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The Potential for Imminent Endangerment to Human Life and the Environment from the Mirador Open Pit Copper Mine in Southeastern Ecuador

Submitted to the InterAmerican Commission on Human Rights

Submitted by:

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English Version

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I. Introduction and Purpose of Report

The Mirador Mine is an open-pit copper-gold project in southeastern Ecuador in the Zamora-Chinchipe Province (Figure 1). It is the first large-scale metal mine ever operated in the country. The mine is held by Quito-based EcuaCorriente SA (ECSA), which is a wholly owned subsidiary of a Chinese consortium called CRCC-Tongguan (Tongling Nonferrous Metals Group Holdings and China Railway Construction Corporation Ltd (CRRC); International Mining, 2021). Tongling Nonferrous Metals Group Holdings Co., Ltd. and China Railway Construction Corporation Limited acquired Corriente Resources in August 2010. The Ministerio de Energía y Recursos Naturales no Renovables (MERNNR) signed an exploitation contract with ECSA in March 2012. This was the first exploitation contract for large-scale mining for the government in decades. In 2015 the project obtained the environmental license for exploitation (IGF, 2019, p. 14). Construction began in December 2015 and production started in July 2019. The mine life is estimated at 30 years, from 2019 to 2049 (International Copper Study Group, 2022).

ECSA began processing ore on a small-scale basis in December 2018 and was processing 30,000 tons per day by late 2019 on its way to 60,000 tons per day capacity. According to the mine, operations were suspended between March 20 and August 26, 2020, due to COVID-19. A doubling of processing is planned for the next phase of expansion that expects to develop Mirador Norte (International Mining, 2021).

The mine has been a target of indigenous anger over forced community displacement, land disputes, and alleged violations of human rights. Additionally, the mine has engendered fear in its neighbors due to the construction and operation of large tailings and mine water dams and impoundments located in an area with known high seismicity, high topographic relief, high precipitation, and increasingly extreme storm events. E-Tech International, with the assistance of consultants David Chambers, PhD, and Steven Emerman, PhD, is responding to concerns over potential "imminent endangerment" of nearby communities from mine discharges and potential tailings dam failures.

Figure 1. Location of the Mirador deposit in southeastern Ecuador

Source: Corriente Resources, Inc. 2018. Figure 4-1.

E-Tech International's first evaluations in 2011 and 2012 responded to requests by former Zamora Chinchipe Prefect Salvador Quishpe and the Ministry of the Environment (MAE, Ministerio del Ambiente) of Ecuador to address environmental concerns related to operation of the mine. At that time, we highlighted serious deficiencies in proposed siting and construction of mine infrastructure, concerns over high precipitation and seismic vulnerability, lack of adequate closure plans and financial assurance, the development of acid mine drainage and contaminant leaching, and adverse water quality effects to surface water and groundwater resources.

In this report we examine the risks associated with the inherent characteristics and management of the Mirador Mine, citing examples of tailings dam failures at mines with similar characteristics, and highlight the known concerns related to mine facilities and the lack of transparent available information and data. We also summarize our attempts to gain the information needed to evaluate whether an imminent danger exists. We are asking the Inter-American Commission on Human Rights (IACHR) to take measures that will result in the release the requested documents, which should be made publicly available according to the Ecuadorian Constitution and the Ley Orgánica de Transparencia y Acceso a la Información that have been requested by lawyers representing the Mirador Mine case filed with the IACHR on 23 December 2013 and by the Asemblea Nacional of Ecuador ("information requests"). We also highlight our grave concern that the Commission ensure that the Government of Ecuador develop an effective program with local communities that protects those living downstream of the Mirador tailings dams.

II. Concerns Related to Inherent Characteristics and Management of the Mirador Mine

The Mirador Mine has large-scale mine facilities and important physical and chemical risks that present a potential imminent danger to the environment and downstream communities. The mine facilities are shown in Figure 2.

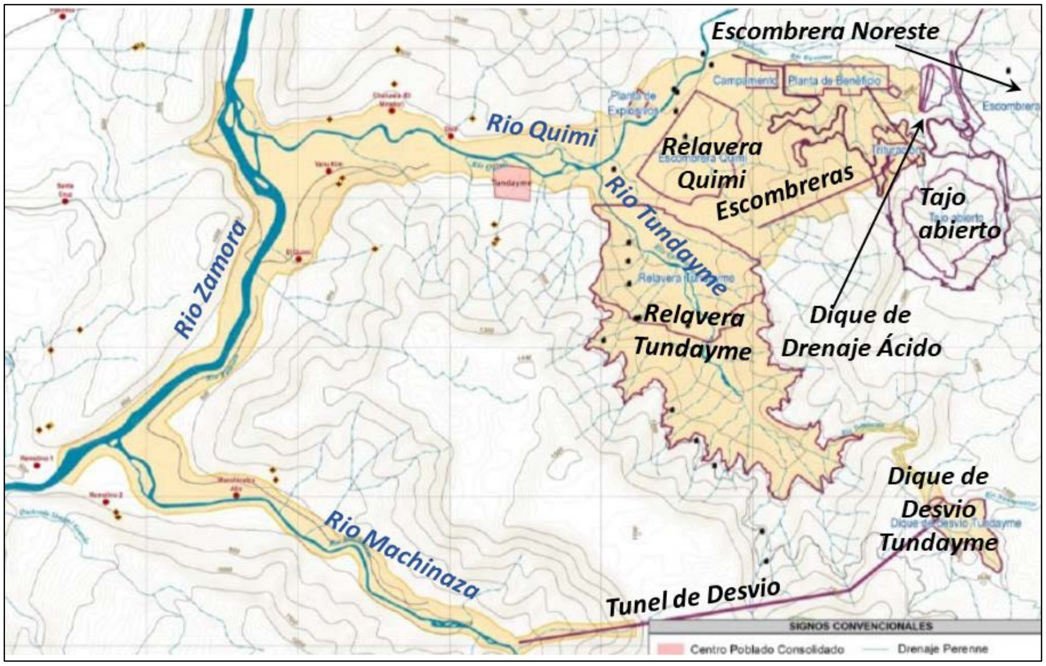

Figure 2. Location of Mirador Mine facilities and areas of impacts to water bodies and water quality
Source: Cardno, 2014a, Fig. 8-12.

1. Physical Risks

a. Overview and Dam Category

From a purely physical point of view, the tailings dams at the Mirador Mine constitute a worst-case scenario because they combine all the following high-risk factors:

1) high seismicity
2) weak foundation (weak soils under the impoundment)
3) high precipitation
4) high topographic relief
5) close proximity to surface water
6) large dam height
7) large volumes of tailings.

In this sense, risk is a combination of the probability of failure and the consequences of failure. The first five physical risk factors relate primarily to the probability of failure, while the last three physical risk factors relate primarily to the consequences of failure. The probability of failure is also related to the human factors of design, construction and operation of the tailings dams, while the consequences of failure are also related to the environmental and socioeconomic context of the tailings dam. In the case of the Mirador Mine, the presence of downstream communities that would be affected or even inundated by a tailings dam breach is the most important risk factor of all (see Section III). The probability of failure (combining both physical and human factors) is evaluated in Section IV.a.

Knight-Piésold (2007), consultants for EcuaCorriente S.A., assigned a dam failure consequence category of Very High to the Quimi dam, based on the classification system of the Canadian Dam Association (2013, 2019), in which Very High consequences include the loss of 10 to 100 lives in the event of dam failure. Knight-Piésold (2007) further explained, "If failure resulted in the release of tailings and/or process water it would have a significant environmental impact on downstream watercourses. The economic consequences and socio-economic impact to the Mine would also be very high."

b. Risks Associated with Earthquakes

As a result of the Very High consequence category, Knight-Piésold (2007) recommended that the Maximum Design Earthquake (MDE) of the Quimi dam should be the Maximum Credible Earthquake (MCE), with a magnitude of 8.0 and a maximum bedrock acceleration of 0.60g. For comparison, the largest earthquake ever recorded had a magnitude of 9.5, while an earthquake with a magnitude of 8.4 was the 20th largest earthquake ever recorded (USGS, 2019). The corresponding peak ground acceleration would be toward the upper limit of the range (0.34-0.65g) of "severe perceived shaking" and "moderate to heavy potential damage" (USGS, 2022a).

Knight-Piésold (2007) also determined that the Operating Basis Earthquake (OBE) for the Quimi dam, the earthquake that is expected to occur during the life of the project, would have a magnitude of 7.5 and a maximum acceleration of 0.20g. Knight-Piésold (2007) furthermore carried out a seismic stability analysis showing that the site for the Quimi dam combined the high-risk factors of both high seismicity and weak foundation. According to Knight-Piésold (2007), "The entire depth of the tailings deposit is potentially liquefiable for the MDE and OBE.

Liquefaction is also predicted for the loose alluvial soils near surface (in the upper 10 meters) for the MDE and OBE." In other words, Knight-Piésold (2007) predicted that the liquefaction of both the tailings and the foundation, with the subsequent failure of the tailings dam, was expected to occur during the 30-year lifetime of the Mirador project. There is no available documentation that discusses the MDE, the MCE, the OBE, the foundation characteristics, or the seismic stability for the Tundayme dam.

Earthquakes that could cause liquefaction and failure of the Quimi dam (magnitude greater than 7.5) are certainly common in the area in the vicinity of the Mirador Mine. The USGS Earthquake Catalog (USGS, 2022b) lists 19 epicenters of earthquakes with magnitudes equal to or greater than 7.5 within 1000 kilometers of the Mirador Mine since 1906 (Figure 3). In fact, three such large earthquakes have occurred since the opening of the mine in 2019. Earthquakes with magnitudes 7.5, 8.0 and 7.5 occurred 218 kilometers northeast of the mine, 434 kilometers southeast of the mine, and 208 kilometers southeast of the mine on February 22, 2019, May 26, 2019, and November 28, 2021, respectively. It is notable that the 1797 Riobamba earthquake with an estimated magnitude of 8.3 and up to 40,000 fatalities had its epicenter 217 kilometers north of the Mirador Mine (see Figure 3). The most important observation of all could be that the Mirador Mine apparently sits in a seismic gap, that is, a region without recorded large earthquakes that is surrounded by recorded large earthquakes (see Figure 3). According to modern seismic prediction theory, such gaps are due for large earthquakes at times that are impossible to predict.

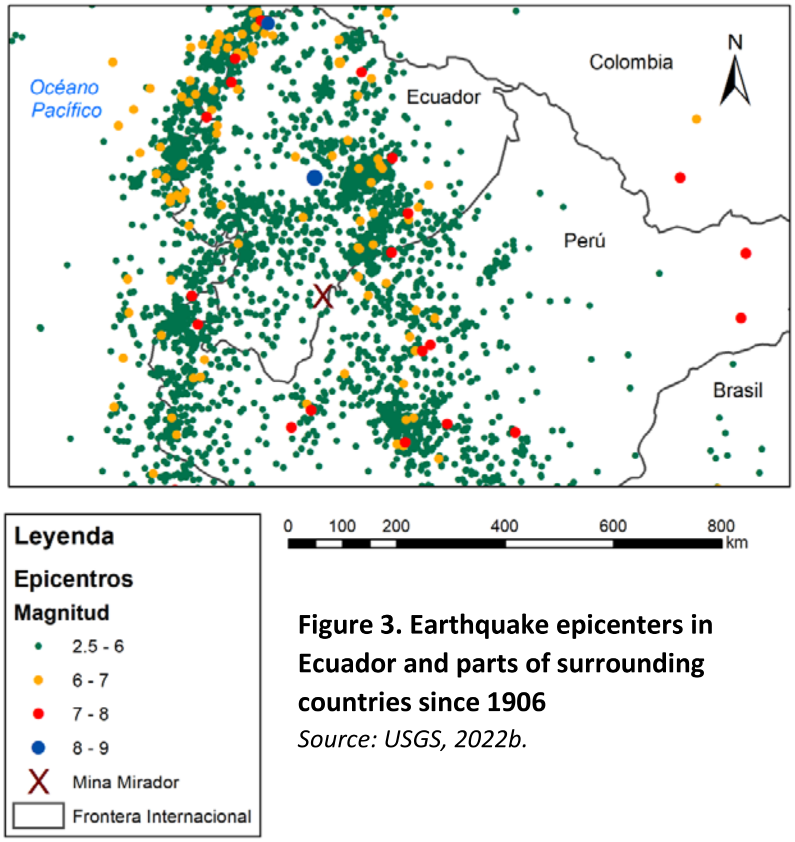

Figure 3. Earthquake epicenters in Ecuador and parts of surrounding countries since 1906

Source: USGS, 2022b.

With further regard to scenarios that are worse than the worst-case scenario, in light of the dire warnings of seismic instability by Knight-Piésold (2007), the response of the Ministry of the Environment of Ecuador to the 2010 Environmental Impact Assessment (EIA) by Walsh Scientists and Engineers (2010a-b) was that the seismic risk, as well as the landslide risk, were both high and poorly known. According to the Ministry of the Environment, "the seismic stability must be the product of a local seismic study of the project area and not regional, as it has been minimally done in the study. Similarly, with respect to landslides that could occur locally in the project area…" (Walsh Scientists and Engineers, 2011). The response of Walsh Scientists and Engineers (2011) did not address the comment in any way, but simply referred to the attached report by Knight-Piésold (2007), which also did not address the comment. The 2014 EIA by Cardno (2014a, b) did not provide any additional information about either seismic or landslide risk.

c. Risks Associated with Precipitation, Storm Events, and Climate Change

Knight-Piésold (2007) recommended that the Quimi dam be designed for a Probable Maximum Precipitation (PMP) event of 300 mm in 24 hours, although they admitted that this criterion was not well-constrained. According to Knight-Piésold (2007), "the available regional records [of precipitation] are not particularly long, nor are the data considered to be of exemplary quality." In a sense, risk factors that are not well-known, but believed to be high, can present a situation that is worse than the worst-case scenario because it is impossible to design for those scenarios. Although high precipitation can lead to failure of the dam by overtopping, the combination of steep slopes and high precipitation also increases the probability of failure by landsliding into the supernatant pond. The landslide potential in the vicinity of the tailings dams is clearly indicated by the numerous landslide scars, one of which had nearly undermined a transmission tower near the Quimi dam by November 2018 (see Fig. 15 in Emerman (2019); attached as Appendix 1).

In addition to the lack of knowledge of present and past precipitation in the area of the Mirador Mine, climate change adds an additional layer of uncertainty to the proper choice for the design flood. In fact, Armenta et al. (2019) have predicted an increase of 10% for precipitation in the watershed of the Santiago River (which includes the Mirador Mine) within 20 years, as well as an increase in the frequency of extreme precipitation events. According to Armenta et al. (2019), "Climate change scenarios for 2040 show that precipitation would increase significantly in the rainy season, with increases of more than 10% compared to current behavior. Likewise, the scenarios show an 'extension' of the rainy season, which would begin earlier (in December) and would have its maximum values in March. Regarding the indices associated with precipitation, the days with extreme rains would increase throughout the year, with January to May being the months that would present a greater increase in the number of days with these events in most of the study area…" The authors of this report have not seen publicly available data for precipitation at a meteorological station at or near the mine site.

Climate Change Effects

It was not common for mining companies and their consultants to take climate change into account in 2007, but it is standard practice at the present time (Muñoz and Hoekstra, 2022). According to the Global Industry Standard on Tailings Management (GISTM), the requirements for mining companies include the following: "To enhance resilience to climate change, evaluate, regularly update and use climate change knowledge throughout the tailings facility lifecycle in accordance with the principles of Adaptive Management … For new tailings facilities, use the knowledge base, including uncertainties due to climate change, to assess the social, environmental and local economic impacts of the tailings facility and its potential failure throughout its lifecycle … If new data indicates that the impacts from the tailings facility have changed materially, including as a result of climate change knowledge or long-term impacts, the

Operator shall update tailings facility management to reflect the new data using Adaptive Management best practices.” Member Companies of the International Council on Mining & Metals (ICMM) are required to fully implement the GISTM by August 2023. It is noteworthy that Association Members of ICMM include Cámara de Minería del Ecuador (CME) [Ecuador Chamber of Mining], International Copper Association, and International Wrought Copper Council (IWCC) (ICMM, 2022).

d. Summary of Physical Risks

The close proximity to surface water, large dam height, and large volumes of tailings all contribute to increasing the consequences of failure. Both the Quimi and Tundayme dams are situated along the banks of the Rio Quimi and the Rio Tundayme, which form one of the headwaters of the Amazon River. The projected height of the Tundayme dam of 260 meters (Cardno, 2014a) would make it the second tallest tailings dam in the world, after the Linga dam at the Cerro Verde Mine in Peru with a height of 265 meters (GRID-Arendal, 2022). The projected effective tailings storage volume of the Tundayme dam of 380 million cubic meters (Cardno, 2014b) would make it the 23rd largest tailings facility in the world (GRID-Arendal, 2022). For comparison, the largest spill of tailings in the world thus far has been less than one-tenth of that volume (32 million cubic meters) from the tailings dam at the Samarco Mine in Brazil in 2015 (Larrauri and Lall, 2018).

2. Chemical Risks and Toxicity of Wastes and Mine Leachate

a. General Geochemical Characteristics of the Mirador Deposit that Produce Acid Mine Drainage

The deposit at the Mirador Mine is a porphyry copper-gold ore body that also contains silver and molybdenum (Corriente Resources, Inc., 2008; Cardno, 2014b). The ore contains high percentages of pyrite, which is the primary mineral responsible for the formation of acid mine drainage. Acid mine drainage contains elevated concentrations of metals and other mine-related contaminants and is one of the most long-lasting and environmentally harmful results of the mining of sulfide ore bodies like the one at the Mirador Mine (INAP, 2009; Price, 2009). Chalcopyrite is the main copper-bearing mineral in the ore, and it also forms acid mine drainage (Plumlee, 1999; Plumlee et al., 1999). Table 4-2 (Cardno, 2014b) shows that the chalcopyrite content of the ore varies from 0.6 to 1.96%, and the pyrite content varies from 4.2 to 6.59%. Therefore, on a weight basis, the ore contains more pyrite than copper sulfide mineral.

The ore extracted from the open pit will be crushed and ground and sent to the flotation plant to separate the minerals bearing copper, gold, and silver from the waste (see Corriente Resources, Inc., 2008, Figures 19-2 and 19-3). Nearly all the ore will become waste: 98% of the ore will become tailings, and only 2% will become the concentrate that is shipped to China for processing (Corriente Resources, Inc., 2008, p. 5, 86). The EIAs and feasibility studies do not discuss a separate circuit for removing pyrite as part of the beneficiation process; therefore, much of the pyrite will report to the tailings facilities, and the tailings themselves will be acid-generating.

Even if all the copper sulfide minerals in the ore are removed in the beneficiation process, the remaining waste (tailings) will contain more than enough pyrite to produce acid mine drainage.

The neutralizing potential of the ore appears to be low, and no information is presented on the potential in any of the mine wastes. However, the limited information on geochemical testing and the types of water management facilities at the mine indicate that mine-influenced water associated with the waste rock and the tailings will be acidic with elevated metal concentrations.

b. Geochemical Testing Results

Geochemical testing of the ore, waste rock, tailings, and pit walls is needed to determine the acid generation and contaminant leaching potential of the mined materials that will remain on the site in perpetuity. The most common types of tests conducted are acid-base accounting (ABA) tests and humidity cell or other type of longer-term kinetic testing. The ABA tests will provide an indication of the overall balance between the acid-neutralizing and acid-generating potential of the wastes. If the acid-neutralizing content is less than 2 or 3 times the acid-generating content, the materials are considered potentially acid generating. Kinetic tests estimate the longer-term potential for acid and other mine-related contaminants of concern, including metals and sulfate, to be leached from mine wastes (Price, 2009; Maest et al., 2005). These results should be used to determine mine waste management practices, the need for water treatment, and the types of contaminants to measure in surface water and groundwater monitoring samples.

Geochemical testing was conducted, but none of the numeric test results are presented in any publicly available mine document, including the feasibility studies for the original 30,000 tons/day or the EIAs for the expanded 60,000 tons/day project. For example, wall rock testing conducted by AMEC in 2004 included 99 samples. In places the general results of the testing are described. A brief summary in the EIA for exploitation (EIA Explotación) noted that the sulfur content and the tendency to produce acid varied, but the majority of the samples did not have sufficient neutralizing potential to avoid the formation of acid (Cardno, 2014b, p. 4-7). The same EIA noted that waste rock contains approximately 2.38% sulfur (S), which implies that that drainage from the open pit and the waste rock dumps will be acidic (Cardno, 2014b, p. 4-64). The pit will produce a large amount of mine drainage water (18,600 m^3/day under “normal” conditions that are not defined, and 30,000 m^3/day for a 20-year precipitation event); the pit drainage was estimated to have a pH of 4 (Cardno, 2014b, p. 4-65). Any pH value below 6 is considered acidic, and each lower pH unit is 10 times more acidic (Price, 2009).

Although the actual numeric results of the geochemical tests are not presented, enough information is available to confirm that the mined material at the Mirador Mine will be acid-generating and leach elevated concentrations of mine-related contaminants -- and that this leaching has already adversely affected water quality in and around the mine.

III. Examples of tailings dam failures and similarities to the Mirador situation

In the past eight years three large tailings dam failures have mobilized mining companies and regulators to upgrade procedures and regulations related to the design, construction, operation, and closure of tailings dams to attempt to minimize the occurrence of these failures (ICMM-UNEP-PRI, 2020). Civil society and communities have also been mobilized because they typically suffer the impacts of these dam failures more directly, including loss of lives, homes, and livelihoods. They too have developed recommendations to be added to those developed by the mining industry and regulators (Morrill et al., 2022). The civil society/community recommendations emphasize safety, while the industry recommendations modify the existing approach to tailings management in a way that attempts to balance safety and economic considerations.

1. Static tailings dam failures and management errors

Two of these catastrophic tailings dam failures occurred in Brazil, and one in Canada. All these failures are termed "static" failures. That is, the dams failed due to a buildup of pressure within the dam and its foundation, with no external force applied (like an earthquake or flood). Static failures are very difficult to predict. In order to prevent static failures, a combination of conservative design and construction, and careful monitoring to detect any unplanned changes in the dam, is required.

a. Brumadinho tailings dam failure, Brazil

The failure of the tailings dam at the Córrego do Feijão Mine, Brumadinho, Brazil, on January 25, 2019 (Figure 4), took place during midday when employees were actively working at the mine (Robertson et al., 2019). The dam failed almost instantaneously. There were no warnings from the instruments monitoring the dam, even though the dam was well instrumented. There were no visual signs that dam was about to fail. However, it was known that the drain system for the dam was not working properly, and the employees working on the dam were attempting to assess and fix these problems. According to Robertson et al. (2019), the immediate cause of the failure was static liquefaction, which was triggered by heavy rainfall. Common aspects between the Mirador and Brumadinho sites are (1) steep embankments (2) upstream construction and (3) excessive water behind the dam.

Figure 4. Tailings dam failure at Brumadinho, Brazil, 18 seconds after the initiation of the failure

Source: Robertson et al., 2019.

Employee offices and the cafeteria were located directly downgradient from the dam, and many employees were eating lunch at the time of the dam failure. A total of 270 people died as a result of this accident, most of them mine employees. The mudflow destroyed the town of Brumadinho, nearby rural properties, as well as sections of a railway bridge. Agricultural areas in the valley below the dam were also damaged by the failure. Suspended sediment from tailings were flushed over 600 kilometers and reached the Atlantic Ocean.

b. Fundão tailings failure, Minas Gerais, Brazil

The Fundão tailings dam in Minas Gerais, Brazil, failed on November 5, 2015 (Morgenstern et al., 2016). Like the dam at Brumadinho, there was no warning from instrumentation of the imminent failure. And like Brumadinho, it was known that the drain system for the dam was malfunctioning, and efforts were continuing to be made to correct this deficiency when the dam failed. The accident resulted in 19 people being killed, including 14 working on the dams at the time. The waste discharge also reached the Atlantic Ocean. The immediate cause was static liquefaction that was triggered by a minor earthquake (Morgenstern et al., 2016). Important similarities between the Samarco and Mirador dams are: (1) upstream construction (2) inadequate characterization of the foundation (underlying geologic materials).

c. Mount Polly tailings dam failure, British Columbia, Canada

The dam failure at Mount Polley, British Columbia, Canada, on August 4, 2014, took place late at night when only a few mine employees were on the site (Independent Expert Engineering Investigation and Review Panel, 2015). There were no downstream residences, and the accident resulted in no fatalities. But like the dam failures at Brumadinho and Fundão, there was no warning visually, or from the dam instrumentation, that a failure was imminent. The immediate cause of the failure was foundation failure followed by overtopping (Independent Expert Engineering Investigation and Review Panel, 2015). The important similarities between the Mirador and Mount Polley dams are: (1) inadequate characterization of the foundation (2) upstream construction (3) lack of adherence to design (4) excessive water (4) overly steep embankments. Knight Piésold was the Mirador Mine Engineer of Record and was also the Engineer of Record at Mount Polley during the design, permitting, and operation stages from 1995 to 2011. A formal handover of design, construction, and monitoring responsibilities was conducted in March 2011 when AMEC Earth and Environmental became the new Engineer of Record. Knight Piésold stated that the Mount Polley tailings failure occurred with a substantially greater quantity of water in the impoundment at the time of the breach than when they were the Engineer of Record.[1]

2. Dynamic tailings dam failures

In addition to static failures, dams are also subject to "dynamic" failure forces (Vick, 1990; Hall et al., 2022). One dynamic force is an earthquake, which can shake a structure with enough energy that it collapses, just like a building can collapse under shaking from an earthquake. And like buildings, some dam designs stand up better under shaking than others, just like a steel building can withstand earthquake shaking better than a brick building. Water is another dynamic force. Dams are not designed to be overtopped by flowing water. If overtopped, the dam itself can be eroded and allow large amounts of tailings to be flushed from the impoundment.

