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The potential for imminent danger to human life and the environment from the Mirador open-pit copper mine in south-eastern Ecuador

Submitted to the Inter-American Commission on Human Rights

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Spanish version

Content

<u>**Annexes**</u>

Annex 1: Tailings Dam Design and Construction Assessment for the Mirador Mine, Zamora Chinchipe, Ecuador. Report prepared by Steven Emerman, PhD, 2019, for E-Tech International.

Annex 2: Preliminary list of communities affected by the environmental, safety, and other social impacts of the Mirador Mine.

Annex 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.

Annex 4: Letter from the National Assembly to the Ministry of Energy and Non-Renewable Natural Resources. Subject: Request for Information. Oficio No. AN-QLS-2022-0030-O. 2022.

I. Introduction and purpose of the report

The Mirador mine is an open-pit copper-gold project in southeastern Ecuador in the province of Zamora-Chinchipe (Figure 1). It is the first large-scale metal mine operated in the country. The mine is owned 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 Ministry of Energy and Non-Renewable Natural Resources (MERNNR) signed a mining contract with ECSA in March 2012. This was the first large-scale mining contract for the government. In 2015 the project obtained the environmental licence for mining (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).

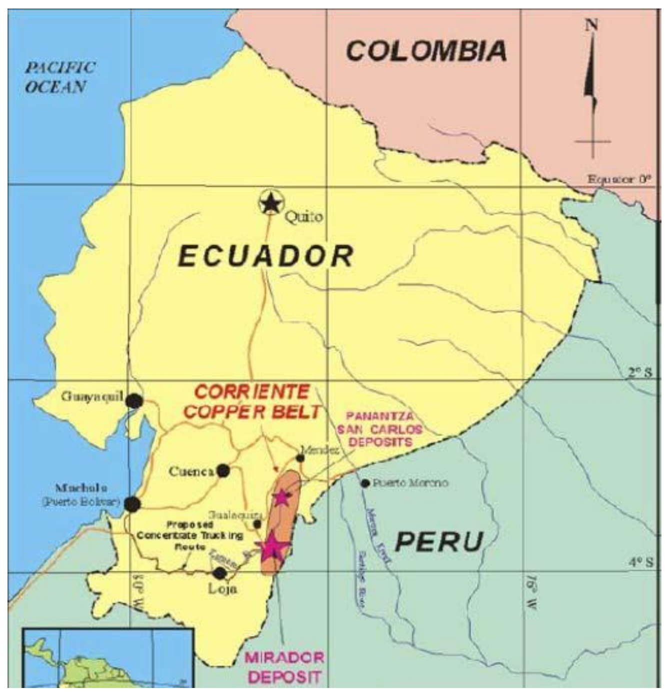

Figure 1: Location of the Mirador mine. *Source: EcuaCorrientes 2018.*

ECSA started processing ore on a small scale in December 2018 and was processing 30 000 tonnes per day by the end of 2019 on its way to a capacity of 60 000 tonnes per day. According to the mine, operations were suspended between 20 March and 26 August 2020, due to COVID-19. A doubling of processing is planned for the next phase of expansion that Mirador Norte hopes to develop (International Mining, 2021).
In addition, the mine has generated fear among residents due to the construction and operation of large dams and mine tailings impoundments located in an area known for high seismicity, high topographic relief, high rainfall and storms. increasingly extreme. E-Tech International, with the assistance of consultants David Chambers, PhD, and
Steven Emerman, PhD, is responding to concerns about possible "imminent danger" to nearby communities from mine discharges and possible tailings failures.

E-Tech International's first assessments in 2011 and 2012 responded to requests from the former prefect of Zamora Chinchipe, Salvador Quishpe, and Ecuador's Ministry of Environment (MAE) to address environmental concerns related to the mine's operation. At that time, we highlighted serious deficiencies in the proposed location and construction of the mine's infrastructure, concerns about high rainfall and the vulnerability of the mine's infrastructure, and concerns about the mine's environmental impact.

seismic activity, lack of adequate closure plans and lack of financial assurance, acid mine drainage and leaching of contaminants, and adverse effects on water quality for surface 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 concerns related to mine facilities and the lack of transparent information. We also summarised our attempts to obtain the information necessary to assess whether an imminent danger exists. We are requesting the Inter-American Commission on Human Rights (IACHR) to take steps that will result in the release of the requested documents, which should be made available to the public in accordance with the Ecuadorian Constitution and the Organic Law on Transparency and Access to Information that have been requested by the lawyers representing the Mina Mirador case filed with the IACHR on 23 December 2013 and by the National Assembly of Ecuador.
We also highlight our serious concern that the Commission ensure that the Government of Ecuador develops an effective programme with local communities that protects those living downstream of the Mirador tailings dams.

II. Concerns related to the inherent characteristics and management of the Mirador Mine

The Mirador Mine has large-scale mining facilities and significant physical and chemical hazards that potentially present an imminent danger to the environment and downstream communities. The mine facilities are shown in Figure 2.

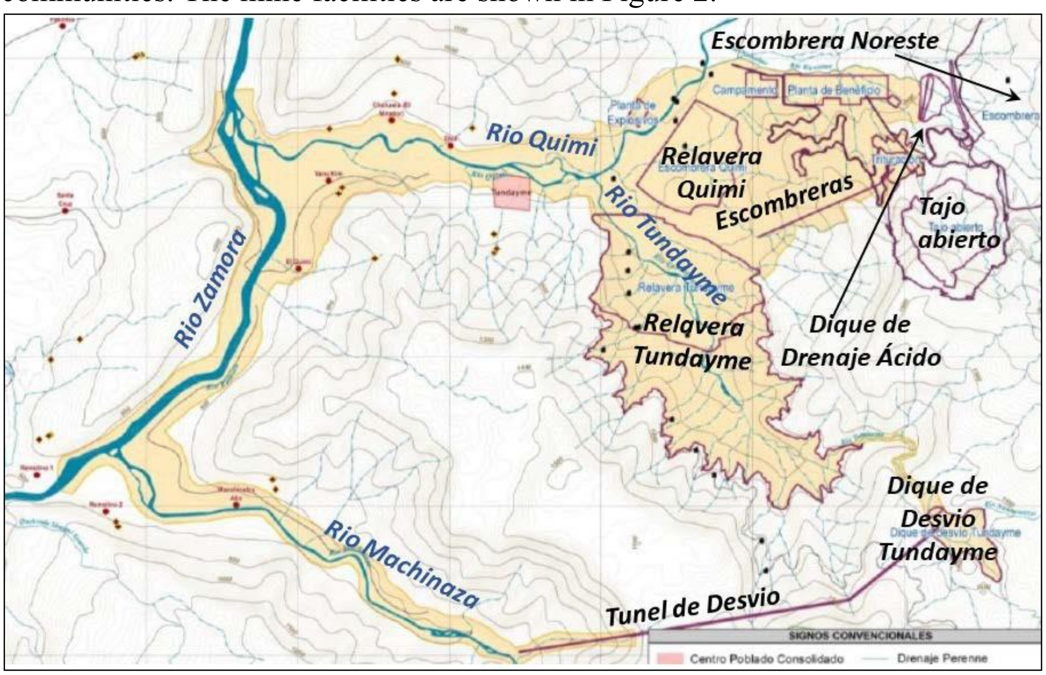

Figure 2. Location of facilities and water quality impact zones.
Source: Cardno, 2014a, Fig. 8-12.

1. Physical Risk

a. General description and type of dam

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

1) high seismicity
2) weak foundations (weak soils under the tailings dam)
3) high precipitation
4) topographic high relief
5) close proximity to surface water
6) high 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 facilities, while the consequences of failure are also related to the environmental and socio-economic context of the tailings facilities. In the case of the Mirador mine, the presence of downstream communities that would be affected or even wiped out by a tailings dam failure is the most important risk factor of all (see Section IV). The likelihood of failure (combining physical and human factors) is assessed in Section V.a.

Knight-Piésold (2007), consultants to EcuaCorriente S.A., assigned a dam failure consequence category of "VERY HIGH" to the Quimi dam, based on the Canadian Dam Association (2013, 2019) classification system, 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 were to result 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 for the Mine would also be very high".

b. Risks associated with seismicity

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 ground acceleration of 0.60 g. 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 maximum ground acceleration would be towards the upper limit of the range (0.34-0.65 g) of "severe perceived shaking" and "moderate to severe potential damage" (USGS, 2022a).

