Instrument) 43-101 Technical Report (CIM, 2011). Thus, the release of the Pre-Feasibility Study is also an opportunity for investors to decide whether they should increase or decrease their investments or to wholly divest from a company or a particular mining project. Moreover, the Pre-Feasibility Study provides critical information to other stakeholders, such as the communities that might be impacted by mining. Finally, although regulatory agencies usually have their own requirements for studies that should be included with permit applications, which may or may not be available to the public, those studies are typically expected to be consistent with the information provided to investors, such as the Pre-Feasibility Study.

The Cascabel Property covers 4979 hectares within the Ibarra canton of the Imbabura province (see Fig. 2). The property includes the Alpala deposit, the Tandayama-America deposit, and the Aguinaga deposit (see Fig. 3). The current state of mine planning is most advanced for the Alpala deposit and least for the Aguinaga deposit. The Alpala deposit would be mined using block caving, which is a method of underground mining in which panels or blocks of ore are undercut to cause caving. The broken ore falls to the drawpoint from where it is removed for processing. Block caving results in a subsidence crater with appearance and environmental impacts similar to an open pit (see Fig. 4). Both open-pit and underground mining are still under consideration for the Tandayama-America deposit with no mining plan yet proposed for the Aguinaga deposit (SRK Consulting (Canada) Inc., 2024).

The Pre-Feasibility Study identifies three high-risk factors, which are negative pressure from the community, uncontrolled and unanticipated rockfalls within the underground mine, and seismic events within the mine, all of which are regarded as equally risky. With regard to the threat of negative pressure from the community, the Pre-Feasibility Study elaborates, “In particular: Open Pit and new TSF [Tailings Storage Facility] location” (SRK Consulting (Canada) Inc., 2024). In response to the threat, the Pre-Feasibility Study states one of the proposed actions as “Do not publish the location of any controversial infrastructure (e.g. Tailings, Open Pit)” (SRK Consulting (Canada) Inc., 2024). It is difficult to understand how the locations of an open pit or tailings storage facility could be kept secret. Moreover, it is unclear as to why the authors of the Pre-Feasibility Study believe that an open pit would be objectionable to the community, while block caving would be acceptable, since the surface expression and environmental impacts have a great deal in common (see Fig. 4), especially from the viewpoint of the community. A summary of community concerns from the viewpoint of the community is presented in Zorrilla and Acosta (2024).

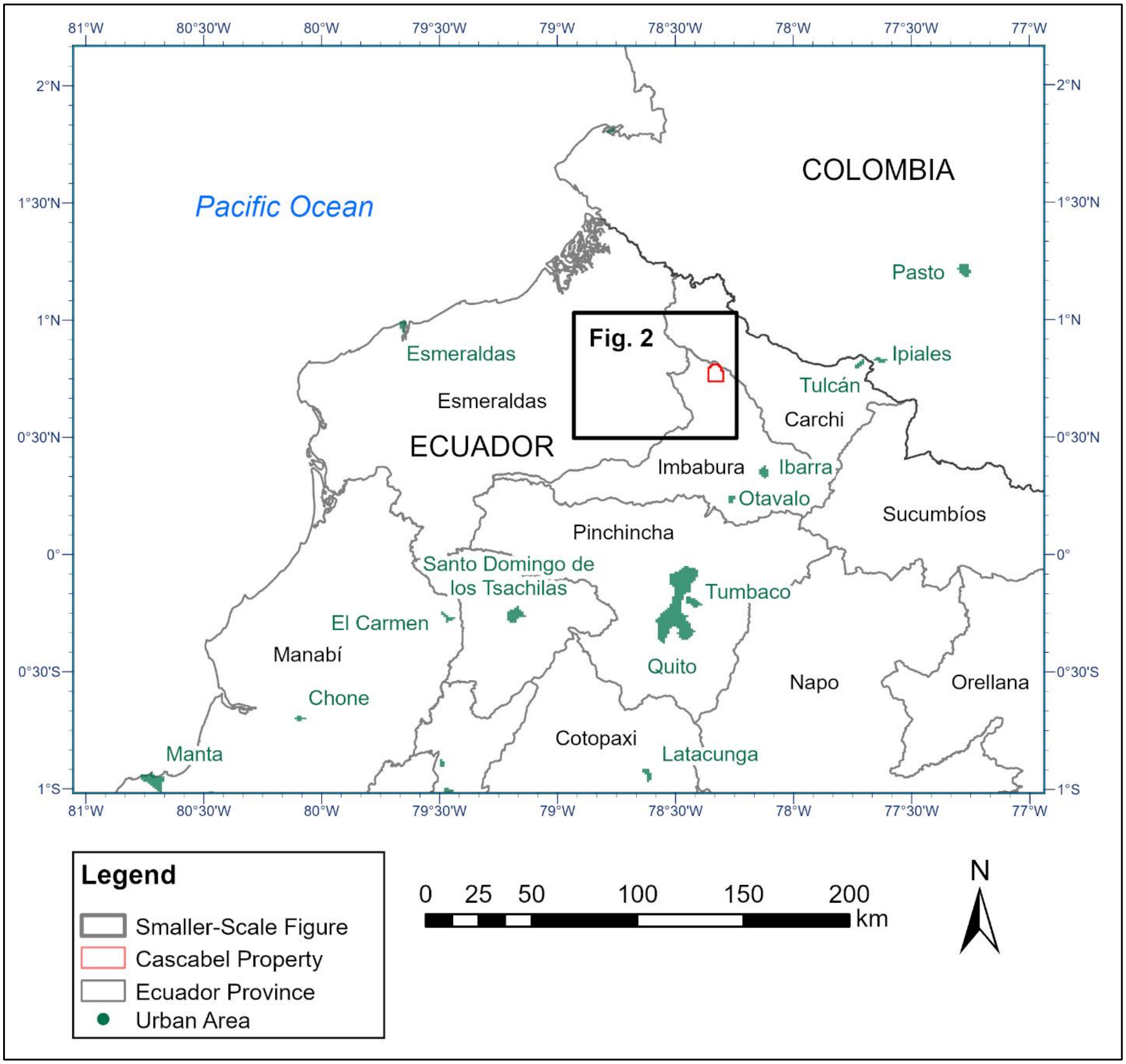


Figure 1. SolGold has released a Pre-Feasibility Study for the proposed Cascabel gold-silver-copper project in Imbabura province of northern Ecuador. See smaller-scale view in Fig. 2. Cascabel Property traced from map in SRK Consulting (Canada) Inc. (2024).

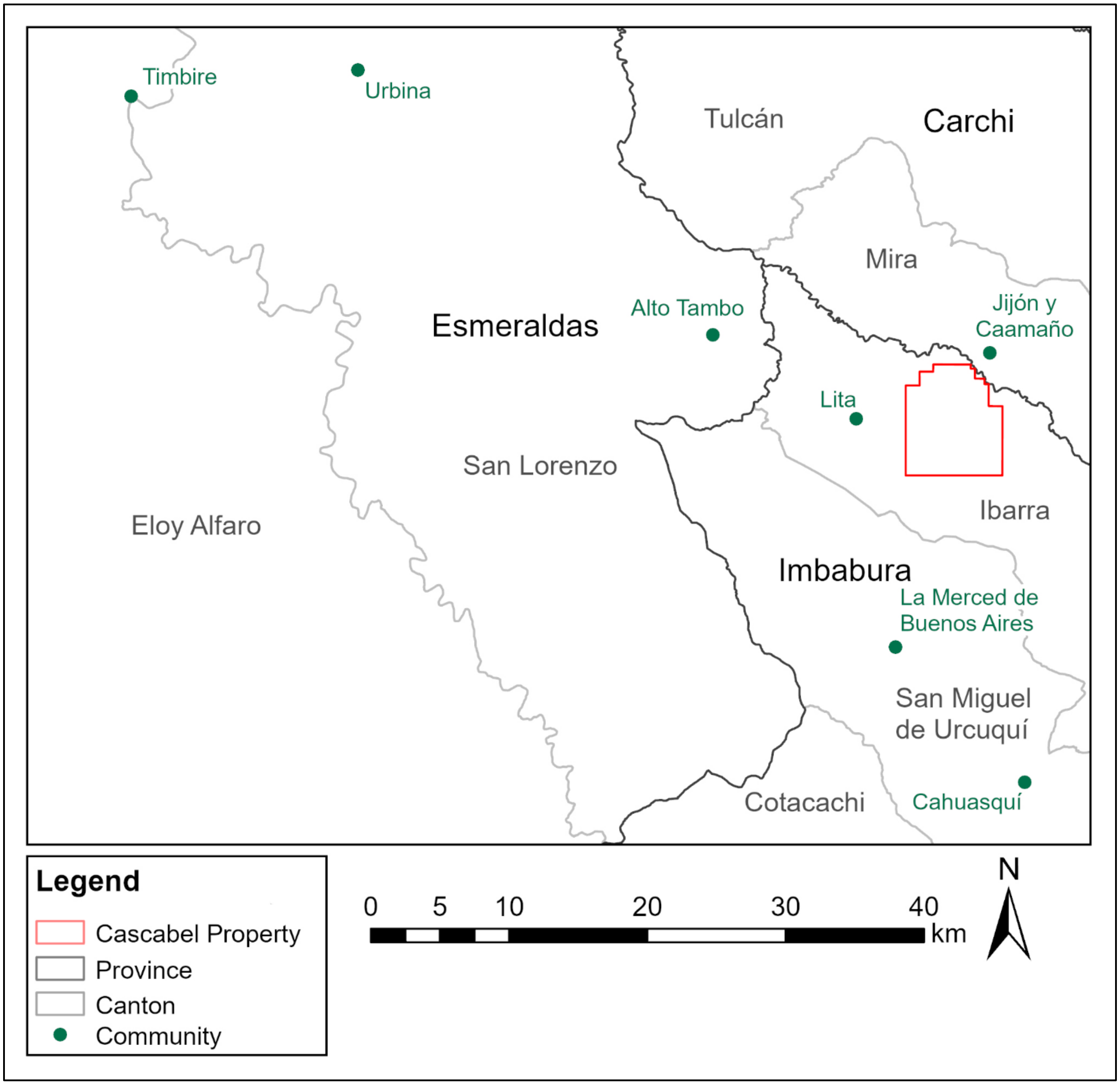
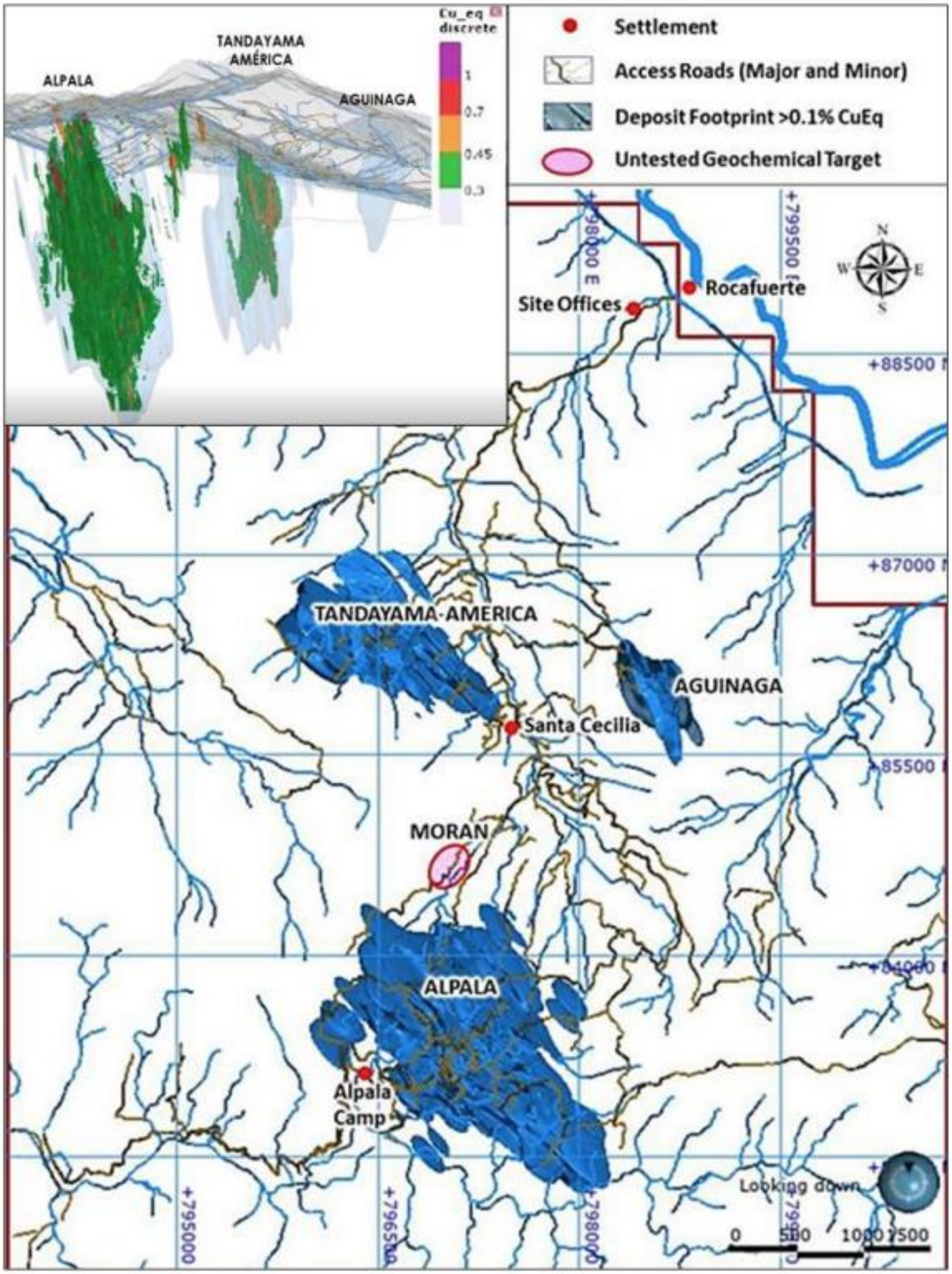


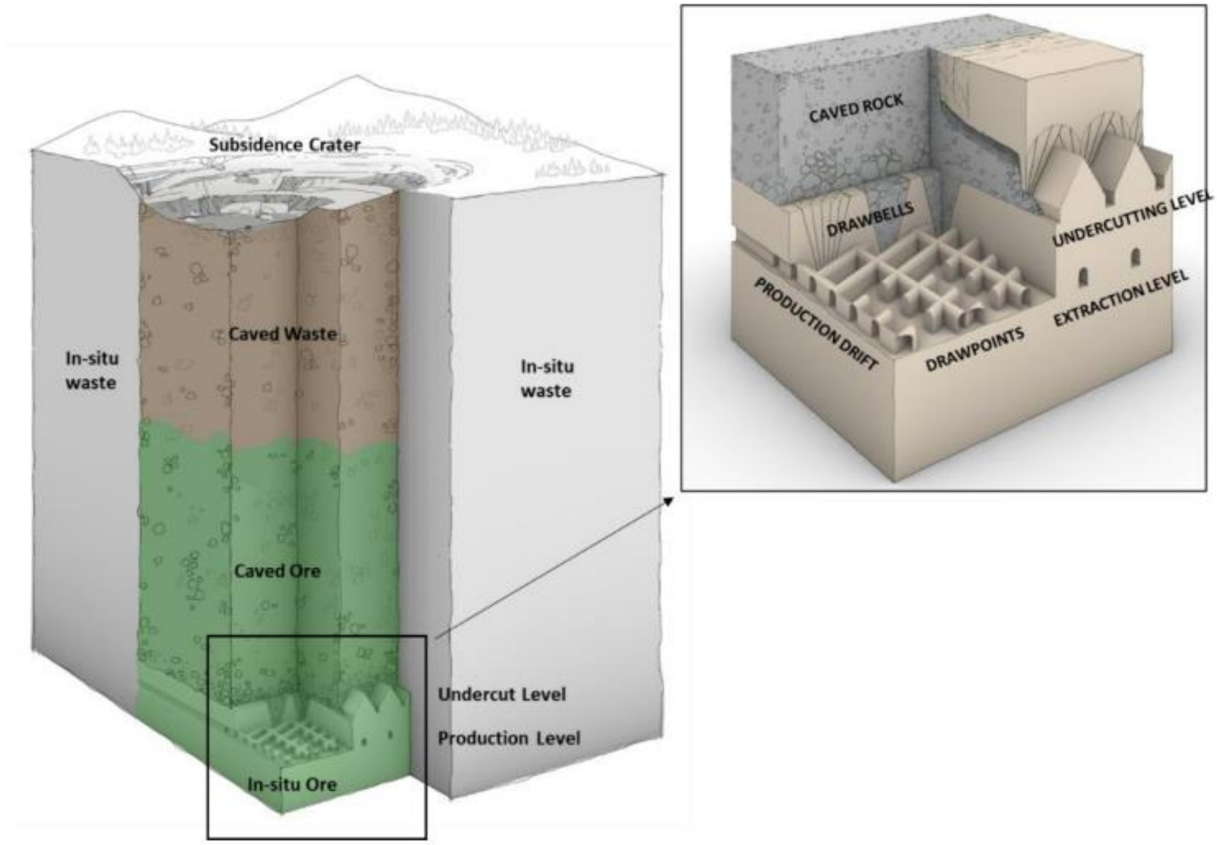
Figure 2. SolGold has released a Pre-Feasibility Study for the proposed Cascabel gold-silver-copper project in Ibarra canton of Imbabura province. See larger-scale view in Fig. 1. Cascabel Property traced from map in SRK Consulting (Canada) Inc. (2024).



Source: Artica et al., 2022

Figure 10-1: Porphyry deposits at the Cascabel concession in northern Ecuador

Figure 3. The Pre-Feasibility Study reports proven and probable reserves for the Alpala deposit, but only indicated resources for the Tandayama-America deposit (see Figs. 5a-b). An underground mine using block caving is proposed for the Alpala deposit, while both open pit and underground mining are being studied for the Tandayama-America deposit. Map from SRK Consulting (Canada) Inc. (2024).