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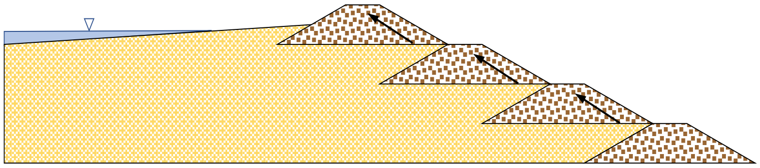
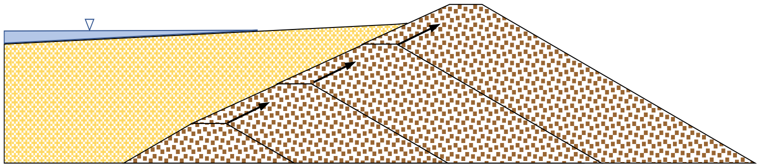
[1] https://knightpiesold.com/en/news/articles/statement-by-knight-piesold-ltd-regarding-the-mount-polley-mining-incident/

Earthquakes and floods are two major sources of tailings dam failures, and the Mirador Mine is in an area of very high risk for earthquakes and large flood events.

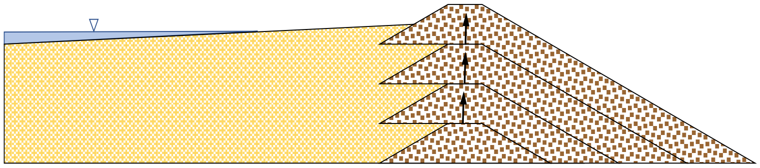
Both static and dynamic dam failures are influenced by the type of dam construction. Unlike water retention dams (i.e. water supply and storage dams), which are all essentially downstream-type construction, tailings dams can utilize the tailings themselves for partial support for the dam. There are three basic construction types – downstream, centerline, and upstream, as shown in Figure 5. Downstream-type construction is statistically the safest. Centerline-type dam construction uses the tailings for horizontal support and is significantly less expensive to build because only half of the material that would be used for downstream-type construction is required. The safety record of centerline-type dam construction is not as good as for downstream-type construction, but it is still relatively safe. Upstream-type dam construction uses the tailings themselves for vertical support. Upstream-type dams have the worst safety record, but they are also the least costly to construct.



B) Upstream Raised Embankment



B) Downstream Raised Embankment



C) Centerline Raised Embankment

Figure 5. TDF Structure Types (after Vick 1990): (a) Upstream, (b) downstream, and (c) centerline construction

Mirador Mine tailings dams and waste and water management uncertainties

At this time, we do not conclusively know what type of construction was used for the Quimi and Tundayme dams. Most regulatory agencies make this information readily available to the public, but this information is not publicly available for the Mirador Mine.

Figure 6. Quimi TDF almost full of water in June 2020

Source: Imagery © 2022 Planet Labs Inc.

It appears that the mine is currently switching from using the Quimi Tailings Disposal Facility (TDF) to using the Tundayme TDF. It is not clear whether the Quimi TDF will be closed, or whether it will be maintained in an operational status as a backup in case there are problems with the Tundayme TDF. It would be safer to close the Quimi TDF because an active facility will typically have ponded water on its surface, making the tailings facility inherently less stable because of the volume of saturated material (Figure 6).

Knowing the construction details and the closure plans for the Tundayme TDF is also important. As presently planned, the Tundayme TDF will be one of the largest dams in the world. The photograph at the right gives some perspective of the size of the tailings disposal facility. The towers under construction in the photo (Figure 7) are the structures that will drain water from the top of the tailings supernatant pond and return it to be used in the mill. In other words, the top of the TDF will be slightly below the height of the top of the decant towers. As the tailings pond fills, the drain point needs to be moved higher in elevation. As each drain tower is buried by tailings, the next uphill drain tower will become operational. The water could be pumped from a floating barge, avoiding the construction costs for these drain towers, but the long-term costs of pumping are probably higher than the costs to build the drain towers, which can use gravity to move the water back to the mill.

Figure 7. Decant Towers under construction. The tower in the lower left appears to be operational. Towers higher on the hillside are for future use. Late May 2022. *Source: locally provided photograph.*

In addition to uncertainty about the dam construction methods used for the Quimi and Tundayme dams, the current water and tailings management approaches employed by ECSA are unknown. This is especially important for the large Tundayme TDF.

In summary, the following tailings management and inherent site characteristics highlight what the Mirador tailings impoundments have in common with the three great failures of the last decade:

- Lack of adherence to design (Mirador, Mount Polley)
- Upstream construction (Mirador, Mount Polley, Samarco, Brumadinho)
- Overly steep embankments (Mirador, Mount Polley, Brumadinho)
- Inadequate characterization of the foundation (Mirador, Mount Polley, Samarco)
- Seismicity (Mirador, Samarco)
- Heavy rainfall (Mirador, Brumadinho)
- Excessive water behind the dam (Mirador, Mount Polley, Brumadinho).

Catastrophic failures of tailings dams are low-probability, high-consequence events. As the failures in Brazil and Canada have demonstrated, these failures can result in the loss of many lives and the widespread destruction of homes and livelihoods. Understanding the potential impacts and putting plans in place to provide as much warning as possible in the event of such a failure are important parts of mine planning and the protection of, and communication with, local civil society.

IV. Vulnerable Downstream Communities

1. Communities located in the area of operations of the Mirador project, in the province of Zamora Chinchipe

Exploitation of the Mirador Mine, which is operated by the company EcuaCorriente SA, a subsidiary of the Chinese consortium Tongling Nonferrous Metals Group Holdings & China Railway Construction Corporation, Ltd (CRRC), is directly affecting the villages of Tundayme and El Güismi of the Pangui neighborhood (canton), in the Amazonian province of Zamora Chinchipe, because these villages are at the center of the mining concessions and operations. The information in this section has been provided by Acción Ecológica and CEDHU, who are co-plaintiffs in the IACHR case.

The mining operation has directly impacted and continues to impact the Yanúa Kim Shuar community, the Churuwia and Etsa Shuar centers, the San Carlos de Numpaim Shuar center, farms and properties in San Antonio and Santa Cruz, the Quimi Valley, El Quimi, Machinaza Alto, Chuchumbletza, Remolino 2, and more communities and populated centers.

The location of the communities directly affected by the Mirador Mine is shown in Figure 8. In addition, the creation of the Tundayme diversion in the headwaters of the Rio Tundayme upstream of the Mirador Mine (see Figure 2: Dique de Desvio Tundayme and Tunel de Desvio) brings additional water into the Rio Machinaza and threatens communities along the Machinaza with a heightened risk of flooding.

a. Displacements and evictions

One of the main effects has been the forced displacement and eviction of more than 30 peasant and indigenous families (in many cases, violent evictions), from the Tundayme and El Güismi villages, which occurred during the first 15 years of the 2000s. These actions include the destruction of the town of San Marcos and Tundayme village, the forced displacement of its 19 families, and the destruction of their infrastructure (school, community spaces, church). Crops, forests, houses, and rivers have been transformed for mining operations.

This process of eviction of families continues to advance as the Chinese consortium intensifies its mining operations to reach the production of 60,000 tons/day of ore.

Figure 8. Location of communities downstream of the Mirador Mine along the Quimi River and nearby Rio Zamora

Source: Cliff Jones, Planet Labs Inc remote sensing images.

b. Destruction of self-sustaining activities

The communities that remain in the areas surrounding the project, mostly indigenous, can no longer engage in their traditional activities, including agriculture, livestock raising, forestry, and forest harvesting, due to the destruction and contamination of forests, soils, and rivers. As a result of contamination of the Tundayme and Wawayme rivers, they cannot use their waters for human consumption, animal watering, fishing, rituals, or recreation, as they have traditionally done. Their self-sustaining crops have been destroyed by the removal of soil, contamination, and overflow of watercourses, with no other possible economic support other than dependence on working for the mining company.

2. Mining exploitation that puts the province of Morona Santiago at risk

The communities and precincts mentioned are not the only ones affected, the repercussions of mining intensification and the increase in toxic waste threaten to contaminate soils, forests and water sources of communities, precincts and towns located in the course of the Zamora River (in the province of Morona Santiago) where the waters of the Quimi River and its tributaries (located in the Tundayme mining operations center) reach. Furthermore, there is an imminent danger (according to scientific analyses) of a possible rupture of the tailings dams of the Mirador project that would result in a spill towards the confluence between the Zamora and Santiago rivers.

In other words, the impact of Mirador implies a large multi-ethnic territory (indigenous Shuar and peasant farmers), located both in the province of Zamora Chinchipe and in the adjoining province of Morona Santiago, in what constitutes the Cordillera del Cóndor. The downstream communities at risk of a tailings dam break include those shown in Figure 8 and the communities along the Zamora River to the confluence with the Santiago River, as shown in Figure 9.

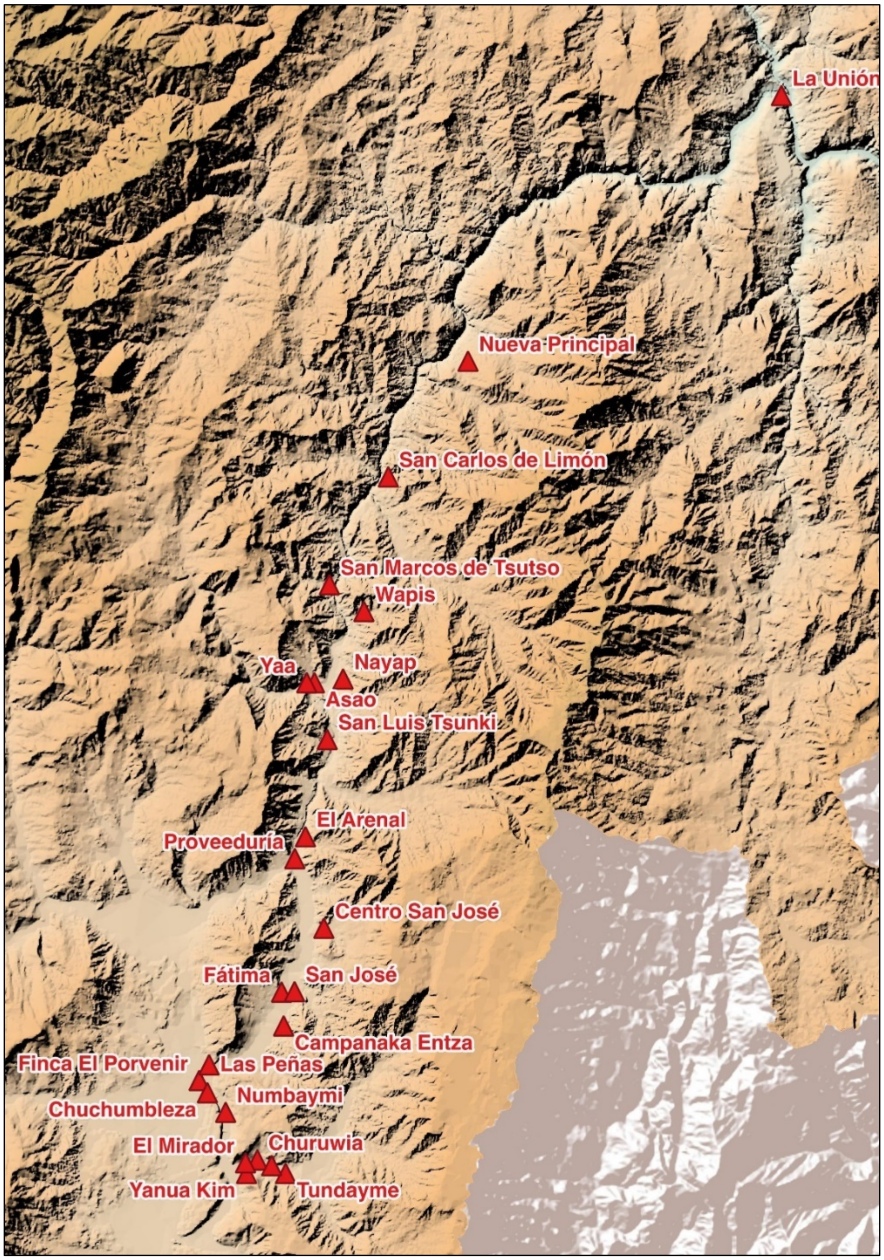


Figure 9. Location of communities affected by a potential tailings dam failure at the Mirador Mine
Source: Cliff Jones, Open Street Map; base map from the Instituo Geografico Militar

Appendix 2 contains a preliminary list by Tarquino Cajamarca, Morona Santiago attorney and former Provincial head of the Defensoría del Pueblo, of the communities concerned with environmental, safety, and other social impacts from the Mirador Mine. The list is not a comprehensive list of potentially affected communities; it is a result of local residential concerns expressed in interviews. The communities shown in Figures 8 and 9, and the communities along the Rio Machinaza downstream of the Tunel de Desvio, may provide a more comprehensive of potentially affected communities.

3. Socio-ecological characteristics of the Cordillera del Cóndor that are seriously threatened

The information in this section is taken from Acción Ecológica (2021). The ecological area and function are an integral part of the indigenous communities.

a. Biodiverse area shared between Ecuador and Peru

The Cordillera Del Cóndor, where the Mirador project is located, is part of the eastern foothills of the Andes and Ecuadorian-Peruvian Amazon lands. The surface of this mountain range is 1.1 million hectares, of which 700,000 are located in Ecuador and 400,000 in Peru.

This mountain range is representative of the mega-diversity of Ecuador. It has 16 ecosystems located between 800 and 1680 meters above sea level. Its peculiar geography and topography have given rise to unique biological niches. It has been classified as a priority for the conservation of flora and birds of high biodiversity and endemism. There is diversity of mammals in *sui géneris*[2] habitats.

Several sites in the Cordillera Del Cóndor have been incorporated into the National System of Protected Areas and Protective Forests. Among them, the El Zarza Wildlife Refuge, the El Cóndor Binational Park, the El Quimi Biological Reserve, the Cordillera del Cóndor Protected Forest and the Nangaritza River Basin Protected Forest. These places are protected by the Constitution (Arts. 405 and 407) for their ecological functions and for being key to the conservation of biodiversity and genetic heritage.

b. Generation of water wealth that feeds the Amazon basin

The Cordillera del Cóndor is key to the water systems of the Amazon and its forests. Springs and rivers that are born in this mountain range contribute to the formation of great rivers such as Zamora, Santiago (in Ecuador), and Marañón (in Peru). The water sources that originate and flow where the project operates are severely affected in this first stage of copper exploitation (Ministerio del Ambiente, 2015). The more than 200 sources and water springs run the same risk, which according to the Contraloria of the State of Ecuador are within the area that the project impacts (Contraloria, 2012).

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[2] unique or endemic; one-of-a-kind

c. Ecosystems necessary for the environmental balance of the planet

Zamora Chinchipe and Morona Santiago are Amazonian provinces and, according to the Constitution (Art. 250), are part of a larger ecosystem necessary for the environmental balance of the planet.

d. Historical-social zone of ancient cultures

In Tundayme, which is in the Mirador project area (as well as in contiguous areas), according to archaeological studies, there is evidence of cultural landscapes configured by pre-Hispanic terraces with corrugated ceramics that form part of the Upper Amazon Rainforest complex.

e. Ancestral home of the Shuar People

The Cordillera del Cóndor crosses the political boundaries of Ecuador to Peru and constitutes the ancestral home of the Shuar nationality, known as "people of the sacred waterfalls," which maintains an accumulated knowledge about forests and rivers, conservation, and uses of food, medicinal, artisanal species, on which the conservation of the genetic heritage of the two countries is based.

V. Concerns Related to Failure of the Mine Facilities and Lack of Adequate Plans

The most important environmental and human health concerns related to the mine and its operations are failure of the tailings dams and negative impacts to water quality. Based on the available information, the potential for the failure of the tailings dams and impacts to water quality are discussed in this section. The mine facilities are shown in Figure 2. Based on the available information, the site monitoring, closure plans, and financial assurance are inadequate to protect, prevent, minimize, or mitigate the adverse effects of the mine operation. In addition, the government of Ecuador has extremely limited experience regulating large-scale mines. In fact, the Mirador Mine is the first large-scale mining operation the country has ever experienced.

1. Potential for failure of the tailings dams

The central issue that is driving the high probability of failure of the tailings dams at the Mirador Mine is the lack of adherence to analyses, designs, proposals, and permits. In fact, due to the numerous contradictions within the 2014 EIA by Cardno (2014a-b), it is difficult to tell which were the real designs and proposals. For example, although in some places, there is discussion of using the Quimi dam during the first few years of the project, followed by the use of the Tundayme dam, Capítulo 5: Alternativas Estudiadas [Chapter 5: Studied Alternatives] of Cardno (2014a) clearly evaluates the Quimi and Tundayme dams as two mutually exclusive alternatives, in which costs, environmental impacts, and all other aspects were evaluated separately for each alternative. Since both tailings storage facilities have been constructed, it is impossible to determine the real plans of the Mirador Mine and which of those plans, if any, have been subjected to the type of rigorous analysis that was carried out by Knight-Piésold (2007) for only the Quimi dam.

a. Dam embankment slopes are too steep

Although all previous analyses, designs, proposals, and permits for the Quimi dam specified an outer embankment slope of 1V:2H (one meter vertical for two meters horizontal), the outer embankment of the Quimi dam was constructed at the much steeper slope of 1V:1H (see Fig. 17 in Emerman (2019); Appendix 1). The slope of 1V:2H for the Quimi dam was assumed in the seismic stability analyses by Knight-Piésold (2007) (see Fig. 10 in Emerman (2019); Appendix 1) and was specified in both the 2010 and 2014 Environmental Impact Studies (Walsh Scientists and Engineers, 2010a-b; Cardno, 2014a-b). By comparison, the U.S. Army Corps of Engineers (2000) and Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022) require outer embankment slopes no steeper than 1V:5H. For tailings dams constructed using the upstream method, the European Commission recommends slopes no steeper than 1V:3H (Garbarino et al., 2018), while a widely cited industry paper recommends slopes no steeper than 1V:4H (Martin et al., 2002). Many jurisdictions, such as British Columbia in Canada, require outer embankment slopes of tailings dams to be no steeper than 1V:2H (Ministry of Energy and Mines (British Columbia), 2016). In fact, a slope of 1V:1H is generally regarded as the maximum critical angle for the prevention of failure by internal erosion, the process by which seepage through the dam washes out solid particles, so that the dam loses its structural integrity (Holtz et al., 2011; LePoudre, 2015). Thus, the Quimi dam should be considered as temporarily existing at the cusp of failure.

b. Dam construction methods compared to plans

In the upstream construction method, the tailings dam is constructed on top of the uncompacted tailings that are being confined (see Fig. 5a in Emerman (2019); Appendix 1). This construction method is the least expensive because it requires the minimum amount of construction material, but is also the most dangerous because, if the underlying tailings liquefy, the dam can fail simply by falling into or sliding over the liquefied tailings. The downstream method is the most expensive because it requires the greatest amount of construction material, but it is the safest because there are no uncompacted tailings underneath the dam (see Fig. 5b in Emerman (2019)). The centerline method is a compromise between the upstream and downstream methods both in terms of cost and safety (see Fig. 5c in Emerman (2019)). The upstream construction method has been prohibited in Brazil (ANM, 2019), Chile (Ministerio de Minería (Chile) [Ministry of Mining (Chile)], 2007), Ecuador (Ministerio de Energía y Recursos Naturales no Renovables [Ministry of Energy and Non-Renewable Natural Resources] (Ecuador), 2020), and Peru (Sistema Nacional de Información Ambiental (Perú) [National System of Environmental Information (Peru)], 2014). Ecuador has gone further than the other countries in preferring the downstream method and permitting the centerline method only under special circumstances. According to Ministerio de Energía y Recursos Naturales no Renovables (2020), "The use of the upstream method is prohibited. In a standardized way, the construction method will be downstream, including the starter dike. The centerline construction method will be approved in cases where the morphology or space of the land does not allow for downstream growth, only and when it meets favorable conditions for the physical stability of the tailings deposit."

The seismic stability analysis by Knight-Piésold (2007) was conducted assuming that the Quimi dam would be constructed using the centerline method (compare Figs. 5c and 10 in Emerman

(2019; Appendix 1)). The first EIA also explicitly stated that the Quimi dam would be constructed using the centerline method (Walsh Scientists and Engineers, 2010a-b). Although the construction methods were never explicitly stated in the second EIA (Cardno, 2014a), the discussion of the impermeable layers for both the Quimi and Tundayme dams made it clear that the upstream construction method was not intended, since the use of the upstream method would not provide any place to put those layers (Emerman, 2019; Appendix 1). A particular feature of the upstream method is that the downstream edge of the starter dike marks the maximum downstream extent of the tailings dam (see Fig. 5a in Emerman (2019); Appendix 1). Thus, the location of the downstream edge of the starter dike at the edge of the highway (see Fig. 16 in Emerman (2019); Appendix 1) indicates the intention to construct the entire dam using the most dangerous upstream method. It is not possible to advance the tailings dam any farther in the downstream direction without covering the highway, and on the other side of the highway is the steep slope going down to the Rio Quimi. In summary, the Quimi dam appears to have been constructed using the upstream method, which has the highest probability of failure, and which is now prohibited in Ecuador because it is so unsafe.

A common feature of the use of the upstream construction method and the excessive steepening of embankments used for the Quimi tailings dam is that they both minimize the required amount of construction material for the tailings dams. Thus, both deviations from prior analyses, designs, proposals, and permits could have resulted from an unanticipated lack of construction material. The lack of appropriate and legally available construction material would also be consistent with the illegal extraction of river rock (Quishpe Lozano et al., 2018; see Fig. 20 in Emerman (2019)). According to Quishpe Lozano et al. (2018), "Here the extraction of rock material was carried out in a portion of the Rio Tundayme. As in the Rio Quimi and the Rio Waywayme, the extraction of rock material in this area is not carried out within any mining concession for the exploitation of aggregates and rock … It should be noted that in the review conducted for the National Mining Registry, mining titles are not registered for the exploitation of rock material within the Mirador project in the aforementioned area." It is alarming that the steepening of the outer embankment and the switch from the centerline to the upstream method as a result of the lack of construction material was the exact sequence of events that led to the failure of the tailings dam at the Mount Polley mine in Canada in 2014 (Independent Expert Engineering Investigation and Review Panel, 2015). In fact, another common feature is the lack of characterization of the foundation, which, in the case of the Mount Polley mine, would have indicated that steepening of the embankment would result in failure of the foundation (Independent Expert Engineering Investigation and Review Panel, 2015.

c. Probability of dam failures

At this point, it is appropriate to consider the probability of failure of the tailings dams at some time during the 30-year life of the Mirador project. Knight-Piésold (2007) defined the OBE as the earthquake with a return period of 475 years, which is equivalent to an annual exceedance probability of 0.21% and a probability of exceedance during the 30-year life of the project of 6.13%. Since Knight-Piésold (2007) also showed that the Quimi dam would fail in response to the OBE, the preceding sets the probability of failure during the life of the project at 6.13%. If the same analysis applies to both the Quimi and Tundayme dams, then the probability of failure of at least tailings dam due to earthquake during the life of the project is 11.88%. In addition, the tailings dams have been designed to withstand a 500-year flood (Cardno, 2014a), corresponding to an annual exceedance probability of 0.20%, contrary to Knight-Piésold (2007), who recommended design for the Probable Maximum Flood (PMF), which has no defined return period, but which is considered to be significantly more rare than a 10,000-year flood (USACE-HEC, 2003). Based on the annual probability of failure due to flooding, the probability of failure of a single tailings dam over the life of the project is 5.83%, leading to a probability of failure of either tailings dam due to flooding of 11.32% over the life of the project. In summary, the probability of failure of either tailings dam due to either earthquake or flooding over the life of the project is 21.85%.

However, in addition to the preceding physical factors, the following human factors must be taken into consideration:

1) The seismic stability analysis assumed that the maximum dam height would be 63 meters (although the Tundayme dam will be 260 meters high).
2) The seismic stability analysis assumed centerline construction (although the Quimi dam uses upstream construction).
3) The seismic stability analysis assumed an outer embankment slope of 1V:2H (although the Quimi dam has an outer embankment slope of 1V:1H and the design slope for the outer embankment of the Tundayme dam is 1V:1.5H).
4) The seismic stability analysis was not carried out for the much steeper slope of the Tundayme site (the Quimi Valley has 7% slope down to the Rio Quimi, while the Tundayme Valley has 13% slope down to the Rio Quimi).
5) There has been no study of local faults and seismicity.
6) There has been no study of the foundation at the Tundayme site.
7) There has been no evaluation of the risk of landslides or the high erosion rate in the area.
8) The design for the 500-year flood did not take climate change into account.
9) There is apparently no commitment to construct and operate the dams in concordance with the analyses, designs, proposals, and permits.

Based upon the preceding considerations, the probability of failure of one or both tailings dams at the Mirador Mine at some time during or after the life of the project is so high that it should be treated as inevitable in terms of mine monitoring, management, and planning. It should be remembered that the risk of failure does not end after the project ends but continues in perpetuity. The long-term risk is especially acute, considering that the plan seems to be to maintain the tailings in a saturated state in perpetuity. Knight-Piésold (2007) wrote "post-closure surface grading will ensure the cleaner tailings remain saturated in perpetuity." Both the 2010 and 2014 EIA used the exact same language in confirming that a permanent water cover over the tailings will provide conditions of anoxia, which will prevent the generation of acidic water, maintaining the neutral conditions of the lake (Walsh Scientists and Engineers, 2010b; Cardno, 2014a). There is certainly no plan to carry out monitoring, inspection, and maintenance of the tailings dams in perpetuity. According to Andrews et al. (2022), "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 is no demonstrated precedent for the legacy of permanent submergence being constructed today."

2. Impacts to water quality from a failure based on currently known water quality

As noted in Section II 2., the Mirador wastes and mined materials are known to have elevated acid drainage and contaminant leaching potential, largely due to the presence of metal sulfides in the ore and the wastes. In addition to geogenic constituents contained in the mined materials themselves (e.g., metals, sulfur from ore minerals), blasting agents are added to remove the ore and waste rock from the pit. The most common type of blasting agent is ammonium nitrate-fuel oil (ANFO), which generates elevated concentrations of ammonia and nitrate during mining and for some period of time after mining stops (Ministry of Environment and Climate Change Strategy, 2018). Unlike the residue from blasting agents, concentrations of geogenic contaminants such as metals and sulfate do not decrease after mining ceases without a significant investment in effective mitigation measures. Downgradient groundwater and surface water will therefore contain elevated concentrations of metals, sulfate, acidity, nitrate, ammonia (ammonia is more common in groundwater and mine water), and other constituents as a result of mining. Mine water held and created in the facilities, including water entrained in tailings and waste rock and the supernatant tailings pond will also contain these mine contaminants. When a tailings dam break occurs or an uncontrolled release of water from the acid drainage storage impoundment occurs, downstream and downgradient water quality will additionally be impacted by mine-influenced water.