Knight-Piésold (2007) also determined that the Operational Base Earthquake (OBE) of the Quimi Dam, the earthquake 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) also carried out a seismic stability analysis which showed that the site for the Quimi dam combined the factors of high risk of high seismicity and weak foundations. 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 the surface (in the upper 10 metres) for the MDE and OBE". In other words, Knight-Piésold (2007) predicted that liquefaction of both tailings and foundations, with subsequent tailings dam failure, was expected to occur during the 30-year life of the Mirador project. No documentation is available that discusses the DEM, ECM, EBO, foundation characteristics or seismic stability for the Tundayme tailings dam.

Earthquakes that can cause liquefaction and failure of the Quimi Dam (magnitude greater than 7.5) are certainly common in the area around the Mirador Mine. The USGS Earthquake Catalogue (USGS, 2022b) lists 19 earthquake epicentres with magnitudes equal to or greater than 7.5 within 1000 kilometres of the Mirador Mine since 1906 (Figure 3). In fact, three such large earthquakes have occurred since the mine opened in 2019. Earthquakes with magnitudes 7.5, 8.0 and 7.5 occurred 218 kilometres northeast of the mine, 434 kilometres southeast of the mine and 208 kilometres southeast of the mine in February 22, 2019, May 26, 2019 and November 28, 2021, respectively. It is worth noting that the 1797 Riobamba earthquake with an estimated magnitude of 8.3 and up to 40,000 fatalities had its epicentre 217 kilometres north of the Mirador Mine (see Figure 3). The most important observation of all may be that the Mirador mine apparently lies in a "seismic gap", i.e. a region without large recorded earthquakes that is surrounded by large recorded earthquakes (see Figure 3). According to seismic prediction theory, such gaps are susceptible to large earthquakes at times that are impossible to predict.

With respect to the worst-case scenario, in light of Knight-Piésold's (2007) dire warnings of seismic instability, the Ecuadorian Ministry of Environment's response to Walsh Scientists and Engineers' (2010a-b) Environmental Impact Assessment (EIA) was that the seismic risk, as well as the landslide risk, was high and poorly understood. According to the Ministry of Environment, "seismic stability should be the product of a local seismic study of the project area and not regional, as has been done minimally in the study. Similarly, with respect to landslides that could occur locally in the project area..." (Walsh Scientists and Engineers, 2011). Walsh Scientists and Engineers (2011) response did not address the comment in any way, but simply referred to the accompanying Knight-Piésold (2007) report, which also did not address the comment. The 2014 EIA by Cardno (2014a, b) did not provide any additional information on seismic or landslide risk.

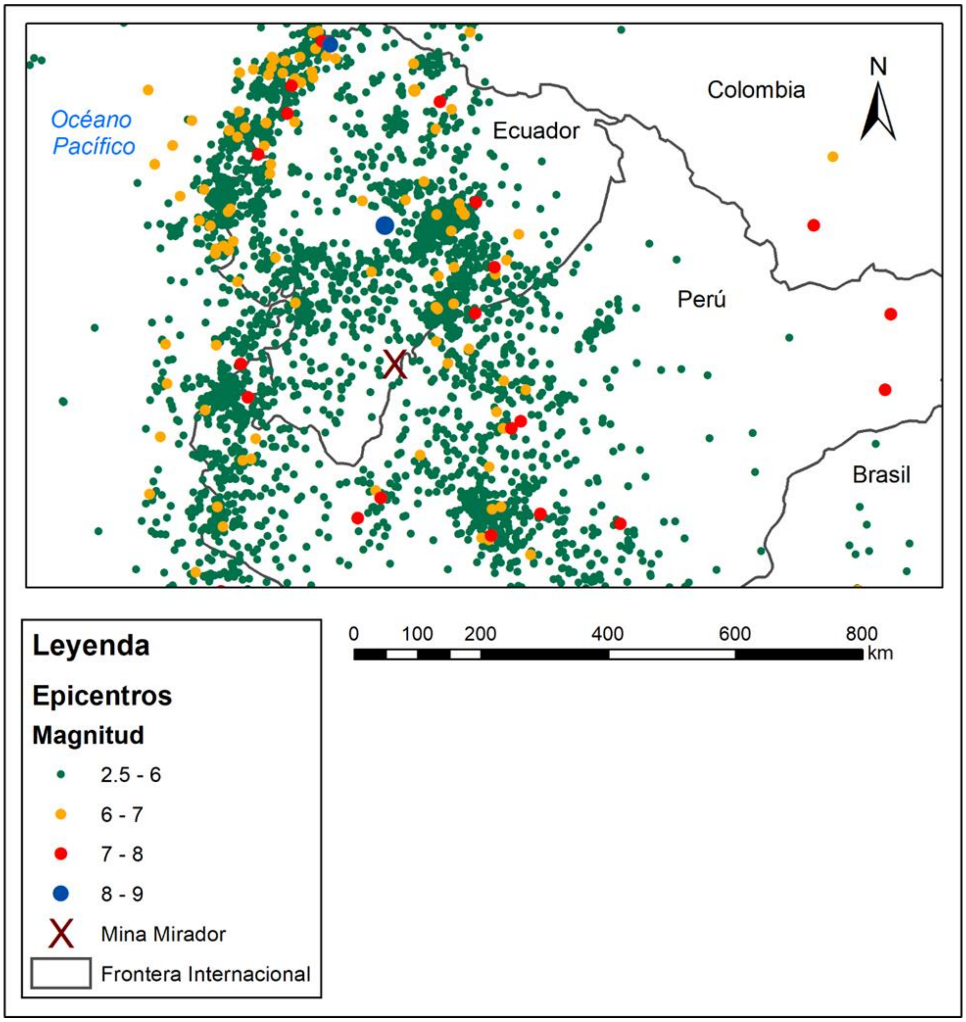

Figure 3. Epicentres of earthquakes in Ecuador since 1906
Source: USGS, 2022b.

c. Risks associated with precipitation, storms, 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 he admitted that the use of this criterion was not well defined. According to Knight-Piésold (2007), "the available regional [precipitation] records are not particularly extensive, nor are the data considered to be of exemplary quality". In a sense, risk factors that are not well known, but are believed to be high, may present a worse-than-worst-case scenario because it is impossible to design for such scenarios. While high rainfall can lead to dam failure by overtopping, the combination of steep slopes and high rainfall also increases the likelihood of landslide failure of the supernatant pool in the tailings dam. The potential for landslides in the vicinity of the tailings dams is clearly indicated by the numerous landslide scars, one of which had almost undermined a transmission tower near the tailings dam.

Quimi Dam in November 2018 (see Fig. 15 in Emerman (2019); attached as Annex 1).

In addition to the lack of knowledge of present and past precipitation in the Mirador mine area, climate change adds an additional layer of uncertainty to the appropriate choice for design flooding. Indeed, Armenta et al. (2019) have predicted a 10% increase in precipitation in the Santiago River basin (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% over current behaviour. The scenarios also show an 'extension' of the rainy season, starting earlier (in December) and peaking in March. As for the indices associated with precipitation, the number of days with extreme rainfall would increase throughout the year, with January to May being the months that would show the greatest increase in the number of days with these events in most of the study area...". The authors of this report have found no publicly available data for precipitation at a weather station at or near the mine site.

Effects of climate change

It was not common for mining companies and their consultants to take climate change into account in 2007, but it is standard practice today (Muñoz and Hoekstra, 2022). According to the Global Industry Standard for Tailings Management (GISTM), requirements for mining companies include the following: "To improve resilience to climate change, assess, periodically update and use climate change knowledge throughout the life cycle of tailings facilities 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 local social, environmental and economic impacts of tailings facilities and their potential failure over their life cycle.... If new data indicate that the impacts of tailings facilities have changed materially, including as a result of knowledge of climate change or long-term impacts, the operator will update the management of the tailings facility to reflect the new data using Adaptive Management best practice. Member companies of the International Council on Mining and Metals (ICMM) must fully implement GISTM by August 2023. Notably, ICMM Association members include the Chamber of Mines of Ecuador (CME), International Copper Association and International Wrought Copper Council (IWCC) (ICMM, 2022).

d. Summary of physical hazards

The proximity to surface water, the high height of the dam and the large volumes of tailings contribute to the consequences of the failure. Both the Quimi and Tundayme dams are located along the banks of the Quimi River and Tundayme River, which form one of the headwaters of the Amazon River. The Tundayme dam's projected height of 260 metres (Cardno, 2014a) would make it the second highest tailings dam in the world, after the Linga dam at the Cerro Verde mine in Peru with a height of 265 metres (GRID-Arendal, 2022). The

The Tundayme tailings dam's projected effective tailings storage volume of 380 million cubic metres (Cardno, 2014b) would make it the 23rd largest tailings facility in the world (GRID-Arendal, 2022). By way of comparison, the largest tailings spill in the world so far has been less than a tenth of that volume (32 million cubic metres) from the tailings dam at the Samarco mine in Brazil in 2015 (Larrauri and Lall, 2018).