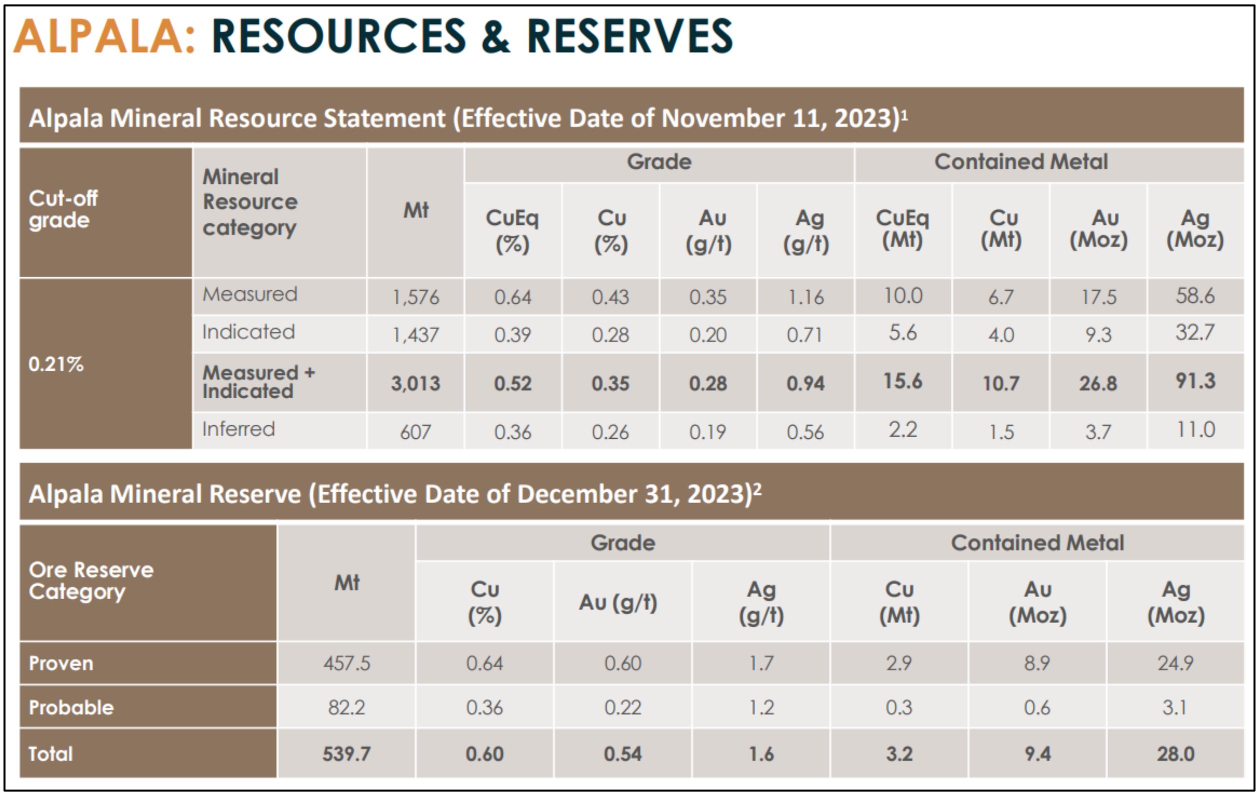
Source: Jakubec et al. 2023

Figure 16-2: Block cave mining method example

Figure 4. Block caving is a method of underground mining in which panels or blocks of ore are undercut to cause caving. The broken ore falls to the drawpoint from where it is removed for processing. Block caving results in a subsidence crater with appearance and environmental impacts similar to an open pit. Figure from SRK Consulting (Canada) Inc. (2024).

Both the Pre-Feasibility Study and a follow-up corporate presentation to investors (SolGold, 2024) emphasize the size of the resources on the Cascabel Property, but do not draw adequate attention to the low grade of those resources. The Alpala deposit has measured and indicated resources of 3013 million metric tons at a gold grade of 0.28 grams per metric ton, silver grade of 0.94 grams per metric ton, and copper grade of 0.35% (see Fig. 5a). The Tandayama-America deposit has indicated resources of 722 million metric tons with a gold grade of 0.19 grams per metric ton and copper grade of 0.23%, with no mention of a silver grade (see Fig. 5b). For reference, average grades of existing mines are 0.8 grams per metric ton for gold, 10 grams per metric ton for silver, and 0.64% for copper (Nassar et al., 2022a-b). According to the corporate presentation, “Cascabel has one of the largest gold resources amongst primary gold mines and assets worldwide, the second largest not controlled by a major” (SolGold, 2024). The claim might be true, but for the comparison group of nine other deposits that is provided in the presentation (see Fig. 6a), the Alpala and Tandayama-America deposits rank 9th and 11th, respectively, in terms of the grade of gold (see Table 1a). According to the same corporate presentation, “Cascabel is the largest undeveloped copper resource in Latin America not controlled by a major” (SolGold, 2024). Again, the claim might be true, but for the comparison group of 10 other deposits that is provided in the presentation (see Fig. 6b), the Alpala and

Tandayama-America deposits rank 8th and 12th, respectively, in terms of the grade of copper (see Table 1b).



ALPALA: RESOURCES & RESERVES

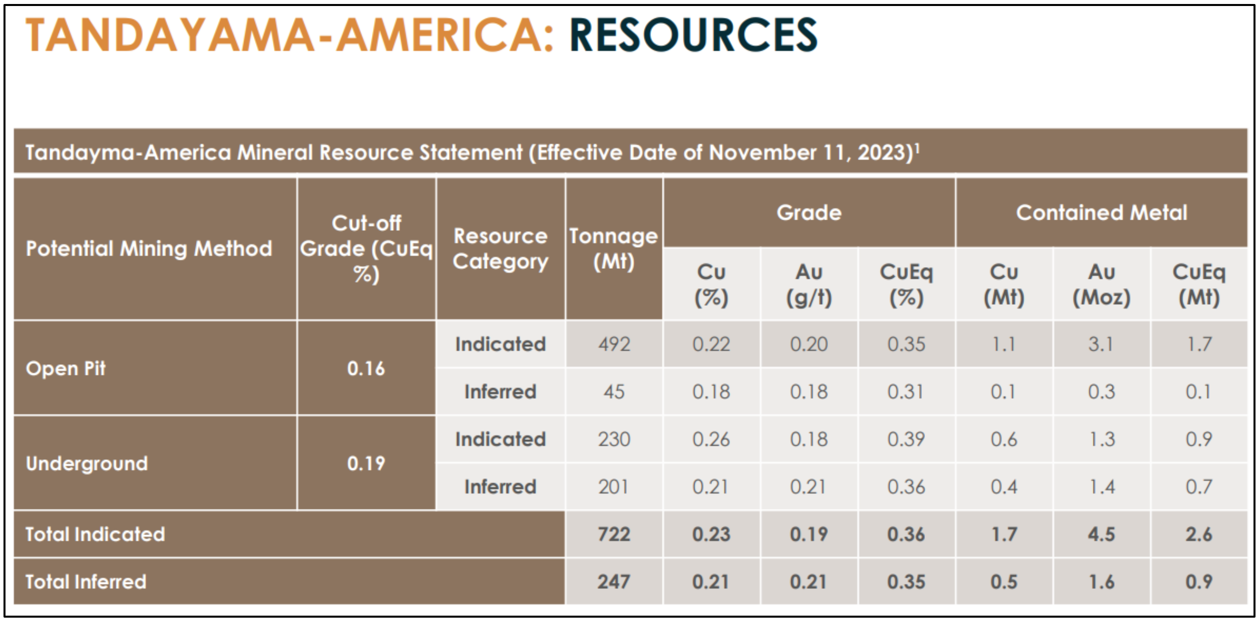
Alpala Mineral Resource Statement (Effective Date of November 11, 2023)[1]

Cut-off grade	Mineral Resource category	Mt	Grade				Contained Metal			
			CuEq (%)	Cu (%)	Au (g/t)	Ag (g/t)	CuEq (Mt)	Cu (Mt)	Au (Moz)	Ag (Moz)
0.21%	Measured	1,576	0.64	0.43	0.35	1.16	10.0	6.7	17.5	58.6
	Indicated	1,437	0.39	0.28	0.20	0.71	5.6	4.0	9.3	32.7
	Measured + Indicated	**3,013**	**0.52**	**0.35**	**0.28**	**0.94**	**15.6**	**10.7**	**26.8**	**91.3**
	Inferred	607	0.36	0.26	0.19	0.56	2.2	1.5	3.7	11.0

Alpala Mineral Reserve (Effective Date of December 31, 2023)[2]

Ore Reserve Category	Mt	Grade			Contained Metal		
		Cu (%)	Au (g/t)	Ag (g/t)	Cu (Mt)	Au (Moz)	Ag (Moz)
Proven	457.5	0.64	0.60	1.7	2.9	8.9	24.9
Probable	82.2	0.36	0.22	1.2	0.3	0.6	3.1
Total	**539.7**	**0.60**	**0.54**	**1.6**	**3.2**	**9.4**	**28.0**

Figure 5a. The Pre-Feasibility Study determined that the Alpala deposit had 539.7 million metric tons of proven and probable reserves and 3013 million metric tons of measured and indicated resources. The essential distinction is that "a Mineral Reserve is the economically mineable part of a Measured and/or Indicated Mineral Resource" (CIM, 2014). Table from SRK Consulting (Canada) Inc. (2024).

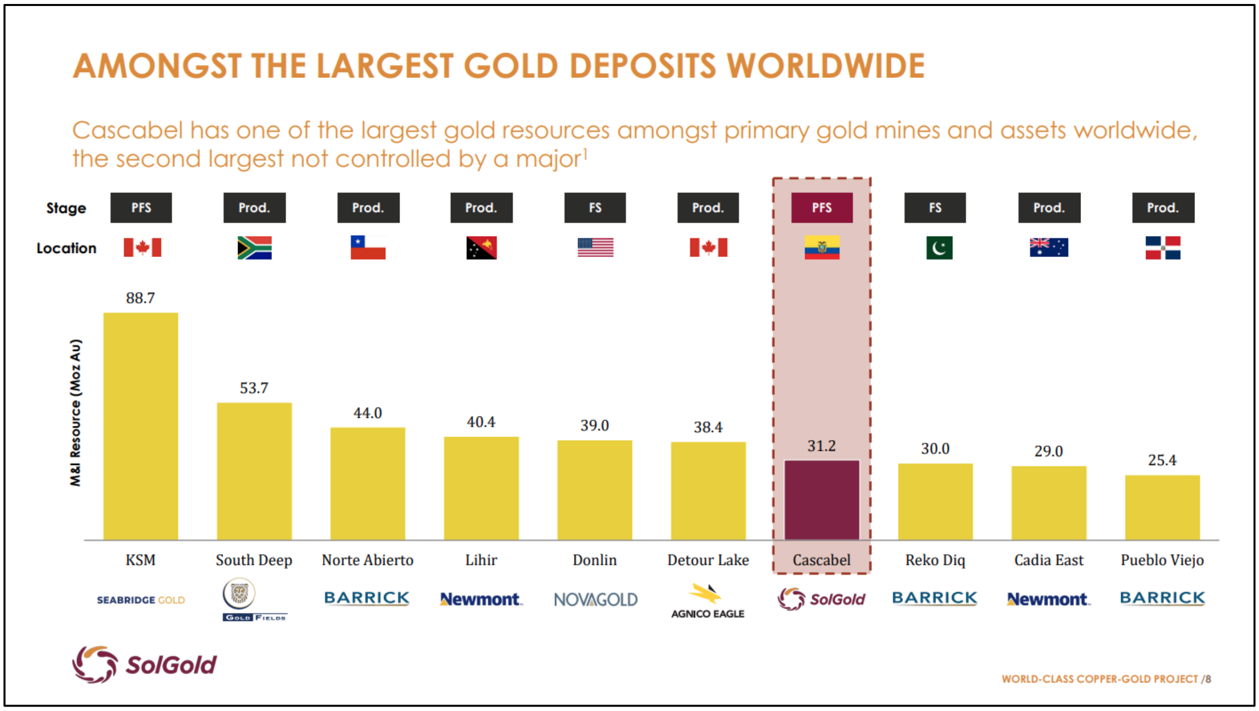


TANDAYAMA-AMERICA: RESOURCES

Tandayma-America Mineral Resource Statement (Effective Date of November 11, 2023)[1]

Potential Mining Method	Cut-off Grade (CuEq %)	Resource Category	Tonnage (Mt)	Grade			Contained Metal		
				Cu (%)	Au (g/t)	CuEq (%)	Cu (Mt)	Au (Moz)	CuEq (Mt)
Open Pit	0.16	Indicated	492	0.22	0.20	0.35	1.1	3.1	1.7
		Inferred	45	0.18	0.18	0.31	0.1	0.3	0.1
Underground	0.19	Indicated	230	0.26	0.18	0.39	0.6	1.3	0.9
		Inferred	201	0.21	0.21	0.36	0.4	1.4	0.7
Total Indicated			**722**	**0.23**	**0.19**	**0.36**	**1.7**	**4.5**	**2.6**
Total Inferred			**247**	**0.21**	**0.21**	**0.35**	**0.5**	**1.6**	**0.9**

Figure 5b. The Pre-Feasibility Study determined that the Tandayama-America deposit had 722 million metric tons of indicated resources, no measured resources, and no reserves. The difference between indicated resources and measured resources is that indicated resources can be used "to support mine planning and evaluation of the economic viability of the deposit," while measured resources can be used "to support **detailed** mine planning and **final** evaluation of the economic viability of the deposit" (emphasis added) (CIM, 2014). The essential distinction between resources and reserves is that "a Mineral Reserve is the economically mineable part of a Measured and/or Indicated Mineral Resource" (CIM, 2014). Table from SRK Consulting (Canada) Inc. (2024).

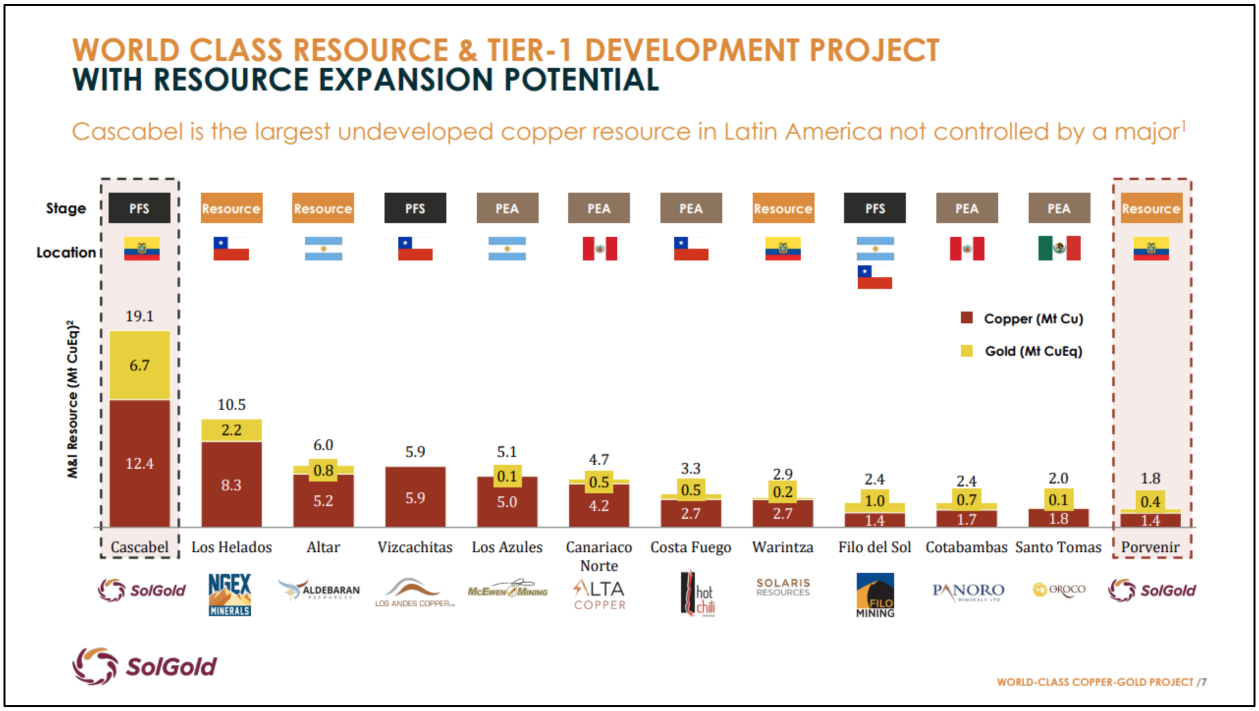


AMONGST THE LARGEST GOLD DEPOSITS WORLDWIDE

Cascabel has one of the largest gold resources amongst primary gold mines and assets worldwide, the second largest not controlled by a major[1]

WORLD-CLASS COPPER-GOLD PROJECT /8

Figure 6a. According to a corporate presentation by SolGold (2024), "Cascabel has one of the largest gold resources amongst primary gold mines and assets worldwide, the second largest not controlled by a major." The claim might be true, but it leaves out the information that the measured and indicated gold resources are very low-grade. With grades of 0.28 grams per metric ton for the Alpala deposit and 0.18 grams per metric ton for the Tandayama-America deposit, in terms of the grade of gold, the Alpala and Tandayama-America deposits rank 9th and 11th, respectively, for the above comparison group of nine other deposits (see Table 1a). The average grade of existing gold mines is 0.8 grams per metric ton. Figure from SolGold (2024).



WORLD CLASS RESOURCE & TIER-1 DEVELOPMENT PROJECT
WITH RESOURCE EXPANSION POTENTIAL

Cascabel is the largest undeveloped copper resource in Latin America not controlled by a major[1]

Figure 6b. According to a corporate presentation by SolGold (2024), "Cascabel is the largest undeveloped copper resource in Latin America not controlled by a major." The claim might be true, but it leaves out the information that the measured and indicated copper resources are very low-grade. With grades of 0.35% for the Alpala deposit and 0.23% for the Tandayama-America deposit, the Alpala and Tandayama-America deposits rank 8th and 12th, respectively, for the above comparison group of 10 other deposits (see Table 1b). The average grade of existing copper mines is 0.64%. Figure from SolGold (2024).

Because of the low grade of the resources, two issues that come to the forefront are the plans for the management of mine tailings and the availability of electricity for the mine project. Out of the 3013 million metric tons of resources for the Alpala deposit, the Pre-Feasibility Study identifies 539.7 million metric tons of proven and probable reserves (see Fig. 5a) that would be mined over a period of 28 years. Thus, mining of the Alpala deposit requires a plan for the permanent storage of 529 million metric tons of tailings (SRK Consulting (Canada) Inc., 2024). No mineral reserves have yet been identified for the Tandayama-America deposit (see Fig. 5b).