The 2008 Feasibility Study (Corriente Resources, Inc. 2008, p. 5), which was created for the smaller 30,000 ton/day operation, listed the greatest risks for tailings management. During ongoing operations, the greatest risks for tailings management are seen to be:

(1) failure of the waste dump(s) upslope of the Rio Quimi TMF;
(2) acid rock drainage developing in the waste dump(s) and impacting site water quality;
(3) rupture or leakage from the pipelines and pump station that are established in the Rio Quimi River corridor and
(4) failure of the bridge crossing on which these pipelines are carried across the Rio Zamora to the Pangui TMF."

The list of greatest risks for tailings management acknowledges some of the risks that have and will continue to adversely impact water quality. However, importantly, the list does not include the potential failure of one or both tailings dams, as discussed in Section IV.a. Since the 2008 Feasibility Study was published, the increase in the volume and geographic extent of the waste rock piles has greatly increased the amount of acid rock drainage and the impact to site water quality. A bridge has been constructed across the Rio Zamora, but the Pangui tailings disposal facility does not currently exist. Instead, the much larger (than the Quimi impoundment) Tundayme TMF, located upgradient from the Quimi TMF, was created. The location and size of the Tundayme impoundment increased the likelihood of tailings dam failure and the effects of leakage on site water quality.

a. Facilities created to store and treat acid mine drainage

The mine wastes at the Mirador Mine are generating and will continue to generate large quantities of acidic and metalliferous drainage. Even though the transparency of information is very low, the presence of certain facilities on the site makes it clear that the mine owners understand the toxic nature of their operations and the potential effects on the environment. However, even with these facilities, capture of the mine-influenced waters is consistently unreliable, especially at large copper mine sites like the Mirador Mine (Gestring, 2019). In addition, the facilities have not been constructed to withstand the large precipitation events expected as a result of climate change (see Section II.1.c). The presence of the following mine facilities indicates that the waste rock, tailings, and the open pit are producing acidic, metalliferous drainage:

- Impoundment for acid drainage from the waste rock pile and the open pit: Because the waste rock contains 2.38% sulfur, rain falling on the waste rock will produce acidic water that could cause environmental damage if discharged directly to the river (Cardno, 2014b, p. 4-59). The open pit will also produce acidic water that will be sent to the impoundment (Cardo, 2014b, p. 4-65). The expected volumes of acidic water from each source is 30,000 m^3/day from the Northeast waste rock dump and 40,000 m^3/day from the open pit (Cardno, 2014b, Figure 4-26). The impoundment is designed for a total capacity of 3.15 million m^3 to store the acidic water and a storm with a return period of only 50 years (a storm predicted to occur once in 50 years). The location of the acid drainage impoundment is in the Rio Wawayme watershed and is shown in Figure 2 (Dique de Drenaje Acido).
- Treatment plant for acidic waters from the waste rock pile and the open pit: A lime treatment plant is located 700 m east of the impoundment to treat the combined acidic water from the open pit and the northeast waste rock pile (Cardno, 2014b, p. 4-66).
- Collection and treatment of acidic leachate from other waste rock piles: It is unclear if the impoundment or the treatment plant will capture and treat water from the other waste rock dumps located to the west of the open pit (see Figure 2). According to Corriente Resources, Inc. (2008, p. 103): Collection and treatment of ARD from the waste dumps will continue for as many years as required, until the levels of acidity and metals abate to the extent that they will be acceptable for release or that can be adequately treated by passive systems. This statement acknowledges that the original waste rock piles are expected to create acid mine drainage, but details on the collection and treatment of the drainage are not presented.
- Acid water treatment plant for the tailings impoundments: According to the 2014 EIA Explotacion (Cardno, 2014b), the acidic waters generated at both the Tundayme and Quimi tailings impoundments will be combined in the Quimi tailings impoundment. An acid water treatment station will be constructed near the Quimi tailings impoundment (Cardno, 2014b, p. 4-56). Earlier statements noted that the cleaner tailings, which would include a potentially reactive pyrite component, would be discharged to the Quime TMF and maintained underwater to help to minimize any potential for oxidation and production of acid (Corriente Resources, Inc., 2008, p. 86). But after year 5, the cleaner and rougher tailings will be mixed together and disposed of in the Tundayme TMF

> (Cardno, 2014a, p. 4-30). The plan to collect acidic waters from both tailings impoundments and treat it is a strong indication that, regardless of disposal methods, acidic waters are expected to be produced.

The information presented demonstrates that large quantities of acidic water will be produced from the open pit, waste rock piles, and the tailings impoundments. The results also indicate that if the acid water storage facility, the waste rock facilities, or the tailings facilities fail, the mine-influenced water spilled will be highly toxic to aquatic life and downstream communities. Although facilities exist to collect and treat the acidic, metal-rich waters, not all mine-influenced water is able to be captured, and the effects on the environment are evident based on limited information available for surface water quality.

b. Known effects of mine drainage from the Mirador Mine on surface water quality

According to the Contraloria (2020) report, water quality in surface water located downstream of the waste rock piles and the tailings impoundment have exceeded baseline values (concentrations before mining began; IIGE, 2018) and Ecuadorian water quality criteria. Limited additional water quality data were obtained from information requests to MERNNR and MAE). As an example, results from the Contraloria (2020) report for Rio Wawayme will be presented.

Rio Wawayme drains the large waste rock pile known as Escombrera Noreste, and surface water monitoring locations close to the piles and just upstream of where it flows into the Rio Quimo have water quality standard exceedences of many metals, including copper, iron, aluminum, lead, manganese, and zinc and low pH values (< pH 6). The locations with the highest metal concentrations and lowest pH values are WQ-04, WQ-05, and WQ-34, which are located in tributaries to Rio Wawayme that drain Escombrera Noreste and the open pit (Table 1 and Figure 10[3]). Metal concentrations near the mouth of Rio Wawayme (WQ-06) were generally lower and pH values were somewhat higher, based on limited additional data obtained as part of the information requests. The elevated metal concentrations and low pH values compared to pre-mining conditions are a strong indication that surface water is adversely impacted by mining and that the contaminants derive from leaching of waste rock in Escombrera Noreste. The lower concentrations farther away from the waste rock pile indicate that the source is the pile, and dilution occurs downstream; however, concentrations are still elevated at the mouth. The results also show that environmental control measures to capture mine-influenced water from the waste pile are not effective.

The Contraloria (2020) report also shows elevated concentrations of metals and low pH values in Rio Tundayme and Rio Quimi compared to baseline values (IIGE, 2018) and Ecuadorian water quality criteria. The upper Rio Tundayme receives water from tributaries draining the open pit area, and the lower Rio Tundayme contains the Quimi TDF. The 2008 Feasibility Study (Corriente Resources, Inc., 2008) shows that large waste rock dumps were planned for the west side of the open pit that would drain to the Rio Tundayme watershed, as shown in Figure 11.

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[3] Note that not all sampling locations are shown on this figure, which was sourced from the 2014 EIA Explotacion.

Table 1. Concentrations of metals and pH values in Rio Wawayme close to the Escombrera Noreste waste rock pile in 2016 compared to baseline values and Ecuadorian water quality criteria

Locations	Analyte (units)	Measured Range	Background value (IIGE, 2018)	Ecuadorian water quality criteria
WQ-04, WQ-05, WQ-34 on individual sampling dates in 2016 (Contraloria, 2020)	pH (s.u.)	4.5-5.5	7.36	6.5-9
	Copper (mg/L)	0.54-1	0.015	0.005
	Manganese (mg/L)	3.2-6.8	0.14	0.1
	Lead (mg/L)	0.064-0.15	0.0018	0.001
	Zinc (mg/L)	0.15-0.307	0.0176	0.03

Sources: Contraloria, 2020; IIGE, 2018.

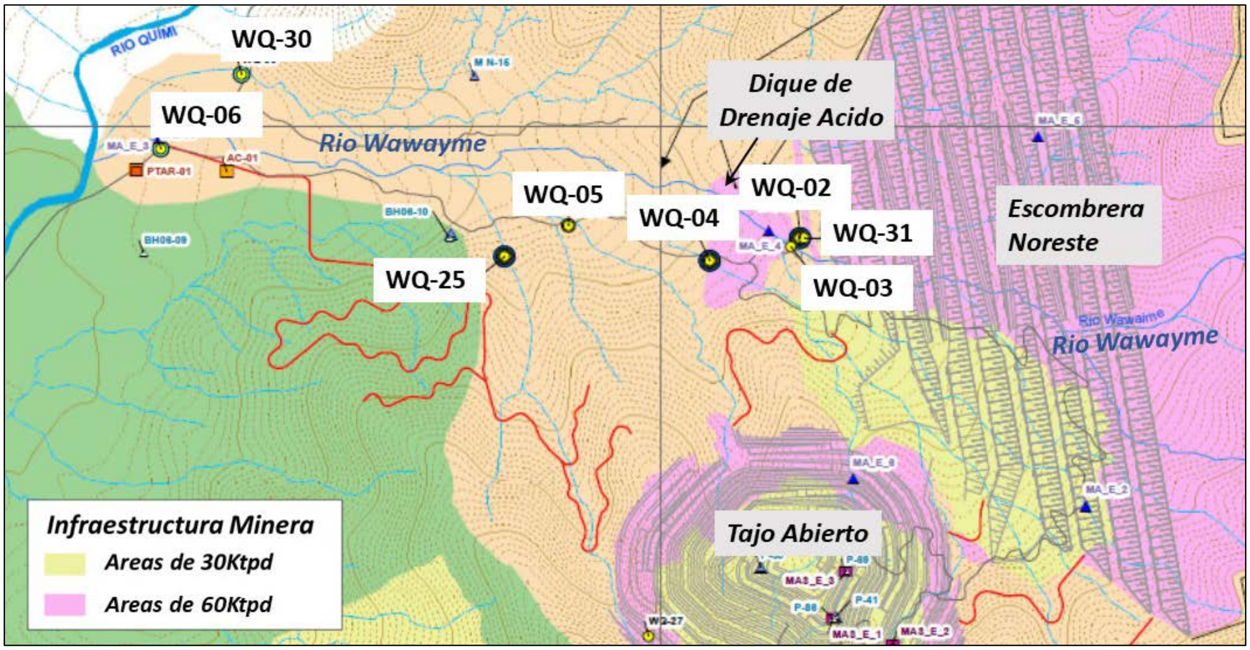
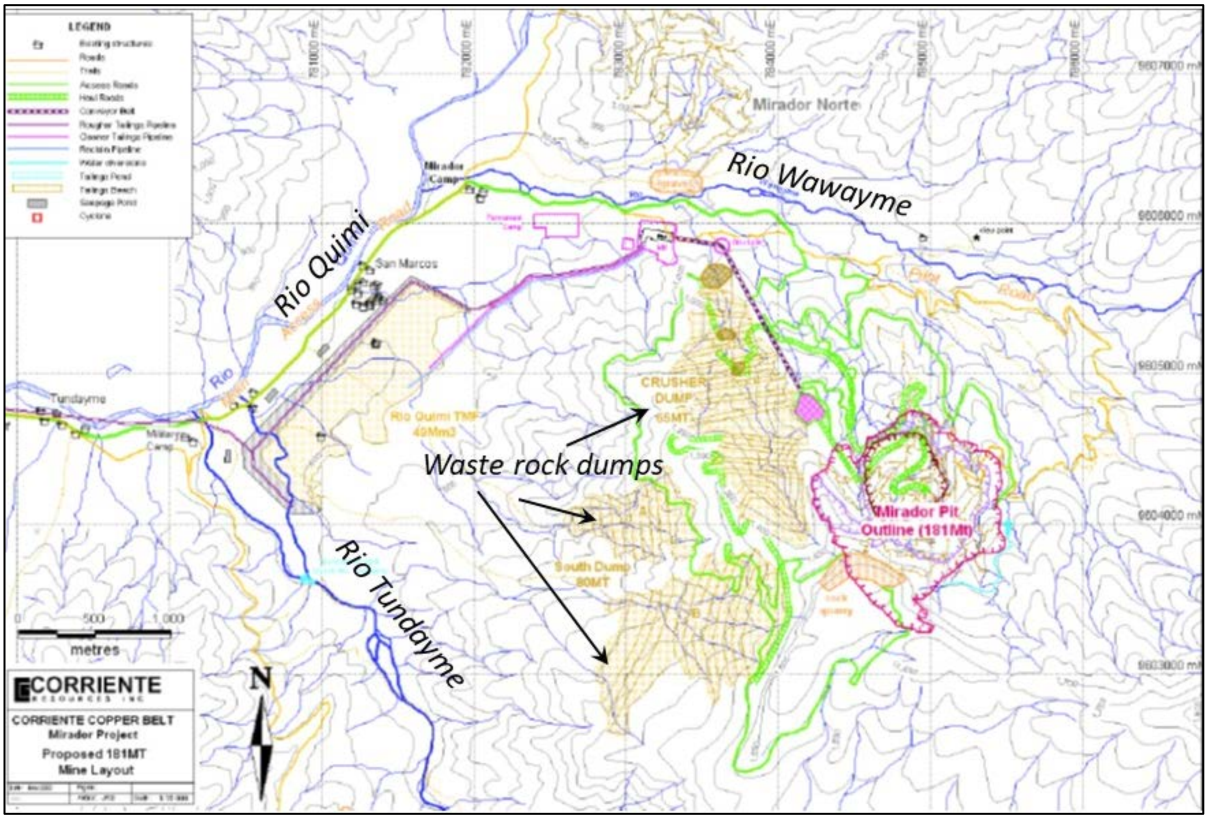


Figure 10. Surface water sampling locations on Rio Wawayme and waste rock and open pit facilities
Source: Modified from Cardno, 2014b, Anexo D, Mapa 7.3-12

Rio Quimi drains all areas affected by Mirador mining and also has upstream locations that should not be affected by mining activity. More water quality data and improved locational information are needed to conduct a detailed investigation. However, the limited available data and information indicate that the Mirador Mine has important sources of mine-related contaminants, including acidity and metals, has not successfully captured mine-influenced water, and would release large amounts of contaminated water if a catastrophic failure of the waste rock pile or the tailings impoundments occurred.

The limited water quality data received from the information requests and the data in the Contraloria (2020) report also confirm that the streams draining the mine site have low metal concentrations, low hardness, and low alkalinity in the absence of mining influence (baseline water quality). Metals are more toxic to aquatic life when the water has low hardness and low pH (Campbel and Stokes, 1985; Pascoe et al., 1986), and the low alkalinity indicates that the surface waters would not be able to neutralize the acidic water released from mining. The purity of the waters draining the mine site also increases the consequences of a potential breach of mine waste impoundments.

Figure 11. Mine layout for the 30,000 ton/day operation showing waste rock dumps in the Tundayme and Wawayme watersheds



Source: Corriente Resources, Inc. 2008, Figure 19-1.

The allowable permit limits for discharge of mine-influenced water are much higher than Ecuadorian surface water quality criteria (Table 2). Therefore, the permit allows contamination of downstream water quality that can adversely impact aquatic life and human health.

Table 2. Comparison of allowable limits for Mirador Mine water discharged directly to surface water with Ecuadorian surface water quality criteria

Constituent (units)	Permitted Discharge Limit	Ecuadorian surface water quality criteria	Criteria/Permit Limit
pH (s.u.)	6-9	6.5-9	NA*
Arsenic (mg/L)	0.1	0.05	2
Cadmium (mg/L)	0.1	0.001	100
Copper (mg/L)	0.3	0.005	60
Lead (mg/L)	0.2	0.001	200
Zinc (mg/L)	0.5	0.03	16.7

Sources: Permitted discharge limits: Cardno, 2014b, Table 4-32; Ecuadorian water quality criteria: Contraloria, 2020. NA* not applicable, but permit allows for lower-pH water to be discharged than allowable under Ecuadorian law

3. Inadequate financial assurance amounts

E-Tech International commissioned Jim Kuipers, P.E. to conduct an analysis of the adequacy of the financial assurance for the Mirador Project in 2012 (included as Appendix 3 to this report). His comments and recommendations are based on review of the Knight Piésold (2007) and are limited to financial assurance amounts for the proposed 30,000 ton/day operation that was proposed at the time.

Mr. Kuipers found that the costs estimated by AMEC (2004) were more than an order of magnitude underestimated. AMEC estimated an “Indicative Closure Cost” of US$55,000,000 for mine reclamation and closure that included direct closure costs, indirect closure costs, and post-closure costs. The cost estimate was not a detailed estimate due to limited information on actual reclamation and closure designs and costs at the time. AMEC did not provide a technical basis for the costs used in the estimate.

Mr. Kuipers estimated financial assurance costs at US$568,000,000. The figure represents the cost of the regulatory agency conducting the reclamation and closure activities in the event the company does not do so. His estimates are consistent with those derived for U.S.-located copper porphyry mines containing acid drainage generating materials and in close proximity to water resources. Examples of mine cost estimates which have been used in this estimate include that of the Chino and Tyrone Mines in New Mexico, the Morenci and Bagdad Mines in Arizona, and the Continental Mine in Montana. The costs are also consistent with US Federal Reclamation and Closure Guidance issued by the US Environmental Protection Agency (EPA), US Forest Service, and US Bureau of Land Management. Mr. Kuipers regularly reviews such estimates conducted by other agencies and routinely conducts such estimates for the EPA.

The Kuipers 2012 estimate reflects both the acid generating nature of the site and modern financial assurance reclamation and closure practice typical of U.S. Federal regulatory agencies. The Kuipers 2012 estimate for Mirador, while showing a very high potential liability, is consistent with costs estimated for similar acid-generating copper porphyry mine facilities in the US and elsewhere for financial assurance purposes.

A financial assurance amount has not been calculated, or is not publicly available, for the 60,000 ton/day operation. Based on the much larger size of the operation and higher potential for acid drainage production and tailings dam failures, the financial assurance amount for the 60,000 ton/day operation would obviously be much larger than $568,000,000. These are the costs that would be borne by the government and the people of Ecuador if the Mirador Mine closed unexpectedly and inadequate financial reserves had not been collected by the regulator agencies.

4. Inadequate emergency response plans and environmental and facility monitoring

According to Cardno (2014a, p. 9-16), in the event of a spill, ECSA will activate the Emergency Response Plan to prevent a major impact. And in response to a collapse of the tailings dams, (Cardno 2014a, p. 9-109), an emergency response plan for a possible collapse will be developed prior to the construction phase to assist ECSA in determining the type of response to abnormal conditions and educating downstream communities about the safety of the dam and what to do in the event of a dam breach.

Based on information in the 2014 Cardno EIAs and the limited information we have been able to obtain from the government, an Emergency Action Plan does not exist for the Mirador Mine. Such a plan is an absolute necessity to warn, educate, and protect downstream affected communities in the case of spills due to a collapse of the tailings dams or other mine facilities, including the waste rock pile and the acid drainage impoundment.

5. Lack of experience of Ecuador with regulating large-scale mining operations

The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) conducted an assessment of the mining policy framework of the country of Ecuador in 2019 (IGF, 2019). As noted in the introduction to this report, the mining contract with ECSA for the Mirador Mine was the first exploitation contract for large-scale mining for the government in decades. The IGF report found that Ecuador needs to do more to improve its regulation of large-scale mining by developing specific regulations or guidelines for better environmental management, including the management of the large volumes of waste from large-scale mining and creating a mine closure system. The EIA system in the country requires different EIAs for initial and advanced exploration, exploitation, beneficiation, smelting, and refining (IGF, 2019). This fractured system does not allow the consideration of combined impacts from all phases of mining, including closure and post-closure and limits the ability of the regulators and the communities to understand large-scale mining’s cumulative effects. The IGF report also noted challenges in creating specific requirement for adequate solid waste management, water quality management, detailed closure plans, and the training of agency staff to implement such detailed requirements (IGF, 2019). Additionally, the report recommended the government focus on the problems of indigenous communities related to the effects of mining (IGF, 2019).

As an example, E-Tech International was first asked by MAE in 2011 to assist them with the evaluation of the exploitation EIA for the Mirador Mine because they lacked experience. E-Tech evaluated the EIA and subsequently conducted a training session for MAE on large-scale mining. We returned approximately six months later to find a near complete turnover of agency staff. We have no evidence that the staff has become more experienced with large-scale mining since that time. The lack of experience in regulating large-scale mines combined with the prioritizing of large-scale mining as an economic activity adds to the degree of scrutiny that we feel must be applied to the Mirador Mine.

VI. Information needed to evaluate whether an imminent danger exists and transparency of information

Two requests for access to information related to the Mirador Mine were submitted on March 30, 2021, to the MAE and the MERNNR. The requests were submitted under the Constitution of Ecuador (Sections 18, 66.23) and the Ley Orgánica de Transparencia y Acceso a la Información Publica (Sections 1, 4, 5, and 9). The requests were labelled Tramite No. MERNNR-MERNNR-2021-0630-EX. The requests that were handled by the MERNNR were responded to in an incomplete manner. Another request was submitted for the remaining information. This time the government denied the request, arguing that, according to the contract signed with the mining company, the information requested was confidential. The Asemblea Nacional also submitted an official request to the MERNNR (Appendix 4).

In terms of transparency of information, as an example, with the assistance of the World Bank, Ecuador joined the Initiative for the Transparency in Extractive Industries (EITI) in October 2020.[4] In addition, Ecuador ratified the Acuerdo de Escazú, which also addresses transparency of environmental information, in May 2020.[5] The fact that Ecuador has obligations under both of these international agreements argues strongly that all environmental information related to the safety of the mine and the effects of the mine on the environment and human health should be made publicly available.

We respectfully request that the IACHR require the Government of Ecuador, represented by the Subministry of Mines of the MERNNR (Viceministerio de Minas), to enter into transparent dialogue with E-Tech International and the attorneys who have solicited the documents. The dialogue should result, in a defined limited period of time, the release of requested information related to the construction, operation, and management of the Mirador Mine. This information will allow the detailed evaluation of the potential for imminent endangerment related to the operation and management of the mine.

VII. Summary and Request to the IACHR

The tailings dams at the Mirador Mine have substantial physical and chemical risks that greatly increase the probability and consequences of failure. These risks include:

- The close proximity to surface water, the large planned Tundayme dam height (second largest in the world), large volumes of tailings, high seismicity, and high precipitation
- The high percentages of pyrite in the ores and wastes ensure that acid mine drainage will form. Acid mine drainage is one of the most long-lasting and environmentally harmful results of the mining of sulfide ore bodies like the one at the Mirador Mine. Water quality downstream of the large waste rock piles is already showing the impact of acid mine drainage.

If the dams or other waste impoundments at the site are breached, the large volume of tailings, the toxicity of the tailings and the impoundment water, and the purity of the water surrounding the mine absent mining impacts will increase the consequences of a spill for the downstream communities and the environment.

In the past eight years three large tailings dam failures have occurred around the world (Brumadinho, Brazil; Samarco, Brazil, and Mount Polley, Canada) that have resulted in the loss of many lives and the widespread destruction of homes and livelihoods. Based on the available information, the Mirador Mine's tailings management and inherent site characteristics are similar to those that resulted in these failures, including:

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[4] See https://eiti.org/news/ecuador-joins-eiti and https://eitiec.org/eng/the-process-of-ecuador

[5] See https://observatoriop10.cepal.org/en/treaties/regional-agreement-access-information-public-participation-and-justice-environmental

- Lack of adherence to design criteria
- Upstream dam construction
- Overly steep embankments
- Inadequate characterization of the underlying geologic materials
- High seismicity and rainfall, and
- Excessive water held behind the dam.

Other important factors that increase the likelihood and consequences of short- and long-term adverse impacts from the Mirador Mine include:

- Inadequate financial assurance
- Inadequate emergency response plans and environmental and facility monitoring
- Lack of experience of Ecuador's agencies with regulating large-scale mining
- Lack of transparency and engagement with potentially affected communities.

If a tailings dam break occurs, the impacts could be felt as far downstream as the confluence of the Rio Zamora with the Rio Santiago. Approximately 24 communities live downstream of the mine along the Rio Quimi and the Rio Zamora and are threatened by mine activities and the potential failure of the Mirador tailings dams and other mine facilities that retain toxic mine waste and mine-influenced water. In addition, the creation of the Tundayme diversion in the headwaters of the Rio Tundayme upstream of the Mirador Mine brings additional water into the Rio Machinaza and threatens communities along the Machinaza with a heightened risk of flooding.

The potential risks and consequences associated with the Mirador Mine outlined in this report are based on limited data and information in the publicly available documents and from the information requests that were only partially complied with from MAE and MERNNR. We respectfully request that the IACHR require the Government of Ecuador, represented by the Subministry of Mines of the MERNNR (Viceministerio de Minas), to enter into a transparent dialogue that will result in the timely release of information related to the construction, operation, and management of the Mirador Mine. This information will allow the detailed evaluation of the potential for imminent endangerment related to the operation and management of the mine. We further request, given the potential risks to human life and the environment and taking the Precautionary Principle into account, that the IACHR require the Government of Ecuador and ECSA to immediately develop an effective emergency alert and response plan in conjunction with communities living in areas affected by the Mirador Mine.

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Appendices

Appendix 1: Evaluation of the Design and Construction of the Tailings Dams for the Mirador Mine, Zamora Chinchipe, Ecuador. Report prepared by Steven Emerman, PhD, 2019, for E-Tech International.

Appendix 2: Preliminary list of the communities concerned with environmental, safety, and other social impacts from the Mirador Mine.

Appendix 3: Ecuacorriente Resources Mirador Project, Ecuador. Mine Reclamation and Closure, Financial Assurance Cost Estimate. Report prepared by Jim Kuipers, PE, 2012, for E-Tech International.