2. Chemical hazards and toxicity of wastes and leachates

a. General geochemical characteristics of the Mirador deposit that produce acid mine drainage

The deposit at the Mirador mine is a porphyry copper-gold orebody that also contains silver and molybdenum (Corriente Resources, Inc., 2008; Cardno, 2014b). The ore contains high percentages of pyrite, which is the main 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 damaging results of mining sulphide ore bodies such as the Mirador mine (INAP, 2009; Price, 2009). Chalcopyrite is the main copper-bearing mineral in the ore and 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, by weight, the ore contains more pyrite than copper sulphide ore.

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

Even if all copper sulphide minerals in the ore are removed in the beneficiation process, the remaining waste (tailings) will contain pyrite in more than sufficient quantities to produce acid mine drainage. The neutralisation potential of the ore appears to be low and no information on this potential is presented for any of the mine wastes. However, limited information on geochemical testing and the types of water management facilities at the mine indicate that the mine-influenced water associated with the waste rock and tailings will be acidic with elevated concentrations of metals.

b. Geochemical sample results

Geochemical testing of ore, waste rock, tailings and pit walls is required to determine the acid generation and contaminant leaching potential of mined materials that will remain on site in perpetuity. The most common types of tests performed are acid-base accounting (ABA) tests and wet cell or other long-term kinetic testing. ABA tests will provide an indication of the overall balance between the acid neutralising and acid generating potential of the materials to be extracted.

waste. If the acid neutralisation content is less than 2 to 3 times the acid generation content, the materials are considered potentially acid-generating. Kinetic tests estimate the long-term potential for acid and other mine-related contaminants of concern, including metals and sulphate, to be leached from mine waste (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 and groundwater monitoring samples.

Geochemical tests were conducted, but none of the numerical test results are presented in any publicly available mine documents, including the feasibility studies for the original 30,000 tonnes/day project or the EIAs for the expanded 60,000 tonnes/day project. For example, wall rock tests conducted by AMEC in 2004 included 99 samples. The overall results of the tests are described in some places. A brief summary in the mining EIA noted that the sulphur content and tendency to produce acid varied, but most samples did not have sufficient neutralising potential to prevent acid formation (Cardno, 2014b, p. 4-7). The same EIA noted that the tailings (processed rock) contain approximately 2.38% sulphur (S), which implies that drainage from the open pit and dumps will be acidic (Cardno, 2014b, p. 4- 64). The pit will produce a large amount of mine drainage water (18,600 m3/day under undefined "normal" conditions and 30,000 m3/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 pH unit is 10 times more acidic (Price, 2009).

While the actual numerical results of the geochemical tests are not presented, there is not enough information available to confirm that the material mined at the Mirador mine will generate acid and leach elevated concentrations of mine-related contaminants, and that this leaching has already affected water quality in and around the mine (see Section V.2).

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

In the past eight years, three major tailings dam failures have mobilised mining companies and regulators to improve procedures and regulations related to tailings dam design, construction, operation and closure to try to minimise the occurrence of these failures (ICMM-UNEP-PRI, 2020). Civil society and communities have also mobilised because they often suffer the impacts of these dam failures most directly, including the loss of lives, homes and livelihoods. They have also developed recommendations to add to those developed by the mining industry and regulators (Morrill et al., 2022). The civil society/community recommendations emphasise safety, while the industry recommendations modify the existing approach.

for tailings management in a way that attempts to balance economic and safety considerations.

1. Static failures of tailings dams and management errors

Two of these catastrophic tailings dam failures occurred in Brazil and one in Canada. All of these failures are referred to as "static" failures. That is, the dams failed due to a build-up of pressure within the dam and its foundations, without any external force (such as an earthquake or flood) being applied. Static failures are very difficult to predict. To avoid static failures, a combination of good design and construction and careful monitoring to detect any unplanned changes in the dam is required.

a. Brumadinho Tailings Fault, Brazil

The tailings dam failure at the Córrego do Feijão mine, Brumadinho, Brazil, on 25 January 2019 (Figure 4), occurred during midday when employees were actively working in the mine (Robertson et al., 2019). The dam collapsed 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 the dam was about to collapse. However, the dam's drainage system was known to be malfunctioning and employees working on the dam were attempting to assess and fix these problems. According to Robertson et al. (2019), the cause

Figure 4. Brumadinho Fault, Brazil, 18 seconds after onset

Source: Robertson et al., 2019.

The immediate cause of the failure was static liquefaction, which was triggered by heavy rainfall. Common features between the Mirador and Brumadinho sites are (1) steep embankments (2) construction using the "upstream" method and (3) excess water behind the dam.

The employee offices and cafeteria were located directly downstream of 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 the tailings moved for 600 kilometres and reached the Atlantic Ocean.

b. Fundão Tailings Fault, Minas Gerais, Brazil (Samarco)

The Fundão tailings dam in Minas Gerais, Brazil, owned by the mining company Samarco, failed on 5 November 2015 (Morgenstern et al., 2016). Like the Brumadinho dam, there was no warning from the instrumentation of the impending failure. And like Brumadinho, the dam's spillway system was known to be malfunctioning and work was still ongoing to correct that deficiency when the dam broke. The accident resulted in the deaths of 19 people, including 14 who were working at the tailings dam at the time. The waste spill also reached the Atlantic Ocean. The immediate cause was static liquefaction caused by a minor earthquake (Morgenstern et al., 2016). Important similarities between the Samarco and Mirador dams are: (1) construction with the "upstream" method (2) inadequate characterisation of the foundations (underlying geological materials).

c. Mount Polley Tailings Fault, British Columbia, Canada

The dam failure at Mount Polley, British Columbia, Canada, on 4 August 2014, occurred at night when only a few mine employees were on site (Independent Engineering Expert Review and Investigation Panel, 2015). There were no residences downstream and the accident did not result in fatalities. But like the dam failures at Brumadinho and Fundão, there was no visual or instrumentation warning from the dam that failure was imminent. The immediate cause of the failure was foundation failure followed by overtopping (Independent Engineering Expert Review and Investigation Panel, 2015). The important similarities between the Mirador and Mount Polley dams are: (1) inadequate foundation characterisation (2) construction using the "upstream" method (3) lack of design adherence (4) excess water (4) steep embankments. Knight Piésold was the engineer of record for the Mirador mine and was also the engineer of record at Mount Polley during the design, permitting and operational stages from 1995 to 2011. A formal handover of design, construction and monitoring responsibilities took place 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 substantially more water in the impoundment at the time of breach than when they were the engineer of record.[1]

2. Tailings dynamic 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 to collapse, just as a building can collapse under earthquake shaking, and like buildings, some dam designs withstand shaking better than others, just as 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 moving water. If overtopped, the dam itself can erode and allow large quantities of tailings to be released from the reservoir. Earthquakes and

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

flooding are two main sources of tailings dam failures, and the Mirador mine is located in an area of very high risk of earthquakes and major flooding.

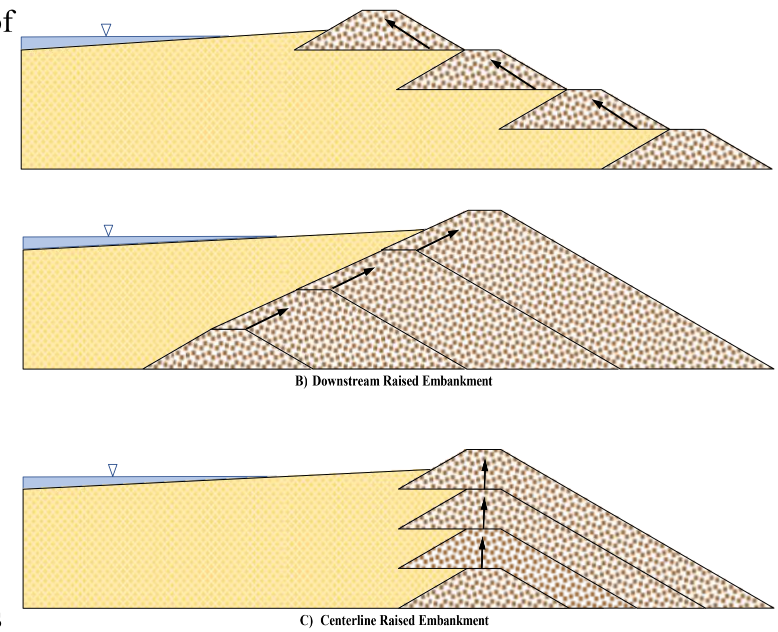


Figure 5. Types of construction (from Vick 1990): (a) upstream, (b) downstream, (c) centreline.