The connection between ore grade and electricity is that all of the excavated ore must be crushed for extraction of the commodity of value, regardless of the grade of the ore. The Pre-Feasibility Study clarifies that no electricity is currently available in the area and the mining project depends upon the anticipated future availability of electricity. According to the Pre-Feasibility Study, "The site power will be supplied from new hydroelectric power projects near the site. Multiple hydroelectric projects are currently in the advanced planning stage, with a total capacity of 200 MW having been identified in the local area. The Project plans to participate in these projects and secure the supply of power from them. Additional power from solar is being considered but is not developed enough to incorporate into this study" (SRK Consulting (Canada) Inc., 2024).

Table 1a. Ranking of Cascabel Project among comparison group for gold grade of measured and indicated resources[1]

Company	Project	Measured + Indicated Resources Gold Grade (g/t)
Gold Fields[2]	South Deep	6.92
Novagold[3]	Donlin	2.24
Newmont[4]	Lihir	2.20
Barrick[5]	Pueblo Viejo	2.01
Agnico Eagle[6]	Detour Lake	1.21
Barrick[7]	Norte Abierto	0.54
Seabridge Gold[8]	KSM	0.51
Newmont[9]	Cadia East	0.35
SolGold[10]	Cascabel (Alpala)	0.28
Barrick[11]	Reko Diq	0.26
SolGold[10]	Cascabel (Tandayama-America)	0.19

[1] Comparison group from SolGold (2024) (see Fig. 6a)

[2] Gold Fields (2012)

[3] Hanson et al. (2021)

[4] Gleason et al. (2020a)

[5] Yuhasz et al. (2023)

[6] Leite et al. (2020)

[7] Barrick (2023)

[8] Tetra Tech, Inc. et al. (2022)

[9] Gleason et al. (2020b)

[10] SRK Consulting (Canada) Inc. (2024)

[11] Barrick (2022)

Table 1b. Ranking of Cascabel Project among comparison group for copper and copper-equivalent grade of measured and indicated resources[1]

Company	Project	Measured + Indicated Resources	
		Copper Grade (%)	Copper-Equivalent Grade (%)
Aldebaran Resources[2]	Altar	0.430	0.474
NGEx Minerals[3]	Los Helados	0.40	0.51
LTA Copper[4]	Cañariaco Norte	0.39	0.42
Los Andes Copper[5]	Vizcachitas	0.383	0.436
Hot Chili[6]	Costa Fuego	0.38	0.47
Solaris Resources[7]	Warintza	0.37	0.53
SolGold[8]	Porvenir	0.35	0.44
SolGold[9]	Cascabel (Alpala)	0.35	0.52
Panoro Minerals[10]	Cotabambas	0.33	0.43
Oroco[11]	Santo Tomás	0.330	0.37
Filo Mining[12]	Filo del Sol	0.33	
SolGold[9]	Cascabel (Tundayama-America)	0.23	0.36

[1] Comparison group from SolGold (2024) (see Fig. 6b)
[2] Marek et al. (2021)
[3] SLR Consulting (Canada) Ltd (2023)
[4] Ausenco (2022)
[5] Los Andes Copper Ltd. (2022)
[6] Hot Chili Limited (2022)
[7] Solaris Resources (2024)
[8] Junior Mining Network (2022)
[9] SRK Consulting (Canada) Inc. (2024)
[10] AGP Mining Consultants Inc. (2024)
[11] Ausenco (2023)
[12] Filo (2023)

The objective of this report is to critically examine the plans for tailings management and the generation of electricity for the proposed Cascabel gold-silver-copper project. The critical examination will then be used to answer the following question: At this stage, should the mining company advance the project to the Feasibility Study, re-do the Pre-Feasibility Study, or abandon the project? Of course, the answer to the above question will have implications as to what actions should be taken or not taken by investors, regulatory agencies, the local community, and other stakeholders. To facilitate reading by non-specialists, this report includes a tutorial on key mining concepts, including tailings and tailings dams, tailings pipelines, acid mine drainage and metal leaching, mineral resources and mineral reserves, multiple accounts analysis, and the stage-gate process for mine planning, with particular emphasis on the Pre-Feasibility Study. The subsection on “Tailings Pipelines” includes a compilation of 61 tailings pipeline failures that has not previously been published. After a summary of the Pre-Feasibility Study, the objective will be refined into a series of six questions in the “Methodology” section.

TUTORIAL ON KEY MINING CONCEPTS

Tailings and Tailings Dams

The management or storage or disposal of mine waste is a critical component of any modern, large-scale mining project, regardless of the ore grade. Waste rock and tailings comprise the vast majority of mine waste. Waste rock is the rock that must be removed to reach the ore body. Whether a particular body of rock is regarded as ore or waste rock can vary as the cut-off grade varies, in which the cut-off grade is the minimum concentration of the commodity of value for which a particular rock body can be processed at a profit under particular social, economic and technical circumstances. The tailings are the wet and crushed rock particles that remain after the commodity of value, such as gold, silver and copper, have been extracted from the ore body.

Because of the typical size of the blocks, waste rock can often be deposited as a free-standing waste rock dump. By contrast, because they are wet and fine-grained, tailings require confinement behind a dam. In conventional tailings management, the wet tailings are piped to a tailings storage facility with no dewatering, so that solids contents are in the range 20-40% by mass (Klohn Crippen Berger, 2017). The mixture of tailings and water is then discharged into the tailings pond from the crest of the dam through spigots that connect to a pipe that comes from the ore processing plant (see Figs. 7a-b). Tailings can be divided into two sizes with very different physical properties, which are the coarse tailings or sands (larger than 0.075 mm) and the fine tailings or slimes (smaller than 0.075 mm). The hydraulic discharge results in the separation of the sizes of tailings by gravity. The larger sands settle closer to the dam to form a beach. The smaller slimes and water travel farther from the dam to form a settling pond where the slimes slowly settle out of suspension. Typically, water is reclaimed from the settling pond and pumped back into the mining operation.

Because of the well-known detrimental impact of high water content on the stability of tailings dams, it is now regarded as a best practice to partially dewater the tailings before shipment to a tailings storage facility. Figs. 7a-b shows conventional tailings that are hydraulically discharged from the crest of a tailings dam with a solids content of 35%. Thickened tailings have solids contents in the range 40-60% by mass, while high-density thickened or paste tailings have solids contents in the range 60-75% by mass. Finally, filtered tailings have solids content greater than 80% and cannot be pumped, but must be transported to the tailings storage facility by truck or conveyor. It is important that the distinctions among the different degrees of dewatering does not strictly depend upon the solids content, but upon the shear stress required to initiate flow. Thus, some tailings with solids content as high as 60% can still behave like conventional tailings (Klohn Crippen Berger, 2017).

Mineral processing can proceed through a sequence of steps that produce different types of tailings with different requirements for permanent storage. The earlier steps produce what are called "rougher tailings." The goal of the earlier steps is to recover as much of the commodity of value as possible, even if it produces a relatively low-grade concentrate with a large amount of potentially toxic impurities. Thus, the rougher tailings should contain very little of the commodity of value, as well as very little of any toxic impurities that would follow the same chemical pathway as the commodity of value. The later steps produce what are called "cleaner tailings." The goal of the later steps is to increase the grade of the concentrate as much as possible, which involves removing as much of the impurities as possible, some of which may be toxic. Therefore, compared with the rougher tailings, the cleaner tailings should contain less of the commodity of value and more of the potentially toxic impurities. Typically, the volume of rougher tailings is much greater than the volume of cleaner tailings, since the cleaner tailings are produced from a concentrate. In summary, contrary to what the name implies, the cleaner tailings could be more toxic with stricter controls needed for safe and permanent storage.

Although tailings dams and water-retention dams are both built for the purpose of restricting the flow of water or waste containing water, they are fundamentally different types of civil engineering structures. This important point was emphasized in the textbook by Vick (1990) entitled Planning, Design, and Analysis of Tailings Dams. According to Vick (1990), "A recurring theme throughout the book is that there are significant differences between tailings embankment and water-retention dams … Unlike dams constructed by government agencies for water-retention purposes, tailings dams are subject to rigid economic constraints defined in the context of the mining project as a whole. While water-retention dams produce economic benefits that presumably outweigh their cost, tailings dams are economic liabilities to the mining operation from start to finish. As a result, it is not often economically feasible to go to the lengths sometimes taken to obtain fill for conventional water dams."

Figure 7a. A mixture of water and tailings is hydraulically discharged behind the Cobre tailings dam at the Atalaya Mining Riotinto copper mine in Spain. The mixture has a solids content of 35% by mass. For the Cascabel Project, the cleaner tailings would have a solids content of 45% by mass, while the rougher tailings would have a solids content of 55% by mass. See close-up view of hydraulic discharge in Fig. 7b. Photo taken by the author on June 21, 2019.

Figure 7b. A mixture of water and tailings is hydraulic discharged behind the Cobre tailings dam at the Atalaya Mining Riotinto copper mine in Spain. The mixture has a solids content of 35% by mass. For the Cascabel Project, the cleaner tailings would have a solids content of 45% by mass, while the rougher tailings would have a solids content of 55% by mass. See long view of hydraulic discharge in Fig. 7a. Photo taken by the author on June 21, 2019.

In addition to the economic unfeasibility of traveling the distances that are sometimes ideal for obtaining appropriate fill, Vick (1990) gives many other examples of ways in which it is not economically feasible to build a tailings dam in the same way as a water-retention dam. An earthen water-retention dam is constructed out of rock and soil that is chosen for its suitability for the construction of dams. However, a tailings dam is normally built out of construction material that is created by the mining operation, such as waste rock, the coarser fraction of the tailings, or rockfill or earthfill that is quarried from the mine site. In addition, a water-retention dam is built completely from the beginning before its reservoir is filled with water, while a tailings dam is built in stages as more tailings are produced that require storage, as more material from the mining operation (such as waste rock) becomes available for construction, and as financing becomes available for further construction. The implications of staged construction were summarized in the SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook. According to Snow (2022), "The construction of a TSF over an operational period of many years or even decades introduces the potential for discontinuity in construction oversight, quality control, monitoring, and recognition of performance factors that can affect operation and safety."

The consequences of the very different constructions of tailings dams and water-retention dams are the very different safety records of the two types of structures. According to a widely-cited paper by Davies (2002), “It can be concluded that for the past 30 years, there have been approximately 2 to 5 ‘major’ tailings dam failure incidents per year … If one assumes a worldwide inventory of 3500 tailings dams, then 2 to 5 failures per year equates to an annual probability somewhere between 1 in 700 to 1 in 1750. This rate of failure does not offer a favorable comparison with the less than 1 in 10,000 that appears representative for conventional dams. The comparison is even more unfavorable if less ‘spectacular’ tailings dam failures are considered. Furthermore, these failure statistics are for physical failures alone. Tailings impoundments can have environmental ‘failure’ while maintaining sufficient structural integrity (e.g. impacts to surface and ground waters).” Both the total number of tailings dams and the number of tailings dams failures cited by Davies (2002) are probably too low. However, the Independent Expert Engineering Investigation and Review Panel (2015a) found a similar failure rate in tailings dams of 1 in 600 per year during the 1969-2015 period in British Columbia (Canada).

The preceding discussion largely contrasts tailings dams and water-retention dams that are in active operation. At the end of its useful life, or when it is no longer possible to inspect and maintain the 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. However, the permanent storage of tailings, which has already been mentioned several times, cannot be overemphasized. A tailings dam can never be dismantled unless the tailings can be moved to another location, such as an exhausted open pit. Typically, a tailings dam is expected to confine the often toxic tailings in perpetuity, although normally the inspection, monitoring, maintenance, and review of the dam cease at some point after the end of the mining project.

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 tailings storage facility, aside from moving the tailings to a belowground location, such as an exhausted open pit. The relevance of the GISTM will be further discussed in the subsection "Multiple Accounts Analysis."

In a conference presentation, Vick (2014a) concluded that "System failure probabilities much less than 50/50 are unlikely to be achievable over performance periods greater than 100 years … system failure probability approaches 1.0 after several hundred years." Vick (2014a) continued, "For closure, system failure is inevitable … so closure risk depends solely on failure consequences." In the accompanying conference paper, Vick (2014b) elaborated, "Regardless of the return period selected for design events, the cumulative failure probability will approach 1.0 for typical numbers of failure modes and durations. This has major implications. For closure conditions, the likelihood component of risk becomes unimportant and only the consequence component matters … This counterintuitive result for closure differs so markedly from operating conditions that it bears repeating. In general, reducing failure likelihood during closure—through more stringent design criteria or otherwise—does not materially reduce risk, simply because there are too many opportunities for too many things to go wrong. In a statistical sense, all it can do is to push failure farther out in time. System failure must be accepted as inevitable, leaving reduction of failure consequences as the only effective strategy for risk reduction during closure." It should be noted that Vick (2014a-b) did not explicitly address the issues of long-term lack of maintenance, but simply the multitude of things that could go wrong even if maintenance were carried out in perpetuity.

Tailings Pipelines

Tailings storage facilities are usually close to the ore processing plant, so that tailings pipelines are typically short, such as a few kilometers or less (see Fig. 8). On the other hand, in some cases, there has been no workable site for a tailings storage facility, so that some tailings pipelines have extended up to hundreds of kilometers in length. These long-distance tailings pipelines have experienced an uncomfortable failure rate. According to the SME (Society for Mining, Metallurgy and Exploration) Surface Mining Handbook, "For quite some time, the mining industry has been dealing with the problems and consequences caused by pipeline failures. Failures often result in environmental damage that may affect people that live near pipelines (e.g., in the case of water or land contamination, or as a direct effect of flooding populated areas). They are very costly in the sense that they take considerable time and efforts to be fully identified and corrected. Any failure in a pipeline can trigger an entire check of the operation, and even lead to revoking licenses and even the closure of an operation. Furthermore, the reputational damage caused by a pipe failure can be considerable. In addition, there are the human and environmental impacts. A failure in a slurry pipeline may involve fatal events and environmental contamination, which can affect the livelihood of local habitants" (Ihle and Valencia, 2023). It should be noted that the preceding passage from the SME Surface Mining Handbook refers not only to tailings pipelines, but to slurry pipelines at mining operations in general, including pipelines for transport of crushed ore and mineral concentrates.

Figure 8. At the Barrick Pueblo Viejo gold mine in the Dominican Republic, tailings are transported by pipeline about 3.5 kilometers from the ore processing plant to the El Llagal tailings storage facility. Photo taken by the author on July 13, 2023.

Table 2 lists 61 documented failures of tailings pipelines, in which failure is defined as an accidental release of tailings. The most recent documented tailings pipeline failure occurred at the Coeur Alaska Kensington mine north of Juneau, Alaska (USA) on January 31, 2024, in which 400 cubic meters of tailings were released into the Johnson Creek watershed (Coeur Alaska, 2024; see Table 2). A tailings pipeline coming from the Codelco Andina mine southeast of Los Andes, Valparaiso Region, Chile, ruptured in the crossing over Rio Blanco, so that 2500 cubic meters of tailings were released into the river (Universidad de Valparaíso—Chile, 2019; see Table 2). The preceding event occurred on January 23, 2019, so that it was overshadowed by the release of 9.7 million cubic meters of tailings with 270 fatalities that occurred at the Córrego do Feijão mine near Brumadinho in Minas Gerais, Brazil, only two days later. Later in 2019 a tailings pipeline from the Freeport McMoRan Chino mine southeast of Silver City, New Mexico (USA) ruptured, releasing 7500 cubic meters of tailings into Whitewater Creek (Earthworks, 2019; see Table 2). The worst tailings pipeline failure in history occurred on April 26, 1999, at the Manila Mining Corp. Surigao Del Norte Placer in the Philippines, in which the rupture of a tailings pipeline released 400,000 cubic meters of tailings that traveled 12 kilometers, resulting in four deaths and the burial of 17 homes and 51 hectares of rice fields (Center for Science in Public Participation, 2022; see Table 2).