Appendix 4: Letter from the Asemblea Nacional to the Ministerio de Energia y Recursos Naturales no Renovables. Asunto: Solicitud de Informacion. Oficio Nro. AN-QLS-2022-0030-O. 2022.

Appendix 1: Evaluation of the Design and Construction of the Tailings Dams for the Mirador Mine, Zamora Chinchipe, Ecuador. Report prepared by Steven Emerman, PhD, 2019, for E-Tech International.

Evaluation of the Design and Construction of the Tailings Dams for the Mirador Mine, Zamora Chinchipe, Ecuador

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Figure 1. The author (on the left) and Luis Sanchez Zhiminaycela (activist with Comunidad Amazónica de Acción Social Cordillera del Cóndor Mirador) study the starter dike of the Quimi tailings dam at the Mirador mine. Photo taken by Evelyne Blondeel on November 6, 2018.

LIGHTNING SUMMARY

An earlier design of the tailings dam for the Mirador mine, Zamora Chinchipe, Ecuador, included a height of 63 meters, an outer embankment slope of 1V:2H, centerline construction, and the ability to withstand the Probable Maximum Flood. A stability analysis determined that the tailings and the foundation would liquefy during the earthquake that is expected to occur during the life of the project. The tailings dam currently under construction includes an outer embankment slope of 1V:1H, upstream construction (more susceptible to failure due to both seismic liquefaction and overtopping), the ability to withstand only a 500-year flood, and a projected height of 260 meters (the tallest ever constructed). Failure due to earthquakes, overtopping or internal erosion is inevitable. An immediate moratorium on the further construction of the Mirador mine is recommended, followed by the convening of an independent panel of international experts for the evaluation of the Mirador tailings management facilities.

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ABSTRACT

An earlier design of the dam for the Quimi tailings management facility at the Mirador copper mine, Zamora Chinchipe, Ecuador, included a height of 63 meters, an outer embankment slope of 1V:2H (vertical to horizontal ratio), centerline construction, and the ability to withstand the Probable Maximum Flood (significantly rarer than even a 10,000-year flood). A stability analysis carried out by consultants hired by the mining company (EcuaCorriente S.A.) determined that the total depth of the tailings, as well as the foundation, would liquefy during the earthquake that is expected to occur during the life of the project. An independent evaluation critiqued the excessive amount of water that would be stored with the tailings and the lack of a geosynthetic liner to prevent contamination of groundwater. The subsequent Environmental Impact Study (EIS) included two alternatives for the expansion of the proposed production from 30,000 metric tons per day to 60,000 metric tons per day: a Quimi tailings management facility (the earlier design with dewatering of tailings) or a Tundayme tailings management facility (preferred by the mining company) with a height of 260 meters (the tallest ever constructed), an outer embankment slope of 1V:1.5H, centerline construction, and the ability to withstand only a 500-year flood. Both alternatives included the use of non-sulfidic tailings (non-acid generating) for the construction of the dams with no error bounds in the estimation of the available amount of non-sulfidic tailings and no plan as to what to do if there are not enough non-sulfidic tailings. In contradiction with the EIS, both alternatives (Quimi and Tundayme tailings management facilities) are currently under construction, although currently only the Quimi facility has the starter dike for the dam. The location of the starter dike requires the upstream construction method (more susceptible to failure due to both seismic liquefaction and flooding) and has an outer embankment slope of 1V:1H (considered as the maximum critical angle for the prevention of internal erosion with no margin for error). The provincial government has denounced EcuaCorriente for quarrying river rocks for construction material in violation of permits, which suggests that there is a lack of material for the proper construction of the dams. Based on the above, the failure of any of the tailings dams due to earthquakes, overtopping or internal erosion should be regarded as inevitable. An immediate moratorium on further construction of the Mirador mine is recommended, followed by the convening of an independent panel of international experts for the evaluation of the Mirador tailings management facilities.

OVERVIEW

The Chinese-owned mining company EcuaCorriente S.A. is currently constructing the Mirador mine in the province of Zamora Chinchipe, Ecuador (see Figs. 1 and 2). At full production, this mine will process 60,000 metric tons of ore per day for 30 years to produce copper, gold and silver concentrates. Since the vast majority of the ore is not copper, gold or silver, after crushing and floating the ore, the processing of the ore will result in almost 60,000 metric tons per day of waste, which are called mine tailings or simply tailings. Tailings are toxic due to the toxic elements that tend to be associated with ore bodies, as well as their ability to produce acid mine drainage. These tailings will be confined within two tailings management facilities that are under construction. These facilities include dams that prevent the release of tailings to the environment and soil liners that prevent contamination of groundwater by the confined tailings. The purpose of this report is to answer the following question: Is the design and construction of the tailings dams consistent with widely-recognized safety guidelines?

Before addressing this question, I will review the methods of tailings dam construction, the common causes of tailings dam failures, and the methods for preventing the failure of tailings dams. Much of this information is available in the standard textbook on tailings dams by Vick (1990). This report analyzes only the prevention of dam failures based on the construction of the dam and other aspects of the tailings management facility. Methods to prevent failure by altering the nature of tailings, such as the conversion of tailings into a paste, are analyzed elsewhere (Klohn Crippen Berger, 2017).

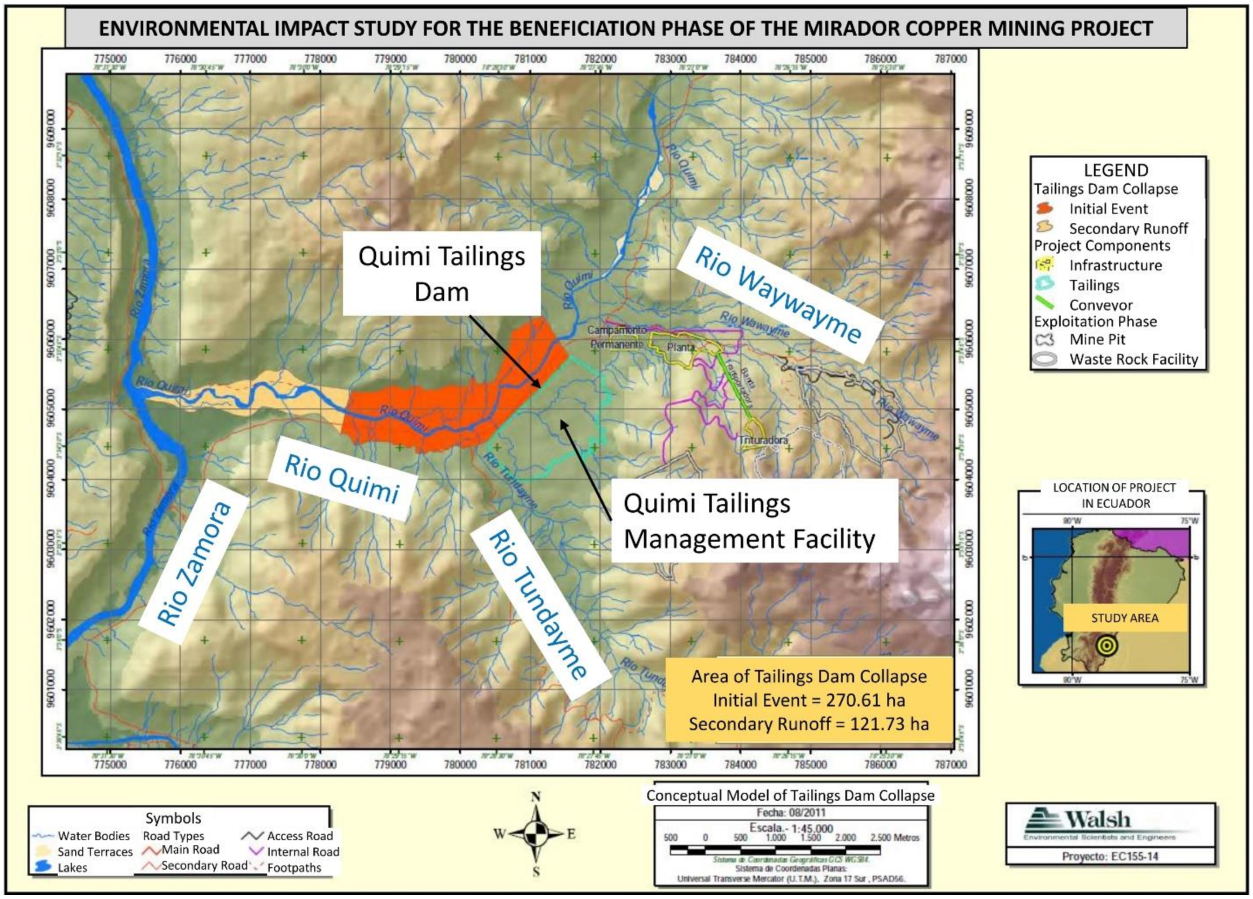


Figure 2. The Mirador copper mine is currently under construction by EcuaCorriente S.A. in Zamora Chinchipe, Ecuador. An earlier Environmental Impact Study (EIS) in 2010 proposed a single tailings management facility (called the Quimi tailings management facility) and calculated the extent of the tailings spill after failure of the dam. The extent of the initial event (orange) was calculated using a formula that has been shown to be incorrect. The extent of secondary runoff was not based on any calculation, but was simply a drawing. In fact, the spilled tailings will be transported by the Rio Zamora to the headwaters of the Amazon River. Figure modified from Walsh Scientists and Engineers (2011b).

REVIEW OF TAILINGS DAMS

Tailings Dams and Water-Retention Dams

Although tailings dams and water-retention dams are built for the purpose of restricting the flow of material, they are fundamentally different types of civil engineering structures. This important point was emphasized by 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." Vick (1990) gave an example of how a tailings dam could be built in the same way as a water-retention dam, although he emphasized the economic unfeasibility of such construction (see Fig. 3). (The importance of the features in Fig. 3, such as the impermeable core, the filter and the drainage zone, will be discussed later.)

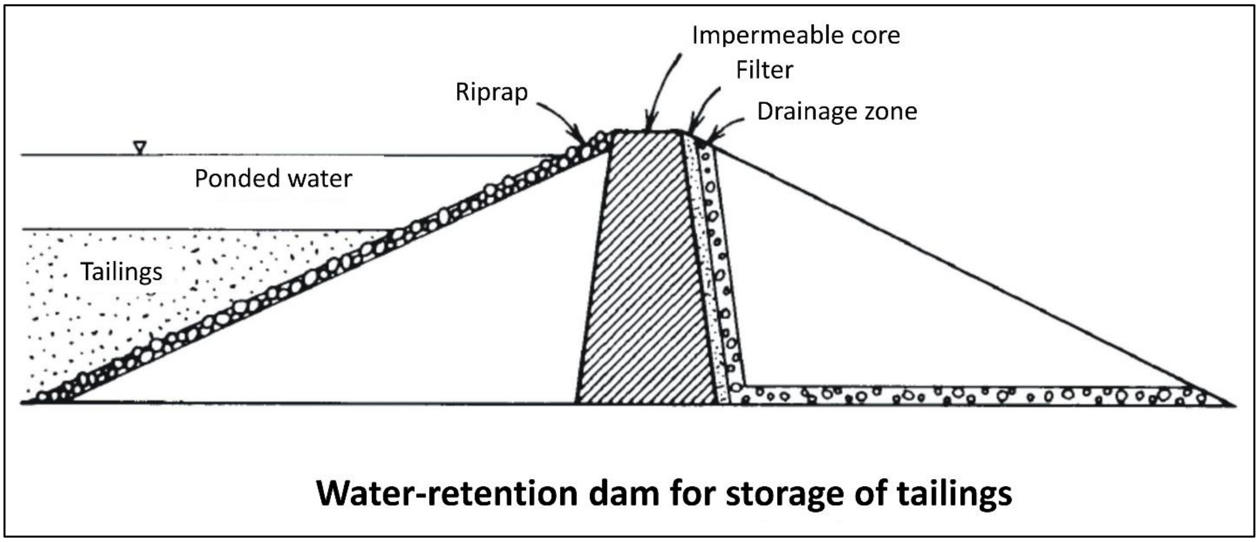


Figure 3. Tailings dams and earthen water-retention dams are fundamentally different civil engineering structures. Vick (1990) showed how a tailings dam could be constructed in the same way as a water-retention dam and that it would be as safe as a typical water-retention dam. The design includes an impermeable core and a drainage zone to lower the water table at the toe of the dam, and a filter to prevent internal erosion (transport of solid particles out of the dam by seepage). However, the design would not be economically feasible for a tailings dam. Figure modified from Vick (1990).

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 the waste rock that is removed before reaching the ore, or the mine tailings themselves after proper compaction. 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 and as material from the mining operation (such as waste rock) becomes available for construction. Finally, 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. On the other hand, a tailings dam is expected to confine the toxic tailings in perpetuity, although normally the inspection and maintenance of the dam cease after the end of the mining project.

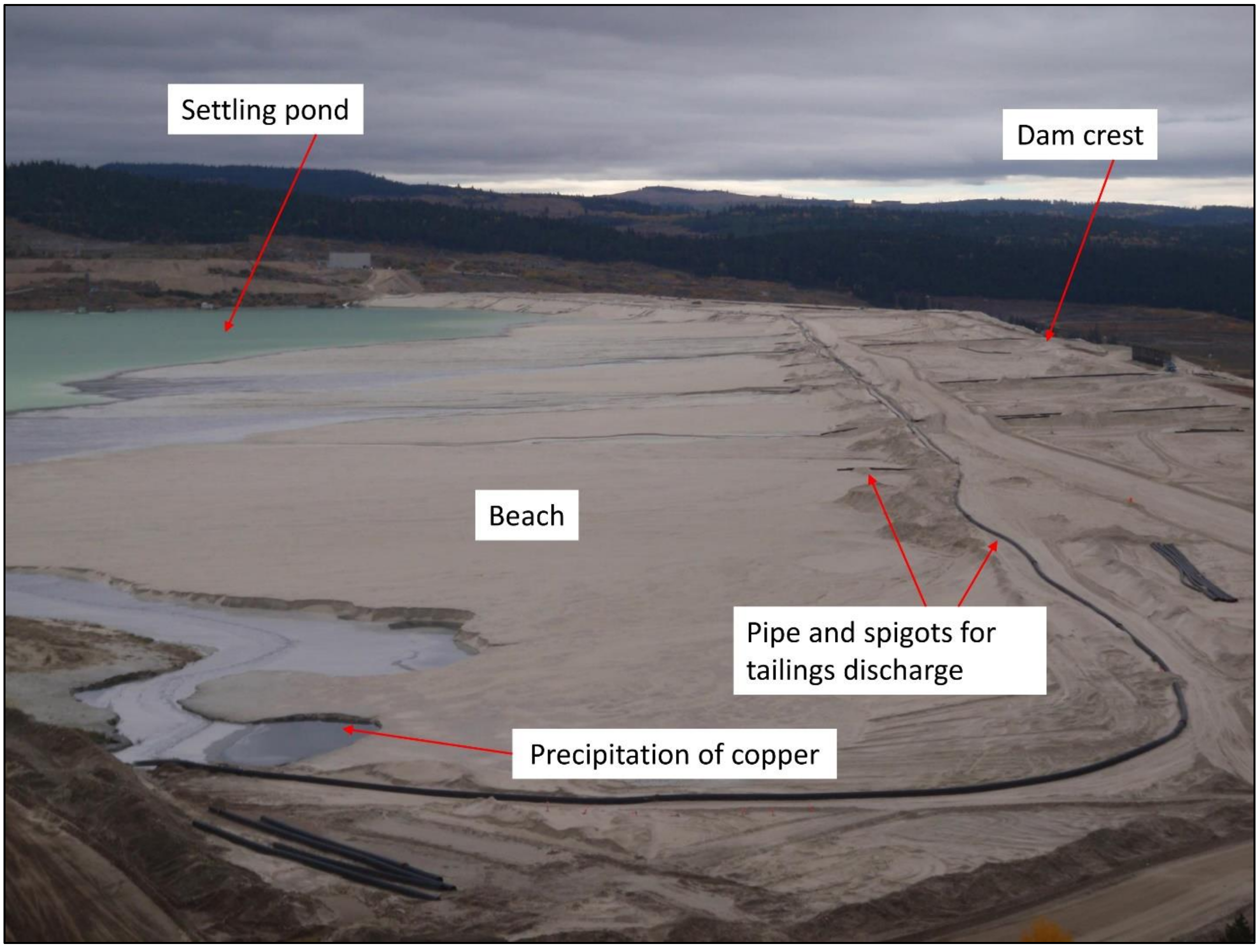


Figure 4. At the tailings storage facility of the Highland Valley Copper mine in British Columbia, wet tailings are discharged in the upstream direction from a pipe and spigots along the crest of the dam. The larger particles (sands) are deposited near the dam to form a beach. The smaller particles (slimes) are transported farther from the dam to form a settling pond. The precipitation of copper in the tailings pond indicates the incomplete extraction of copper from the ore. The narrow beach (especially on the opposite side, where the beach is almost non-existent) makes the dam susceptible to failure by overtopping. Photo taken by the author on September 27, 2018.

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 (World Mine Tailings Failures, 2018). However, the Independent Expert Engineering Investigation and Review Panel (2015) found a similar failure rate in tailings dams of 1 in 600 per year during the

1969-2015 period in British Columbia. (See World Mine Tailings Failures (2018) for the most up-to-date information on mine tailings failures.)

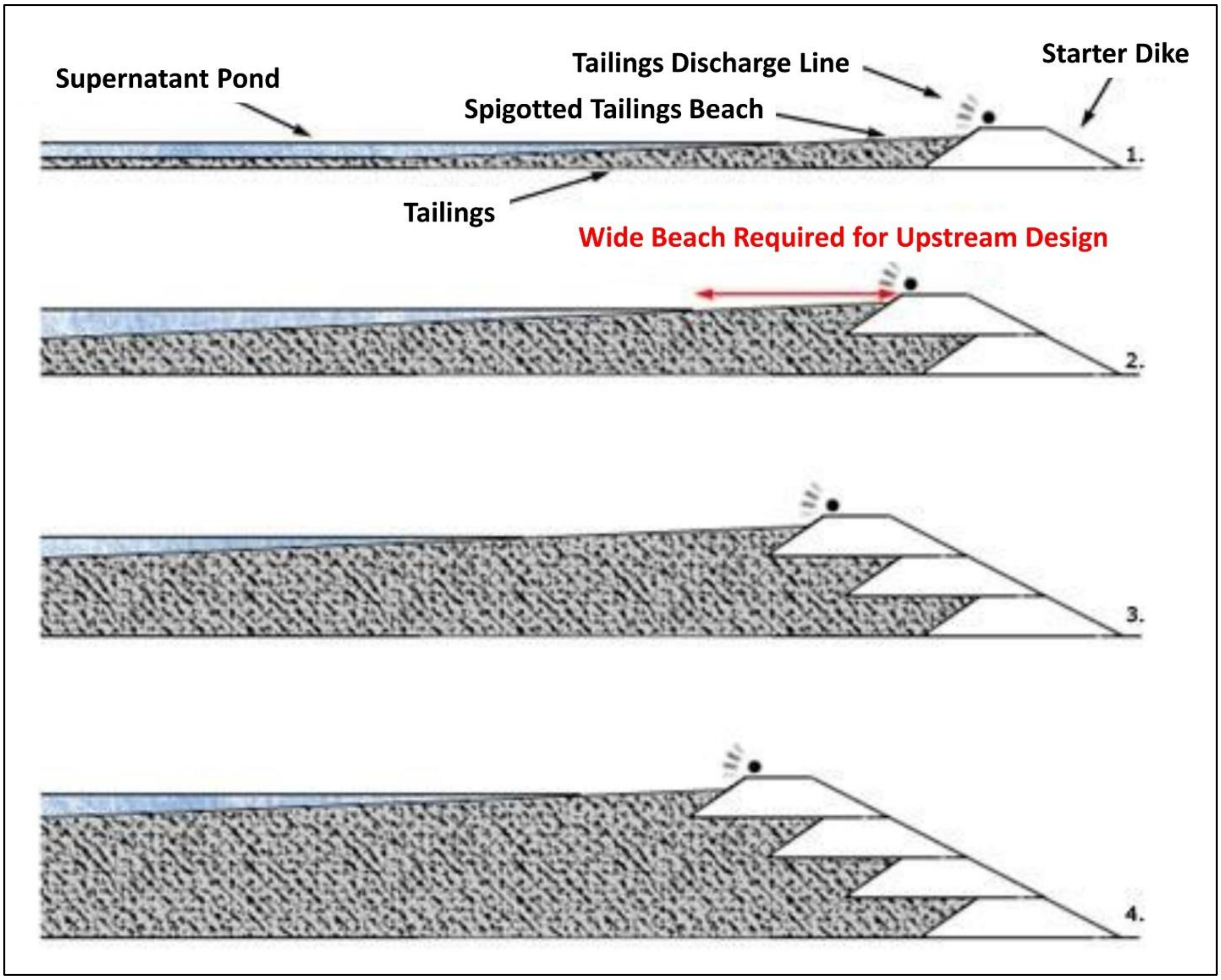


Figure 5a. In the upstream construction method, successive dikes are built in the upstream direction as the level of stored tailings increases. The dikes can be constructed out of mining waste rock, natural soil or the coarser fraction of tailings (with appropriate compaction). The advantage of the method is its low cost since very little material is required for the construction of the dam. The disadvantage is that the dam is susceptible to failure by seismic liquefaction since the wet uncompacted tailings are underneath the dam. For this reason, the upstream construction method is illegal in some countries with seismic activity, such as Chile. Dams built by this method are also likely to fail by overtopping when the beach is too narrow due to insufficient sand in the discharged tailings or excessive water in the settling pond. Figure modified from TailPro Consulting (2018).

Methods of Construction of Tailings Dams

All methods of construction of tailings dams are means of taking advantage of the very different physical properties of the two sizes of tailings, which are the sands (larger than 0.075 mm) and the slimes (smaller than 0.075 mm). These two sizes are separated by gravity in tailings management facilities. Normally, a mixture of tailings and water is 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 Fig. 4). 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. It should be noted that the beach is essential for preventing the pond from reaching the crest of the dam.

Each of the three common methods of building tailings dams (upstream, downstream and centerline) begins with a starter dike, which is constructed from natural soil, waste rock or the tailings from an earlier episode of ore processing (see Figs. 5a-c). In the upstream construction method, successive dikes are built in the upstream direction as the level of stored tailings increases. As mentioned earlier, it is most common to build successive dikes from waste rock or the coarser fraction of tailings (with appropriate compaction). The advantage of the method is its low cost since very little material is required for the construction of the dam (see Fig. 5a).

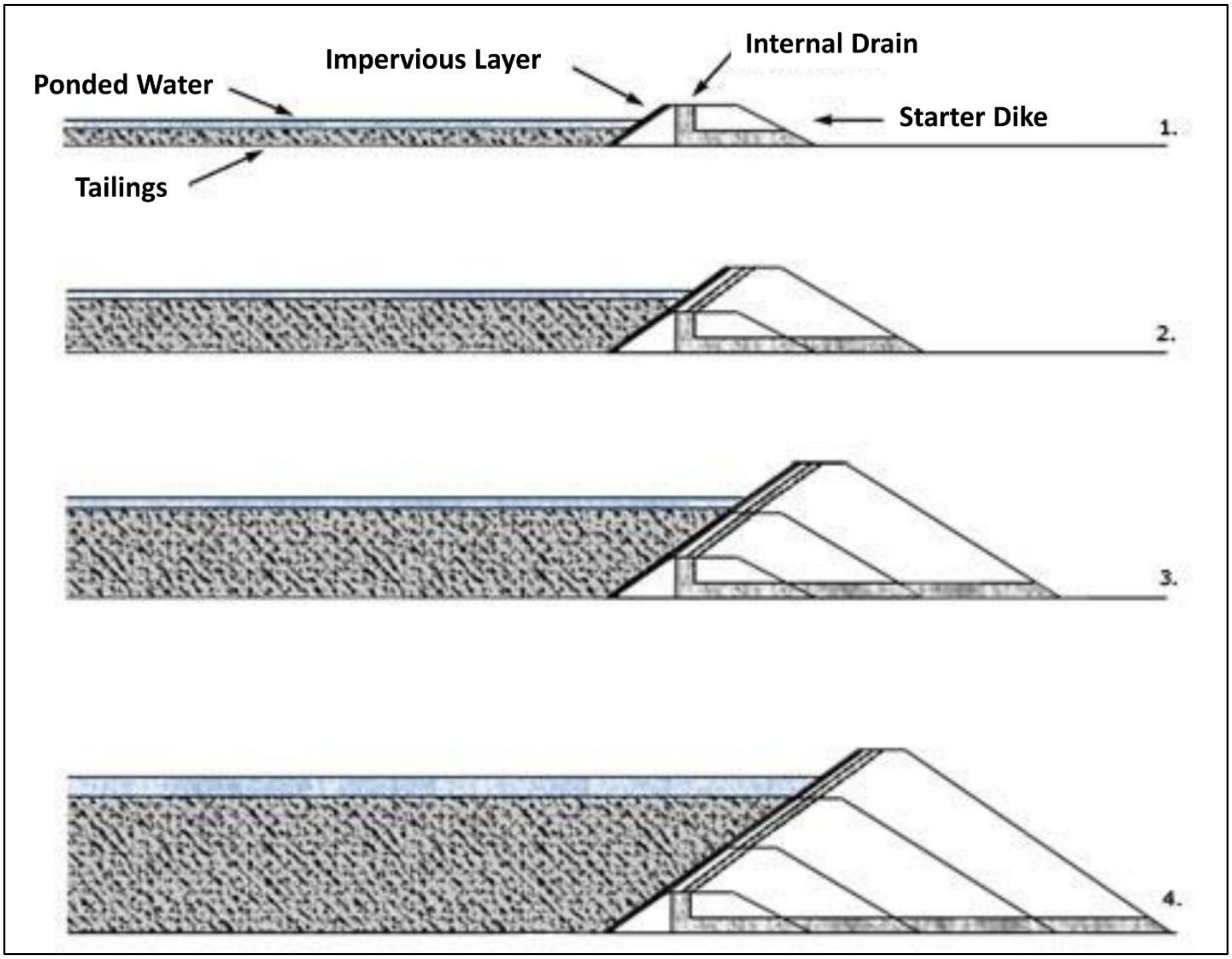


Figure 5b. In the downstream construction method, successive dikes are built in the downstream direction as the level of stored tailings increases. The dikes can be constructed out of waste rock, natural soil or the coarser fraction of tailings (with appropriate compaction). The ability to install impermeable layers and internal drains decreases the danger of dam failure due to overtopping, internal erosion, static liquefaction and foundation failure, all of which may result from excessive water. The seismic resistance is high because there are no uncompacted tailings underneath the dam. The disadvantage of the method is its high cost due to the amount of material required to build the dikes (compare the volumes of dikes in Figs. 5a and 5b). In fact, this construction method is not very different from the construction of an earthen water-retention dam (see Fig. 3). The differences are that a water-retention dam would be built entirely from a suitable natural soil (instead of tailings) and built completely before filling the reservoir with water. Figure modified from TailPro Consulting (2018).