Both static and dynamic dam failures are influenced by the type of dam construction. In contrast to dams of water retention (i.e. water supply and storage dams), which are essentially "downstream" type constructions, tailings dams can use the tailings themselves as partial support for the dam. There are three basic types of construction: upstream, downstream, and centreline, as shown in Figure 5. The downstream type of construction is statistically the safest. The construction of centreline dams uses tailings as a horizontal support and is significantly less expensive to construct because only half as much material is required as would be used for downstream construction. The safety record of centreline dam construction is not as good as that of downstream construction, but it is still relatively safe. Upstream type dam construction uses the same tailings for vertical support. Upstream type dams have the worst safety record, but are also the least expensive to build.

Mirador mine closure and tailings, waste and water management uncertainty

At this stage, we are not sure what type of construction was used for the dams. Quimi and Tundayme. Most regulatory agencies make this information publicly available, but this information is not publicly available for the Mirador mine.

Figure 6. Quimi spring saturated in June 2020

Source: Imagery © 2022 Planet Labs Inc.

It appears that the mine is currently switching from using the Quimi tailings facility (TDF) to using the Tundayme TDF. It is unclear whether the Quimi TDF will be closed or whether it will be kept in operational status as a backup in case there are problems with the Tundayme TDF. It would be safer to close the tailings dam

Quimi because an active installation will normally have standing water on its surface, which makes the tailings dam inherently less stable due to the volume of saturated material (Figure 6).

It is also important to know the construction details and closure plans for the Tundayme tailings dam. As currently planned, the Tundayme tailings dam will be one of the largest dams in the world.

Figure 7. Decanting towers under construction. The tower in the lower left appears to be operational. The higher towers on the hillside are for future use. End of May 2022. *Source: local supplier*

world. The photograph on the right provides a 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 pond and return it for use in the mill. In other words, the upper part of the tailings pond will shall be slightly below the height of the top of the settling towers. A As the tailings pond fills, the dewatering point must move higher. As each drainage tower is buried by tailings, the next drainage tower higher up will begin to operate. Water could be pumped from a floating barge, avoiding the construction costs of these drainage towers, but the long-term pumping costs are likely to be higher than the construction costs of the drainage towers, which can use gravity to move the water back to the mill.

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

In summary, the management and inherent characteristics of the site highlight what the Mirador tailings have in common with the three major faults of the last decade:

- Lack of adherence to design (Mirador, Mount Polley)
- Probable upstream construction (Mirador, Monte Polley, Samarco, Brumadinho)
- Steep embankments (Mirador, Monte Polley, Brumadinho)

- Inadequate foundation characterisation (Mirador, Mount Polley, Samarco)
- Seismicity (Mirador, Samarco)
- Heavy rains (Mirador, Brumadinho)
- Excess water behind the dam (Mirador, Monte Polley, Brumadinho).

Catastrophic tailings dam failures are low-probability, high-consequence events. As failures in Brazil and Canada have demonstrated, these failures can result in the loss of many lives and 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 protection 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.

The exploitation of the Mirador Mine, which is operated by the company EcuaCorriente SA, 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 del Pangui (canton), in the Amazonian province of Zamora Chinchipe, because these villages are at the centre 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 centres, the San Carlos de Numpaim Shuar centre, farms and properties in San Antonio and Santa Cruz, the Quimi Valley, El Quimi, Machinaza Alto, Chuchumbletza, Remolino 2, and more communities and population centres.

The location of communities directly affected by the Mirador Mine is shown in Figure 8. In addition, the creation of the diversion at the headwaters of the Tundayme River upstream of the Mirador Mine (see Figure 2: Tundayme Diversion Dam and Diversion Tunnel) brings additional water to the Machinaza River and threatens communities along the Machinaza with increased risk of flooding.

a. Displacement 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 villages of Tundayme and El Güismi, which occurred during the first 15 years of the 2000s. These actions include the disappearance of the village of San Marcos and the adverse effects on the people of Tundayme, the forced displacement of its 19 families and the destruction of its infrastructure (school, community spaces, church). Crops, forests, houses and rivers have been transformed for mining operations.

This process of evicting families continues as the Chinese consortium intensifies its mining operations to reach a production of 60,000 tonnes/day of ore.

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

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 carry out their economic and social activities, including agriculture, livestock, forestry and logging, due to the destruction and contamination of forests, soils and rivers. As a result of the contamination of the Tundayme and Wawayme rivers, they cannot use their waters for human consumption, watering, fishing, rituals or recreation, as they have traditionally done. Their self-sustaining crops have been destroyed by soil removal, contamination and overflowing of waterways - leaving them with no other possible economic livelihood than dependence on working for the mining company.

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

The communities and peoples mentioned are not the only ones affected; the impact of mining intensification and the increase in toxic waste threatens to contaminate soils, The project is located in the Zamora River (in the province of Morona Santiago) where the waters of the Quimi River and its tributaries (located in the mining operations centre of Tundayme) reach the communities and villages, mostly indigenous and peasant, located along the course of the Zamora River (in the province of Morona Santiago). In addition, there is a potential imminent danger of a rupture of the Mirador project tailings that would result in a spill towards the confluence of the Zamora and Santiago rivers.

In other words, the impact of Mirador involves a large multi-ethnic territory (indigenous Shuar and campesinos), located in both the Zamora Chinchipe province and the adjacent Morona Santiago province, in what constitutes the Cordillera del Cóndor. Downstream communities at risk from a tailings fault include those shown in Figure 8 and communities along the Zamora River to the confluence with the Santiago River, as shown in Figure 9.

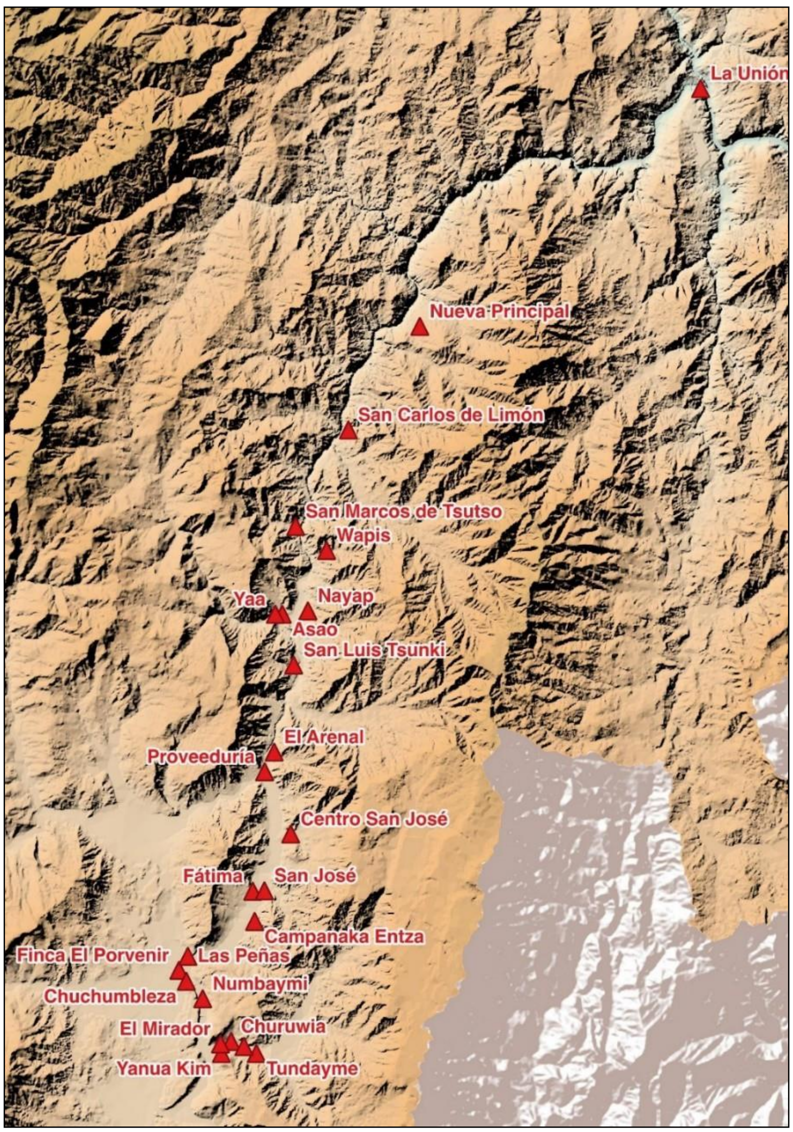


Figure 9. Location of communities affected by a potential tailings failure at the Mirador Mine
Source: Cliff Jones, Open Street Map; base map from the Instituo Geografico Militar

Annex 2 contains a preliminary list from Tarquino Cajamarca, a lawyer from Morona Santiago and former provincial director of the Ombudsman's Office, of communities concerned about the environmental, security and other social impacts of the Mirador Mine. The list is not a complete list of potentially affected communities; it is the result of local concerns expressed in interviews. The communities shown in Figures 8 and 9, and the communities along the Machinaza River downstream of the diversion tunnel, of the Tundayme River may provide a more complete picture of potentially affected communities.