Table 2. Chronology of documented failures of tailings pipelines

Mine	Location	Date	Damage/Details
Coeur Alaska Kensington mine[1]	72 km north of Juneau, Alaska, USA	January 31, 2024	Release of 400 m^3 of tailings into Johnson Creek watershed
St Barbara Simberi mine[2]	Simberi Island, New Ireland Province, Papua New Guinea	May 2021	Deep sea tailings placement (DSTP) pipeline at water depth of 54 m
Codelco Andina mine[3]	34 km southeast of Los Andes, Valparaiso Region, Chile	January 23, 2019	Release of 2500 m^3 of tailings into Río Blanco
Freeport McMoRan Chino mine[4]	19 km southeast of Silver City, New Mexico, USA	2019	Release of 7500 m^3 of tailings into Whitewater Creek with entry of tailings into James Canyon Reservoir
KGHM International Robinson mine[5]	Eastern Nevada, USA, 11 km west of Ely	November 30, 2016	Release of 20.8 m^3 of tailings
Sumitomo Metal Mining Pogo mine[6]	145 km southeast of Fairbanks, Alaska, USA	May 7, 2015	Release of 350 m^3 of tailings and cement
Jaduguda uranium mill[7]	Jharkhand, India	2015	
ArcelorMittal Minorca mine[8]	Virginia, Minnesota, USA	May 2013 - April 2014	Failures on three occasions released 6500 m^3 of tailings into wetlands
Zangezur Copper Molybdenum Combine[9]	Kajaran, Syunik Province, Armenia	November 15, 2013	Tailings flowed into Norashenik River for several days
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	August 27, 2013	Release of tailings into Koekemoer Spruit
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	July 2, 2013	Release of tailings onto property of Matlosana Municipality
Newmont Twin Creeks mine[5]	42 km northeast of Golconda, Nevada, USA	June 30, 2013	Release of 723 m^3 of tailings
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	June 1, 2013	Release of tailings onto area of 7500 m^2
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	March 8, 2013	Release of tailings onto previously impacted area
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	March 4, 2013	Release of tailings onto area of 1500 m^2
Newmont Twin Creeks mine[5]	42 km northeast of Golconda, Nevada, USA	February 20, 2013	Release of 35 m^3 of tailings with 0.24 kg of cyanide

AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	February 19, 2013	Release of tailings onto area of 1000 m^2
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	January 12, 2013	Release of tailings onto area of 500 m^2
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	March 5, 2012	Release of tailings onto area of 350 m^2 of adjacent property
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	February 24, 2012	Release of tailings onto area of 350 m^2 of adjacent property
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	August 8, 2011	Release of tailings onto mine road
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	August 3, 2011	Release of tailings onto road and into scrubland
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	March 8, 2011	Release of tailings onto mine property
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	March 8, 2011	Release of tailings into scrubland
Kennecott Bingham Canyon mine[11]	Southwest of Salt Lake City, Utah, USA	2011	Release of 380-1100 m^3 of tailings
Asarco Mission Complex mine[11]	29 km south of Tucson, Arizona, USA	2011	Release of tailings into dry wash
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	July 28, 2010	Release of tailings onto N12 highway
Revett Minerals Troy mine[12]	Northwestern Montana, USA	September 30, 2009	Release of 36 metric tons of tailings into Stanley Creek
AngloGold Stilfontein tailings reprocessing project[10]	North West Province, South Africa	2009	Release of tailings onto road and scrubland
Jaduguda uranium mill[13]	Jharkhand, India	August 16, 2008	Release of tailings reaching nearby homes
Kinross Barrick Smoky Valley/Round Mountain mine[5]	Nye County, Nevada, USA, 86 km north of Tonopah	April 18, 2008	Release of 2.83 m^3 of tailings
Newmont Phoenix mine[5]	North-central Nevada, USA, 19 km southwest of Battle Mountain	February 26, 2008	Release of 185 m^3 of tailings
Jaduguda uranium mill[13]	Jharkhand, India	February 21, 2008	Release of tailings reaching nearby homes
Jaduguda uranium mill[13]	Jharkhand, India	April 10, 2007	

ASARCO Ray mine[11]	Near Kelvin, Arizona, USA	February 4, 2007	Release of tailings into Gila River
Jaduguda uranium mill[13]	Jharkhand, India	December 25, 2006	Release of tailings into tributary of Subranarekha River
Kinross Barrick Smoky Valley/Round Mountain mine[5]	Nye County, Nevada, USA, 86 km north of Tonopah	December 20, 2006	Release of 114 m^3 of tailings
Vedanta Konkola Copper Mines[9]	Nchanga, Chingola, Zambia	November 6, 2006	Release of tailings into Kafue River with loss of drinking water supply for downstream communities
Kinross Barrick Smoky Valley/Round Mountain mine[5]	Nye County, Nevada, USA, 86 km north of Tonopah	June 9, 2006	Release of 14.11 m^3 of tailings
Kinross Barrick Smoky Valley/Round Mountain mine[5]	Nye County, Nevada, USA, 86 km north of Tonopah	2006	Release of 141.567 m^3 of tailings
Kinross Barrick Smoky Valley/Round Mountain mine[5]	Nye County, Nevada, USA, 86 km north of Tonopah	November 17, 2005	Release of 21 m^3 of tailings
Newmont Twin Creeks mine[5]	42 km northeast of Golconda, Nevada, USA	October 11, 2005	Release of 5.7 m^3 of tailings containing 51 mg/L cyanide
KGHM International Robinson mine[5]	Eastern Nevada, USA, 11 km west of Ely	May 5, 2004	Release of 680 m^3 of tailings
Kinross Barrick Smoky Valley/Round Mountain mine[5]	Nye County, Nevada, USA, 86 km north of Tonopah	December 12, 2001	Release of 2.83 m^3 of tailings
Asarco Mission Complex mine[11]	29 km south of Tucson, Arizona, USA	2001	Release of 200 metric tons of tailings into dry stream channel
Kennecott Bingham Canyon mine[11]	Southwest of Salt Lake City, Utah, USA	2001	
Cleveland-Cliffs Mile Post 7 Tailings Storage Facility[14]	Northeastern Minnesota, USA	October 23, 2000	Release of 38,000 m^3 of tailings into Beaver River watershed
Freeport McMoRan Chino mine[11]	19 km southeast of Silver City, New Mexico, USA	2000	Release of 1800 m^3 of tailings with 350 m^3 entering Whitewater Creek
Manila Mining Corp. Surigao Del Norte Placer[9]	Philippines	April 26, 1999	Release of 400,000 m^3 of tailings traveled 12 km, resulting in 4 deaths and burial of 17 homes and 51 ha of riceland
Freeport McMoRan Chino mine[11]	19 km southeast of Silver City, New Mexico, USA	1999	Release of 12,300 m^3 of tailings into Whitewater Creek
ASARCO Ray mine[11]	Near Kelvin, Arizona, USA	1999	Release of 125 m^3 of tailings

Freeport McMoRan Chino mine[11]	19 km southeast of Silver City, New Mexico, USA	1997	Release of 380 m^3 of tailings into Whitewater Creek
Freeport McMoRan Chino mine[11]	19 km southeast of Silver City, New Mexico, USA	1996	Release of 580 m^3 of tailings into Whitewater Creek
Barrick Turquoise Ridge mine[5]	113 km north of Winnemucca, Nevada, USA	May 5, 1995	Release of 11 m^3 of tailings
Barrick Golden Sunlight mine[5]	8 km northeast of Whitehall, Montana, USA	1994	Release of 43.8 metric tons of tailings
Freeport McMoRan Chino mine[11]	19 km southeast of Silver City, New Mexico, USA	1993	Release of 345 m^3 of tailings into Whitewater Creek over 6 incidents
Freeport McMoRan Chino mine[11]	19 km southeast of Silver City, New Mexico, USA	1992	Release of 450 m^3 of tailings into a basin
Goldcorp Marigold mine[5]	5 km south of Valmy, Nevada, USA	April 3, 1991	
Freeport McMoRan Chino mine[11]	19 km southeast of Silver City, New Mexico, USA	1991	Release of 12 m^3 of tailings into Whitewater Creek
Clayton mine[9]	Idaho, USA	1983	Release of 11 m^3 of tailings with 2.2 kg of cyanide
Homestake Mining[9]	Milan, New Mexico, USA	1977	Pipeline rupture caused failure of tailings dam and release of 30,000 m^3 of tailings

[1] Coeur Alaska (2024)
[2] St Barabara Limited (2021)
[3] Universidad de Valparaíso—Chile (2019)
[4] Earthworks (2019)
[5] Earthworks and Great Basin Resource Watch (2017)
[6] Anchorage Daily News (2015)
[7] WISE Uranium Project (2016)
[8] Minnesota Pollution Control Agency (2015)
[9] Center for Science in Public Participation (2022)
[10] WISE Uranium Project (2023)
[11] Earthworks (2012)
[12] Flathead Beacon Productions (2009)
[13] WISE (2008)
[14] Minnesota Pollution Control Agency (2017)

The 61 documented failures of tailings pipelines in Table 2 should in no way be regarded as a complete list and consists only of those failures that were easily found in publicly available sources. Many of the tailings pipeline failures have been documented at particular mining operations at which close attention was being paid for some reason. For example, there are 15 documented tailings pipeline failures at the AngloGold Stilfontein tailings reprocessing project in North West Province, South Africa, eight documented tailings pipeline failures at the Freeport McMoRan Chino mine, and six documented tailings pipeline failures at the Kinross Barrick

Smoky Valley/Round Mountain mine in Nye County, Nevada (USA) (see Table 2). There are five documented tailings pipeline failures at the Jaduguda uranium mill in Jharkhand State, India (see Table 2). Some of these failures have released tailings into nearby homes (see Figs. 9a-c) and into a tributary of the Subranarekha River (see Fig. 9d) (WISE Uranium Project, 2008).

Figure 9a. According to the SME Surface Mining Handbook, "For quite some time, the mining industry has been dealing with the problems and consequences caused by pipeline failures. Failures often result in environmental damage that may affect people that live near pipelines (e.g., in the case of water or land contamination, or as a direct effect of flooding populated areas) … In addition, there are the human and environmental impacts. A failure in a slurry pipeline may involve fatal events and environmental contamination, which can affect the livelihood of local habitants" (Ihle and Valencia, 2023). On February 21, 2008, a new tailings pipeline burst near Jaduguda in the state of Jharkhand, India, causing a spill of uranium mill tailings that reached nearby homes. Photo from WISE Uranium Project (2008).

Figure 9b. According to the SME Surface Mining Handbook, “For quite some time, the mining industry has been dealing with the problems and consequences caused by pipeline failures. Failures often result in environmental damage that may affect people that live near pipelines (e.g., in the case of water or land contamination, or as a direct effect of flooding populated areas) … In addition, there are the human and environmental impacts. A failure in a slurry pipeline may involve fatal events and environmental contamination, which can affect the livelihood of local habitants” (Ihle and Valencia, 2023). On February 21, 2008, a new tailings pipeline burst near Jaduguda in the state of Jharkhand, India, causing a spill of uranium mill tailings that reached nearby homes. Photo from WISE Uranium Project (2008).

Figure 9c. According to the SME Surface Mining Handbook, “For quite some time, the mining industry has been dealing with the problems and consequences caused by pipeline failures. Failures often result in environmental damage that may affect people that live near pipelines (e.g., in the case of water or land contamination, or as a direct effect of flooding populated areas) … In addition, there are the human and environmental impacts. A failure in a slurry pipeline may involve fatal events and environmental contamination, which can affect the livelihood of local habitants” (Ihle and Valencia, 2023). On February 21, 2008, a new tailings pipeline burst near Jaduguda in the state of Jharkhand, India, causing a spill of uranium mill tailings that reached nearby homes. Photo from WISE Uranium Project (2008).

Figure 9d. According to the SME Surface Mining Handbook, "For quite some time, the mining industry has been dealing with the problems and consequences caused by pipeline failures. Failures often result in environmental damage that may affect people that live near pipelines (e.g., in the case of water or land contamination, or as a direct effect of flooding populated areas) … In addition, there are the human and environmental impacts. A failure in a slurry pipeline may involve fatal events and environmental contamination, which can affect the livelihood of local habitants" (Ihle and Valencia, 2023). On December 25, 2006, the tailings pipeline carrying uranium mill tailings from the Jaduguda uranium mill to tailings dam No. 3 ruptured, releasing tailings into a tributary of the Subranarekha River in the state of Jharkhand, India. Photo from WISE Uranium Project (2008).

The general cause of pipeline failure is thickness reduction due to corrosion or mechanical wear. The SME Surface Mining Handbook lists the following causes of pipeline failure (Ilhe and Valencia, 2023):

1) External corrosion
2) Internal corrosion
3) Scale formation
4) Corrosion under stress
5) Bacteriological corrosion
6) Soil corrosivity
7) Soil movement
8) Inefficient cathodic protection system
9) Electrical interference
10) Pipeline abrasion

Besides the many possible causes of pipe thickness reduction, an additional risk factor is the need to monitor, inspect and maintain tens to hundreds of kilometers of pipelines. According to the SME Surface Mining Handbook, "Besides the common operational use of emergency ponds, it is common to locate one or more of these ponds at intermediate points to provide a means of flushing the slurry upstream of a rupture point in the line. Although there is no guarantee that spills will never happen, these ponds provide a means of minimizing environmental damage in case a failure does occur. The existence of emergency ponds needs to be complemented with active monitoring, such as leak detection systems" (Ilhe and Valencia, 2023).

The high water consumption of tailings pipelines is recognized as a significant disadvantage (Ilhe and Valencia, 2023). For example, simply filling a pipe with a diameter of 20 centimeters and length of 100 kilometers requires about 3.1 million liters of water. Of course, tailings pipelines are run with water for testing prior to the introduction of tailings. After the initiation of production, one of the major concerns is the settling of tailings within the pipeline with the possible plugging of the pipeline. To prevent settling and plugging, it is common to alternate pumping tailings and water through the pipeline with pumping of water without tailings. If settling of tailings does occur, either through improper or a sudden shutdown in production, then a substantial flow of water through the pipeline can be required to re-mobilize the tailings (Ilhe and Valencia, 2023).

Acid Mine Drainage and Metal Leaching

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

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^+ \qquad (1a)$$

or in words as

$$\text{pyrite} + \text{oxygen} + \text{water} \rightarrow \text{dissolved iron} + \text{sulfuric acid} \qquad (1b)$$

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. Despite the available tools, it is important to note that there are no examples of mines that have exploited sulfide ore deposits without acid mine drainage or other forms of contamination of groundwater or surface water (Emerman, 2023).

Mineral Resources and Mineral Reserves

A critical component of mine planning is the estimation of the mineral resources and mineral reserves. In general terms, mineral resources refer to the size of an ore body containing a commodity of value (typically, above some specified cut-off grade), while mineral reserves refer to the quantity of ore that can be economically mined given current technology. Since SolGold trades on the Toronto Stock Exchange and because the Pre-Feasibility Study (SRK Consulting (Canada) Inc., 2024) follows the requirements for an NI 43-101 Technical Report, the precise definitions of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) will be reviewed in this subsection. According to CIM (2014), "A Mineral Resource is a concentration or occurrence of solid material of economic interest in or on the earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction." Since there must be "reasonable prospects for eventual economic extraction," the conversion of an ore body into a commodity cannot be only a theoretical possibility. In other words, the estimation of resources must be based upon a particular cut-off grade with an assumed commodity price, along with many other factors. The conversion of resources into reserves is based upon "Modifying Factors," which may include "mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors" (CIM, 2014).

Mineral resources are then subdivided into inferred resources, indicated resources and measured resources, according to the level of confidence in the existence of the resources, with the greatest confidence placed in measured resources, and the least confidence in inferred resources. CIM (2014) explains, "An Inferred Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling." On the other hand, "An Indicated Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit" (CIM, 2014). The difference between indicated resources and measured resources is that measured resources can be used to support "**detailed** mine planning and **final** evaluation of the economic viability of the deposit" (emphasis added; CIM, 2014).

By contrast, "a Mineral Reserve is the economically mineable part of a measured and/or Indicated Mineral Resource" (CIM, 2014). Note that an inferred mineral resource cannot be regarded as a mineral reserve, or economically mineable. By analogy with mineral resources, mineral reserves are subdivided into probable reserves and proven reserves. According to CIM (2014), "A Probable Mineral Reserve is the economically mineable part of an indicated, and in some circumstances, a Measured Mineral Resource. The confidence in the Modifying Factors applying to a Probable Mineral Reserve is lower than that applying to a Proven Mineral Reserve...A Proven Mineral Reserve is the economically mineable part of a Measured Mineral Resource. A Proven Mineral Reserve implies a high degree of confidence in the Modifying Factors." Clearly, the specified cut-off grade and the anticipated commodity price are important factors in determining which portion of an indicated or measured resource is an economically mineable reserve and whether a reserve is probable or proven.

Multiple Accounts Analysis

In response to the catastrophic failure of a tailings dam at Brumadinho, Brazil, in January 2019, which resulted in 270 deaths, including 258 mineworkers, the International Council on Mining & Metals (ICMM), the United Nations Environment Programme (UNEP), and Principles for Responsible Investment (PRI) released the Global Industry Standard on Tailings Management (GISTM) on August 5, 2020 (ICMM-UNEP-PRI, 2020). Company Members of ICMM were obligated to fully comply with the GISTM by August 5, 2023 (ICMM, 2020, 2021). Although SolGold is not a Company Member, it is noteworthy that Association Members of ICMM include the Australasian Institute of Mining and Metallurgy (AusIMM), the Cámara de Minería del Ecuador (CME) [Ecuador Chamber of Mining], the International Copper Association (ICA), the International Wrought Copper Council (IWCC), the Minerals Council of Australia (MCA), and the World Gold Council (ICMM, 2024). Thus, the expectation for compliance with the GISTM is well-established in Ecuador, in Australia, and in the copper and gold mining industries. Moreover, the Pre-Feasibility Study even states the intention by SolGold to comply with or even exceed the requirements of the GISTM. According to the Pre-Feasibility Study, "The key design objectives for the Tailings Management System are summarised as follows: • Eliminate, manage or control environmental, health and safety risks with a zero-harm aspiration • Design of the tailings management system to meet or exceed the requirements of … international tailings design guidelines, standards and regulations including … GISTM (2020)" (SRK Consulting (Canada) Inc., 2024).

The key aspects of the GISTM are the emphasis on safety and transparency. The first paragraph of the Preamble of the GISTM states, "The Global Industry Standard on Tailings Management (herein 'the Standard') strives to achieve the ultimate goal of zero harm to people and the environment with zero tolerance for human fatality. It requires Operators to take responsibility and prioritise the safety of tailings facilities, through all phases of a facility's lifecycle, including closure and post-closure. It also requires the disclosure of relevant information to support public accountability" (ICMM-UNEP-PRI, 2020), Safety is promoted through the rigorous application of a multiple accounts analysis (called a multi-criteria alternatives analysis in the GISTM). In a multiple accounts analysis, the various options for tailings management technologies and sites for tailings storage facilities are compared by defining accounts (also called criteria or factors), such as a technical account, an environmental account, and a social account, together with a scoring system and appropriate weighting for the account. Usually each account has subaccounts, again with appropriate weighting and scoring systems.

The GISTM clarifies that a multiple accounts analysis has two and only two purposes. According to Requirement 3.2 of the GISTM, "For new tailings facilities, the Operator shall use the knowledge base and undertake a multi-criteria alternatives analysis of all feasible sites, technologies and strategies for tailings management. The goal of this analysis shall be to: (i) select an alternative that minimises risks to people and the environment throughout the tailings facility lifecycle; and (ii) minimise the volume of tailings and water placed in external tailings facilities" (ICMM-UNEP-PRI, 2020). The GISTM further explains that the alternatives analysis "should objectively and rigorously consider all available options and sites for mine waste disposal. It should assess all aspects of each mine waste disposal alternative throughout the project life cycle (i.e. from construction through operation, closure and ultimately long-term monitoring and maintenance). The alternatives analysis should also include all aspects of the project that may contribute to the impacts associated with each potential alternative. The assessment should address environmental, technical and socio-economic aspects for each alternative throughout the project life cycle" (ICMM-UNEP-PRI, 2020).