The downstream construction method is the most expensive since it requires the most construction material (compare Figs. 5a and 5b). In this method, successive dikes are constructed in the downstream direction as the level of stored tailings increases. In fact, this construction method is not very different from the construction of an earthen water-retention dam (compare Figs. 3 and 5b). The differences are that a water-retention dam would be built entirely from a suitable natural soil (instead of tailings or waste rock) and would be built completely before filling the reservoir with water.

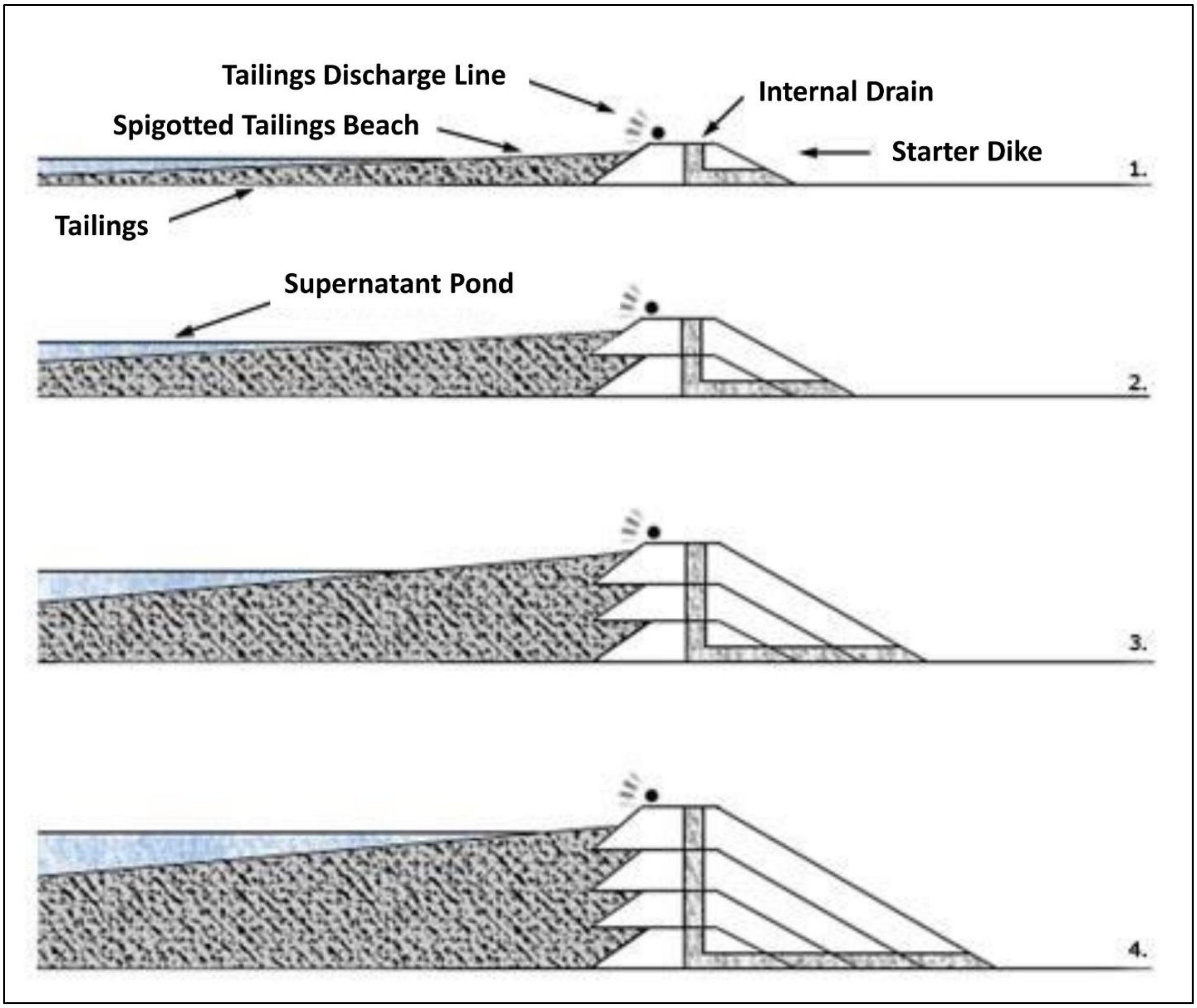


Figure 5c. In the centerline construction method, successive dikes are constructed by placing construction material on the beach and on the slope downstream of the previous dike. The center lines of the raises coincide as the dam is built upwards. The dikes can be constructed out of waste rock, natural soil or the coarser fraction of tailings (with appropriate compaction). The ability to install impermeable layers (see Fig. 8) and internal drains decreases the danger of dam failure due to overtopping, internal erosion, static liquefaction and foundation failure, all of which may result from excessive water. The centerline method is intermediate between the upstream and downstream methods (see Figs. 5a-b) in terms of cost and risk of failure. The seismic resistance is moderate because there are still some uncompacted tailings underneath the dikes. It is still necessary to maintain an adequate beach to prevent overtopping of the dam. Therefore, dams constructed by this method are suitable for temporary, but not permanent, storage of water (Vick, 1990). Currently, the centerline construction method is the most common method of building tailings dams in the world. Figure modified from TailPro Consulting (2018).

The centerline construction method is a balance between the advantages and disadvantages of the downstream and upstream construction methods (compare Figs. 5a-c). In this method, successive dikes are constructed by placing construction material on the beach and on the slope downstream of the previous dike. The center lines of the raises coincide as the dam is built upwards (see Fig. 5c). Although there are few data on the frequency of different types of tailings dam construction (World Mine Tailings Failures, 2018), the centerline construction method is probably the most common method for building tailings dams in the world. The advantages and disadvantages of different types of construction in terms of their ability to resist catastrophic failures will be discussed after reviewing the common causes of failure of tailings dams.

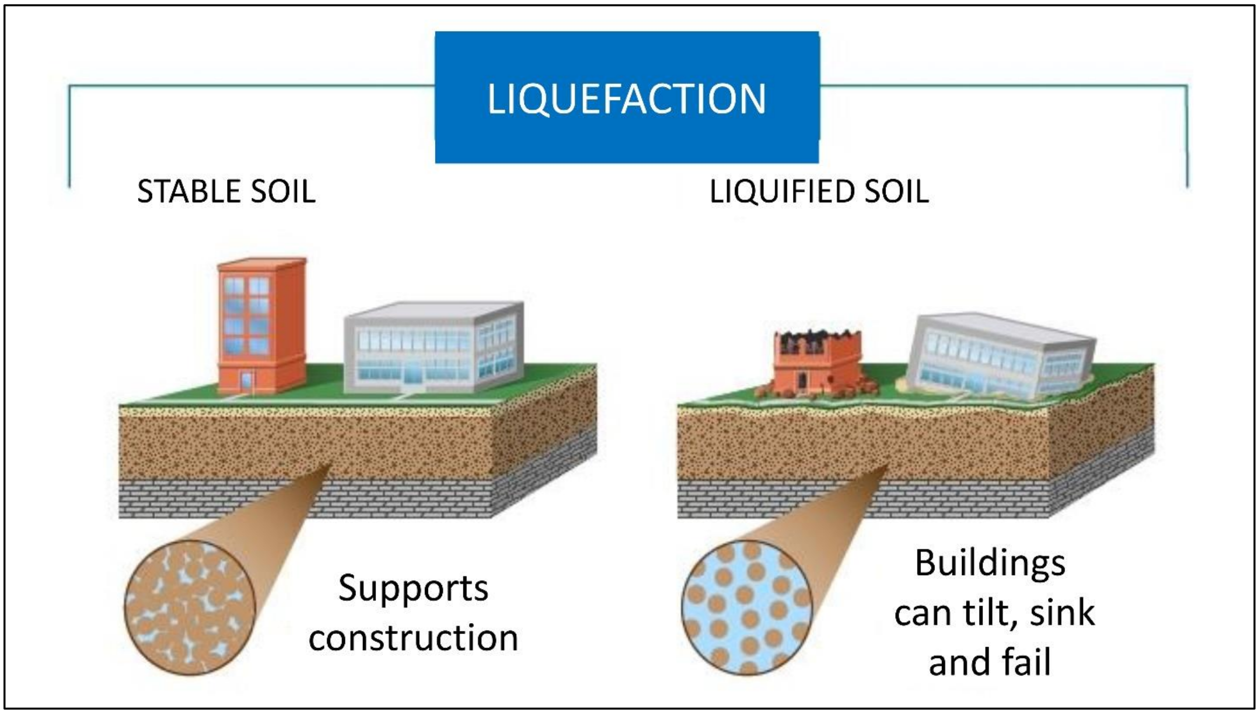


Figure 6. In a tailings deposit or natural soil, although there is interstitial water in the pores between the solid particles, the particles touch each other, so that the load is supported by the solid particles (and partially by the water). In the phenomenon of static liquefaction, a combination of excessive water and excessive loading causes the particles to separate, so that the interstitial water supports the entire load. As a result, the mass of solid particles and water behaves like a liquid. The phenomenon of seismic (or dynamic) liquefaction occurs when, during seismic shaking, the particles settle into a state of higher density. If this happened slowly, the water between the particles would be forced up and out of the spaces between the particles. However, because seismic shaking occurs so rapidly, water does not have time to escape from between the particles. Instead, the water is compressed and the high water pressure causes the particles to separate so that they do not touch each other. Tailings ponds are especially susceptible to both static and seismic liquefaction because the tailings are very loosely packed due to the discharge into the pond without compaction (see Fig. 4).

Causes of Failure of Tailings Dams

The immediate cause of most catastrophic failures of tailings dams is the phenomenon of liquefaction (see Fig. 6). Normally, although there is interstitial water between the solid particles in soil or tailings, the particles touch each other so that the load is supported by the solid particles (and partially by the water). During liquefaction, the solid particles separate so that water enters between the particles, the particles no longer touch each other, and the water supports the entire load. As a result, the mass of solid particles and water behaves like a liquid with no shear strength.

The five most important causes of failure of tailings dams are overtopping, earthquakes, static liquefaction, foundation failure, and internal erosion. Each of these five causes can be understood in terms of the phenomenon of liquefaction. The shaking that occurs during earthquakes causes the tailings to settle into a state of higher density. This settlement is much more common in tailings than in a natural soil because the tailings are very loosely packed due to the discharge into the pond without compaction (see Fig. 4). If the settlement occurred slowly, the water between the particles would be forced up and out of the spaces between the particles. However, because seismic shaking occurs so rapidly, water does not have time to escape from between the particles. Instead, the water is compressed and the high water pressure causes the particles to separate so that they do not touch each other.

Figure 7. Internal erosion (also called piping) caused the failure of an earthen dam in Tunbridge, Australia, in 2005. During internal erosion, seepage washes solid particles out of the dam so that the dam loses its structural integrity. Internal erosion can be considered a type of liquefaction because the water supports the load of the dam. Internal erosion is promoted by an excessively steep embankment and the resulting high hydraulic gradient, forcing water to flow through the dam. Photo modified from Fisher et al. (2017).

In addition to the dynamic liquefaction that occurs during earthquakes, static liquefaction can occur simply due to the consolidation (settlement) of tailings. Static liquefaction can result from a combination of excessive load, excessive water and an excessive rate of tailings addition. If the permeability of the mass of tailings is low enough, then the tailings can be consolidated with insufficient time for the water to escape. Instead, the water is compressed and the high water pressure causes the particles to separate so that they do not touch each other. As with seismic liquefaction, static liquefaction is promoted by the initial loosely-packed state of the tailings. Failure of the foundation (the earth beneath the tailings management facility or beneath the dam itself) is also usually a type of static liquefaction. Foundation failure can occur when excessive loading or excessive water in the mass of tailings forces the water into a foundation that has insufficient permeability for the water to pass through the foundation.

Floods that cause water to overtop earthen dams almost always result in the complete failure of the dam. Water above the crest of the dam causes saturation of the dam and the excessive weight on top of the dam can force the separation of solid particles, which is a type of liquefaction. Floods can also destroy dams by removing the upper parts of the dam. In addition to spilling the contents behind the dam, the removal of the upper parts of the dam reduces the total weight of the dam and, therefore, the dam's ability to withstand the pressure of the material behind the dam. In addition, tailings dams can fail simply due to water flowing over the embankment, which causes erosion of the dam.

The last common cause of failure of tailings dams is internal erosion, which occurs when the seepage of water through the dam washes the tailings or other construction material out of the dam (see Fig. 7). Internal erosion can create an open pipe in the dam (so that internal erosion is also called piping), which causes the dam to lose structural integrity. Internal erosion can be considered a type of liquefaction because the water supports the load of the dam. Internal erosion is promoted by an excessively steep embankment and resulting high hydraulic gradient, forcing the water to flow through the dam (note the excessively steep embankment in Fig. 7). (The hydraulic gradient is the drop in the water table across the dam divided by the length of the dam.)

Methods of Construction and Causes of Failure

The common methods of tailings dam construction can now be analyzed in terms of their vulnerability to the common causes of tailings dam failures. It will not be surprising that the more expensive construction methods are also less vulnerable to failure. In particular, the upstream construction method is the most susceptible to failure during earthquakes. Since the upstream construction method builds the dam on top of the uncompacted tailings (see Fig. 5a), the liquefaction of these tailings will result in the inevitable collapse of the dam, since the dam will have no support. For this reason, the upstream construction method is illegal in Chile, due to its high potential for strong earthquakes (Fourie et al., 2013) and even in Brazil, where the potential for large earthquakes is much lower (Imprensa Nacional [National Printer], 2019). In addition, the upstream construction method is the most susceptible to overtopping failures because the only infrastructure that prevents the pond from reaching the dam is the presence of the beach. The beach can be overtaken by the pond if there is heavy rainfall in the watershed of the tailings management facility or even if there is not enough sand in the tailings to form a suitable beach. For example, the tailings pond at the Highland Valley Copper mine has a very narrow beach, which hardly exists on the far side of the tailings pond (see Fig. 4). This narrow beach is probably the result of insufficient coarse particles in the tailings stream from the ore processing plant. (The tailings dam at the Highland Valley Copper mine was actually built by the centerline method. Although a suitable beach is still important, tailings dams built by the centerline method have other means to reduce the risk of overtopping, as explained below.)

It should be clear that lowering the water table within tailings management facilities and especially within the tailings dam can reduce the risk of all forms of liquefaction. The water table can be lowered in the downstream and centerline construction methods by installing low-permeability cores on the upstream side of the dam (see Figs. 5b and 8). In the upstream construction method, there is no place to put a low-permeability core or an impermeable layer, so that any mention of an impermeable layer should indicate that the upstream construction method is not being used. Both the downstream and centerline construction methods allow the installation of chimney drains and blanket drains (see Figs. 5b-c and 9), which are other ways of lowering the water table. The upstream construction method does not have any place to install a chimney drain (see Fig. 5a), although blanket drains are possible (see Fig. 9).

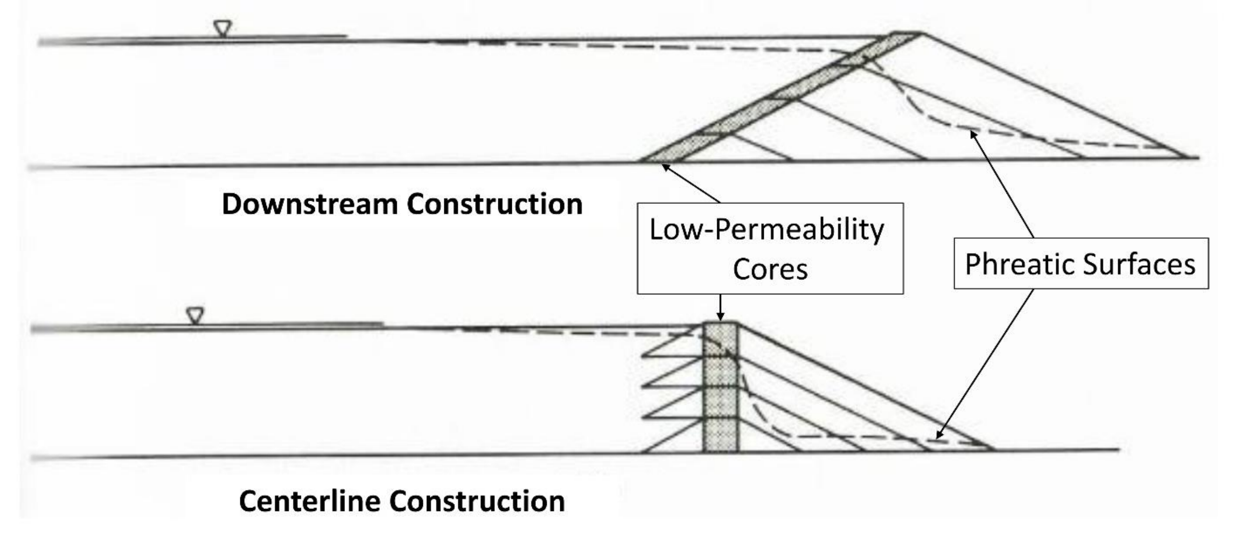
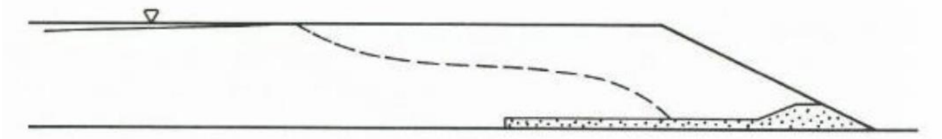


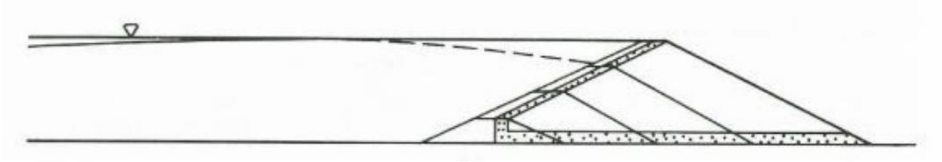
Figure 8. One of the advantages of the downstream and centerline construction methods is that it is possible to install low-permeability cores to lower the water table at the toe of the dam. This decrease in the water table reduces the likelihood of internal erosion of the dam (see Figure 7), static liquefaction of the dam, and foundation failure under the dam. These low-permeability cores are almost impossible to install when using the upstream construction method (see Fig. 5a). Figure modified from Vick (1990).

The possibility of internal erosion can also be reduced by lowering the water table. In addition, filters can be installed to prevent the transport of construction material out of the dam by seepage (see Fig. 3). These filters must be designed so that they trap fine particles, allow water to pass through (so that the water table is kept low), and not become clogged with fine particles. However, since the main driving force for internal erosion is the hydraulic gradient, which is essentially the slope of the embankment, an inclination of 1V:1H (a vertical drop of one meter over a horizontal distance of one meter, equivalent to 45°), is considered as the maximum critical angle for the prevention of internal erosion (Le Poudre, 2015). According to the European Commission (2009), “the upstream dam should have a downstream slope of less than 1V:3H.” In addition, the European Commission (2009) recommends that the slopes of the embankment should not be more pronounced than 1V:3H for any dam that stores tailings of base metals (including copper ores). The U.S. Army Corps of Engineers is even more conservative and requires that “for sand levees, a 1V on 5H landside slope is considered flat enough to prevent damage from seepage exiting on the landside slope” (USACE, 2000). Although there is no database of embankment slopes for tailings dams, the author's experience is that a slope of 1V:2H (equivalent to 26.6° with respect to the horizontal) is the most common.

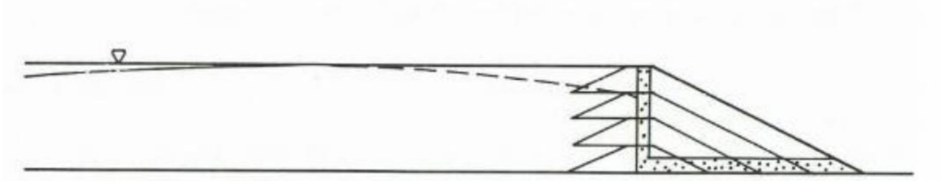
On the issue of preventing internal erosion, it is worth considering this passage from the standard textbook on geotechnical engineering by Holtz et al. (2011), “For practical problems, especially where there is a danger that i [the hydraulic gradient] could approach i_c [the critical hydraulic gradient], you should be very conservative in your design. Use a factor of safety of at least 5 or 6 in such cases. For one thing, failure is usually catastrophic and occurs rapidly and with little warning. For another, it is extremely difficult to know exactly what is going on underground, especially locally. Local defects, gravel pockets, etc., can significantly alter the flow regime and concentrate flow, for example, where you might not want it and not be prepared for it…Since failure of cofferdams is often catastrophic, it is extremely important that large factors of safety be used, especially where people's lives are at stake. Failures of earth structures resulting from piping have caused more deaths than all other failures of civil engineering structures combined. Therefore, your responsibility is clear – be careful and conservative, and be sure of your ground conditions and design."



Upstream Construction with Blanket Drain



Downstream Construction with Chimney Drain and Blanket Drain



Centerline Construction with Vertical Chimney Drain and Blanket Drain

Figure 9. It is possible to install blanket drains using all three construction methods, although chimney drains can be installed using only the downstream and centerline construction methods. These drains lower the water table and reduce the likelihood of internal erosion of the dam (see Fig. 7), seismic liquefaction of the tailings, static liquefaction of the dam or tailings deposit, and failure of the foundation under the tailings. Figure modified from (1990).

Safety Criteria for Design of Tailings Dams

The most important step in designing dams in order to avoid catastrophic failures from floods and earthquakes is to choose the appropriate design flood and the appropriate design earthquake. The design earthquake is really a design seismic acceleration, which depends upon the magnitude of the design earthquake, the distance from the fault at which the earthquake is expected to occur, and the nature of the material under the dam. These design criteria depend on the hazard potential or the consequences of failure. For example, the (U.S.) Federal Emergency Management Agency classifies dams into three categories according to the hazard potential (FEMA, 2013). High Hazard Potential means "probable loss of life due to dam failure or misoperation." It is clarified that "probable loss of life" refers to "one or more expected fatalities" and that "economic loss, environmental damage or disruption of lifeline facilities may also be probable but are not necessary for this classification." Significant Hazard Potential means "no probable loss of human life but can cause economic loss, environmental damage, or disruption of lifeline facilities due to dam failure or misoperation." Low Hazard Potential means "no probable loss of human life and low economic and/or environmental losses due to dam failure or misoperation."

Each of the hazard potential classifications corresponds to an inflow design flood (FEMA, 2013). A dam with a Low Hazard Potential must be designed for a 100-year flood (flood with a 1% probability of exceedance in any given year) or "a smaller flood justified by rationale." A dam with Significant Hazard Potential should be designed for a 1,000-year flood (flood with an exceedance probability of 0.1% in any given year). However, a dam whose failure is expected to result in the loss of at least one life (High Hazard Potential) must be designed for the Probable Maximum Flood (PMF), which is defined as "the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin under study." The magnitude of the PMF is normally derived from the Probable Maximum Precipitation (PMP), which is defined as "the theoretical greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year." The magnitudes of PMP have been determined for most of the United States (NWS-HDSC, 2017), as well as for most of the developed world. The procedures for determining the PMP have been described by the World Meteorological Organization (WMO, 2009). It is worth noting that, according to the U.S. Army Corps of Engineers, "the PMF does not incorporate a specific exceedance probability, but is generally thought to be well beyond the 10,000 year recurrence interval" (USACE-HCE, 2003).

In a similar way, each of the hazard potentials corresponds to a design earthquake. According to the Federal Emergency Management Agency, the Maximum Credible Earthquake (MCE) is "the largest earthquake magnitude that could occur along a recognized fault or within a particular seismotectonic province or source area under the current tectonic framework" (FEMA, 2005). In addition, for dams with High Hazard Potential, "the MDE [Maximum Design Earthquake] usually is equated with the controlling MCE." Just as for design floods "where the failure of the dam presents no hazard to life, a lesser earthquake may be justified, provided there are cost benefits and the risk of property damage is acceptable." In the same way, the U.S. Army Corps of Engineers has emphasized, "There is no return period for the MCE" (USACE, 2016). However, some older non-governmental guidelines, such as those of the (U.S.) National Fire Protection Association defined the MCE as "ground motion having a 2 percent probability of exceedance within a 50 year period (2475 year return period)" (NFPA, 2001).

The guidelines of the Canadian Dam Association (2013) are also widely recognized. These guidelines include five risk categories. The risk for any permanent population places a dam in the three highest risk categories, in which the high risk, very high risk and extreme risk categories correspond to expected deaths of ten or less, 100 or less, and more than 100, respectively. The guidelines consider flood and earthquake design criteria based on both a risk-informed approach and a traditional, standards-based approach. According to the risk-informed approach, the minimum annual exceedance probability for the design flood or earthquake in the category of very high risk or extreme risk should be 1/10,000 (corresponding to a return period of 10,000 years). According to the traditional, standards-based approach, for a dam in the very high risk category, the design flood should be 2/3 between the 1,000-year flood and the PMF, while the design earthquake should be halfway between the 2,475 year earthquake and either the

10,000 year earthquake or the MCE. For a dam in the extreme risk category, the design flood should be the PMF, while the design earthquake should be either the 10,000-year earthquake or the MCE. There are many other guidelines for design floods in use worldwide and these were exhaustively reviewed by FEMA (2012).