3. Socio-ecological features of the Cordillera del Cóndor that are under serious threat

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

a. Biodiverse area shared between Ecuador and Peru

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

This mountain range is representative of Ecuador's megadiversity. It has 16 ecosystems located between 800 and 1680 metres above sea level. Its peculiar geography and topography have given rise to unique biological niches. It has been catalogued as a priority for the conservation of flora and birds of high biodiversity and endemism. There is a diversity of mammals in sui generis habitats.

Several sites in the Cordillera del Cóndor have been incorporated into the National System of Protected Areas and Protected Forests. These include the El Zarza Wildlife Refuge, the El Cóndor Binational Park, the El Quimi Biological Reserve, the Cordillera del Cóndor Protected Forest and the Cuenca del Río Nangaritza Protected Forest. These sites are protected by the Constitution (Arts. 405 and 407) because of their ecological functions and because they are key for 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. The springs and rivers that originate in this mountain range contribute to the formation of large rivers such as the Zamora, the Santiago (in Ecuador) and the Marañón (in Peru). The water sources that originate and flow through where the project operates are severely affected in this first stage of copper exploitation (Ministry of Environment, 2015). The same risk is faced by the more than 200 water sources and springs, which according to the Ecuadorian State Comptroller's Office are located within the project's impact area (Comptroller's Office, 2012).

c. Ecosystems necessary for the planet's environmental balance

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. Social-historical zone of ancient cultures

In Tundayme, which is located in the area of the Mirador project (as well as in adjacent areas), archaeological studies show cultural landscapes made up of pre-Hispanic terraces with corrugated pottery that form part of the Upper Amazonian Forest complex.

e. Ancestral territory of the Shuar People

The Cordillera del Cóndor crosses the political boundaries between Ecuador and Peru and constitutes the ancestral territory of the Shuar nationality, known as the "people of the sacred waterfalls", who maintain an accumulated knowledge of forests and rivers, conservation and uses of food, medicinal plants, handicraft species, on which the conservation of the genetic heritage of the two countries is based.

V. Concerns related to the failure of the mine facilities and lack of adequate plans

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

1. Tailings Failure Potential at Mirador

The central issue that is driving the high probability of tailings failure at the Mirador mine is the lack of compliance with analyses, designs, proposals and permits. Indeed, due to the numerous contradictions within Cardno's 2014 EIA (2014a-b), it is difficult to know what the actual designs and proposals were. For example, although in some places the use of the Quimi dam during the early years of the project is discussed, followed by the use of the Tundayme dam (Chapter 5: Alternatives Studied, by Cardno, 2014a) clearly evaluates the Quimi and Tundayme dams as two mutually exclusive alternatives, in which costs, environmental impacts and other aspects were evaluated separately for each alternative. Because both tailings storage facilities have been constructed, it is impossible to determine the actual plans for the Mirador mine and which of those plans have been subjected to the kind of rigorous analysis that Knight-Piésold (2007) conducted for the Quimi tailings dam alone.

a. The slopes of the dam are too steep.

Although all previous analyses, designs, proposals and permits for the Quimi Dam specified an outer embankment slope of 1V:2H (one metre vertical by two metres horizontal), the outer embankment of the Quimi Dam was constructed with a much steeper slope.

1V :1H slope (see Fig. 17 in Emerman (2019); Appendix 1). The 1V:2H slope for Quimi Dam was assumed in the Knight-Piésold (2007) seismic stability analyses (see Fig. 10 in Emerman (2019); Appendix 1) and specified in the 2010 and 2014 Environmental Impact Studies (Walsh Scientists and Engineers, 2010a-b; Cardno, 2014a-b). In comparison, the US Army Corps of Engineers (2000) and Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022) require dam exteriors with a slope 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 document recommends slopes no steeper than 1V:4H (Martin et al., 2002).). Many jurisdictions, such as British Columbia in Canada, require that outer slopes of tailings dams have a slope no steeper than 1V:2H (Ministry of Energy and Mines (British Columbia), 2016). In fact, a slope of 1V:1H is generally considered to be the maximum critical angle for the prevention of internal erosion failure, the process by which seepage through the dam carries away solid particles so that the dam loses its structural integrity (Holtz et al., 2011; LePoudre, 2015). Therefore, the Quimi dam should be considered as temporary on the cusp of a fault.

b. Dam construction methods compared to plans.

In the upstream construction method, the tailings dam is constructed over the uncompacted tailings being confined (see Fig. 5a in Emerman (2019); Annex 1). This construction method is the least expensive because it requires the least amount of construction material, but it is also the most dangerous because, if the underlying tailings liquefy, the dam can fail simply by falling or sliding over the liquefied tailings. The downstream method is the most expensive because it requires the most construction material, but it is the safest because there are no uncompacted tailings below the dam (see Fig. 5b in Emerman (2019)). The centreline method is a balance 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 banned 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 Environmental Information System (Peru)], 2014). Ecuador has gone further than the other countries by preferring the downstream method and allowing the centreline method only in special circumstances. According to the Ministry of Energy and Non-Renewable Natural Resources (2020), "The use of the upstream method is prohibited. In a standardised manner, the construction method shall be downstream, including the starter dam. The centreline method of construction shall be approved in cases where the morphology or spacing of the terrain does not allow for downstream growth, only and when it meets conditions favourable to the physical stability of the tailings deposit."

The Knight-Piésold (2007) seismic stability analysis was conducted assuming that the Quimi dam would be constructed using the centreline method (compare Figs. 5c and 10 in Emerman (2019; Appendix 1)). The first EIA also explicitly stated that the dam at

Quimi would be constructed using the centreline method (Walsh Scientists and Engineers, 2010a-b). Although the construction methods were never explicitly stated in the second EIA (Cardno, 2014a), the discussion of impervious layers for the Quimi and Tundayme dams made it clear that the upstream construction method was not intended, as using the upstream method would not provide any place to place these layers (Emerman, 2019; Appendix 1). A particular feature of the upstream method is that the downstream edge of the initial embankment marks the maximum downstream extent of the tailings dam (see Fig. 5a in Emerman (2019); Appendix 1). Therefore, the location of the downstream edge of the initial dam at the edge of the road (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 edge of the tailings dam further downstream without covering the road, and on the other side of the road is the steep slope down to the Quimi River. In short, the Quimi dam appears to have been built using the upstream method, which has the highest probability of failure and is now banned in Ecuador as being very unsafe.

A common feature of the use of the upstream construction method and the excessive slope of the embankments used for the Quimi tailings dam is that both minimise the required amount of construction material for the tailings dams. Therefore, both deviations from previous analyses, designs, proposals and permits could have resulted from an unforeseen lack of construction material. The lack of appropriate and legally available construction material would also be consistent with 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 stone material took place in a portion of the Tundayme River. As in the Quimi and Wawayme rivers, the extraction of stone material in this area is not carried out within any mining concession for the exploitation of aggregates and stone ...". It should be noted that a review of the national Mining Cadastre shows no mining titles for the exploitation of stone material within the Mirador project in the aforementioned area" It is alarming that the sloping of the outer embankment and the shift of the centreline 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 Engineering Expert Review and Investigation Panel, 2015). Indeed, another common feature is the lack of foundation characterisation, which, in the case of the Mount Polley mine, would have indicated that the slope of the embankment would lead to foundation failure (Independent Engineering Expert Review and Investigation Panel, 2015.

c. Probability of failure of Mirador tailings dam

At this point, it is appropriate to consider the probability of failure of the tailings dams at some point 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 equates to an annual exceedance probability of 0.21% and an exceedance probability over the 30-year life of the project of 6.13%. Given that Knight-Piésold (2007) also showed that the Quimi dam would fail in the event of an OBE, the above establishes the probability of failure during the life of the project by 6.13%. If the same analysis is applied to the Quimi and Tundayme dams, then the probability of failure of at least the tailings dam due to an earthquake during the life of the project is 11.88%. Furthermore, the tailings dams have been designed to withstand a 500-year flood (Cardno, 2014a), which corresponds to an annual exceedance probability of 0.20%, contrary to Knight-Piésold (2007), who recommended designing for the Probable Maximum Flood (PMF), which has no defined return period, but is considered significantly rarer 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 any one tailings dam due to flooding of 11.32% over the life of the project. In summary, the probability of failure of any of the tailings dams due to earthquakes or flooding over the life of the project is 21.85%.