The important point is that cost is not one of the "aspects" (also called one of the "accounts" in a multiple accounts analysis) that should be considered, which is consistent with the primacy of safety in the GISTM. The usage of the word "economic" throughout the GISTM clarifies that it refers to the local economy, not to the economics of the mining company. For example, Requirement 2.1 states that operators should "develop and document knowledge about the social, environmental and local economic context of the tailings facility, using approaches aligned with international best practices" (ICMM-UNEP-PRI, 2020). In fact, the inclusion of cost as a consideration would be inconsistent with the two purposes of a multiple accounts analysis, which are the minimization of risk to people and the environment and the minimization of the aboveground storage of tailings and water. The consideration of cost would certainly be inconsistent with the "ultimate goal of zero harm to people and the environment with zero tolerance for human fatality" and the obligation to "prioritise the safety of tailings facilities" (ICMM-UNEP-PRI, 2020), as stated in the first paragraph of the Preamble to the GISTM.

A similar approach is taken in the Guidelines for the Assessment of Alternatives for Mine Waste Disposal by Environment Canada (2013), which is the basis for the discussion of multiple accounts analysis in the SME Tailings Management Handbook (Malgesini and Chapman, 2022). According to Environment Canada (2013), "A project proponent seeking to use a natural water body as a TIA [Tailings Impoundment Area] must conduct an assessment of alternatives for mine waste disposal … This alternatives assessment must objectively and rigorously assess all feasible options for mine waste disposal. The project proponent must demonstrate through the EA [Environmental Assessment] and this assessment that the proposed use of the water body as a TIA is the most appropriate option for mine waste disposal from environmental, technical and socio-economic perspectives. It should also be demonstrated that the option offers the greatest overall benefit to current and future generations of Canadians …" Thus, Environment Canada (2013) also does not include cost as one of the relevant perspectives. Environment Canada (2013) clarifies that "socio-economic perspectives" does not refer to the cost of the alternative, but that "this account focuses on how a proposed TIA may influence local and regional land users. Elements that are considered here include characterization and valuation of land use, cultural significance, presence of archaeological sites and employment and/or training opportunities."

It is now a well-established concept in the areas of both tailings dams and water-retention dams that safety is the priority and that there can be no trade-off between safety and any other benefits, including costs. According to the U.S. Army Corps of Engineers (USACE, 2014), "A key mission of the USACE dam safety program is to achieve an equitable and reasonably low level of risk to the public from its dams. USACE executes its project purposes guided by its commitment and responsibility to public safety. Since 'Life Safety is Paramount,' it is not appropriate to refer to balancing or trading off public safety with other project benefits. Instead, it is after tolerable risk guidelines are met that other purposes and objectives will be considered." According to the expert panel report on the failure of the tailings dam at the Mount Polley mine in British Columbia, "Safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor … Future permit applications for a new TSF [Tailings Storage Facility] should be based on a bankable feasibility that would have considered all technical, environmental, social and economic aspects of the project in sufficient detail to support an investment decision, which might have an accuracy of ±10%–15%. More explicitly, it should contain the following: … b. Detailed cost/benefit analyses of BAT [Best Available Technology] tailings and closure options so that economic effects can be understood, recognizing that the results of the cost/benefit analyses should not supersede BAT safety considerations" (Independent Expert Engineering Investigation and Review Panel, 2015a). The preceding quote should also help to clarify the purpose of a cost/benefit analysis, which is most certainly not to enable a trade-off between safety and cost. Thus, any discussion of cost in Environment Canada (2013) or the SME Tailings Management Handbook (Malgesini and Chapman, 2022) should be understood in light of the preceding quote.

A report by UNEP in response to the failure of the tailings dam at the Samarco mine in Brazil further confirmed that safety must be evaluated separately from cost. According to Roche et al. (2017), "The approach to tailings storage facilities must place safety first by making environmental and human safety a priority in management actions and on-the-ground operations. Regulators, industry and communities should adopt a shared zero-failure objective to tailings storage facilities where 'safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor' [Independent Expert Engineering Investigation and Review Panel, 2015a]." Finally, the first guideline in Safety First: Guidelines for Responsible Mine Tailings Management is to "Make safety the guiding principle in design, construction, operation, and closure" (Morrill et al., 2022). Morrill et al. (2022) further explained, "Specifically, tailings management must ensure zero harm to people and zero tolerance for human fatalities … Safety must be evaluated by independent third-parties, such as an Independent Tailings Review Board, to ensure that cost reduction is not prioritized at the expense of people and the environment. Operating companies must document that, at all points of design, operation, closure, and post-closure of tailings facilities, protecting human and environmental health and safety is the primary concern … If a mining project is uneconomic due to the costs of a safe tailings disposal system, then it is uneconomic — costs and risks must not be transferred to the environment, communities or host governments."

The Pre-Feasibility Study and the Stage-Gate Process

Nearly all modern mine planning proceeds through a sequence of studies (called stages) that are followed by critical decisions regarding the mining projects (called gates) (Henderson and Morrison, 2022; Carter and Tolmer, 2023; Clark and Dağdelen, 2023; Turek, 2023). The typical sequence of stages consists of the following (see Table 3):

1) Conceptual Study
2) Scoping Study
3) Pre-Feasibility Study
4) Feasibility Study
5) Definitive Feasibility Study

Each successive stage consists of more accurate cost estimates, more detailed planning and engineering, and the reduction of options (such as options for the site of the tailings storage facility). Each successive stage also consists of more accurate estimates of mineral resources and mineral reserves, with the Pre-Feasibility Study typically being the critical stage at which resources are identified as reserves. According to CIM (2014), "The CIM Definition Standards requires the completion of a Pre-Feasibility Study as the minimum prerequisite for the conversion of Mineral Resources to Mineral Reserves." CIM (2014) further defines the Pre-Feasibility Study as "a comprehensive study of a range of options for the technical and economic viability of a mineral project that has advanced to a stage where a preferred mining method, in the case of underground mining, or the pit configuration, in the case of an open pit, is established and an effective method of mineral processing is determined. It includes a financial analysis based on reasonable assumptions on the Modifying Factors and the evaluation of any other relevant factors which are sufficient for a Qualified Person, acting reasonably, to determine if all or part of the Mineral Resource may be converted to a Mineral Reserve at the time of reporting. A Pre-Feasibility Study is at a lower confidence level than a Feasibility Study."

Table 3. Comparison of critical stages in mine planning

Stage	Accuracy of Cost Estimate[1] (%)	Completion of Engineering: Overall[2] (%)	Completion of Engineering: Tailings Management[3] (%)
Conceptual Study	-50 to +100	—	—
Scoping Study	-30 to +50	<3	<5
Pre-Feasibility Study[4]	-20 to +25	<10	15-20
Feasibility Study	-10 to +15	<30	60-80
Definitive Feasibility Study	—	—	70-90

[1] Turek (2023)
[2] Carter and Tolmer (2023)
[3] Henderson and Morrison (2022)
[4] Also called the Preliminary Economic Assessment

The purpose of the stage-gate process is to complete a significant portion of the planning and engineering early when changes are still relatively easy and inexpensive to make. At the same time, it is important to not spend excessive time and money on a project that is not going to be carried through to completion. Thus, it is essential that the completion of a stage (or the gate) be viewed as a serious opportunity to either proceed to the next stage, to re-do a stage, or to abandon the project. According to the SME Surface Mining Handbook, "The stage-gate process is there for a reason. If the criteria are not met, the gate closes … Too many projects have moved through the gates simply to progress to the next step; however, often there is insufficient or incomplete information to justify the advance. Assumptions are made to fill the gaps and the project moves on. Subsequent work and studies are then also completed with incomplete information, often resulting in false expectations. Combined with this disrespect for the process, the result is that the work required never gets completed or never to the level required, resulting in unpleasant surprises or revelations during execution."

Because many regulatory agencies and other stakeholders insist on clarity on the plan for tailings management, the industry standard is that, at each stage, a greater portion of the engineering be completed for tailings management than for other aspects of mine planning. According to the SME Tailings Management Handbook, "The level of engineering complete for a TSF [Tailing Storage Facility] is greater than the level of engineering required for the rest of a mining project to support permitting requirements" (Henderson and Morrison, 2022). For example, at the stage of the Pre-Feasibility Study, less than 10% of the overall mine engineering should be complete, while 15-20% of the engineering for tailings management should be complete (see Table 3). At this stage, cost estimates should be accurate within the range of 20% less than the best estimate to 25% greater than the best estimate (see Table 3) both for the mining project as a whole and for the tailings management plan (see Table 3).

The SME Tailings Management Handbook gives a list of 44 aspects of the tailings management plan that should be complete at the time of release of the Pre-Feasibility Study (Henderson and Morrison, 2022). A partial set of the aspects that are relevant to this report are listed as follows:

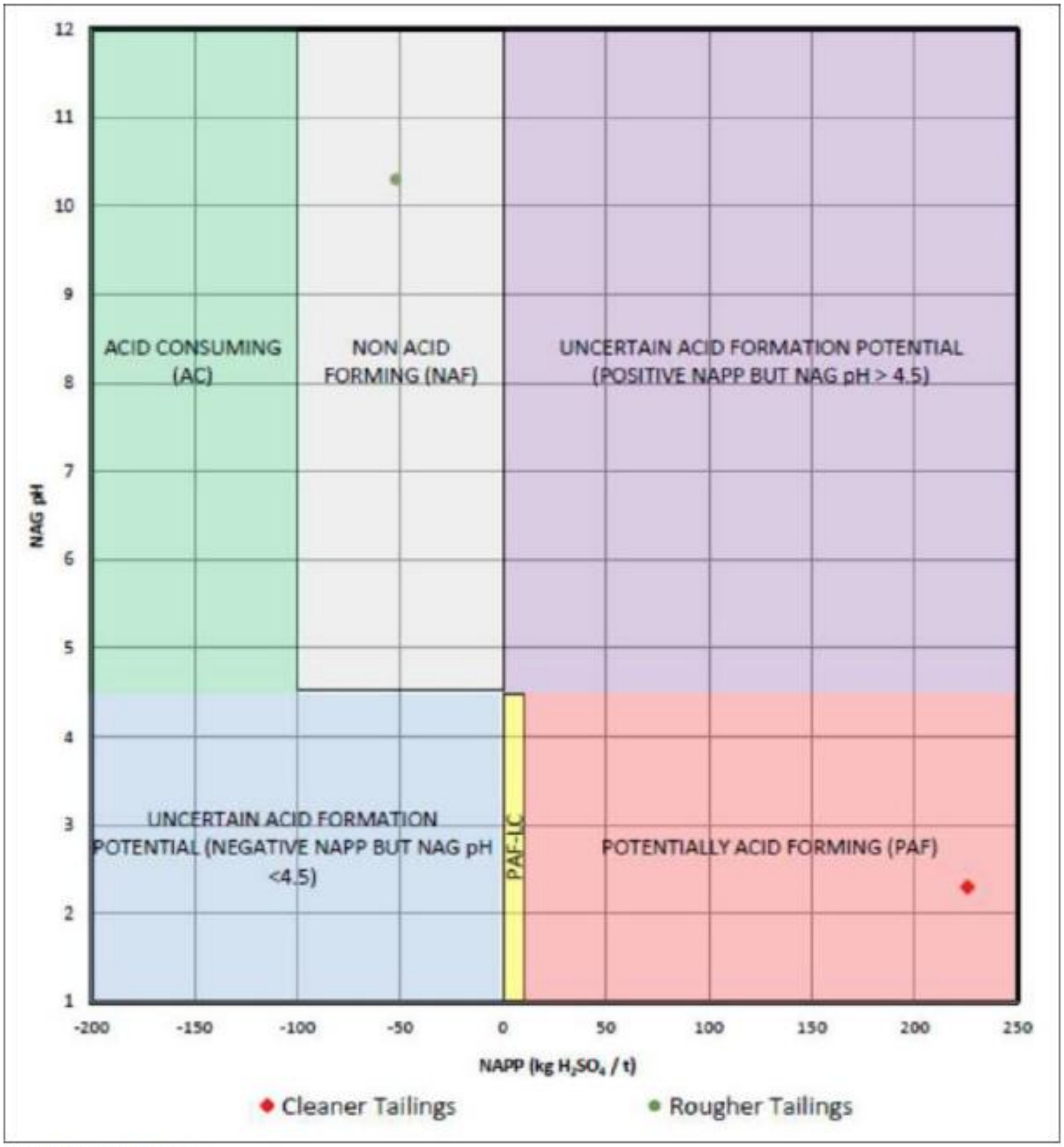
1) Tailings samples should be available from ore processing at the laboratory scale.
2) There should be basic geotechnical testing of laboratory samples of tailings.
3) The potential for acid mine drainage should be evaluated.
4) There should be a preliminary geotechnical investigation of the proposed site of the tailings storage facility.
5) There should be basic laboratory testing of samples from the proposed site of the tailings storage facility.
6) The failure-consequence classification of the tailings storage facility should be based upon a preliminary dam breach analysis.
7) There should be preliminary analyses of stability of and seepage from the proposed tailings storage facility.
8) The regional groundwater regime should be defined for the proposed site of the tailings storage facility.
9) Regional hydrologic information should be reviewed for the proposed site of the tailings storage facility.
10) Long-duration field studies should have been initiated for the proposed site of the tailings storage facility.
11) Baseline data collection should have begun for the proposed site of the tailings storage facility.

SUMMARY OF PRE-FEASIBILITY STUDY

The Cascabel Project would not produce refined metals, but would produce an average of 465,000 metric tons per year of a mixed gold-silver-copper concentrate over a 28-year period. According to the Pre-Feasibility Study, “LOM [Life of Mine] average final cleaner concentrate is expected to have a copper grade of 22.0% Cu, with 88.4% of the contained copper recovered, and 70.8% of the gold recovered at a grade of 15.9 g/t Au” (SRK Consulting (Canada) Inc., 2024). It is not clear how to reconcile the above statement with contradictory criteria that were used to determine the mineral reserves of the Alpala deposit. Also according to the Pre-Feasibility Study, “The economic criteria for the Cascabel project PFS Mineral Reserves Statement were as follows … Average LOM concentrate grade was 28% Cu and 17 g/t Au” (SRK Consulting (Canada) Inc., 2024). The Pre-Feasibility Study does not contain any information about the silver recovery or the anticipated silver grade in the gold-silver-copper concentrate. The concentrate would be shipped in trucks from the ore processing plant on the Cascabel Property to the Port of Esmeraldas on the Pacific coast, from where it would be transported by ship to refining facilities that have not yet been identified.

The conversion of the crushed ore into a mixed metal concentrate would generate 529 million metric tons of tailings, including 460 million metric tons of rougher tailings and 69 million metric tons of cleaner tailings. Prior to shipment to a permanent tailings storage facility, the rougher and clear tailings would be thickened to solids contents by mass of 55% and 45%, respectively. Thus, both the rougher and cleaner tailings should be described as “thickened” by comparison with the range of solids contents of 40-60% by mass for thickened tailings that was stated by Klohn Crippen Berger (2017). Based on a single sample of tailings, it was determined that the rougher tailings will be non-acid forming, while the cleaner tailings will be potentially acid forming (see Fig. 10).

A multiple accounts analysis (MAA) was carried out to determine the best sites and technologies for tailings management. The result of the analysis was that a site about 40 kilometers to the northwest of the ore processing plant, called Coastal Plains East TSF, was the preferred option (see Fig. 11a). A site slightly west and overlapping with Coastal Plains East TSF, called Coastal Plains Main TSF, was the second preferred option (see Fig. 11b). Two other sites on the Cascabel Property, called Parambas TSF and Cachaco TSF, were regarded as two other viable, but less preferred options. According to the Pre-Feasibility Study, “The preferred option for this study was the facility named the Coastal Plains East TSF … all four options were found to be viable options” (SRK Consulting (Canada) Inc., 2024). The final dam heights for the Coastal Plains East TSF, Coastal Plains Main TSF, Parambas TSF and Cachaco TSF would be 190 meters, 132 meters, 225 meters, and 250 meters, respectively. The final dam crest lengths for the Coastal Plains East TSF, Coastal Plains Main TSF, Parambas TSF and Cachaco TSF would be 3.3 kilometers, 4.6 kilometers, 1.1 kilometers, and 1.3 kilometers, respectively. Thus, the sites on the Cascabel Property would clearly be in much narrower valleys, which would be consistent with the much greater dam heights.



Source: Artica et al, 2022

Figure 18-2: Tailings acid formation plots

Figure 10. Based upon a single sample of cleaner tailings and a single sample of rougher tailings, the Pre-Feasibility Study determined that the cleaner tailings would be potentially acid forming, while the rougher tailings would be non-acid forming. By contrast, according to industry standards, multiple samples should have been tested for acid generating potential, even at the stage of the Pre-Feasibility Study. Figure from SRK Consulting (Canada) Inc. (2024).