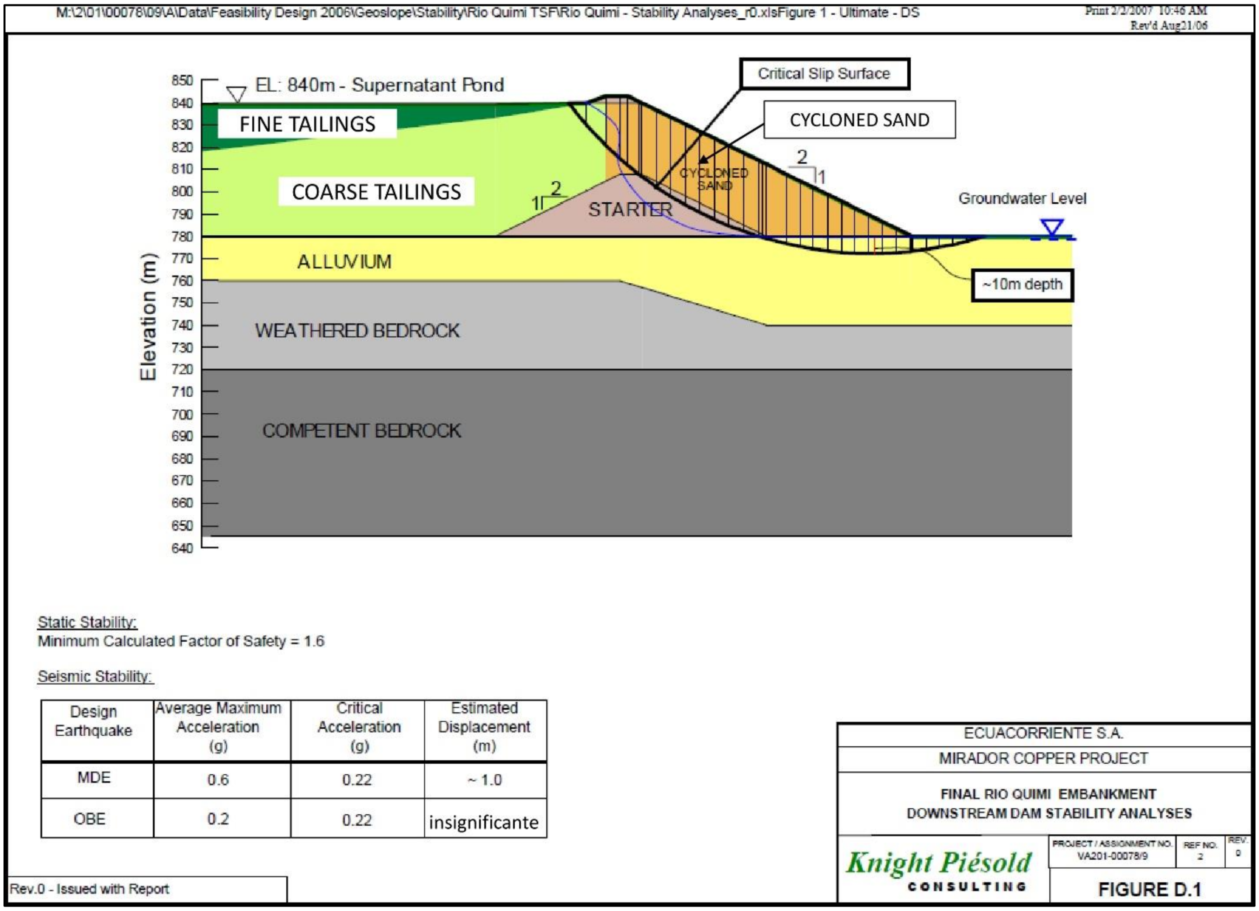
DESIGN OF THE TAILINGS MANAGEMENT FACILITY AT THE MIRADOR MINE

Earlier Version and its Critiques

Before the submission of the first Environmental Impact Study for the Mirador mine in 2010 (Walsh Scientists and Engineers, 2010a-b, 2011a), EcuaCorriente S.A. hired Knight-Pièsold (2007) to review the design of the tailings management facility. The English-language review by Knight-Pièsold (2007) also contains an excellent summary of the design. The earlier design included the processing of 27,000 metric tons of ore per day with permanent storage of the tailings in the Quimi tailings management facility (see Fig. 2). The foundation of the facility would be alluvial soil with competent bedrock at a depth of 75-100 meters. The Quimi dam would be 63 meters high after its final raise and would be built using the centerline method with an outer embankment slope of 1V:2H (see Fig. 10). Ore processing would result in 2% concentrate (intended for shipment for further processing), 87% coarser tailings (sands) and 11% finer tailings (slimes). The mixture of water and tailings would be transported to the Quimi tailings management facility without dewatering with 66.5% water content for the coarser tailings and 79% water content for the finer tailings (weight percentage). The starter dike for the dam would be built with locally available natural soil. The construction material for the successive dikes would be obtained by cyclonic separation of the sand-sized tailings for separation of the coarsest fraction, estimated at 23% of the sand-sized tailings, which would be suitable for the construction of the dam. It was emphasized that “the entire cycloned sand production, based on the 23% recovery, is required to provide the quantity of fill required to raise the embankment during operations” (Knight-Pièsold, 2007).

A significant part of the design involved the means by which contamination of groundwater by acid mine drainage (AMD) would be avoided. The main component of AMD is sulfuric acid, which results from the oxidation of sulfide minerals after they are exposed to oxygen on the surface as tailings. If AMD is allowed to enter groundwater or surface water, it can negatively impact public water supply and aquatic organisms through acidification and contamination by heavy metals that were part of the crystalline structure of the sulfidic minerals. Acidification of downstream rivers can also mobilize heavy metals that are stored in sediments in river beds. The possibility of AMD was addressed in the proposal to compact the natural soil to create a low-permeability layer at the base of the facility. In addition, it was found that only the finer tailings would be sulfidic and, therefore, potential generators of AMD. These finer tailings would be discharged below the level of the pond at the back of the tailings management facility to prevent oxidation. Finally, “post-closure surface grading will ensure the cleaner [finer] tailings remain saturated in perpetuity” (Knight-Pièsold, 2007).

Based on the potential for loss of life and the environmental and economic consequences that would result from the failure of the tailings dam, Knight-Pièsold (2007) gave the tailings dam a risk assessment of VERY HIGH (its capitalization) using the classification system of the Canadian Dam Association (2013). Knight-Pièsold (2007) recommended that the dam be designed using the PMF as the safety criterion, which is even stricter than what is recommended by the Canadian Dam Association (2013). However, Knight-Piesold (2007) admitted the difficulty of correctly estimating the PMF since “the available regional records [of precipitation] are not particularly long, nor are the data considered to be of exemplary quality.” Besides, “the only appropriate data that were obtained [for estimating streamflow] are for gauging stations on the Zamora and Sabanilla rivers, which are located to the southwest of the project area.” In addition, Knight-Pièsold (2007) recommended that the maximum design earthquake (MDE) should be the MCE, which is also stricter than what is recommended by the Canadian Dam Association (2013).



Static Stability:
Minimum Calculated Factor of Safety = 1.6

Seismic Stability:

Design Earthquake	Average Maximum Acceleration (g)	Critical Acceleration (g)	Estimated Displacement (m)
MDE	0.6	0.22	~ 1.0
OBE	0.2	0.22	insignificante

ECUACORRIENTE S.A.
MIRADOR COPPER PROJECT
FINAL RIO QUIMI EMBANKMENT
DOWNSTREAM DAM STABILITY ANALYSES

Knight Piésold
CONSULTING

PROJECT / ASSIGNMENT NO. VA201-00078/9
REF NO. 2
REV. 0
FIGURE D.1

Rev.0 - Issued with Report

Figure 10. Knight-Pièsold (2007), consultants hired by EcuaCorriente S.A., determined that “the entire depth of the tailings deposit is potentially liquefiable for the MDE and OBE [Operating Basis Earthquake]. Liquefaction is also predicted for the loose alluvial soils near surface (in the upper 10 meters) for the MDE and OBE.” Knight-Pièsold (2007) identified the MDE (Maximum Design Earthquake) with the MCE (Maximum Credible Earthquake). The Operating Basis Earthquake is the earthquake that is expected to occur during the life of the project. Note that it was predicted that the maximum accelerations during the MCE and OBE would be 0.6*g* and 0.2*g*, respectively, while the critical acceleration for liquefaction was calculated to be 0.22*g*, where *g* is the acceleration due to gravity. Knight-Piesold (2007) recommended that “ground improvement to increase the liquefaction resistance of these loose soils will be required within the embankment footprint and for a distance downstream of the embankment. Stability analyses indicate that a 100 meter wide zone of ground will require treatment along the embankment alignment.” However, there were no details nor guarantees that the “ground improvement” would eliminate the possibility of liquefaction of the foundation. The Knight-Pièsold diagram (2007) clarifies that the earlier design of the Quimi tailings dam included centerline construction and an outer embankment slope of 1V:2H. Figure modified from Knight-Pièsold (2007).

The critical part of the Knight-Pièsold review (2007) was the seismic stability analysis, which said that "the entire depth of the tailings deposit is potentially liquefiable for the MDE and OBE [Operating Basis Earthquake]. Liquefaction is also predicted for the loose alluvial soils near surface (in the upper 10 meters) for the MDE and OBE." The OBE is the earthquake that is expected to occur during the life of a project. Knight-Piesold (2007) defined the OBE as the earthquake with a return period of 475 years, which is equivalent to an annual exceedance probability of 0.21% and a probability of exceedance during the 30-year life of the project of 6.13%. In other words, Knight-Piesold (2007) said the probability was 6.13% that the entire mass of tailings, as well as the foundation, will undergo seismic liquefaction at some time during the 30 years of the life of the project. However, it should be noted that the risk of seismic liquefaction does not end at the end of the mining project, but continues forever as the dam is supposed to store wet tailings in perpetuity. Knight-Piesold (2007) recommended that "ground improvement to increase the liquefaction resistance of these loose soils will be required within the embankment footprint and for a distance downstream of the embankment. Stability analyses indicate that a 100 meter wide zone of ground will require treatment along the embankment alignment." However, there were no details nor guarantees that the "ground improvement" would eliminate the possibility of liquefaction of the foundation. There is no evidence that this type of seismic stability analysis has ever been repeated, even when the proposed height of the tailings dam increased.

The description of the project in the subsequent Environmental Impact Study (Walsh Scientists and Engineers, 2010a-b, 2011a) differed little from the Knight-Pièsold (2007) report, except that the ore processing rate increased to 30,000 metric tons per day. Walsh Scientists and Engineers (2010b) clarified that "*El embalse de relaves se mantendrá como una facilidad permanente posterior al cierre del proyecto*" [The tailings reservoir will be maintained as a permanent facility after project closure] and that "*una cobertura permanente de agua sobre los relaves proveerá de condiciones de anoxia, el cual prevendrá la generación de agua ácida, manteniendo las condiciones neutras del lago*" [a permanent water cover over the tailings will provide conditions of anoxia, which will prevent the generation of acidic water, maintaining the neutral conditions of the lake]. One of the comments of the Ministry of Environment of Ecuador was the convincing observation that "*la estabilidad sísmica debe ser producto de un estudio de sísmica local de la zona del proyecto y no regional como ligeramente se lo ha realizado en el estudio. De igual manera con respecto a los deslizamientos de tierra que localmente podrían ocurrir en la zona del proyecto…*" [the seismic stability must be the product of a local seismic study of the project area and not regional, as it has been minimally done in the study. Similarly, with respect to landslides that could occur locally in the project area…] (Walsh Scientists and Engineers, 2011b). The response of Walsh Scientists and Engineers (2011b) did not address the comment in any way, but simply referred to the attached report by Knight-Pièsold (2007), which also did not address the comment. The same document of responses to the Ministry of Environment of Ecuador (2011b) included a map showing the distribution of tailings that would occur along the Rio Quimi after the dam collapsed (see Fig. 2). The initial surge of tailings was calculated using a formula (Jeyapalan et al., 1983) that has been shown to be based on incorrect assumptions and algebraic errors (Connors et al., 2016). The correct calculation of the initial surge will be treated in the Discussion section.

An independent review (not contracted by the mining company) included a wide range of critiques of the plan for the tailings management facility as it existed at that time (Kuipers, 2012). The most important critique from the point of view of prevention of catastrophic failures was that the water content of the tailings (66.5% water for the coarser tailings and 79% water for the finer tailings) was excessively high. The most typical industry standards require partial dewatering of tailings to no more than 50% water before exporting them to tailings management facilities. On the contrary, it should be borne in mind that, in response to the failure of the tailings dam at the Mount Polley mine, the Independent Expert Engineering Investigation and Review Panel (2015) recommended that all tailings be completely dewatered before storage. The most important critique from the point of view of the prevention of contamination of groundwater was that Kuipers (2012) recommended a geosynthetic liner at the base of the facility, instead of relying on the low-permeability soil for the prevention of seepage from the facility.

Two other areas of critique addressed the design methodology and the financial guarantee. Kuipers (2012) criticized the explicit dependence on the "Observational Method" in Knight-Pièsold (2007). According to Independent Expert Engineering Investigation and Review Panel (2015), "This commonly accepted approach uses observed performance from instrumentation data for implementing preplanned design features or actions in response." Independent Expert Engineering Investigation and Review Panel (2015) repeated the concerns of Kuipers (2012) in affirming that "the Observational Method is useless without a way to respond to the observations." Finally, Kuipers (2012) criticized AMEC's estimate (2004) that a financial guarantee of $55 million would be sufficient for the closure and reclamation of the mine, and said that $568 million would be more reasonable. It is important to note that the financial guarantee estimate has not been reconsidered for the much larger project currently under construction.

Two other independent reviews questioned the accuracy of the predictions of the consequences of dam failure (Emerman 2014, 2015). Given that the tailings will spill into the Rio Quimi (see Fig. 2), after the initial surge, the flow of the rivers will carry the tailings even farther in the downstream direction. The termination of the flow of tailings at the confluence of the Rio Quimi and the Rio Zamora was not justified by Walsh Scientists and Engineers (2011b). In fact, there is no reason why the transport of tailings should end at the confluence of these two very steep rivers. Emerman (2015) found that, under normal river flow, the finer tailings in suspension should reach the next main confluence with the Rio Santiago (approximately 88 km downstream of the confluence of the Rio Quimi and the Rio Zamora) in approximately 19 hours. If the collapse of the dam occurred during the annual maximum flow (flood with a return period of one year), the tailings would reach the Rio Santiago in just five hours.

Final Version and its Critiques

In 2014, a new Environmental Impact Study with a new consulting firm (Cardno, 2014a-b) proposed two alternatives to increase the ore processing rate from 30,000 metric tons per day to 60,000 metric tons per day. Alternative 1 (preferred by the mining company) was to replace the Quimi tailings management facility with the Tundayme tailings management facility (see Figs. 11-12) in the steep valley of the Rio Tundayme, which would have more space for tailings. Alternative 2 was to keep the Quimi tailings management facility, keep the tailings at a minimum water content by converting them into a paste, and add Portland cement to immobilize heavy metals. The advantage of dewatering was to reduce the volume of the tailings, so that twice the mass of the tailings could be confined in the same space. While the both the Quimi and the Tundayme tailings management facilities were discussed throughout the Environmental

Impact Study, it is clear in Capítulo 5: Alternativas Estudiadas [Chapter 5: Studied Alternatives] of Cardno (2014a) that these were two alternatives, in which costs, environmental impacts and all other aspects were evaluated separately for each alternative.

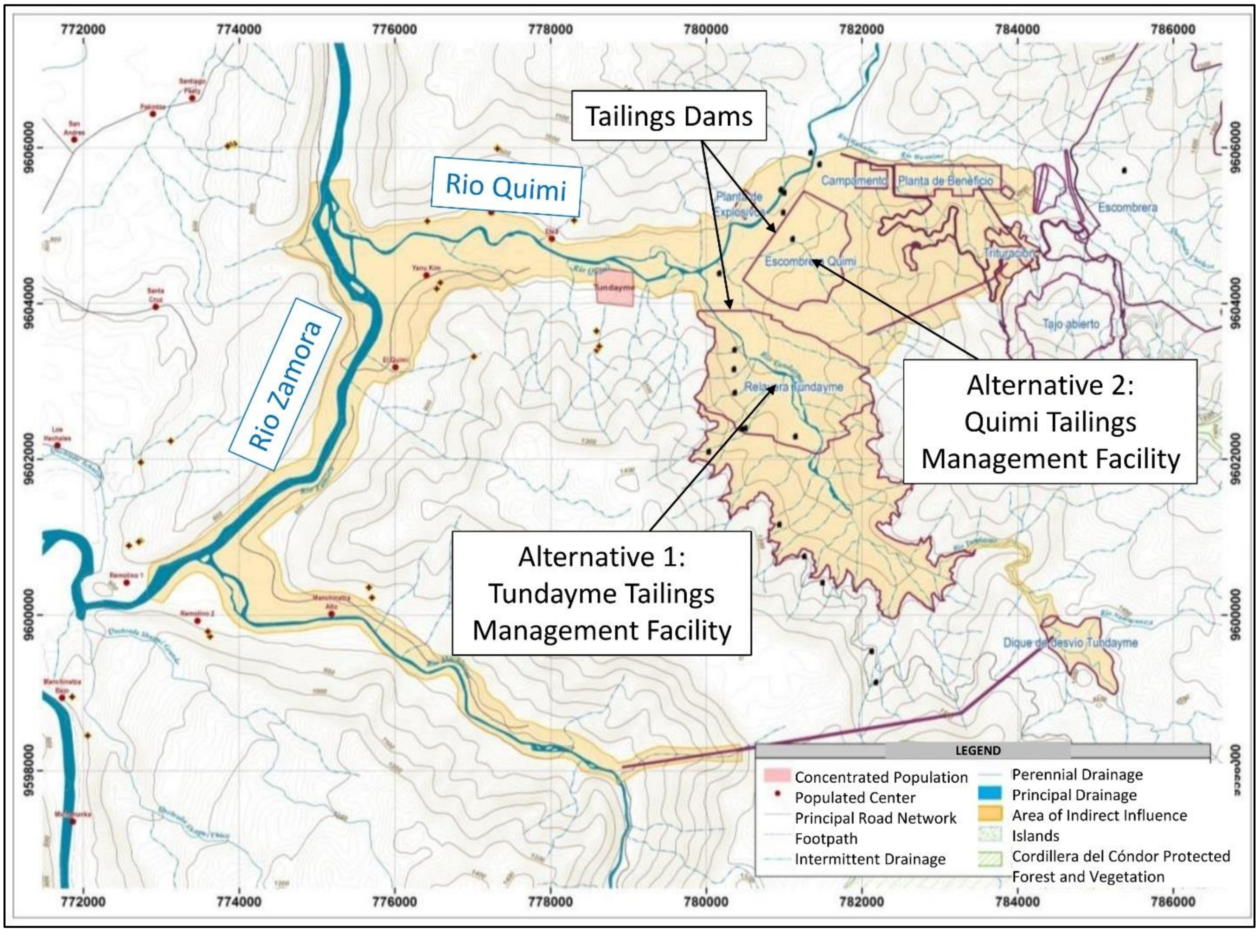


Figure 11. The second Environmental Impact Study (Cardno, 2014a) proposed two alternatives for increasing the production of copper ore from 30,000 to 60,000 metric tons per day. Alternative 1 was to replace the Quimi tailings management facility with the Tundayme tailings management facility, for which the dam would be 260 meters high, the tallest tailings dam ever built. Alternative 2 was to keep the Quimi tailings management facility, but increase its capacity by dewatering the tailings. Alternative 1 was preferred due to its lower cost, although it would have a greater environmental impact (Cardno, 2014a). Both alternatives are currently under construction, which is inconsistent with the Environmental Impact Study (Cardno, 2014a). Figure modified from Cardno (2014a).

The Tundayme dam had a planned height of 260 meters, which would be the tallest tailings dam in the world. (The current tallest tailings dam is the Quillayes dam at the Los Pelambres mine in Chile (Campaña et al., 2015)). The height of the Quimi dam remained unchanged at 63 meters. The outer embankment slopes were 1:1.5H and 1V:2H for the Tundayme dam and the Quimi dam, respectively. Although the construction methods were never explicitly stated, the discussion of the impermeable layers for both dams made it clear that the upstream construction method was not intended, as discussed above. For example, with respect to the Tundayme dam, Cardno (2014a) wrote "*En el talud aguas arriba del dique inicial se colocarán instalaciones impermeables (una capa impermeable y una capa de filtro). La capa impermeable consiste en geotextil de 2 mm + esteras de bentonita (4800 g/m^2)*" [On the upstream slope of the starter dike, impermeable infrastructure (an impermeable layer and a filter layer) will be placed. The impermeable layer consists of 2 mm geotextile + bentonite mats (4800 g/m^2)]. The storage volume of the Tundayme tailings management facility was 380,097,000 m^3. The storage volume of the Quimi tailings management facility could be correspondingly smaller due to the removal of water from the tailings.

Figure 12. The cost of construction would be cheaper for the Tundayme tailings management facility because it is possible to take advantage of the steep slopes of the Tundayme valley (shown above) for confinement of the tailings (Cardno, 2014a). However, the steep slope of the valley (around 13%) in the direction towards the Rio Quimi (see Fig. 11) increases the risk of failure due to the increase in gravitational force that would act on the dam. In addition, steep side slopes pose a risk of landslides into the tailings pond, which could cause dam failure by overtopping. Photo taken by the author on November 6, 2018.

An important change compared to the earlier Environmental Impact Study was the reduction in the magnitude of the design flood from the earlier choice of the Probable Maximum Flood. The design flood for the Tundayme dam was the 500-year flood during the first five years, at which time the dam would be 90 meters high. The design flood was the 1000-year flood until the end of the ninth year, when the dam would be 155 meters high. After the ninth year, the design flood would be increase to the PMF. The reduction in the magnitude of the design flood was presumably an inappropriate response to the greater flooding that would occur in the Tundayme Valley. According to Cardno (2014a), "*La relavera Tundayme se ubica aguas abajo del río Tundayme, ocupando una gran área para el escurrimiento de agua lluvia en la zona* *superior del río (52 km^2). Debido a los grandes caudales, se dificulta el control de inundaciones en temporadas lluviosas*" [The Tundayme tailings management facility is located downstream of the Rio Tundayme, occupying a large area for runoff of rainwater in the upper area of the river (52 km^2). Due to the large flows, flood control is difficult in the rainy seasons]. In general, much less information was available on the Quimi dam than on the Tundayme dam, presumably because the Tundayme dam was the preferred alternative.

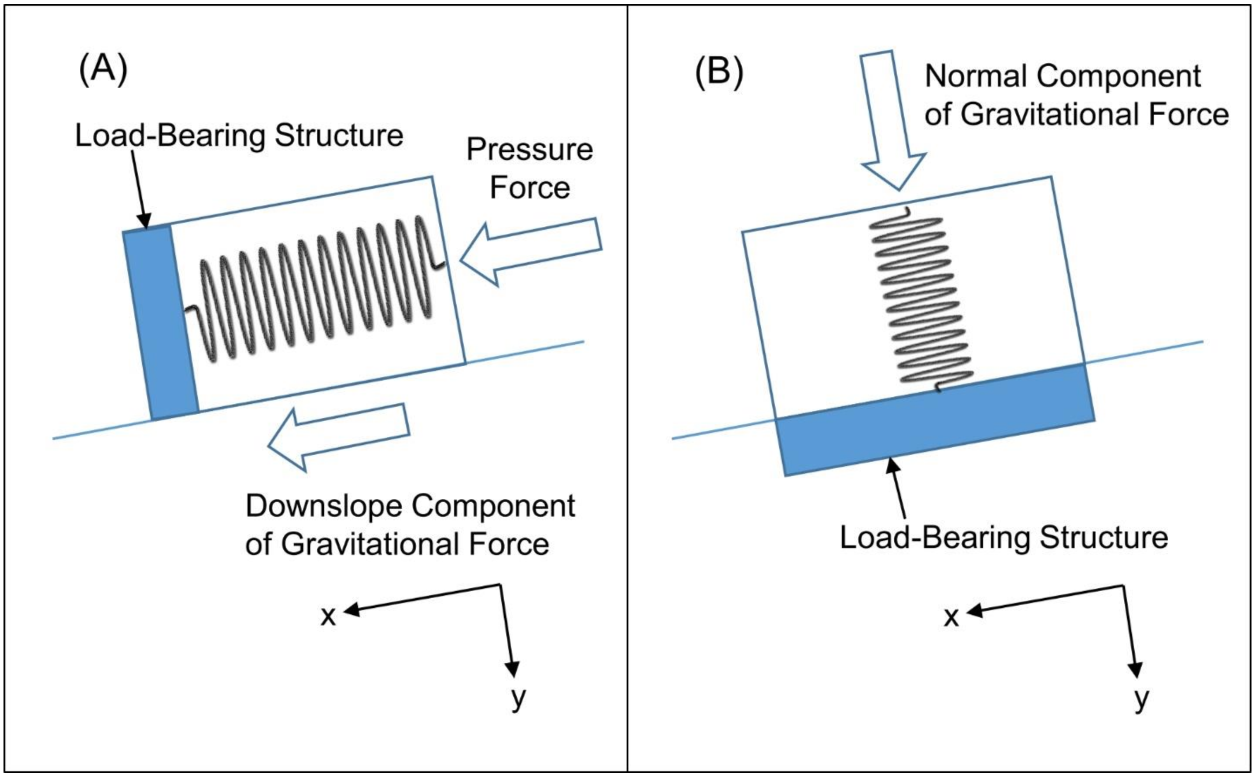


Figure 13. A loaded spring is the simplest model for any deformable solid that has not been stressed beyond its yield point. (A) In the case of a concrete dam, there are some load-bearing structures (shown here as a single reinforced column) that prevent the movement of the dam in the downslope direction (x-direction). Most earthen dams and all tailings dams lack reinforced columns or other defined load-bearing structures, so that the load is supported by the entire dam. The dam acts as a spring oriented in the downslope direction (x-direction) that is compressed against the load-bearing structure by the pressure force of the mixture of water and tailings upstream of the dam and by the downslope component of the gravitational force. (B) The dam could also be considered as a spring oriented in the y-direction and which is being compressed by the normal component of gravity. In this case, the foundation of the dam acts as the load-bearing structure. Figure from Emerman (2016).