However, in addition to the above physical factors, the following human factors must be taken into account:

1) The seismic stability analysis assumed that the maximum height of the dam would be 63 metres (although the Tundayme dam will have a height of 260 metres).
2) The seismic stability analysis assumed a centreline construction (although the Quimi dam probably uses an upstream construction).
3) The seismic stability analysis assumed an outboard slope of 1V:2H (although the Quimi dam has an outboard slope of 1V:1H and the design slope for the Tundayme dam outboard is 1V:1.5H).
4) The seismic stability analysis was not performed for the much steeper slope of the Tundayme site (the Quimi valley has a slope of 7 % towards the Quimi river, while the Tundayme valley has a slope of 13 % towards the Quimi river).
5) A study of local geological faults and seismicity has not been carried out.
6) No foundation studies have been carried out at the Tundayme site.
7) The risk of landslides and the high rate of erosion in the area have not been assessed.
8) The design of the 500-year flood did not take climate change into account.
9) There appears to be no commitment to construct and operate the tailings dams in accordance with the analyses, designs, proposals and permits.

Based on the above considerations, the likelihood of failure of one or both tailings facilities at the Mirador mine at some point during or after the life of the project is so high that it must be treated as inevitable in terms of mine monitoring, management and control. It should be remembered that the risk of failure does not end after the project ends and that the tailings and their hazard continue in perpetuity. The long-term risk is especially acute, considering that the plan appears to be to maintain the tailings in a saturated state in perpetuity.

Knight-Piésold (2007) wrote that "post-closure surface grading will ensure that the cleanest tailings remain saturated in perpetuity." Both the 2010 and 2014 EIAs used exactly the same language to confirm that a permanent water cover over the tailings will provide anoxic conditions, which will avoid the generation of acidic water, maintaining neutral lake conditions (Walsh Scientists and Engineers, 2010b; Cardno, 2014a). There is certainly no plan to carry out monitoring, inspection and maintenance of tailings dams in perpetuity. According to Andrews et al. (2022), "Where underwater tailings disposal is employed behind constructed dams, the responsibility for dam safety associated with maintaining tailings in a flooded condition also remains.... A dam that retains a large pool of water is inherently less safe than an embankment that does not... there is no proven precedent for the permanent submergence legacy being constructed today."

2. Water quality impacts from a failure based on current water quality As noted in Section II, the tailings and mined materials from Mirador are known to have a high potential for acid drainage and leaching of contaminants, largely due to the presence of metallic sulphides in the ore and tailings. In addition to the geogenic constituents contained in the mined materials themselves (e.g. metals, ore sulphur), blasting agents are added to remove ore and waste rock from the pit. The most common type of blasting agent is ammonium-combustion oil nitrate (ANFO), which generates high concentrations of ammonia and nitrate during mining and for some time after mining stops (Ministry of Environment and Climate Change Strategy, 2018). Unlike residues from blasting agents, concentrations of geogenic contaminants such as metals and sulphates do not decrease after mining ceases without significant investment in effective mitigation measures. Therefore, groundwater and surface water downstream will contain elevated concentrations of metals, sulphate, acidity, nitrate, ammonia (ammonia is most common in groundwater and mine water) and other constituents as a result of mining. Mine water retained and created at the facility, including water entrained in tailings and waste rock, and tailings pond supernatant will also contain these mine contaminants. When a tailings dam is breached or there is an uncontrolled release of water from the acid drainage storage impoundment, water quality downstream and downgradient will also be affected by mine-influenced water.

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

(1) failure of the waste dump(s) upstream of the Quimi tailings dam;
(2) acid rock drainage that develops at the waste disposal site(s) and affects the water quality of the site;
(3) rupture or leakage of the pipelines and pumping station established in the Rio Quimi corridor, and
(4) failure of the bridge crossing over which these pipelines are carried across the Zamora River to the Pangui tailings dam".

The list of major risks to tailings management recognises some of the risks that have had and will continue to have a negative impact on water quality. However, what is

Most importantly, the list does not include the potential failure of one or both tailings dams, as discussed in Section V.a. Since the 2008 Feasibility Study was published, the increase in volume and geographic extent of waste rock has significantly increased the amount of acid rock drainage and the impact on site water quality. A bridge has been built over the Zamora River, but the Pangui tailings disposal facility does not currently exist. Instead, the much larger Tundayme tailings dam (than the Quimi impoundment), located upstream of the Quimi tailings dam, was created. The location and size of the Tundayme dam increased the likelihood of tailings dam failures and the effects of leakage on water quality at the site.

a. Facilities set up to store and treat acid mine drainage

Mining waste at the Mirador mine is generating and will continue to generate large amounts of acid and metalliferous drainage. Although transparency of information is very low, the presence of certain facilities on 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 mine-influenced waters is consistently unreliable, especially at large copper mines such as the Mirador mine (Gestring, 2019). In addition, the facilities have not been built to withstand the large precipitation events expected as a result of climate change (see Section III). The presence of the following mining facilities indicates that the waste rock, tailings and open pit are producing metalliferous acid drainage:

- <u>Reservoir for acid drainage from the processed rock and the open pit</u>: Because the rocks contain 2.38% sulphur, rain falling on them will produce acidic water that could cause environmental damage if discharged directly into the river (Cardno, 2014b, p. 4-59). The open pit will also produce acidic water that will be sent to the reservoir (Cardno, 2014b, p. 4-65). The expected volumes of acidic water from each source are 30 000 m3/day from the Northeast rock dump and 40 000 m3/day from the open pit (Cardno, 2014b, Figure 4-26). The reservoir is designed for a total capacity of 3.15 million m3 to store the acidic water and a storm with a return period of only 50 years (a storm that is expected to occur once every 50 years). The location of the acid drainage reservoir is in the Wawayme River catchment and is shown in Figure 2 (Acid Drainage Weir).
- <u>Acid water treatment plant for processed rock and open pit:</u> A lime treatment plant is located 700 m east of the reservoir to treat the combined acid water from processed rock and the open pit (Cardno, 2014b, p. 4-66).
- <u>Collection and treatment of acid leachate from other rock piles:</u> It is unclear whether the impoundment or treatment plant will capture and treat water from the other rock piles located west of the open pit (see Figure 2). According to Corriente Resources, Inc. (2008, p. 103): The collection and treatment of ARD (acid drainage) from the dumps will continue for as many years as necessary, until the levels of acidity and metals decrease to the extent that they are acceptable for release or can be adequately treated by passive systems. This statement recognises that the amounts of waste rock are expected to

produce acid mine drainage, but no details are provided on the collection and treatment of the drainage.

- <u>Acid water treatment plant for the tailings: </u>According to the 2014 Exploitation EIA (Cardno, 2014b), acid water generated at the Tundayme and Quimi tailings will be combined in the Quimi tailings dam. A sour water treatment plant will be built near the Quimi tailings facility (Cardno, 2014b, p. 4-56). Earlier statements noted that cleaner tailings, which would include a potentially reactive pyrite component, would be discharged into the Quimi tailings pond and held underwater to help minimise any potential for oxidation and acid production (Corriente Resources, Inc., 2008, p. 86). But after year 5, the cleaner, rougher tailings will be mixed and disposed of at the Tundayme tailings dam (Cardno, 2014a, p. 4-30). The plan to collect acidic water from both tailings dams and treat it is a strong indication that, regardless of the disposal methods, acidic water is expected to be produced.

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

b. Effects of Mirador mine drainage on surface water quality

According to the Comptroller's report (2020), surface water contaminants downstream of the rock piles and tailings dams 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, the results of the Contraloría report (2020) for Rio Wawayme will be presented.