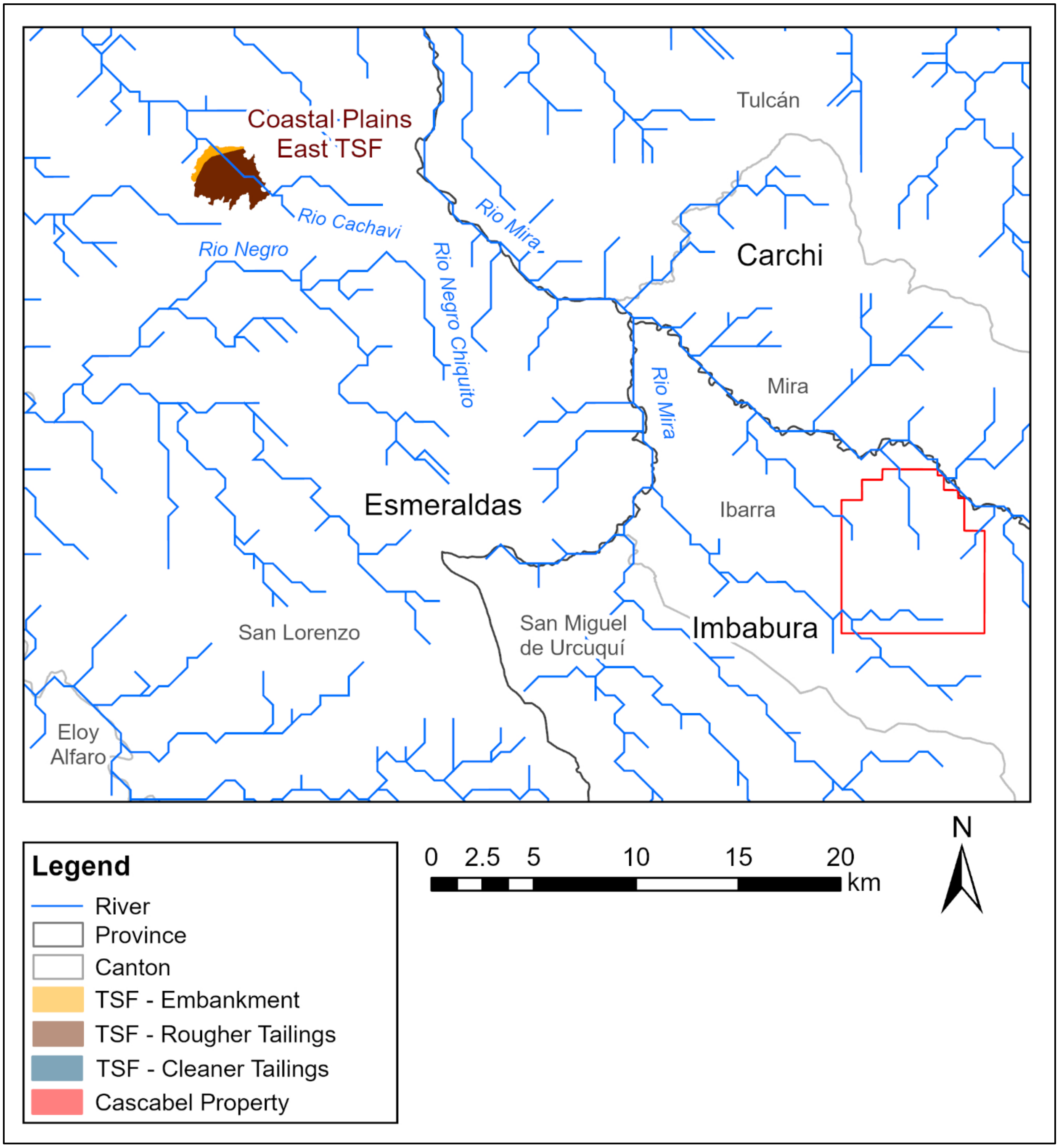


Figure 11a. The preferred option in the Pre-Feasibility Study is the transport of the cleaner tailings and rougher tailings in two separate pipelines over 57 kilometers from the ore processing plant within the Cascabel Property to the Coastal Plains East TSF (Tailings Storage Facility). There is no discussion of the pipeline route, although the pipelines would need to cross numerous rivers, including Rio Mira, Rio Negro Chiquito, and Rio Cachavi, as well as their tributaries. The site of the second preferred option, the Coastal Plains Main TSF (see Fig. 11b), overlaps and is slightly west of the site of the Coastal Plains East TSF. There is no explanation as to why the Coastal Plains East TSF does not include a separate facility for the cleaner tailings (compare with Fig. 11b). Cascabel Property and Coastal Plains TSF traced from maps in SRK Consulting (Canada) Inc. (2024). Rivers from HydroSHEDS (2024).

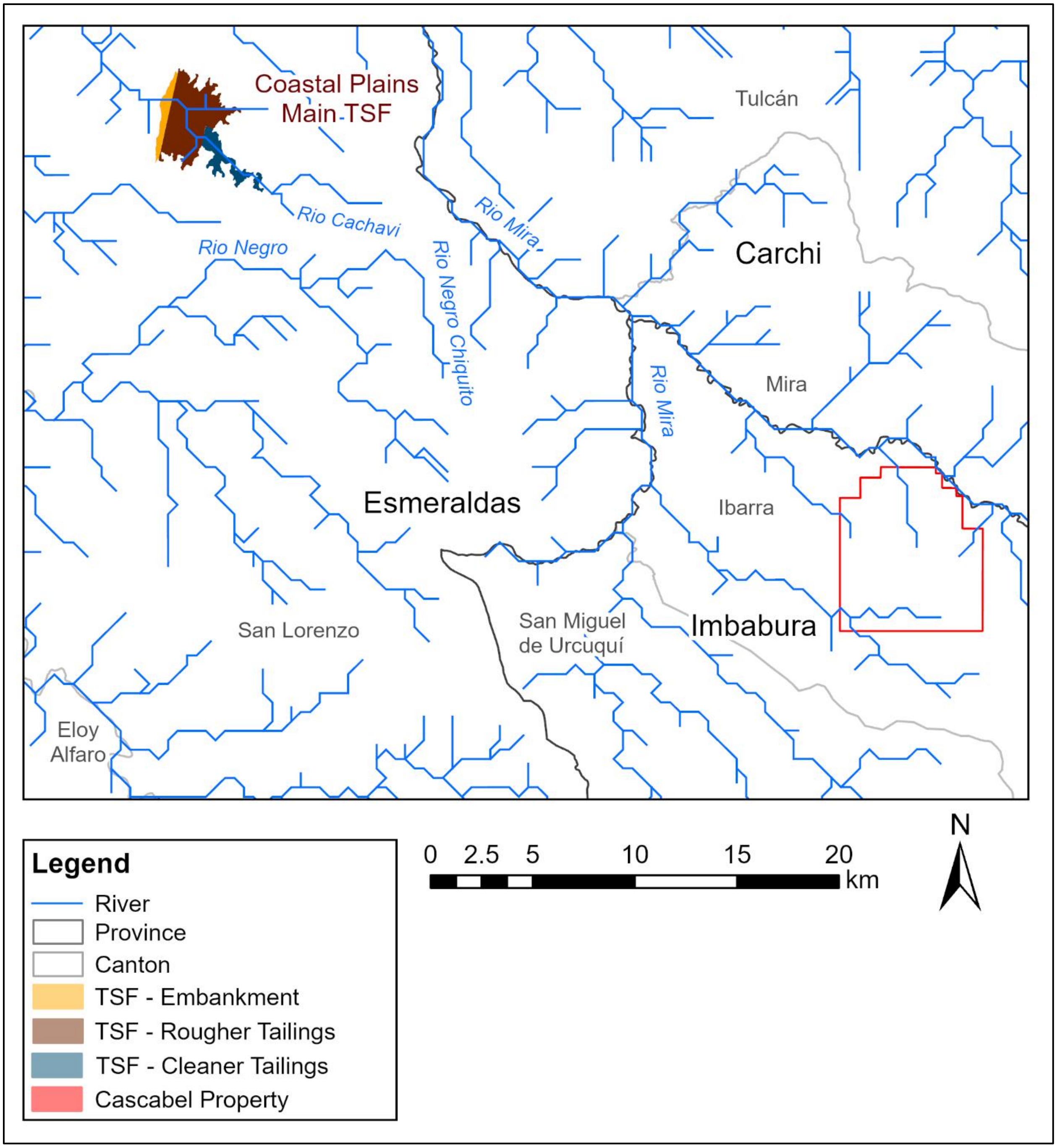


Figure 11b. The second preferred option in the Pre-Feasibility Study is the transport of the cleaner tailings and rougher tailings in two separate pipelines over 57 kilometers from the ore processing plant within the Cascabel Property to the Coastal Plains Main TSF (Tailings Storage Facility). There is no discussion of the pipeline route, although the pipelines would need to cross numerous rivers, including Rio Mira, Rio Negro Chiquito, and Rio Cachavi, as well as their tributaries. The site of the preferred option, the Coastal Plains East TSF (see Fig. 11a), overlaps and is slightly east of the site of the Coastal Plains Main TSF. Cascabel Property and Coastal Plains TSF traced from maps in SRK Consulting (Canada) Inc. (2024). Rivers from HydroSHEDS (2024).

The plan in the Pre-Feasibility Study is to transport the tailings by pipeline from the ore processing plant to Coastal Plains East TSF with transport by pipeline to the Coastal Plains Main TSF as a second option. In both cases, the rougher and cleaner tailings would be transported in two separate pipelines, with each pipeline having a length of about 57 kilometers (see Figs. 11a-b). By contrast with most tailings storage facilities in which water is reclaimed from the tailings pond as the tailings settle out of water, the Cascabel Project would have only a one-way passage of water from the ore processing plant to the tailings storage facility. According to the Pre-Feasibility Study, "No water will be returned to the processing plant from the Coastal Plains facility with water for processing to be sourced from mine dewatering and the Mirra River [see Figs. 11a-b] adjacent to the processing plant" (SRK Consulting (Canada) Inc., 2024). Since excess water will not be reclaimed from the tailings storage facility, it must somehow be discharged into water bodies downstream of the tailings storage facility, although there is no plan for doing so. According to the Pre-Feasibility Study, a risk factor is that "The tailings management system requires discharge of water, permits to discharge water may not be granted" (SRK Consulting (Canada) Inc., 2024).

At the Coastal Plains Main TSF, the cleaner tailings would be stored upstream of the rougher tailings (see Fig. 11b). The maps in the Pre-Feasibility Study do not show a separate storage site for the cleaner tailings at the Coastal Plains East TSF (see Fig. 11a) and the Pre-Feasibility Study does not include any explanation as to why different storage technologies might be used at the two sites. For all four viable sites, a water cover would be maintained over the tailings in perpetuity in order to prevent acid mine drainage. According to the Pre-Feasibility Study, "At closure, the majority of the tailings beach will be covered with rewon topsoil and borrow material and revegetated with the pond retained to maintain saturation of the cleaner tailings post closure" (SRK Consulting (Canada) Inc., 2024).

According to the Pre-Feasibility Study, the initial capital cost would be USD 1554 million with an initial cost of USD 267 million for the tailings storage facility (see Fig. 12a). The operating cost would be USD 0.15 per dry metric ton of processed ore (see Fig. 12b), which would also correspond to USD 0.15 per dry metric ton of tailings. The sustaining capital cost would be USD 2573 million, while the closure cost would be USD 82 million, for a total capital cost of USD 4209 million (see Fig. 12c). The Pre-Feasibility Study did not specify the sustaining capital cost or the closure cost for the tailings storage facility alone. All cost estimates were developed on the assumption that tailings would be stored at the Coastal Plains East TSF, so that the cost of construction and operation of the tailings pipelines ought to be included within the above cost estimates. Further information about the Pre-Feasibility Study will be presented in the "Responses" section.

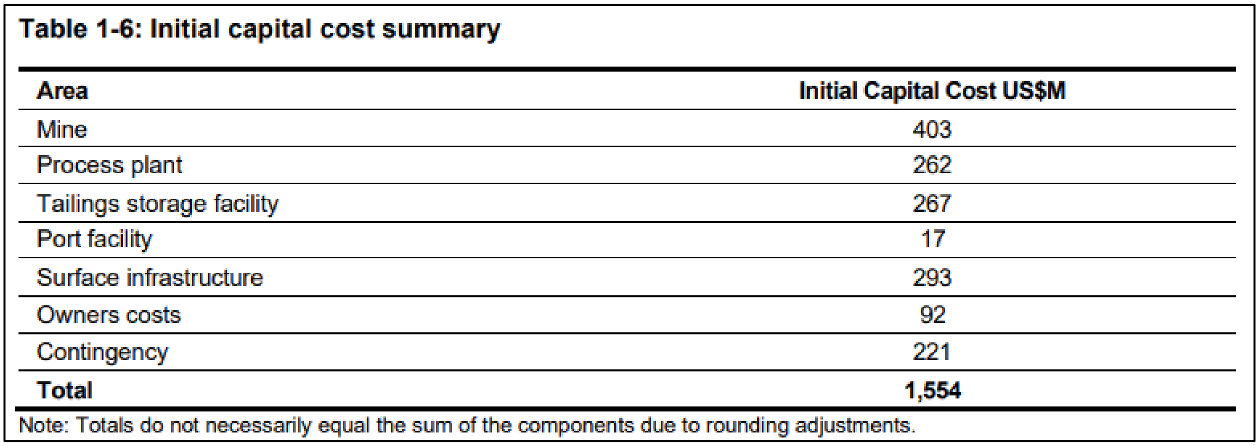


Table 1-6: Initial capital cost summary

Area	Initial Capital Cost US$M
Mine	403
Process plant	262
Tailings storage facility	267
Port facility	17
Surface infrastructure	293
Owners costs	92
Contingency	221
Total	**1,554**

Note: Totals do not necessarily equal the sum of the components due to rounding adjustments.

Figure 12a. The Pre-Feasibility Study estimates an initial capital cost of USD 267 million for the tailings storage facility, which is equivalent to USD 0.50 per dry metric ton of tailings. By contrast, typical initial capital costs for thickened tailings storage facilities are USD 0.75 per dry metric ton (see Table 4a). Table from SRK Consulting (Canada) Inc. (2024).

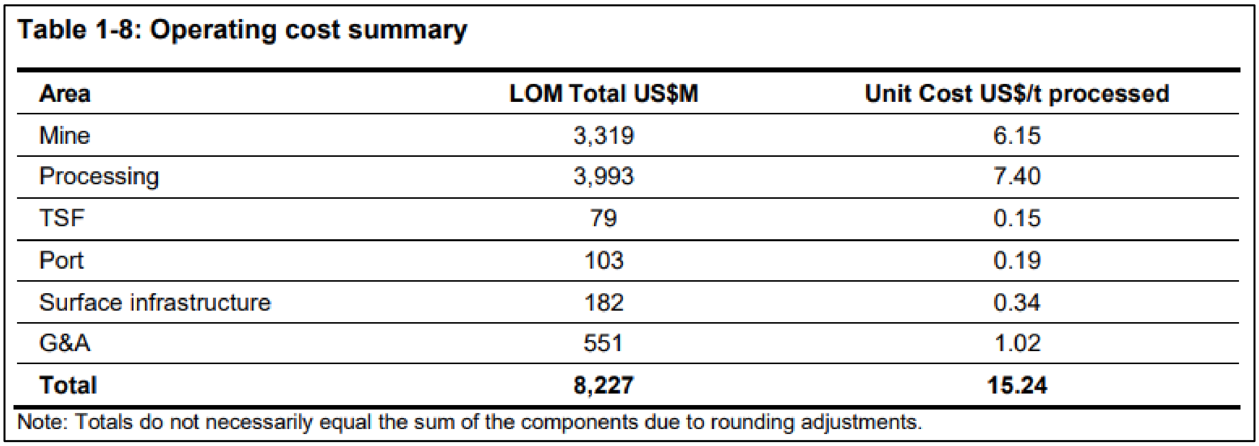


Table 1-8: Operating cost summary

Area	LOM Total US$M	Unit Cost US$/t processed
Mine	3,319	6.15
Processing	3,993	7.40
TSF	79	0.15
Port	103	0.19
Surface infrastructure	182	0.34
G&A	551	1.02
Total	**8,227**	**15.24**

Note: Totals do not necessarily equal the sum of the components due to rounding adjustments.

Figure 12b. The Pre-Feasibility Study estimates an operating cost of the tailings storage facility of USD 0.15 per dry metric ton. By contrast, a typical operating cost for thickened tailings is USD 1.20 with a range of USD 0.50 – 2.50, and with published case studies ranging from USD 0.36 – 2.13 (see Table 4b). Thus, the operating cost seems to be greatly underestimated, especially considering that there is a plan to transport the cleaner and rougher tailings over two pipelines, each with a length of 57 kilometers (see Figs. 11a-b). Table from SRK Consulting (Canada) Inc. (2024).

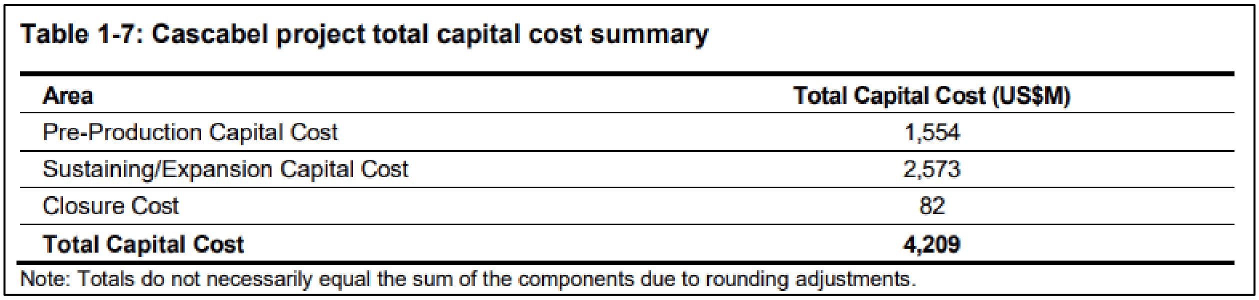


Table 1-7: Cascabel project total capital cost summary

Area	Total Capital Cost (US$M)
Pre-Production Capital Cost	1,554
Sustaining/Expansion Capital Cost	2,573
Closure Cost	82
Total Capital Cost	**4,209**

Note: Totals do not necessarily equal the sum of the components due to rounding adjustments.

Figure 12c. The Pre-Feasibility Study estimates a total closure cost of USD 82 million for the Cascabel Project, but not a closure cost for the tailings storage facility alone. The implied closure cost for the tailings storage facility was calculated by multiplying the total closure cost (USD 82 million) by the ratio of the initial capital cost for the tailings storage facility (USD 267 million) to the total initial capital cost (USD 1554 million) (see Fig. 12a) and dividing by the mass of dry tailings (529 million metric tons), resulting in an estimate of USD 0.03 per metric ton (see Table 4b). By contrast, case studies of closure costs of thickened tailings storage facilities have been in the range USD 0.07 – 1.68 (see Table 4b), so that closure costs have been greatly underestimated. Table from SRK Consulting (Canada) Inc. (2024).

METHODOLOGY

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

1) Does the selection process for the tailings management plan give appropriate emphasis to safety?
2) Has the cost of tailings management been appropriately estimated?
3) Has the risk of tailings pipeline failure been correctly stated?
4) Is the tailings management plan sufficiently advanced for the stage of the Pre-Feasibility Study?
5) Is the plan for a permanent water cover on the tailings consistent with industry standards?
6) Does the Pre-Feasibility Study correctly state the electricity consumption and is there an available source of electricity?