The new Environmental Impact Study (Cardno, 2014a-b) did not include any new seismic stability analysis, although the preferred dam (the Tundayme dam) was in a new location with a different foundation, the height of the dam had increased from 63 meters to 260 meters, the slope of the embankment had increased from 1V:2H to 1V:1.5H, and the dam was in a steeper valley (both along the sides and downslope towards the Rio Quimi). As an attempt to estimate the stability of the preferred dam, Emerman (2016) calculated the change in the relative risk of failure that would result from changing the height of the dam, the height of the tailings, and the density of the mixture of tailings and water (collectively called the scale and mode of operation), without other changes in the design of the dam. The calculation was carried out by modeling the tailings dam as a set of loaded springs and using the compressions of the springs as a measure of progress towards failure (see Fig. 13). It was found that

$$R_x = \frac{\rho_{T,2}(H/H_0)_2 H_2}{\rho_{T,1}(H/H_0)_1 H_1} \tag{1}$$

$$R_y = \left(\frac{H_{0,2}}{H_{0,1}}\right)^2 \tag{2}$$

where R_x is the relative risk of failure in the downslope direction, R_y is the relative risk of failure in the normal direction (gravitational collapse), ρ_T is the density of the mixture of tailings and water, H_0 is the height of the dam, H is the height of the tailings, and the subscripts “1” and “2” refer to the first and second scales and modes of operation, respectively (see Fig. 14). It was found that the valley slope β was a less important factor and Eqs. (1) - (2) are simplified expressions that neglect the valley slope (see Fig. 14). Using the parameter values available in Cardno (2014a), Emerman (2016) found that, in comparison to the original plan (called Alternative 3 in Cardno (2014a)), the risk of failure in the downslope direction increased by a factor of 17.03 for Alternative 1 (Tundayme dam), while the risk of normal failure (gravitational collapse) increased by a factor of 1.76 for Alternative 2 (Quimi dam with dewatered tailings).

METHODOLOGY

The objective of this report has been to answer the following question: Are the design and the construction of the tailings dams consistent with widely-recognized safety guidelines? After reviewing the construction and causes of failure of tailings dams, and the history of tailings dam design at the Mirador mine, the question can be divided into the following questions:

1) Were the dams designed with the correct safety criteria for floods and earthquakes?
2) Is the use of non-sulfidic tailings appropriate for the construction of the tailings dams?
3) Are there additional risks of failure of the tailings dams that were not addressed in the Environmental Impact Studies or in the critiques discussed above?
4) Is the current construction consistent with the designs?

The questions were addressed by comparing the information from the most recent Environmental Impact Study (Cardno 2014a-b) with the standard textbook on tailings dams (Vick, 1990), as well as with widely-recognized guidelines for the choice of design floods and earthquakes (Canadian Dam Association, 2013; FEMA, 2005, 2013). Additional information was obtained from a complaint against EcuaCorriente S.A. by the provincial government of Zamora Chinchipe (Quishpe Lozano et al., 2018). The written information was complemented with photos taken by the author on November 6, 2018, during a visit in the company of Luis Sánchez Zhiminaycela (activist with Comunidad Amazónica de Acción Social Cordillera del Cóndor Mirador; see Fig. 1) and Evelyne Blondeel from E-Tech International. We were not allowed to enter the mine site and all photos were taken from the highway that borders the mine site. It is possible that the answers to my concerns are found in other technical documents that could not be consulted. However, it should be kept in mind that writing this report involved studying 6,384 pages of information produced by the company and its consultants.

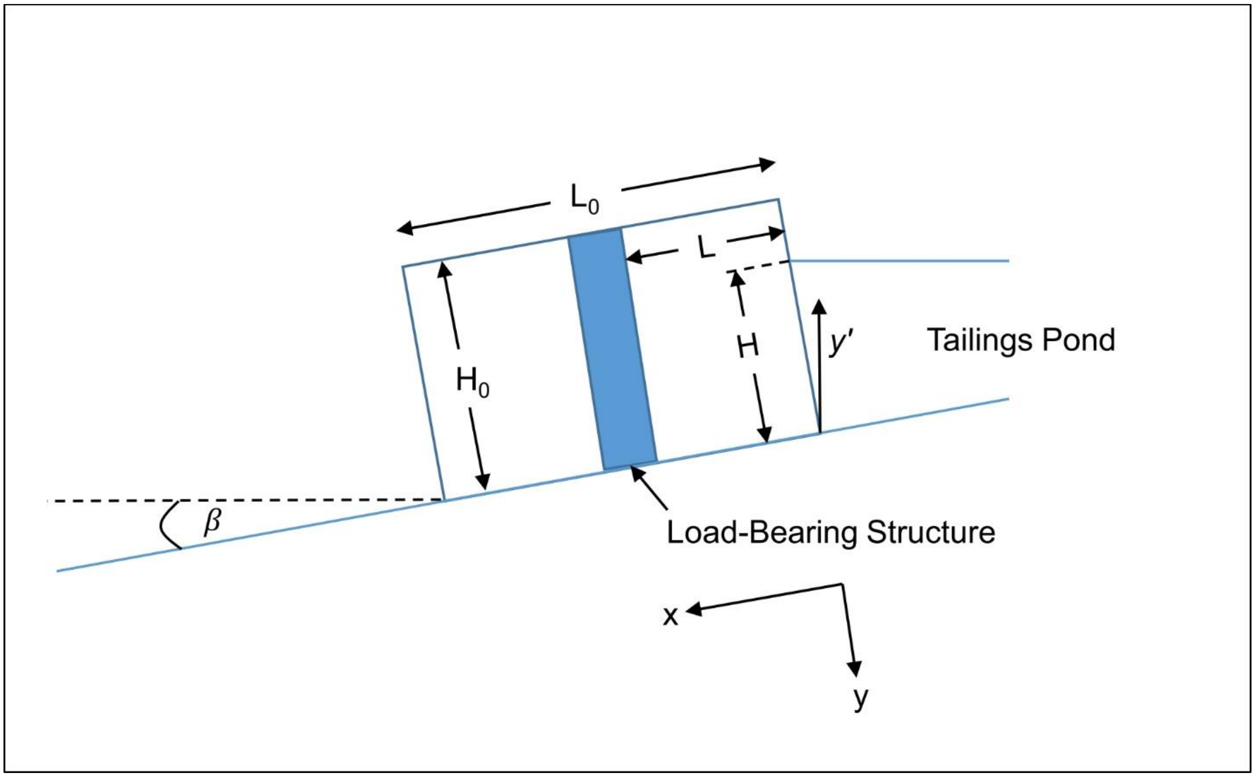


Figure 14. Although the geometry of the earthen dam is greatly simplified, it still captures all the forces acting on the dam and the resistances to those forces. The variable *L* is the spacing in the downslope direction between the reinforced columns or other load-bearing structures, which is shown here as the downslope distance between the upstream edge of the dam and a single load-bearing structure. Since tailings dams lack reinforced columns or other defined load-bearing structures, the load is supported by the entire dam, so that $L = L_0$. Figure from Emerman (2016).

Although the guidelines mentioned above do not legally apply in Ecuador, EcuaCorriente S.A. relied on their compliance with the guidelines of the Canadian Dam Association (2013) in its Environmental Impact Study (Walsh Scientists and Engineers, 2010a) and in its responses to questions from the Ministry of Environment of Ecuador (Walsh Scientists and Engineers, 2011). Therefore, it should be assumed that EcuaCorriente S.A. intends to comply with the guidelines of the Canadian Dam Association (2013) in all aspects of the project. Certainly, a project that was legal in Ecuador but was inconsistent with internationally-recognized guidelines should be a cause for pause and reflection.

RESULTS

Safety Criteria for Floods and Earthquakes

It should be clear at this point that the use of the 500-year flood as the safety criterion for the Tundayme dam is completely inappropriate. The recommendation of the Probable Maximum Flood for the Quimi dam (much smaller than the Tundayme dam) by Knight -Pièsold (2007) was based on their judgment that failure "would have a significant environmental impact on downstream watercourses. The economic consequences and socio-economic impact…would also be very high." According to Knight-Pièsold (2007), the Quimi dam would be at the point of failure during the 475-year earthquake (see Fig. 10). Their seismic stability analysis was not repeated for the much taller Tundayme dam. The relevant risk category corresponding to the design for a 500-year event is “significant” according to the Canadian Dam Association (2013). Using the risk-informed approach, a dam with “low” risk should be designed for a 100-year event, while a dam with “significant” risk should be designed for a 1,000-year event. Using the traditional, standards-based approach, a dam with “significant” risk should be designed for an event with a return period of between 100 and 1,000 years. The interpretation of “significant” risk is that there is a risk only for a temporary population (“seasonal cottage use, passing through on transportation routes, participating in recreational activities”), the restoration of cultural and environmental values or compensation in kind is “ highly possible,” and there will be economic losses only to “recreational facilities, seasonal workplaces and infrequently used transportation routes” (Canadian Dam Association, 2013). It should be clear that the "significant" risk category is irrelevant for a dam that is 1000 meters upstream of the inhabited town of Tundayme.

Use of Non-Sulfidic Tailings for the Construction of the Tailings Dams

The prediction that the coarser tailings will non-sulfidic (non-acid generating) and that only the finer tailings will be sulfidic (potentially acid generating) was based on an analysis of only 21 samples (Walsh Scientists and Engineers, 2010a). This is a very small set of samples, especially compared to the size of the ore body that will be converted into tailings. None of the available documents indicates the size of the rock samples. However, a published procedure establishes that measurements of neutralization potential and acidity potential were made in samples of two grams (Skousen et al., 2001). On that basis, 21 × 2 grams = 42 grams represents less than 10^{-13} (less than one part in ten trillion) of the planned 657 million metric tons of mine tailings (60,000 metric tons per day for 30 years). In addition, none of the documents contains any measure of uncertainty (error limits) in the prediction that 87% of the ore processed will be converted into coarser tailings (assumed to be non-sulfidic).

There is no guarantee, or even estimate of the probability, that there will be enough non-sulfidic tailings to build the dams. There are two possible responses to a future discovery of the lack of non-sulfidic tailings for construction:

1) Sulfidic tailings will be used to build the dams or there will be a change in the cut-off value that defines the sulfide content that counts as “sulfidic.” Any of these changes will involve the generation of acid mine drainage (AMD) from the unconfined dams.
2) There will be a change in the design of the dam to adapt to the lack of construction material. For example, the slope of the embankment will become steeper or there will be a change from centerline construction to upstream construction, which requires less construction material.

As Kuipers (2012) and the Independent Expert Engineering Investigation and Review Panel (2015) mentioned, the “Observational Method” makes sense only if they are ways of adapting to the new observations.

Additional Risks of Failure of the Tailings Dams

None of the documents provided by EcuaCorriente S.A. nor their consultants have addressed the risk of landslides, despite the fact that the Ministry of Environment of Ecuador (Walsh Scientists and Engineers, 2011b) asked them to provide this information. The problem is particularly serious in the steep valley of the Rio Tundayme (see Fig. 12). From the point of view of cost reduction, one of the advantages of this site is that it is possible to use the slopes as walls for the Tundayme tailings management facility, as opposed to the Quimi tailings management facility, which requires the construction of walls on three sides of the tailings reservoir (Cardno, 2014a; see Fig. 1). The main threat of landslides is that rocks falling in the tailings pond could cause water to flow over the top of the dam, which would almost certainly destroy the dam. The high erosion rate in the project area is indicated by the landslide scar below a transmission tower on the north bank of the Rio Quimi, opposite the Quimi tailings dam (see Figs. 11 and 15). The landslide scar also indicates the underestimation of the erosion rate by the engineers who chose the site for the transmission tower that provides electricity for the mine.

Figure 15. The high erosion rate in the project area is indicated by the landslide scar below a transmission tower on the north bank of the Rio Quimi (see Fig. 11), opposite the Quimi tailings dam. Photo taken by the author on November 6, 2018.

Contradictions between Construction and Design

There are three important contradictions between the current construction and the design of the tailings management facilities at the Mirador mine. The first is that the Quimi dam is being built using the upstream method. The starter dike for the Quimi tailings dam was built on the edge of the highway, the other side of which is the Rio Quimi (see Figs. 11 and 16). Since it is not possible to advance the dam farther in the downslope direction, the intention must be to build the entire dam using the upstream method (compare Figs. 5a-c). This is inconsistent with the design evaluated by Knight-Piėsold (2007) and both Environmental Impact Studies (Walsh, 2010b; Cardno, 2014a), which included the centerline construction method for the Quimi tailings dam. Tailings dams built by the upstream method are more susceptible to failures from both earthquakes and floods. Due to the impossibility of installing impermeable layers (see Figs.5a-c, 8), their higher water content also makes them more susceptible to failure due to internal erosion, static liquefaction and foundation failure.

Figure 16. The starter dike for the Quimi tailings dam was built at the edge of the highway, the other side of which is the Rio Quimi (see Fig. 11). Since it is not possible to advance the dam farther in the downslope direction, the intention must be to build the entire dam using the upstream method (compare Figs. 5a-c). This is inconsistent with the design evaluated by Knight-Piėsold (2007) and both Environmental Impact Studies (Walsh Scientists and Engineers, 2010b; Cardno, 2014a), which included the centerline construction method for the Quimi tailings dam. Tailings dams built by the upstream method are more susceptible to failure from both earthquakes and floods. Due to the impossibility of installing impermeable layers (see Figs. 5a-c, 8), their higher water content also makes them more susceptible to failure due to internal erosion, static liquefaction and foundation failure. Photo taken by the author on November 6, 2018.

The second contradiction is that a simple application of trigonometry shows that the starter dike of the Quimi dam (see Fig. 17) has a slope of 1V:1H (45°). This is inconsistent with the design evaluated by Knight-Piėsold (2007; see Fig. 10) and both Environmental Impact Studies, which stated that the slope would be 1V:2H (26.6°). As explained above, a slope of

1V:1H is considered to be the maximum critical angle to prevent internal erosion of the dam without any margin of error (safety factor = 1.0). In other words, the starter dike was built at the point of failure, and is in danger of failing as soon as the tailings management facility is filled with wet tailings.

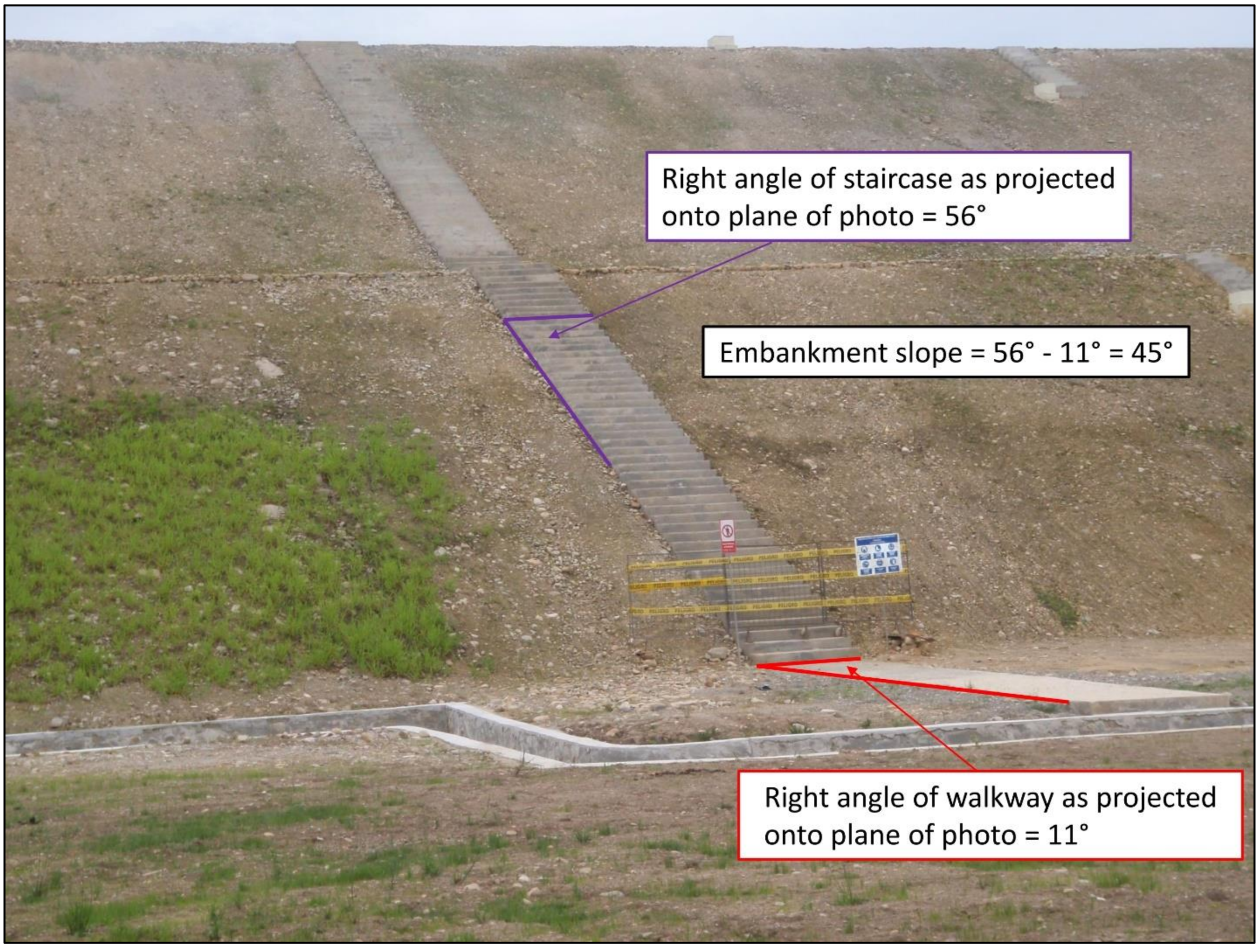


Figure 17. The starter dike for the Quimi tailings dam has a slope of 1V:1H (45°). This is inconsistent with the design evaluated by Knight-Pièsold (2007; see Fig. 10) and both Environmental Impact Studies, which stated that the slope would be 1V:2H (26.6°). A slope of 1V:1H is considered the maximum critical angle to prevent internal erosion of the dam without any margin of error (safety factor = 1.0). In contrast, according to the U.S. Army Corps of Engineers (USACE, 2000), "for sand levees, a 1V on 5H landside slope [11.3°] is considered flat enough to prevent damage from seepage exiting on the landside slope." Photo taken by the author on November 6, 2018.

The most surprising contradiction of all is that both tailings management facilities, Quimi and Tundayme, are currently under construction, although according to the most recent Environmental Impact Study (Cardno, 2014a-b), these were simply two alternatives (see Figs. 1, 11, 16, 17 and 18). There are at least three possible interpretations of the appearance of the two tailings management facilities:

1) The mine will process 60,000 metric tons of ore per day using both tailings management facilities to store the tailings.
2) The mine will process 90,000 metric tons of ore per day by storing 60,000 metric tons of wet tailings per day in the Tundayme tailings management facility and 30,000 metric tons of wet tailings per day in the Quimi tailings management facility.

3) The mine will process 120,000 metric tons of ore per day by storing 60,000 metric tons of wet tailings per day in the Tundayme tailings management facility and 60,000 metric tons of dewatered tailings per day in the Quimi tailings management facility.

It is impossible to decide which interpretation is correct when there is no apparent connection between the designs and the actual construction. In the same way, it is impossible to determine whether there is an intention to store wet tailings behind the Quimi dam, which would have an unacceptable risk of failure by internal erosion due to its excessively steep slope (see Fig. 17).

Figure 18. The sign ("Sedimentation Pond for Construction Phase of Tundayme Tailings Management Facility") clarifies that both the Quimi tailings management facility (see Figs. 1, 16 and 17) and the Tundayme tailings management facility are currently under construction. This is inconsistent with the Environmental Impact Study (Cardno, 2014a), which listed the two tailings management facilities as alternatives. Photo taken by the author on November 6, 2018.

The Tundayme tailings management facility is not even being built with due respect for the protection of the Rio Quimi. Sedimentation ponds are supposed to prevent the flow of muddy water from the construction site from entering the Rio Quimi. However, the overflow from the sedimentation ponds for the Tundayme tailings management facility is discharged into a pipe and flows into the Rio Quimi (see Figs. 19a-b). The gray color of the discharge from the sedimentation ponds demonstrates that the sedimentation ponds are not working (see Fig. 19c), which was also observed by Quishpe Lozano et al. (2018). It is very likely that the sedimentation ponds have not been constructed correctly, so that surface runoff simply flows over the top of the ponds without time for the sedimentation of fine particles.

Figure 19a. The overflow from the sedimentation ponds for the Tundayme tailings management facility is discharged into a pipe and flows to the Rio Quimi (see Fig. 11). Photo taken by the author on November 6, 2018.

DISCUSSION

Explanation for the Contradictions between Construction and Design

A possible explanation for the change from centerline construction to upstream construction (see Fig. 16) and the excessively steep slope of the starter dike (see Fig. 17) can be found in a complaint by the provincial government of Zamora Chinchipe against EcuaCorriente S.A. According to the complaint "*Aquí se realizaba la extracción de material pétreo en una porción del río Tundayme. Al igual que en los ríos Quimi y Waywayme [ver Figs. 2 y 11], la extracción de material pétreo en esta zona no se realiza dentro de ninguna concesión minera para la explotación de áridos y pétreos…Cabe resaltar que en la revisión realizada al Catastro Minero nacional no se registran títulos mineros para la explotación de material pétreo dentro del proyecto Mirador en la zona antes mencionada*" [Here the extraction of rock material was carried out in a portion of the Rio Tundayme. As in the Rio Quimi and the Rio Waywayme [see Figs. 2 and 11], the extraction of rock material in this area is not carried out within any mining concession for the exploitation of aggregates and rock…It should be noted that in the review conducted for the National Mining Registry, mining titles are not registered for the exploitation of rock material within the Mirador project in the aforementioned area] (Quishpe Lozano et al., 2018). A possible explanation for the illegal extraction of construction material from rivers is the lack of other sources of construction material. Less construction material is required to build a dam using the upstream construction method (compare Figs. 5a and 5c) and to build a steeper embankment.

Figure 19b. The pipe from the sedimentation ponds discharges directly into the Rio Quimi. Photo taken by the author on November 6, 2018.

These changes in construction as a result of a shortage of construction material are a repetition of the sequence of events that led to the failure of the tailings dam at the Mount Polley mine. Failure to reevaluate the stability of the dam after the changes were made is also part of the sequence of events. According to the Independent Expert Engineering Investigation and Review Panel (2015), “It was planned to place the Zone C outslope to an ‘interim’ 1.4H:1V inclination—rather than the design basis 2.0H:1V—as a temporary expedient until mine waste delivery could catch up with construction…But instead of rectifying the interim steep slopes at this time as had been intended, such measures were left to future stages of embankment raising… Rather than adhering to a ‘centreline’ configuration, raise 2 utilized entirely ‘upstream’ construction…These as-built conditions were never reconciled with the Stage 2 stability analyses, which had been predicated on the original design configuration.”

Figure 19c. The gray color of the discharge from the sedimentation pond demonstrates that the sedimentation ponds are not working (Quishpe Lozano et al., 2018). Photo taken by the author on November 6, 2018.

Probability of Failure of the Mirador Tailings Dams

It is now appropriate to consider rigorously the probability of failure of the Tundayme and Quimi dams. Knight-Pièsold (2007) determined that the probability of failure of the original design of the Quimi dam due to seismic liquefaction was 0.21% in any given year and 6.13% during the life of the project. (It should always be remembered that the risk of failure does not end after the project ends, but continues in perpetuity.) Emerman (2016) calculated that, if the original design of the Quimi dam would be used to build the Tundayme dam with changes only in the heights of the dam and the tailings, the annual probability of failure would be 17.03 × 0.21% = 3.59%, for a probability of failure during the 30 years of the life of the project of 66.56%. However, the following changes were made that increase the probability of failure of the Tundayme dam:

1) The design slope of the embankment was steepened from 1V:2H to 1V:1.5H.
2) The site was moved from the Quimi Valley (7% slope down to the Rio Quimi) to the Tundayme Valley (13% slope down to the Rio Quimi).
3) The Tundayme tailings are in a larger watershed (with larger floods) and the design flood has changed from the Probable Maximum Flood to the 500-year flood.

4) There seems to be no commitment to build according to the design, especially no commitment to use the centerline construction method. It is important to note that the upstream construction method is more susceptible to all causes of dam failure.

Changes to the Quimi dam (change from centerline construction to upstream construction, steepening of the embankment slope from 1V:2H to 1V:1H) also increase the probability of failure of the Quimi dam. Based on the above, the probabilities of failure of both dams are so high that they should be regarded as inevitable.

Figure 20. According to a complaint by the provincial government of Zamora Chinchipe (Quishpe Lozano et al., 2018), "Here the extraction of rock material was carried out in a portion of the Rio Tundayme [shown above]. As in the Rio Quimi and the Rio Waywayme [see Figs. 2 and 11], the extraction of rock material in this area is not carried out within any mining concession for the exploitation of aggregates and rock…It should be noted that in the review conducted for the National Mining Registry, mining titles are not registered for the exploitation of rock material within the Mirador project in the aforementioned area." A possible explanation for the illegal extraction of construction material from rivers is the lack of other sources of construction material. A shortage of construction material could also explain the change from centerline construction to upstream construction (see Fig. 16) and the excessively steep embankment of the starter dike (see Fig. 17). Photo taken by the author on November 6, 2018.