The Wawayme River drains the large rock pile known as the Northeast Sump, and surface water monitoring sites near the amounts and just upstream of where it flows into the Quimo River have exceedances of water quality standards for many metals, including copper, iron, aluminium and lead, manganese and zinc and low pH values (< pH 6). The locations with the highest concentrations of metals and the lowest pH values are WQ-04, WQ-05 and WQ-34, which are in the tributaries of the Wawayme River draining Escombrera Noreste and the open pit (Table 1 and Figure 10[2]). Metal concentrations near the mouth of the Wawayme River (WQ-06) were generally lower and pH values were somewhat higher, according to limited additional data obtained as part of

[2] It should be noted that not all sampling locations are shown in this figure, which is taken from the 2014 EIA Exploitation.

of the information requests. The elevated metal concentrations and low pH values compared to pre-mining conditions are a strong indication that surface waters are adversely affected by mining and that contaminants are derived from leaching of waste rock at Escombrera Noreste. Lower concentrations further away from the tailings dump indicate that the source is the rock pile and that dilution occurs downstream; however, concentrations remain elevated at the mouth of the river. The results also show that environmental control measures to capture mine-influenced water are not effective.

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

Table 1. Metal concentrations and pH values in the Wawayme River near the "Escombrera Noreste" rock dump in 2016 compared to reference values and Ecuadorian water quality criteria.

Location	Component (units)	Range found	Reference limit (IIGE, 2018)	Ecuadorian criteria for WATER QUALITY
WQ-04, WQ-05, WQ-34 on individual dates 2016 (Comptroller's Office, 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
Source: Comptroller's Office, 2020; IIGE, 2018.				

The Quimi River drains all mining-affected areas of Mirador and also has upstream locations that should not be affected by mining activity. More water quality data and better location information are needed for a detailed investigation. However, the limited information and data available indicate that the Mirador mine has significant sources of mine-related contaminants, including acidity and metals, has not successfully captured mine-influenced water, and would release large quantities of contaminated water if there were a catastrophic failure of mine waste dumps or tailings ponds.

The limited water quality data received from the information requests and data from the Comptroller's report (2020) also confirm that the streams draining the mine site have low concentrations of metals, low hardness and alkalinity in the absence of mining influence (baseline water quality). Metals are most 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 surface waters would not be able to neutralise the acidic water released.

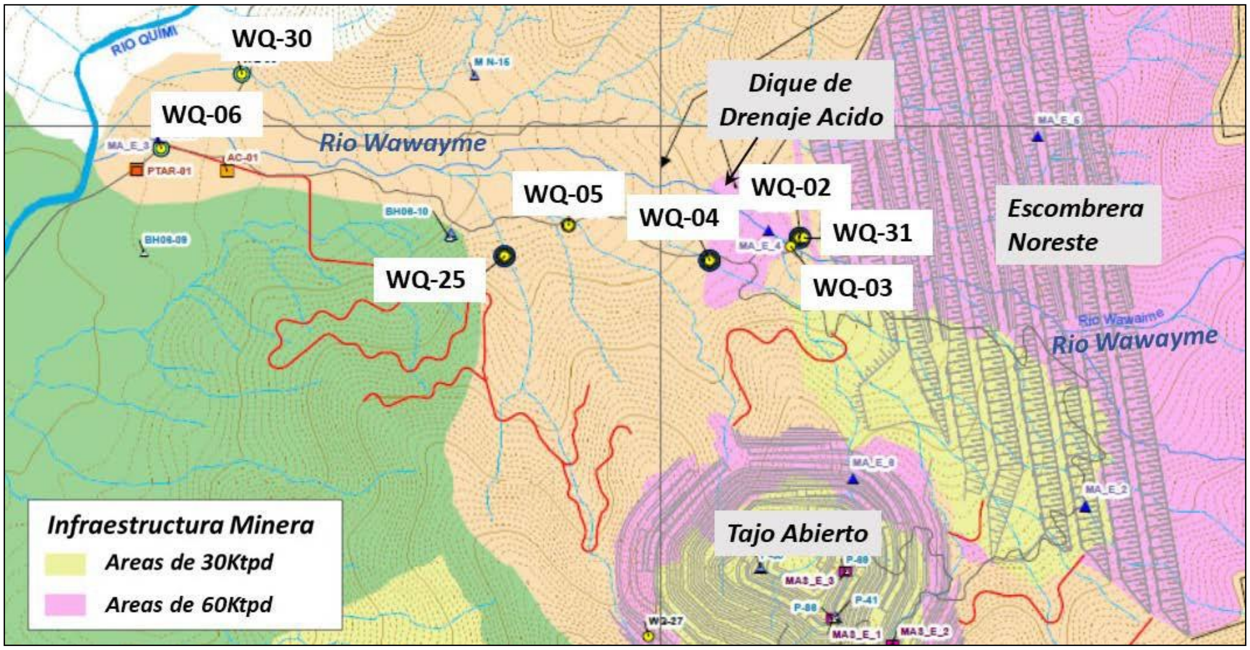
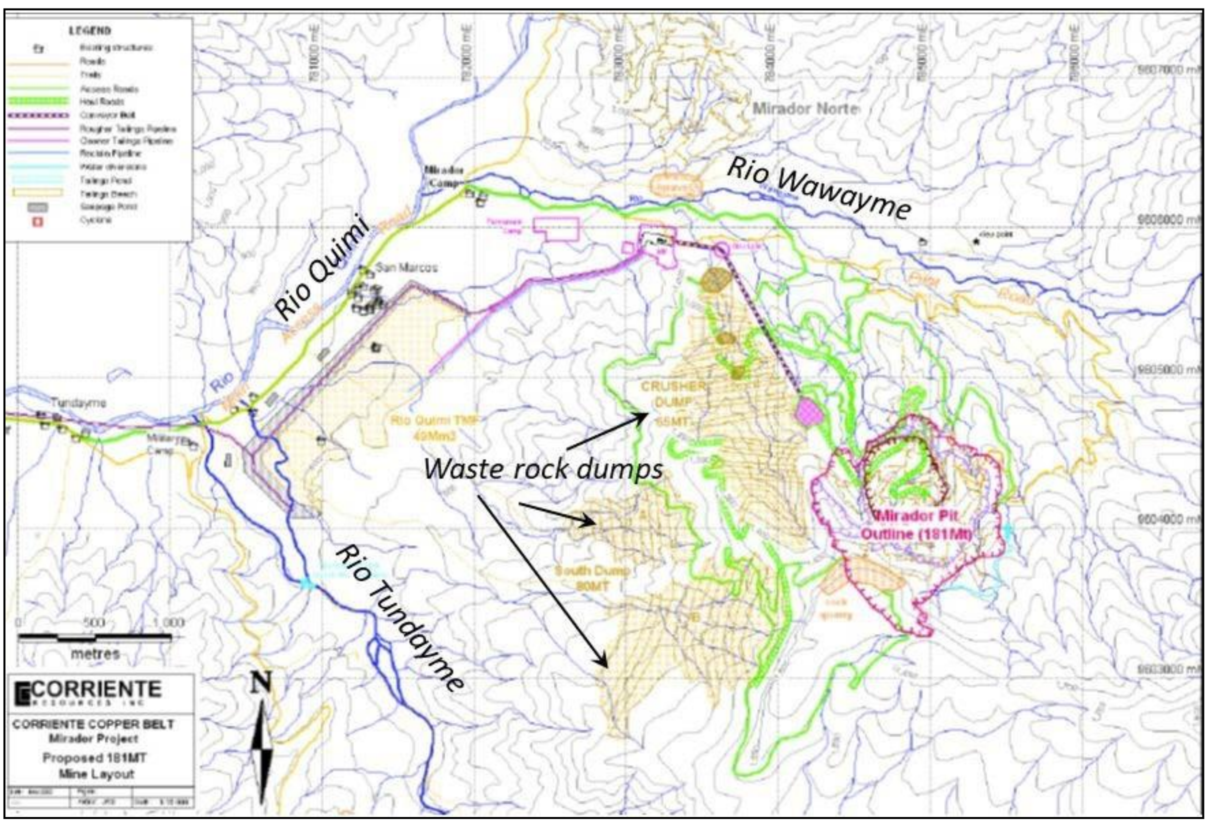


Figure 10. Surface water sampling locations in the Wawayme River, rock piles and open pit *Source: Modified from Cardno, 2014b, Annex D, Map 7.3-12.*

Figure 11. Mine design for 30 000 tonne/day operation showing waste rock piles in the Tundayme and Wawayme catchments.



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

from mining. The purity of the waters draining the mine site also increases the consequences of a possible breach of the mine tailings impoundments.

The permit's permissible limits for mine-influenced water discharge are much higher than Ecuador's surface water quality criteria (Table 2). Therefore, the permit accepts surface water contamination that may adversely affect aquatic life and human health.