The first question was addressed by comparison of the procedures followed in the Pre-Feasibility Study with the requirements of the Global Industry Standard on Tailings Management (GISTM). The second question was addressed by comparing the cost estimates stated in the Pre-Feasibility Study (see Figs. 12a-c) with surveys of cost estimates in the mining industry (Klohn Crippen Berger, 2017) and with hypothetical case studies that are based on unit cost estimates that are standard in the mining industry (Carneiro and Fourie, 2017, 2018, 2019, 2020; Moreno et al., 2018). The main objective of the preceding publications has been to compare costs for management of conventional tailings, thickened tailings, high-density thickened and paste tailings, and filtered tailings. Since the Cascabel Project would use thickened tailings (solids contents by mass of 55% and 45% for the rougher and cleaner tailings, respectively), the cost estimates in the Pre-Feasibility Study were compared with the cost estimates for thickened tailings in the preceding publications. In the absence of any study on the failure rates of tailings or slurry pipelines, the third question about the anticipated failure rate of tailings pipelines in Ecuador was assessed by analogy with failure rates of Mexican oil and gas pipelines (Caleyo, 2007; USEPA, 2014; see Fig. 13). The fourth and fifth questions were addressed by comparing the Pre-Feasibility Study with the recommendations of the SME Tailings Management Handbook (Andrews et al., 2022; Henderson and Morrison, 2022) and other industry documents. The sixth question was addressed by comparison with studies of electricity consumption by underground copper mining (Norgate and Haque, 2010; Bleiwas, 2011; Fagerström, 2015; Koppelaar and Koppelaar, 2016; Rötzer and Schmidt, 2020) and with available information on planned hydroelectric projects in Ecuador.

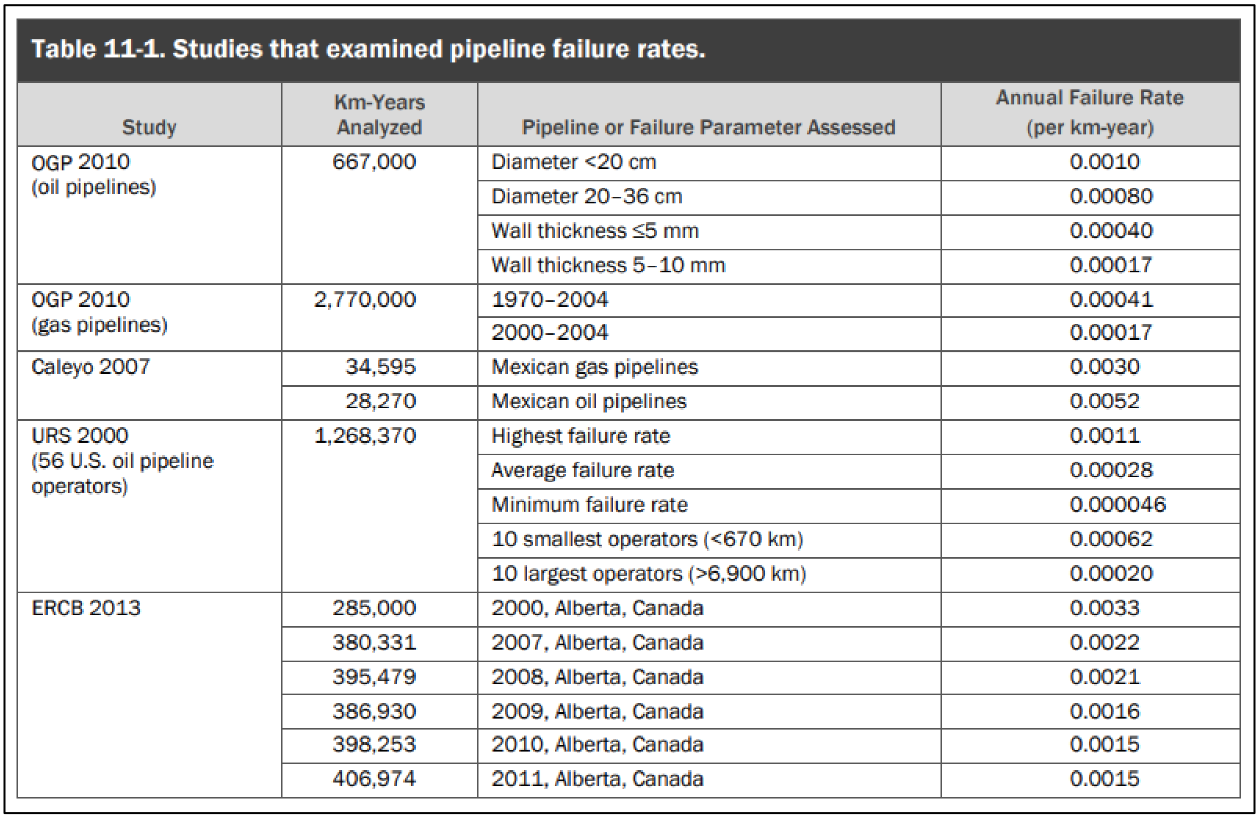


Table 11-1. Studies that examined pipeline failure rates.

Study	Km-Years Analyzed	Pipeline or Failure Parameter Assessed	Annual Failure Rate (per km-year)
OGP 2010 (oil pipelines)	667,000	Diameter <20 cm	0.0010
		Diameter 20–36 cm	0.00080
		Wall thickness ≤5 mm	0.00040
		Wall thickness 5–10 mm	0.00017
OGP 2010 (gas pipelines)	2,770,000	1970–2004	0.00041
		2000–2004	0.00017
Caleyo 2007	34,595	Mexican gas pipelines	0.0030
	28,270	Mexican oil pipelines	0.0052
URS 2000 (56 U.S. oil pipeline operators)	1,268,370	Highest failure rate	0.0011
		Average failure rate	0.00028
		Minimum failure rate	0.000046
		10 smallest operators (<670 km)	0.00062
		10 largest operators (>6,900 km)	0.00020
ERCB 2013	285,000	2000, Alberta, Canada	0.0033
	380,331	2007, Alberta, Canada	0.0022
	395,479	2008, Alberta, Canada	0.0021
	386,930	2009, Alberta, Canada	0.0016
	398,253	2010, Alberta, Canada	0.0015
	406,974	2011, Alberta, Canada	0.0015

Figure 13. In the absence of any estimate of the failure rate of tailings or slurry pipelines, the annual failure rate of Mexican oil and gas pipelines (0.0041 per kilometer per year) was selected as an estimate for the proposed tailings pipelines for the Cascabel project. Based on two tailings pipelines (one for cleaner tailings and one for rougher tailings) each with length 57 kilometers, the annual probability of failure of a tailings pipeline is 47%. Thus, failures of tailings pipelines with release of tailings should be expected to occur during each year of the 28 years of the project. Table from USEPA (2014).

RESPONSES

The Tailings Management Plan should Emphasize Safety, Not Cost

The only information in the Pre-Feasibility Study regarding the multiple accounts analysis is that there were four accounts, with the weighting being 40% technical/engineering, 25% social, 20% financial and 15% environmental. There is no information regarding subaccounts, the criteria for scoring the accounts or subaccounts, the scores for the accounts or subaccounts, or the final scores for each tailings management option. In other words, although the Pre-Feasibility Study states that the Coastal Plains East TSF (see Fig. 11a) was the preferred option, there is no information regarding why that was the preferred option or whether it was the preferred option by a small or a large margin. The Pre-Feasibility Study did recognize that, under certain circumstances, one of the other three options might become preferable to the Coastal Plains East TSF. According to the Pre-Feasibility Study, "The options located on the Cascabel

Mining Concession (Parambas and Cachaco) should be reassessed if open pit mining at Tandayama Americana deposit is incorporated into the mine plan as these facilities become more economical should ex-pit mine waste be available and provide environmental control solutions for the valleys potentially impacted by open pit mining and waste disposal. The Coastal Plains Main TSF provides a much larger capacity (in excess of 1.8 Bt) than required under the current study and should be reassessed if the mine production plan increases" (SRK Consulting (Canada) Inc., 2024).

At the same time, the Pre-Feasibility Study recognized the general lack of information regarding both of the Coastal Plains sites. According to the Pre-Feasibility Study, "The location of the distal tailings storage facility option included in this study has presented challenges in undertaking the study, as access to the site to collect baseline data was limited. Therefore, it is imperative that a clear pathway to land access be developed to allow for the collection of baseline data for the proposed site(s), enabling the designs to be developed in the next phase of study. The restricted access to the coastal plains site has introduced risks to the designs. Engineering judgment had to be applied due to the lack of available physical site data. … Limited rainfall and stream flow data are available within the Coastal Plains TSF catchments, and this could impact the designs" (SRK Consulting (Canada) Inc., 2024). The implications of the lack of information about the Coastal Plains sites will be discussed further in the subsection "The Tailings Management Plan is too Preliminary for a Pre-Feasibility Study."

The main issue regarding the multiple accounts analysis, as well as the choice of the Coastal Plains East TSF as the preferred option, is that, according to the Global Industry Standard on Tailings Management (GISTM), the cost of each option should not even have been one of the accounts. The only accounts should have been technical, environmental, and socioeconomic (referring to the local economy, not the economy of the mining company) and the only objectives of the multiple accounts analysis should have been the minimization of risk to people and the environment and the minimization of the aboveground storage of tailings and water. With the available information, it is impossible to determine what the preferred option would be if cost were not a factor. Considering that cost was a factor in the choice of the tailings management plan, the underestimation of the cost of tailings management comes as a great surprise. The cost estimates in the Pre-Feasibility Study are critiqued in the following subsection.

The Cost of Tailings Management has been Underestimated

Based on 529 million metric tons of tailings, the initial capital cost of USD 267 million for the tailings storage facility (see Fig. 12a) would be equivalent to USD 0.50 per dry metric ton of tailings (see Table 4a). There have not been many estimates of initial capital costs for thickened tailings storage facilities, but Moreno et al. (2018) found USD 0.75 per dry metric ton (see Table 4a). The Pre-Feasibility Study does not state a separate sustaining capital cost for the tailings storage facility (see Fig. 12c), but the sustaining capital cost was estimated by multiplying the total sustaining capital cost (USD 2573 million) by the ratio of the initial capital cost for the tailings storage facility (USD 267 million) to the total initial capital cost (USD 1554 million) (see Fig. 12a) and dividing by the mass of dry tailings to yield USD 0.82 per dry metric ton (see Table 4a). The preceding calculated sustaining cost is quite close to the value of USD 0.80 per dry metric ton stated by Moreno et al. (2018) (see Table 4a). The total capital cost for the tailings storage facility was calculated by adding the stated initial cost and the calculated sustaining cost to obtain USD 1.32 per dry metric ton (see Table 4a). The total capital cost of tailings storage for the Cascabel Project of USD 1.32 per dry metric ton is within the range of USD 0.64 to 1.55 per dry metric ton that has been found for other thickened tailings facilities (see Table 4a).

Table 4a. Comparison of Pre-Feasibility Study for Cascabel Project with typical capital costs for thickened tailings storage facilities

	Initial (USD/t)	**Sustaining (USD/t)**	**Total (USD/t)**
Carneiro and Fourie (2017)[1]			0.92
Moreno et al. (2018)[1]	0.75	0.80	1.55
Carneiro and Fourie (2018)[1]			1.10
Carneiro and Fourie (2019)[1]			0.64 – 0.80
Carneiro and Fourie (2020)[1]			0.82
Pre-Feasibility Study	0.50[2]	0.82[3]	1.32[4]

[1] Converted from AUD using 1 AUD = 0.65 USD

[2] SRK Consulting (Canada) Inc. (2024)

[3] Calculated by multiplying the total sustaining capital cost (USD 2573 million) by the ratio of the initial capital cost for the tailings storage facility (USD 267 million) to the total initial capital cost (USD 1554 million) and dividing the mass of dry tailings (529 million metric tons) (SRK Consulting (Canada) Inc., 2024)

[4] Calculated by adding the initial and sustaining capital costs

Although the capital costs in the Pre-Feasibility Study are reasonable, the operating costs of USD 0.15 per dry metric ton are far below what is typical in the mining industry (see Table 4b). Typical operating costs are USD 1.20 per dry metric ton, or nearly ten times higher than what is stated in the Pre-Feasibility Study, with a range of USD 0.50 to 2.50 per dry metric ton (Klohn Crippen Berger, 2017; see Table 4b). Estimates from case studies are in the range USD 0.36 to 2.13 per dry metric ton (see Table 4b), so that the lowest estimate from a case study is still over three times higher than what is stated in the Pre-Feasibility Study. The very low operating cost provided in the Pre-Feasibility Study is especially surprising since the operating cost should include the operating cost of two long-distance tailings pipelines, which are not typical components of tailings management plans.

Table 4b. Comparison of Pre-Feasibility Study for Cascabel Project with typical operating and closure costs for thickened tailings storage facilities

	Operating (USD/t)	**Closure (USD/t)**
Klohn Crippen Berger (2017)	1.20 (0.50 – 2.50)	
Carneiro and Fourie (2017)[1]	0.50	0.17
Carneiro and Fourie (2018)[1]	0.55	0.13
Carneiro and Fourie (2019)[1]	0.36 – 2.13	0.07 – 0.13
Carneiro and Fourie (2020)[1]	0.43	0.13 – 1.68
Pre-Feasibility Study	0.15[2]	0.03[3]

[1] Converted from AUD using 1 AUD = 0.65 USD

[2] SRK Consulting (Canada) Inc. (2024)

[3] Calculated by multiplying the total closure cost (USD 82 million) by the ratio of the initial capital cost for the tailings storage facility (USD 267 million) to the total initial capital cost (USD 1554 million) (see Fig. 12a) and dividing by the mass of dry tailings (529 million metric tons) (SRK Consulting (Canada) Inc. (2024)

The closure costs of the tailings storage facility for the Cascabel Project are also far below what is typical in the mining industry (see Table 4b). Although the Pre-Feasibility Study does not state a separate closure cost for the tailings storage facility (see Fig. 12c), the cost can be estimated by multiplying the total closure cost (USD 82 million) by the ratio of the initial capital cost for the tailings storage facility (USD 267 million) to the total initial capital cost (USD 1554 million) (see Fig. 12a) and dividing by the mass of dry tailings (529 million metric tons), yielding a closure cost of USD 0.03 per dry metric ton (see Table 4b). By contrast, case studies have estimated closure costs of thickened tailings storage facilities in the range USD 0.07 to USD 1.68 per dry metric ton with a mean of about USD 0.13 per metric ton (see Table 4b). In summary, the Pre-Feasibility Study has greatly underestimated both the operating costs and the closure costs of the tailings storage facility.

The Risk of Tailings Pipeline Failure has been Underestimated

Despite the well-known risks of tailings pipelines, as discussed in the SME Surface Mining Handbook (Ilhe and Valencia, 2023) and the many documented failures of tailings pipelines (see Table 2), there is no mention in the Pre-Feasibility Study that any risk is presented by the tailings pipelines, except for possible increases in costs. According to the Pre-Feasibility Study, “The right of way for the TSF pipeline to the TSF has not been secured. It is assumed to follow the highway for the majority of its route, however, changes to the route could increase the cost due to access for construction” (SRK Consulting (Canada) Inc., 2024). The above quote does clarify that the pipeline route is unknown, although somehow the pipelines would need to cross numerous rivers, including Rio Mira, Rio Negro Chiquito, and Rio Cachavi, as well as their tributaries (see Figs. 11a-b). River crossings should pose a particular risk, due to the many cases in which tailings pipeline ruptures have released tailings into rivers (see Table 2 and Fig. 9d).

Mexican gas pipelines have a failure rate of 0.3% per kilometer per year, while oil pipelines have a failure rate of 0.52% per kilometer per year for an average annual failure rate of 0.41% (see Fig. 13). Based upon the above the annual failure of the two tailings pipelines at the Cascabel Project will be 47%. In other words, the failure of a tailings pipeline will be expected during every year of the 28 years of the Cascabel Project. Thus, it is quite surprising that the Pre-Feasibility Study does not view the use of long-distance tailings pipelines with numerous river crossings as a risk factor. The only possible risk that is considered is not the failure of the pipelines, but the public acceptance of the pipelines. According to the Pre-Feasibility Study, “In the near term, the expansion of engagement and outreach activities to the areas associated with the Coastal Plains TSF, the tailings pipelines, and concentrate shipping corridor is required to ensure that supporting studies and development proceeds uninterrupted” (SRK Consulting (Canada) Inc., 2024).

The Tailings Management Plan is too Preliminary for a Pre-Feasibility Study

Out of the eight authors of the Pre-Feasibility Study, four indicated that they visited the Cascabel Property, while four indicated that they did not (SRK Consulting (Canada) Inc., 2024). However, none of the authors indicated that they visited the sites of the Coastal Plain East TSF, the Coastal Plain TSF, or the potential pipeline route. By contrast, in terms of “Geotechnical assessment,” the SME Tailings Management Handbook states “site visit desirable” (Henderson and Morrison, 2022) even for a Scoping Study (see Table 3). By the time of completion of the Pre-Feasibility Study, a preliminary geotechnical investigation of the proposed sites for a tailings storage facility should have been completed with geotechnical testing of at least laboratory samples from the proposed sites. Moreover, for the proposed sites, the regional groundwater regime should have been defined and regional hydrologic information should have been reviewed. In preparation for the Environmental Impact Study (EIS), at the proposed sites for a tailings storage facility, long-duration field studies should have been initiated and baseline data collection should have begun (Henderson and Morrison, 2022).

As opposed to all of the above steps that should have been completed, the Pre-Feasibility Study emphasizes the lack of geotechnical, hydrologic and environmental knowledge regarding the proposed sites. According to the Pre-Feasibility Study, "The location of the distal tailings storage facility option included in this study has presented challenges in undertaking the study, as access to the site to collect baseline data was limited. Therefore, it is imperative that a clear pathway to land access be developed to allow for the collection of baseline data for the proposed site(s), enabling the designs to be developed in the next phase of study. The restricted access to the coastal plains site has introduced risks to the designs. Engineering judgment had to be applied due to the lack of available physical site data … Additional sites [for surface water quality sampling] will be required to accommodate baseline study of the off-concession infrastructure, including the Coastal Plains tailings storage facility … Baseline studies have been undertaken in the Cascabel concession only to date and are yet to commence for the remaining Project areas … • Minimal geotechnical data is available, and this could impact the designs … • Material availability for dam construction has not been confirmed and the geotechnical properties of the construction materials could impact the designs. • Limited rainfall and stream flow data are available within the Coastal Plains TSF catchments, and this could impact the designs … Environmental baseline studies to date have been limited to the Cascabel concession and are yet to commence for the remaining project areas. The outcomes of these baseline studies could impact aspects of the project design" (SRK Consulting (Canada) Inc., 2024).