Consequences of Failure of the Tailings Dams

Finally, it is appropriate to reconsider the consequences of dam failure (see Fig. 2) based on the increase in height and storage volume of the dam. Larrauri and Lall (2018) published a statistical model to predict the initial surge after the failure based on the history of tailings dam failures. According to this model, the best predictor of the initial surge is the dam factor H_f, defined as

$$H_f = H\left(\frac{V_F}{V_T}\right)V_F \qquad (3)$$

where H is the height of the dam (meters), V_T is the total volume of confined tailings and water (millions of cubic meters), and V_F is the volume of the spill (millions of cubic meters). The volume of the spill and the initial surge D_{max} (kilometers) can be predicted as

$$V_F = 0.332 \times V_T^{0.95} \qquad (4)$$

$$D_{max} = 3.04 \times H_f^{0.545} \qquad (5)$$

Inserting H = 260 meters and V_T = 390.097 million cubic meters (for the Tundayme dam; Cardno (2014a)) in Eqs. (3) - (5) produces V_F = 94 million cubic meters and a D_{max} value of just under 350 kilometers. Although the predicted value of the initial surge may seem incredibly large, the calculation illustrates the difficulty of predicting the consequences of the Tundayme dam failure from the history of the consequences of tailings dam failures. The largest tailings spill in history was due to the failure of the Fundão dam in Brazil in 2015, which spilled 32 million cubic meters of water and tailings (Larrauri and Lall, 2018). With a height of 90 meters, the Fundão dam was also the tallest tailings dam that has ever failed (Larrauri and Lall, 2018). Even that dam with a smaller H and V_F than the Tundayme dam resulted in a measured D_{max} of 657 kilometers (Larrauri and Lall, 2018). The initial surge was clearly increased by the spill of tailings into a river, which would also occur in case of a failure of the Tundayme dam.

Based on the above calculation, the assignment of the risk category of VERY HIGH by Knight-Pièsold (2007) should also be reconsidered. The failure of the tailings dams at the Mirador mine would affect not only the mine and the downstream town of Tundayme, but a significant part of the headwaters of the Amazon River. Using the classification system of the Canadian Dam Association (2013), the only category of risk higher than VERY HIGH is EXTREME. This risk category includes the probable deaths of more than 100 people, the major loss of critical fish habitat and the impossibility of restoration or compensation in kind. To summarize this discussion, the failure of the tailings dams in the Mirador mine is inevitable and the consequences will be extreme.

CONCLUSIONS

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

1) The design criteria of ability to resist a 500-year flood and a 500-year earthquake are inadequate for tailings dams for which failure would result in the loss of human lives and extensive environmental damage.
2) The assumption that coarser tailings will be non-sulfidic cannot be relied upon in the construction of tailings dams from the tailings themselves.

3) There has been no evaluation of the risks posed by landslides or the high rate of erosion in the area of the mining project.
4) Contrary to the design, the Quimi dam is being built using the upstream construction method, which is more susceptible to all causes of failures of tailings dams.
5) Contrary to the design, the Quimi dam has an embankment slope of 1V:1H, which is the maximum critical angle for preventing failure by internal erosion. From this point of view, the dam is susceptible to failure as soon as the tailings management facility is filled with wet tailings.
6) Contrary to the design, both alternatives of the Quimi dam and the Tundayme dam are currently under construction.
7) The failure of the tailings dams at the Mirador mine is inevitable and the consequences will be extreme.

RECOMMENDATIONS

The recommendation of this report is that there should be an immediate moratorium on further construction of the Mirador mine. The moratorium should be followed by the convening of an independent panel of international experts who will evaluate the design and construction of the Mirador tailings management facilities. This panel must be provided with full and complete information from EcuaCorriente S.A., without which it is impossible to make specific recommendations. This panel would be similar to the independent expert panels who evaluated the failures of the Mount Polley (Independent Expert Engineering Investigation and Review Panel, 2015) and Fundão tailings dams (Fundão Tailings Dam Review Panel, 2016). Unlike the previous expert panels, it is recommended that this panel be convened before the disaster and not after.

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Appendix 2: Preliminary list of the communities concerned with environmental, safety, and other social impacts from the Mirador Mine.

	NOMBRE LOCAL	**NOMBRE: OPEN STREETMAP PLACES DATABASE**	**PROVIN-CIA**	**CAN-TÓN**	**PARRO-QUIA**	**Latitud**	**Longitud**
1	Tundayme (cabecera parroquial)	Tundayme	Zamora Chinchipe	El Pangui	Tundayme		
2	Churuwia y Etsa		Zamora Chinchipe	El Pangui	Tundayme		
3	**Valle del Quimi**[1] 3 Km. al sur del proyecto Mirador		Zamora Chinchipe	El Pangui	Tundayme	-3,53794° o 3° 32' 17" sur	-78,45634° o 78° 27' 23" oeste
4	**El Quimi**		Zamora Chinchipe	El Pangui	Tundayme	-3,58672° o 3° 35' 12" sur	-78,51496° o 78° 30' 54" oeste
5	Machinaza Alto		Zamora Chinchipe	El Pangui	Tundayme		
	Yanua Kim		Zamora Chinchipe	El Pangui	Tundayme		
6	Chuchumbletza	Chuchumbletza	Zamora Chinchipe	El Pangui	El Güismi		
7	San Carlos Numpai,		Zamora Chinchipe	El Pangui	Tundayme		
8	Remolino 2 Chuchumbletza						
9	Machinias (Remolino 1)						
10	Bomboiza Gualaquiza-Morona S.		Zamora Chinchipe	Gualaquiza	Bomboiza		
11	Shiram Enta						
12	Campana Entsa	Campana-ka Entsa					
13	Narváez						
14	Ayantás						
15	Piunts-San José						
16	Proveeduría	Proveeduría					
17	Unión de Bomboiza Zamora	Unión de los dos ríos?					

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[1] https://mapcarta.com/es/19867240#:~:text=Valle%20del%20Quimi%20es%20una,norte%20de%20Proyecto%20Minero%20Mirador.

	NOMBRE LOCAL	NOMBRE: OPEN STREETMAP PLACES DATABASE	PROVIN-CIA	CAN-TÓN	PARRO-QUIA	Latitud	Longitud
18	Comunidad Arenal	Arenal					
19	Yantsas San Luis						
20	El Tiink		Morona Santiago				
21	Yukutais						
22	Asau	Asao	Morona Santiago				
23	Centro Shuar Wapis						
24	Fincas poblaciones mestizas aguas abajo de Asau hasta centro Pupú						
25	Pupú						
26	Tsunsuim						
27	Upundios						
28	Parroquia San Carlos de Limón	San Carlos de Limón	Morona Santiago	San Juan Bosco	San Carlos de Limón		
29	Nankints,						
30	Comunidad 27 de Febrero						
31	Akarunts						
32	Poblaciones mestizas de Akarunts hasta la comunidad La Victoria						
33	La Victoria						
34	Shuar Ampam						
35	Ampakai						
36	Mayapis						
37	Yunkumas – Barrio Tarq.						
38	La Unión						
39	Yukiantza						
40	Kuankus						
41	Centro Shuar Kapisun						
42	Centro Shuar Suritiak						

	NOMBRE LOCAL	**NOMBRE: OPEN STREETMAP PLACES DATABASE**	**PROVIN-CIA**	**CAN-TÓN**	**PARRO-QUIA**	**Latitud**	**Longitud**
43	Centro Shuar Pandam						
44	Centro Shuar Nantip						
45	Centro Shuar Kim						
46	Centro Shuar Kushapuk						
47	Ciudad Santiago – Tiwintza						
48	Centro Shuar Mayaik						
49	Centro Shuar Kaputna						
50	Centro Shuar Peñas						
51	Centro Shuar Jempekat (Unión de Yaupi Santiago						
53	Centros Shuar del Perú a orillas del Río Santiago						

Appendix 3: Ecuacorriente Resources Mirador Project, Ecuador. Mine Reclamation and Closure, Financial Assurance Cost Estimate. Report prepared by James Kuipers, PE, 2012, for E-Tech International.

Ecuacorriente Resources Mirador Project, Ecuador Mine Reclamation and Closure Financial Assurance Cost Estimate

James R. Kuipers, P.E.
February 10, 2012

The Mirador Copper Project is proposed as an open pit mining and conventional grinding and flotation plant processing a copper porphyry deposit to produce a copper sulfide concentrate. The project is located in southeast Ecuador, approximately 400 km south of Quito and 300km from the coast on the east side of the Andes Mountains, at an elevation of 800 to 1,400 m above sea level.

This review is based on information identified in the *Preliminary Mine Closure and Reclamation Plan, Mirador Project, Ecuador*, AMEC Earth & Environmental, December 15, 2004 and acreage information contained in the 2011 Exploitation and Beneficiation EIAs.

AMEC estimated an "Indicative Closure Cost" of US$55,000,000 for mine reclamation and closure which included direct closure costs, indirect closure costs, and post-closure costs. The cost estimate, which was not a detailed estimate due to limited information on actual reclamation and closure designs and costs at the time, is shown in Table 1 under the heading AMEC 2004. AMEC did not provide a technical basis for the costs used in the estimate.

The Exploitation and Beneficiation EIAs and other supporting documents for the project, such as for the Rio Quimi TMF, similarly only provide very limited conceptual reclamation and closure plans and provide no cost estimates for carrying out such plans. The EIAs did contain information on surface area for the various mine features which are shown in Table 1 under the heading Surface Area.

I have estimated costs for mine reclamation as shown in Table 1 under the heading Kuipers 2012. The costs shown are consistent with those derived for US located copper porphyry mines containing acid drainage generating materials and in close proximity to water resources. Examples of mine cost estimates which have been used in this estimate include that of the Chino and Tyrone Mines in New Mexico, the Morenci and Bagdad Mines in Arizona, and the Continental Mine in Montana. The costs are also consistent with US Federal Reclamation and Closure Guidance issued by the US Environmental Protection Agency (EPA), US Forest Service, and US Bureau of Land Management. The costs are intended to estimate financial assurance costs which represent the cost of the regulatory agency conducting the reclamation and closure activities in the event the company does not do so. The author regularly reviews such estimates conducted by other agencies and routinely conducts such estimates for the EPA.

Direct Closure Costs

Open Pit

Reclamation and closure measures for open pits range from no earthmoving and revegetation accompanied by only fencing, to some earthmoving and revegetation on benches, to partial and in some cases complete backfilling. In many cases the partial or complete backfilling is required to prevent formation of a pit lake, and in other cases backfilling is used to bury of isolate particularly problematic (e.g. acid drainage forming) waste rock. Backfilling may result in inundation of the waste materials below the groundwater table (decreasing acid generation but potentially increasing solubility of metalloids such as arsenic or selenium) or it may be above the water table. No present modern mine site in the US is known to be permitted to allow a pit lake with adverse water quality to form primarily due to wildlife (e.g. bird death) issues associated some pit lakes.

The AMEC 2004 estimate did not address open pit reclamation at the Mirador Project. However, it is clear from the descriptions in the EIA and other documents that an acidic pit lake is likely to form and also result in pollution being discharged from the open pit via groundwater and possibly surface water. At a minimum it is proposed for conceptual purposes that the cost of preventing a pit lake to form (partial backfill with pit pump sump with pit water to treatment) be included in the estimate. Costs for this activity can range from less than $1.0M to greater than $10M. A value of $5M was used in the Kuipers 2012 estimate.

Waste Rock Dumps

Reclamation and closure methods for waste rock piles typically involve regrading to from 2:1 to 3:1 (horizontal:vertical) slopes, covering with up to 1.0 m of topsoil or growth medium and revegetation consistent with the proposed post-mining land use. In the event of water quality issues source control measures such as engineered covers (e.g. covers with synthetic liners or engineered features such as capillary breaks) may be used together with thicker covers (ranging from three to ten or more feet). In many cases encapsulation of acid generating and potentially acid generating materials within waste rock dumps may be part of source control measures. These measures typically are not included in reclamation and closure plans because they are incorporated as part of mine operations. Another measure recently introduced is lining of waste rock features which similarly are not included in reclamation and closure plans because the lining, which is done to accomplish collection of any seepage from the waste rock feature, is done prior to waste rock placement. In some cases waste rock features causing water contamination may be removed and used as underground or open pit backfill or otherwise are located in a suitable repository.

The AMEC 2004 estimate was $3.0M for waste rock dump reclamation and closure consisting of regrading to 2.5:1 slopes, adding a source control cap (compacted soil and/or geomembrane) and revegetation. On a reclaimed area basis the estimate was the equivalent of $11,364/hectare. This represents the low end of waste rock reclamation costs and would likely not address resloping and revegetation activities, much less installation of a geomembrane cap which could be expected to cost $150,000/hectare alone. A total cost of $185,250/hectare was estimated by Kuipers based on typical US costs for the activities described resulting in an estimate of $49M.

Tailings Management Facility

Reclamation and closure measures typically involve regrading to from 2:1 to 3:1 (horizontal:vertical) slopes, covering with up to 1.0m of topsoil or growth medium and revegetation consistent with the proposed post-mining land use. In the event of water quality issues source control measures such as engineered covers (e.g. covers with synthetic liners and/or features such as capillary breaks) may be used together with thicker covers. Tailings features may require continuous operation result in significant interim (emergency) costs to maintain the safety of the structure, control water levels, and prevent the release of tailings.

The AMEC 2004 estimate assumed the TMF would be maintained as a permanent facility and not reclaimed, therefore no cost was included in the estimate. The Beneficiation EIA suggests that some regrading, cover placement and revegetation would be performed. Considering that the tailings will likely be acid generating it is likely that a source control cover, similar in requirement to that of the waste rock dump cover, would be needed to control infiltration into the TMF. A total cost of $185,250/hectare was estimated by Kuipers based on typical US costs for the activities described resulting in an estimate of $39M.

Surface Facilities

The AMEC 2004 estimate was $7.0M for surface facilities on about 102 hectares as identified in the EIAs. On a reclaimed area basis the estimate was the equivalent of $68,600/hectare. Surface facility costs are highly variable so a more conservative estimate of $123,500/hectare was estimated by Kuipers based on typical US costs for the activities described resulting in an estimate of $13M.

Post-Closure Costs

The AMEC 2004 estimate did not estimate acid drainage treatment plant construction costs. It did estimate acid drainage treatment plant operation costs at $1M/yr, environmental monitoring costs at $100K/yr, and maintenance costs at $200K/yr. The AMEC costs were based on a 30 year period.

The Kuipers 2012 estimate includes $25,000,000 for water treatment plant construction. In the event of bankruptcy it is doubtful that the treatment plant would have been built or that it might need to be replaced. Based on experience at other sites where acid drainage treatment has been necessary, Kuipers 2012 increases the costs to $2M/yr. In addition, Kuipers 2012 uses increased costs of $250K/yr for environmental monitoring and $500K/yr for site maintenance based on experience and costs at other sites for those activities. In addition, Kuipers 2012 cost estimate is based on a 100 year period which has been the standard in the US (the US Bureau of Land Management now uses 500 years as the period).

Indirect Costs

The AMEC 2004 estimate includes indirect costs for engineering, procurement and construction management (EPCM), other site related costs, and a contingency equal to 15% of direct and indirect closure costs only. This results in an indirect cost estimate of $5.5M or 11% of the estimated direct costs.

The Kuipers 2012 estimate is based on typical costs recognized as indirect costs by US regulatory authorities that include mobilization and demobilization, EPCM, contractor profit, agency oversight costs, bond and insurance costs. These costs typically are at least 40% and may be greater than 50% of the estimated direct costs. Kuipers 2012 uses 40% resulting in indirect costs of $162M.

Total Costs

In comparison to the AMEC 2004 estimate of $55M, the Kuipers 2012 estimate for reclamation and closure of the Mirador mine is $568M. The Kuipers 2012 estimate reflects both the acid generating nature of the site and modern financial assurance reclamation and closure practice typical to US Federal regulatory agencies. The Kuipers 2012 estimate for Mirador, while showing a very high potential liability, is consistent with costs estimated for similar acid-generating copper porphyry mine facilities in the US and elsewhere for financial assurance purposes.

Table 1 - Mirador Project Closure Cost Estimate

Area	Surface, Hectares	AMEC 2004		Kuipers 2012	
		Assumption	Cost (US$)	Assumption	Cost (US$)
Direct Closure Costs					
Open Pit	120	no action	$0	prevent lake formation	$5,000,000
Waste Rock Dumps	264	regrade 2.5:1, cap, reveg	$3,000,000	same as AMEC	$48,906,000
Tailings Management Facility	210	maintain as permanent facility	$0	regrade, cap, reveg	$38,902,500
Surface Facilities	102	remove equipment and buildings	$7,000,000	same as AMEC	$12,597,000
Subtotal Direct Closure Costs			$10,000,000		$105,405,500
Post-Closure Costs					
Acid Drainage Treatment Plant Construction		not included			$25,000,000
Acid Drainage Treatment Plant Operation		30 years @ $1M/yr	$30,000,000		$200,000,000
Environmental Monitoring		30 years @ $100K/yr	$3,000,000		$25,000,000
Maintenance		30 years @ $200K/yr	$6,000,000		$50,000,000
Subtotal Post-Closure Costs			$39,000,000		$300,000,000
Indirect Costs					
EPCM		Applied to Direct Closure Costs Only	$1,500,000		
Other Costs			$2,000,000		
Contingency		15% of Direct and Indirect Costs	$2,025,000		
Subtotal - Indirect Costs			$5,525,000		$162,162,200
Indirect Costs, % of Closure and Post-Closure			11%		40%
Total Closure Costs (rounded)			$55,000,000		$568,000,000

Appendix 4: Letter from the Asemblea Nacional to the Ministerio de Energia y Recursos Naturales no Renovables. Asunto: Solicitud de Informacion. Oficio Nro. AN-QLS-2022-0030-O. 2022.

Oficio Nro. AN-QLS-2022-0030-O

Quito, D.M., 17 de febrero de 2022

Asunto: SOLICITUD DE INFORMACIÓN

Señor Ingeniero
Juan Carlos Bermeo Calderon
Ministro de Energía y Recursos Naturales No Renovables
MINISTERIO DE ENERGÍA Y RECURSOS NATURALES NO RENOVABLES
En su Despacho

De mi consideración:

En mi calidad de Asambleísta Nacional para el período 2021 – 2025, le expreso mi cordial saludo, así mismo y conforme a lo dispuesto en la Constitución de la República del Ecuador, en el numeral 9 del artículo 120 y el artículo 18 numeral 2, concordante con los artículos 74, 75 y 110 numeral 3 de la Ley Orgánica de la Función Legislativa en concordancia con los articulo 22 y 23 de la Ley Orgánica de Transparencia y Acceso a la Información Pública y en atención al requerimiento llegado a mi despacho por parte de Acción Ecológica suscrita por la presidenta Ivonne Yánez. Solicito se entregue de forma urgente copias certificadas y foliadas a mi despacho de los siguientes documentos, con respecto al proyecto de minería a gran escala Mirador, que se desarrolla en la provincia de Zamora Chinchipe, cantón El Pangui, parroquias Tundayme y El Gúismi:

1. Información de Sustento del Oficio N° ECSA-HSE-2019-104, de 3 de mayo de 2019, mediante el cual ECSA solicitó a la Coordinación Zonal de Minería Sur el alcance a la emisión de factibilidad de la relavera Tundayme y sus instalaciones optimizadas, adjuntando el Informe “DESCRIPCIÓN DE RELAVERA TUNDAYME Y OPTIMIZACIÓN DE LAS INSTALACIONES, PROYECTO MIRADOR, PRODUCCIÓN 60000 TONELADAS POR DÍA”, de mayo de 2019. De manera particular, la entrega de los siguientes documentos:

- Memoria con la descripción de la Relavera Tundayme y optimización de las instalaciones (impreso y digital).
- ANEXO l. Planos Relavera Tundayme.
- ANEXO 2. Planos Túnel Temporal de Desvío Dique de Arranque.
- ANEXO 3. Planos lnfraestructuras de desvío de Aguas Limpias del Rio Tundayme
- ANEXO 4. Planos de lnfraestructuras de Drenaje de Agua de la Relavera Tundayme
- ANEXO 5. Estudios de Geotecnia (CD)
- ANEXO 6. Planos de Dique Principal - Relavera Tundayme
- ANEXO 7. Planos Canal Interceptor Acceso # 12 - Relavera Tundayme
- ANEXO 8. Planos del Dique de Rebose del Túnel de desvío de Aguas Limpias del Río Tundayme
- ANEXO 9. Estudios (CD).

2. Información de sustento del Informe técnico Nro. 0141-CRMZ-2018, de 21 de febrero de 2018; emitido por la Coordinación Regional de Minas Zamora de la Agencia de Regulación y Control Minero, con asunto: VERIFICACIÓN DE INFORMACIÓN TÉCNICA ANÁLISIS DE PLANOS DEL PROYECTO MINERO MIRADOR (Cia. ECUACORRIENTE S.A.). DE LAS OBRAS

CONDICIONADAS EN LA LICENCIA AMBIENTAL FASE DE EXPLOTACIÓN DE MINERALES METÁLICOS. Solicitamos la entrega de los Informes Técnicos de sustento del Análisis de la Información Presentada de las Obras Condicionadas en la Licencia Ambiental Fase Explotación de Minerales, y de los Anexos de Información Técnica y Memorandos, detallados a continuación:

OBRA	OFICIO	INFORME TÉCNICO	FECHA INFORME
ESCOMBRERA NORESTE (Sur)	ARCOM-Z-CR-2017-0002-OF	No. 03-DTSCT-Z-2017	01 – enero - 2017
CANALES DE DESVÍO DE AGUAS ESCOMBRERA	ARCOM-Z-CR-2016-1694-OF	No. 855-DTSCT-Z-2016	08 – noviembre - 2016
DIQUE Y EMBALCE DE DRENAJE ÁCIDO	ARCOM-Z-CR-2018-0222-OF	INFORME TÉCNICO No-085-CRMZ-2018	28 de enero de 2018
PLANTA DE MEZCLA DE EXPLOSIVOS	ARCOM-Z-CR-2017-0476-OF	MEMO: ARCOM-CGCM-2017-1381-ME	28 – septiembre - 2017
CANALES DE CONTROL DE INUNDACIONES DE EMBALSES DE AGUAS ÁCIDAS	ESTÁ OBRA ESTA INCLUIDO EN EL DRENAJE DE AGUA ÁCIDA	INFORME TÉCNICO No-085-CRMZ-2018	28 de enero de 2018
PLANTA DE TRATAMIENTO DE AGUA ÁCIDA	ESTA OBRA FORMA PLANTA ES PARTE DE LA PLANTA DE BENEFICIO	INFORME TÉCNICO No-1062-DTSCT-Z-2016	27 de diciembre de 2016
PISCINAS DE SEDIMENTACIÓN	ARCOM-Z-CR-2017-1032-OF	ARCOM-CGRCM-2017-0972-MM	14 – junio - 2017
MURO DE CONTENCIÓN DE LA ESCOMBRERA	ESTA OBRA FORMA PARTE DE LA ESCOMBRERA	No. 03-DTSCT-Z-2017	01 – enero - 2017
POZOS DE REVISIÓN DE LOS DIQUES	ES OBRA FORMA PARTE DEL DIQUE DE DRENAJE ÁCIDO	INFORME TÉCNICO No-085-CRMZ-2018	28 de enero de 2018
PLATAFORMAS DE LA PLANTA DE TRITURACIÓN DE MINA Y ROCA ESTÉRIL	ARCOM-Z-CR-2017-0002-OF	No. 01-DTSCT-Z-2017	03 – enero - 2017

Oficio Nro. AN-QLS-2022-0030-O

Quito, D.M., 17 de febrero de 2022

ANEXOS - INFORMES TÉCNICOS Y MEMORANDOS

- No. 03-DTSCT Z -2017.
- NO. 855-DTSCT Z -2016
- INFORME TECNICO N0-085- CRMZ-2018
- ARCOM-CGCM-2017-1381-ME
- INFORME TECNICO No-1062- DTSCT-Z-2016.
- No. 01-DTSCT Z-2017
- ARCOM-CGCM-2017-0972-ME

3. Información de sustento del Informe Técnico Nro. 0137-CRM7.-2018, de 21 de febrero de 2018; emitido por la Coordinación Regional de Minas Zamora de la Agencia de Regulación y Control Minero, con asunto: VERIFICACIÓN DE INFORMACIÓN TÉCNICA Y ANÁLISIS DE PLANOS DE LA RELAVERA TUNDAYME Y SUS INSTALACIONES DEL PROYECTO MINERO MIRADOR (Cia. ECUACORRIENTE S.A). La información de sustento de este Informe es similar a la del Informe técnico Nro. 0141-CRMZ-2018, por lo que ratificamos nuestra solicitud expresa de acceso a la información pública señalada en el numeral anterior.
4. Información de sustento del Informe Técnico Nro. 0156-CGRMZ-2018, de 27 de noviembre de 2018, emitido por la Coordinación Regional de Minas Zamora de la Agencia de Regulación y Control Minero, con asunto: ANÁLISIS DE INFORMACIÓN TÉCNICA DE LA PLANTA DE TRATAMIENTO DE AGUA ÁCIDA DE FILTRACIONES DEL DIQUE DE LA RELAVERA TUDAYME (BENEFICIO). Solicitamos la entrega de la Información presentada por PLANTA DE TRATAMIENTO DE AGUA ÁCIDA DE AGUA DE FILTRACIONES DEL DIQUE DE LA RELAVERA TUNDAYME, 3.1 PLANOS PRESENTADOS:

ANEXO 01

- Implantación general de la planta de Tratamiento de Drenaje Ácido (1 piano).
- Diagrama de flujo del proceso.
- Implantación de la planta de tratamiento de agua ácida.
- Sistema de provisión de agua y tubería de drenaje (1).
- Sistema de provisión de agua y tubería de drenaje (2).
- Corte de la estación de procesamiento.
- Sección longitudinal del dique (2 pianos).

ANEXO 02.

- Implantación general diques de aguas de infiltraciones.

ANEXO 03.

- Calculo de filtración de la estación de tratamiento de aguas ácidas del depósito de relaves

ANEXO 04.

- Plan de manejo ambiental para la fase de beneficio incluye plan de contingencias (1CD).

Con sentimientos de distinguida consideración.

Atentamente,

Documento firmado electrónicamente

Sr. Salvador Quishpe Lozano
ASAMBLEÍSTA

Copia:
Señor Abogado
Edy Alquímedes Jadan Sarango
Asesor Nivel 2

Señor Magíster
Angel Virgilio Medina Lozano
Coordinador General de Relaciones Interinstitucionales