The Pre-Feasibility Study proposes that the studies that should have been completed prior to the release of the Pre-Feasibility Study should simply be incorporated into the Feasibility Study, which is the exact opposite of the purpose of the stage-gate process. According to the Pre-Feasibility Study, " New baseline investigations will be conducted in areas proposed for infrastructure developments, such as the tailings facility, access road, concentrate shipping corridor, and transmission line … Climate and stream flow monitoring should be established within the Coastal Plains TSF catchment … Areas where geotechnical investigations are proposed include: … • Coastal Plains TSF and infrastructure locations … • Pipeline corridor… Recommendations in support of TSF design and tailings management include: • Hydrogeological study of the TSF area to determine the baseline hydrogeological regime. • Geophysical studies to investigate the subsurface structural geology. • Geotechnical studies to investigate dam foundation and borrow material sources. • Establish monitoring of site-specific weather station within the TSF catchment area. • Establish monitoring of all major streams in the tailings area for flow rates and water chemistry" (SRK Consulting (Canada) Inc., 2024).

The Pre-Feasibility Study indicates that tailings have been produced at the laboratory scale and that a single sample of rougher tailings and a single sample of cleaner tailings were tested for acid-generating potential (see Fig. 10). Based on the results of single samples, it would be conservative to assume that the cleaner tailings will be potentially acid generating, but it is not all obvious at this point that the rougher tailings will not be potential acid generating. The Pre-

Feasibility Study does acknowledge, “Limited tailings samples have been geochemically tested, additional samples need to be tested to confirm representativeness of the current data” (SRK Consulting (Canada) Inc., 2024). The preceding acknowledgement is reassuring, but the potential for acid mine drainage should have been evaluated more fully prior to the release of the Pre-Feasibility Study. Moreover, there has been no basic geotechnical testing of laboratory samples of tailings, which should have been completed as part of the Pre-Feasibility Study. Finally, in the absence of any knowledge of the geotechnical properties of the tailings, there have been no analyses of the stability of and the seepage from the proposed tailings storage facility, even at the preliminary level, which should have been completed as part of the Pre-Feasibility Study (Henderson and Morrison, 2022).

According to the SME Tailings Management Handbook, by the time of the release of the Pre-Feasibility Study, the classification of the tailings dam in terms of the consequences of failure should be “informed by preliminary breach analysis.” The Pre-Feasibility Study states, “Based on the Global Industry Standard on Tailings Management (2020), all TSF options have been assigned an ‘extreme’ dam failure consequence category at the PFS stage and the corresponding design criteria reflective of this consequence category have been adopted. This consequence category acknowledges the large environmental impact that could occur should a facility fail” (SRK Consulting (Canada) Inc., 2024). The Global Industry Standard on Tailings Management describes the environmental criteria for Extreme consequences of failure as: “Catastrophic loss of critical habitat or rare and endangered species. Process water highly toxic. Very high potential for acid rock drainage or metal leaching effects from released tailings. Potential area of impact > 20 km^2. Restoration or compensation in kind impossible or requires a very long time (> 20 years)” (ICMM-UNEP-PRI, 2020). The Extreme consequence classification is useful for setting conservative standards for design of the tailings storage facility. However, based upon the preceding quote from the Pre-Feasibility Study, the consequence classification was only an assumption that was made and was not based upon any actual analysis of the consequences of tailings dam failure. Thus, the mining company, its investors, the regulatory agencies, and the affected communities have not been provided with any knowledge as to what may actually happen after the failure of the tailings dam.

A Permanent Water Cover on the Tailings is Excessively Risky

Although, in principle, water covers over tailings can prevent the reaction of the sulfide minerals with oxygen, water covers on aboveground tailings storage facilities are no longer regarded as a best practice because of their detrimental impact on the physical stability of the facility. The panel that investigated the failure of the Mount Polley tailings storage facility in British Columbia (Canada) in 2014 concluded that “The goal of BAT [Best Available Technology] for tailings management is to assure physical stability of the tailings deposit. This is achieved by preventing release of impoundment contents, independent of the integrity of any containment structures. In accomplishing this objective, BAT has three components that derive from first principles of soil mechanics: 1. Eliminate surface water from the impoundment … In short, the most serious chemical stability problem concerns tailings that contain sulfide minerals, particularly in metal and coal mining. In the presence of oxygen, these sulfides react to produce acid that then mobilizes a variety of metals in solution. There are a number of ways to arrest this reaction, and one is to saturate the tailings so that water replaces oxygen in the void spaces. This saturation is most conveniently achieved by maintaining water over the surface of the tailings.

Hence, so-called water covers have sometimes been adopted for reactive tailings during operation and for closure. It can be quickly recognized that water covers run counter to the BAT principles … But the Mount Polley failure shows why physical stability must remain foremost and cannot be compromised. Although the tailings released at Mount Polley were not highly reactive, it is sobering to contemplate the chemical effects had they been. No method for achieving chemical stability can succeed without first ensuring physical stability: chemical stability requires above all else that the tailings stay in one place" (Independent Expert Engineering Investigation and Review Panel, 2015a).

Plans to maintain permanent water covers over reactive mine waste after mine closure in order to prevent the reaction of sulfide minerals with oxygen in perpetuity should be regarded as especially problematic. Independent Expert Engineering Investigation and Review Panel (2015b) defined an "active tailings dam" as "a tailings dam whose impoundment contains surface water," even for tailings storage facilities that are no longer receiving tailings. Independent Expert Engineering Investigation and Review Panel (2015a) continued, "BAT principles should be applied to closure of active impoundments so that they are progressively removed from the inventory by attrition. Where applicable, alternatives to water covers should be aggressively pursued." The SME Tailings Management Handbook further concurred in writing, "Where tailings subaqueous disposal is employed behind constructed dams, the dam safety liability associated with maintaining the tailings in a flooded condition also remains … A dam that retains a large water pond is inherently less safe than an embankment that does not. There are no case records of impoundments designed for perpetual submergence behind constructed dams that have been perpetually submerged. So, there is no demonstrated precedent for the legacy of permanent submergence being constructed today. We have only just started the clock" (Andrews et al., 2022).

There is no Available Electricity for the Project

The Pre-Feasibility does not include any estimation of the electricity consumption of the Cascabel Project. The electricity consumption was estimated in this report by considering five studies of electricity consumption by underground copper mining (see Table 5). Based upon continuous ore production of 539.7 million metric tons over 28 years, copper grade of 0.60%, copper concentrate production of 680 metric tons per day, and depth of 700 meters (SRK Consulting (Canada) Inc., 2024), those studies yielded electricity consumption ranging from 23 to 111 MW (see Table 5). Two estimates were based upon electricity consumption per metric ton of refined copper (Bleiwas, 2011; Fagerström, 2015), resulting in estimates of 36 and 52 MW, while three estimates were based upon electricity consumption per metric ton of ore (Norgate and Haque, 2010; Fagerström, 2015; Rötzer and Schmidt, 2020), resulting in estimates of 63, 91 and 102 MW (see Table 5). Koppelaar and Koppelaar (2016) calculated electricity consumption per metric ton of copper concentrate for underground copper mining using two methods. The first method was a simple unit rate (14.1 megajoules per metric ton of concentrate), yielding an estimate of 111 MW for the Cascabel Project (see Table 5). The second method was the equation

$$E = 1.569 + 0.00066D + 0.0067/G \qquad (2)$$

where E is electricity consumption (MJ per kg of concentrate), D is mine depth in meters, and G is ore grade as a decimal fraction, resulting in an estimate of 25 MW for the Cascabel Project (see Table 5).

Table 5. Estimates for electricity consumption by Cascabel Project based upon unit rates from studies of underground copper mines

Study	Unit Rate[1]	Cascabel Project[2] (MW)
	(kWh/t Cu)[3]	
Bleiwas (2011)	2704	36
Fagerström (2015)	3918	52
	(kWh/t ore)[4]	
Norgate and Haque (2010)	46.6	102
Fagerström (2015)	28.5	63
Rötzer and Schmidt (2020)	41.4	91 (best estimate)
	(MJ/kg concentrate)[5]	
Koppelaar and Koppelaar (2016)	14.1	111
Koppelaar and Koppelaar (2016)[6]	See Eq. (2)	25

[1] Unit rates are applicable for copper mining up to the production of a copper concentrate and do not include smelting or refining.

[2] Assumes continuous ore production of 539.7 million metric tons over 28 years, copper grade of 0.60%, copper concentrate production of 680 metric tons per day, and depth of 700 meters.

[3] Kilowatt hours per metric ton of copper

[4] Kilowatt hours per metric ton of copper ore

[5] Megajoules per kilogram of copper concentrate

[6] Unit rate developed from both open-pit and underground mines and depends upon both the depth and grade.

Estimates of electricity consumption based on metric tons of refined copper are useful for assessing the resource footprint of copper metal. However, for the purpose of estimating the electricity consumption of a particular mine, electricity consumption based on metric tons of ore is more useful, especially for very low-grade ores, because the entire ore body must be crushed for processing regardless of how much copper is extracted. As an extreme case, methodologies that are based on the rate of metal production would predict zero energy consumption for zero-grade ores, no matter how much ore was processed. The estimates based on metric tons of copper concentrate are suspect because the two methodologies used by Koppelaar and Koppelaar (2016) give such different results when applied to the Cascabel Project (see Table 5). Out of the three estimates that are based on electricity consumption per metric ton of ore, the estimate of 91 MW is preferred, since the study by Rötzer and Schmidt (2020) is the most recent and most comprehensive.

Thus, the important question is: From where would the Cascabel Project obtain 90 MW of electricity. The Pre-Feasibility Study states that such a source of electricity is not currently available in northern Imbabura province (see Figs. 1-2). According to the Pre-Feasibility Study, “The site power will be supplied from new hydroelectric power projects near the site. Multiple hydroelectric projects are currently in the advanced planning stage, with a total capacity of 200 MW having been identified in the local area. The Project plans to participate in these projects and secure the supply of power from them. Additional power from solar is being considered but is not developed enough to incorporate into this study” (SRK Consulting (Canada) Inc., 2024).

Although the Pre-Feasibility Study states that the Cascabel Project "plans to participate in these [hydroelectric] projects," such participation has not been included in any of the cost estimates (see Figs. 12a-c).

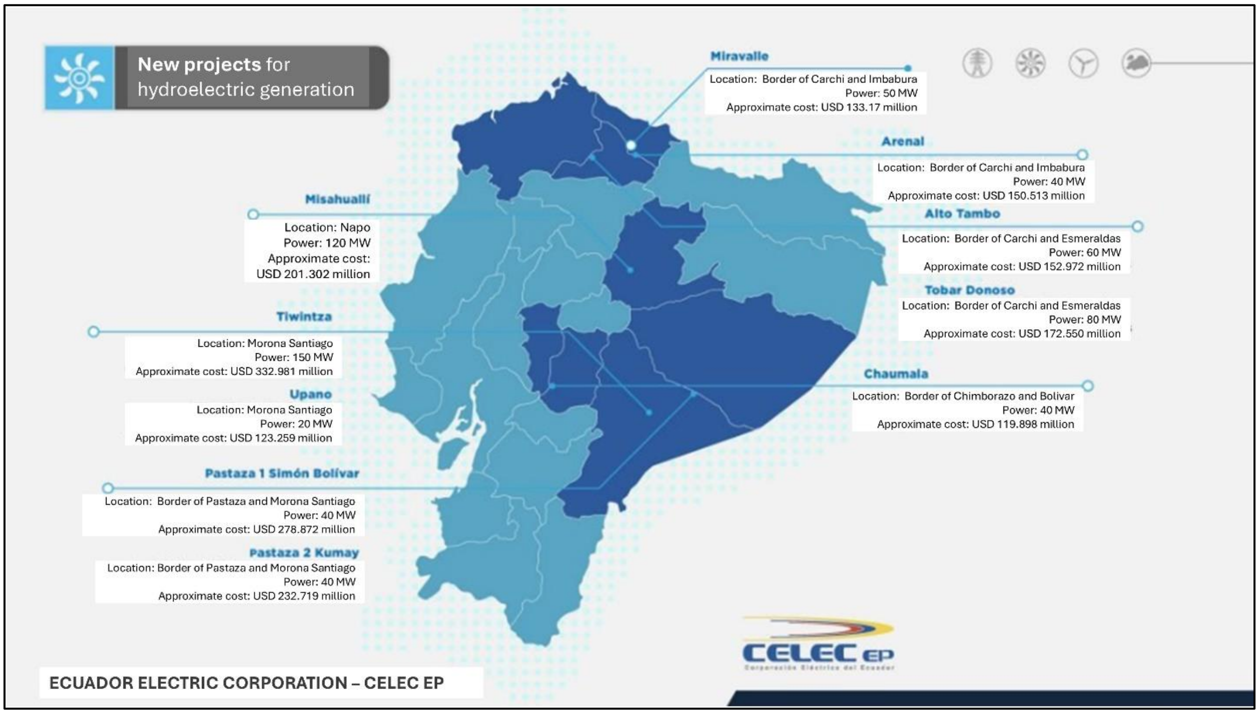


Figure 14. The Pre-Feasibility Study does not include any estimate of the electricity consumption by the Cascabel Project. Based upon a continuous ore production of 539.7 million metric tons over 28 years, the best estimate for electricity consumption is 91 MW (see Table 5). Thus, the Cascabel Project could consume the entire power output of the Miravalle hydroelectric project (power of 50 MW at approximate cost of USD 133.17 million) and the Arenal hydroelectric project (power of 40 MW at approximate cost of USD 150.513 million) on the border of Carchi and Imbabura provinces (see Figs. 1-2). As of 2022, the 10 hydroelectric projects shown on the map were only at the stage of conceptual designs with economic and environmental analyses. Map from Energía Estratégica [Strategic Energy] (2022) with overlay of English labels.

The most recent review of the status of planned hydroelectric projects in Ecuador is Energía Estratégica [Strategic Energy] (2022) (see Fig. 14). Two hydroelectric projects in the planning stage on the border of Carchi and Imbabura provinces (see Figs. 1-2) are the Miravalle hydroelectric project (power of 50 MW at approximate cost of USD 133.17 million) and the Arenal hydroelectric project (power of 40 MW at approximate cost of USD 150.513 million) (see Fig. 14). However, the combined power output of the Miravalle and Arenal projects (90 MW) would be barely equal to the estimated electricity consumption by the Cascabel Project (see Table 5). There is no indication that either the government of Ecuador or the provincial governments of Carchi or Imbabura would consent to dedicate the Miravalle and Arenal hydroelectric projects solely to the operation of the Cascabel gold-silver-copper mine. Moreover, although the Pre-Feasibility Study claims that "multiple hydroelectric projects are currently in the advanced planning stage" (SRK Consulting (Canada) Inc., 2024), Energía Estratégica (2022) states that the ten sites shown in Fig. 14 "*fueron seleccionados para el desarrollo de perfiles con diseños a nivel conceptual, incluido un análisis económico y Ambiental*" [were selected for the development of profiles with designs at the conceptual level, including an economic and environmental analysis]. There is a considerable gap between "conceptual planning" and "advanced planning," similar to the gap between the Conceptual Study and the Feasibility Study for a mining project (see Table 3). In summary, at the present time, there is no available electricity for the Cascabel Project.

SUMMARY CONCLUSIONS

The six questions posed in the "Methodology" section are repeated below, followed by very brief responses. More complete responses can be found in the "Responses" and "Discussion" sections.

1) ***Does the selection process for the tailings management plan give appropriate emphasis to safety?***

No, according to the Pre-Feasibility Study, 20% of the Multiple Account Analysis (MAA) was based on cost. By contrast, according to the Global Industry Standard on Tailings Management (GISTM) and other industry documents, cost should not even be one of the factors in choosing the tailings management plan.

2) ***Has the cost of tailings management been appropriately estimated?***

No, the Pre-Feasibility Study estimates the initial capital cost, operating cost and closure cost of the tailings storage facility as USD 0.50, USD 0.15, and USD 0.03 per dry metric ton of tailings, respectively. By contrast, typical costs are USD 0.75, USD 1.20, and USD 0.13 per dry metric ton of tailings, respectively, so that the costs of tailings management have been greatly underestimated. In addition, there is no consideration of the additional cost of transporting tailings through two pipelines, each with a length of 57 kilometers.

3) ***Has the risk of tailings pipeline failure been correctly stated?***

The Pre-Feasibility Study does not discuss either the likelihood or the consequences of tailings pipeline failure, although the pipelines would need to cross numerous rivers, including Rio Mira, Rio Negro Chiquito, and Rio Cachavi, as well as their tributaries. Based on the failure rates of Mexican oil and gas pipelines, the annual probability of failure of a tailings pipeline would be 47%. Thus, failures of tailings pipelines with release of tailings should be expected to occur during each year of the 28 years of the project.

4) ***Is the tailings management plan sufficiently advanced for the stage of the Pre-Feasibility Study?***

No, based on industry standards, the tailings management plan is not sufficiently advanced for a Pre-Feasibility Study. In particular, there has been no geotechnical testing of tailings samples or of the site foundation, no stability or seepage analyses, and no analysis of the consequences of tailings dam failure.

5) ***Is the plan for a permanent water cover on the tailings consistent with industry standards?***

No, the plan for a permanent water cover over the tailings in order to minimize acid mine drainage is no longer consistent with industry standards because of the detrimental impact of a permanent water cover on long-term stability of the tailings storage facility.

6) ***Does the Pre-Feasibility Study correctly state the electricity consumption and is there an available source of electricity?***

No, the Pre-Feasibility Study does not estimate the electricity consumption of the Cascabel Project and states only that multiple hydroelectric projects are in the advanced planning stage. Based on typical industry unit rates, the electricity consumption would be 91 MW, which would equal the combined power output of the Miravalle and Arenal hydroelectric projects on the border of Carchi and Imbabura provinces. Even so, the Miravalle and Arenal projects are only at the stage of conceptual designs with economic and environmental analyses.

RECOMMENDATIONS

The stage-gate process in mine planning is a sequence of stages (such as a Pre-Feasibility Study) at which critical decisions are made as to whether to proceed with a project. The stage-gate process is not simply a sequence of steps that are carried through that inevitably ends in the construction of a mine, regardless of the information that is provided in the stages. Based upon both the information and the lack of information in the Pre-Feasibility Study, the recommendation of this report is that SolGold should abandon the proposed Cascabel gold-silver-copper project at the present time. As an alternative, investors should decline to invest in the project and regulatory agencies should decline to issue permits for the project.

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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