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

Components (units)	Limit permitted	Ecuadorian criteria for surface water	Criteria/permission limit
pH (s.u.)	6-9	6.5-9	NA* NA* NA* NA* NA* NA* NA* NA* NA* NA* NA* NA
Arsenic (mg/L)	0.1	0.05	
Cadmium (mg/L)	0.1	0.001	100
Copper (mg/L)	0.3	0.005	
Lead (mg/L)	0.2	0.001	200
Zinc (mg/L)	0.5	0.03	16.7
Source: 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 amounts of financial collateral

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

Mr. Kuipers found that the costs estimated by AMEC (2004) were underestimated by more than an order of magnitude. 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 the financial assurance costs at US$568,000,000. The figure represents the cost of the regulatory agency performing reclamation and closure activities should the company fail to do so. Their estimates are consistent with those derived from porphyry copper mines located in the US that contain acid drainage generating materials and are in close proximity to water resources. Examples of mine cost estimates that have been used in this estimate include 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 the U.S. Federal Reclamation and Closure Guidance issued by the U.S. Environmental Protection Agency (EPA), the U.S. Forest Service, and the U.S. Environmental Protection Agency (EPA).

US Bureau of Land Management. Mr. Kuipers regularly reviews such estimates made by other agencies and routinely makes such estimates for the EPA.

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

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

4. Emergency response plans and environmental monitoring of facilities

According to Cardno (2014a, p. 9-16), in the event of a spill, ECSA will activate the Emergency Response Plan to prevent further impact. And in response to a tailings dam collapse (Cardno 2014a, p. 9-109), an emergency response plan for a potential collapse will be developed prior to the construction phase to help ECSA determine the type of response to abnormal conditions and educate downstream communities about dam safety and what to do in the event of a dam breach. Based on the information in Cardno's EIAs (2014) and the limited information we have been able to obtain from the government, there is no Emergency Action Plan for the Mirador Mine. Such a plan is an absolute necessity to warn, educate and protect the lives of affected downstream communities in the event of spills due to the collapse of the tailings dams or other mine facilities, including the waste rock and acid drainage impoundment.

5. Ecuador's lack of experience in regulating large-scale mining operations

The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) conducted an assessment of Ecuador's mining policy framework in 2019 (IGF, 2019). As noted in the introduction to this report, the mining contract with ECSA for the Mirador mine was the first large-scale mining contract 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 standards or guidelines for better environmental management, including the management of the large volumes of tailings from large-scale mining and the creation of 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 for the consideration of the combined impacts of all phases of mining, including closure and post-closure, and limits the capacity of regulators and communities to understand the cumulative effects of large-scale mining. The IGF report also noted challenges in creating specific requirements for proper solid waste management, water quality management, detailed closure plans and training agency staff to implement such detailed requirements (IGF, 2019). In addition, the report recommended that the government focus on the problems of indigenous communities related to the impacts of mining (IGF, 2019).

As an example, MAE first asked E-Tech International in 2011 to assist them with the assessment of the mining EIA for the Mirador mine because they lacked experience. E-Tech assessed the EIA and subsequently conducted a training session for MAE on large-scale mining. We returned approximately six months later and found an almost complete turnover of agency staff. We have no evidence that staff have gained any further experience with large-scale mining since that time. The lack of experience in regulating large-scale mines combined with the prioritisation of large-scale mining as an economic activity adds to the degree of scrutiny we believe should be applied to the Mirador Mine.

VI. Information needed to assess whether imminent danger exists and lack of transparency of information

On 30 March 2021, two access to information requests were issued in relation to the Mirador Mine. One request was sent to the MAE and the other to MERNNNR. The requests were sent under Articles 18 and 66.23 of the Constitution, and 1,4, 5 and 9 of the Organic Law on Transparency and Access to Public Information. The request that was handled by MERNNNR, under process No. MERNNNR-MERNNNR-2021-0630-EX, was answered incompletely, so another request for information was submitted for the missing pieces. The Government of Ecuador denied this new request, arguing that, under the contract signed with the mining company, the information requested was confidential. The National Assembly also sent requests for the same information (Annex 4), and has not received a favourable response.

In terms of information transparency, as an example, with the help of the World Bank, Ecuador joined the Extractive Industries Transparency Initiative (EITI) in October 2020.[3] In addition, Ecuador ratified the Escazu Agreement, which also addresses transparency of environmental information, in May 2020.[4] The fact that Ecuador has obligations under these two international agreements makes a strong case that all environmental information related to mine safety and the effects of the mine on the environment and human health should be made publicly available.

We respectfully request the IACHR to demand that the Government of Ecuador, represented by the MERNNR's Sub-Ministry of Mines, engage in a transparent dialogue with E-Tech.

[3] See https://eiti.org/news/ecuador-joins-eiti and https://eitiec.org/eng/the-process-of-ecuador
[4] See https://observatoriop10.cepal.org/en/treaties/regional-agreement-access-information-public-participation- and-justice-environmental

International and the lawyers who have requested the documents. The dialogue should result, within a defined limited period of time, in the disclosure of the requested information related to the construction, operation and management of the Mirador Mine. This information will allow for a detailed assessment of the potential for imminent danger 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 hazards that greatly increase the likelihood and consequences of failures. These hazards include:

- The proximity to surface water, the planned high height of the Tundayme dam (the second largest dam in the world), large volumes of tailings, high seismicity and high rainfall.
- The high percentages of pyrite in the ores and tailings ensure that acid mine drainage will form. Acid mine drainage is one of the most long-lasting and environmentally damaging results of mining sulphide ore bodies such as the Mirador mine. Water quality downstream of large rock debris already shows the impact of acid mine drainage.

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

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

- Do not adhere to design criteria
- Construction of tailings dams using the "upstream" method
- Dams too steep
- Inadequate characterisation of underlying geological materials
  High seismicity and rainfall, and excess water retained 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 security
- Inadequate emergency response and environmental monitoring plans
- Lack of experience of Ecuador's agencies with large-scale mining regulation
- Lack of transparency and engagement with potentially affected communities.

If a tailings dam breaks, impacts could be felt as far downstream as the confluence of the Zamora River with the Santiago River. Approximately 24 communities live downstream of the mine along the Zamora River.

along the Rio Quimi and 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 at the headwaters of the river upstream of the Mirador mine brings additional water to the Machinaza River and threatens communities along the Machinaza with increased risk of flooding.

The potential risks and consequences associated with the Mirador mine described in this report are based on limited data and information in publicly available documents and requests for information that were only partially fulfilled by MAE and MERNNNR. We respectfully request that the IACHR require the Government of Ecuador, represented by MERNNR's Sub-Ministry of Mines, to engage in a transparent dialogue that will result in the timely provision of information related to the construction, operation and management of the Mirador Mine. This information will allow for a detailed assessment of the potential for imminent danger related to the operation and management of the mine. We further request, given the potential risks to human life and the environment and taking into account the Precautionary Principle, that the IACHR require the Government of Ecuador and ECSA to immediately develop an effective early warning and emergency response plan in conjunction with the communities living in the areas affected by the Mirador Mine.

VIII. References cited

Acción Ecológica, 2021. Public utility and strategic sector, mining artifices for dispossession in Ecuador. Available online at: https://www.accionecologica.org/informe-regional-utilidad-privada-despojo-publico/

AMEC Earth & Environmental (AMEC), 2004. Preliminary Mine Closure and Reclamation Plan, Mirador Project, Ecuador, December 15.

Andrews, J., P. Crouse, M. Henderson, G. McKenna, N. Slingerland, D.J. Williams, and K.F. Morrison, 2022. Chapter 16-Closure planning and landform design: In K.F. Morrison (Ed.), Tailings management handbook-A life-cycle approach (pp. 235-276), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.

ANM (Agência Nacional de Mineração [National Mining Agency]), 2019. Resolução nº 13, de 8 de agosto de 2019 [Resolution No. 13 of August 8, 2019]. Available online at: https://www.in.gov.br/web/dou/-/resolucao-n-13-de-8-de-agosto-de-2019-210037027

Armenta, G. E., C. Sofiea, F. Gordillo, A. Guerrero, and J. L. Villa, 2019. Analysis of future climate threats in the hydrographic basins-Santiago, Mayo, Puyango and Catamayo [Análisis de las amenazas climáticas futuras en las cuencas hidrográficas-Santiago, Mayo, Puyango y Catamayo]: AXIOMA - Revista Científica de Investigación, Docencia y Protección Social [Scientific Journal of Research, Teaching and Social Protection], July - December 2019, No. 21, pp. 5-21. Available online at: http://axioma.pucesi.edu.ec/index.php/axioma/article/view/578/522

Campbel, PGC, and Stokes, PM, 1985. Acidification and Toxicity of Metals to Aquatic Biota. *Canadian Journal of Fisheries and Aquatic Sciences*, 42(12): 2034-2049. https://doi.org/10.1139/f85-251

Canadian Dam Association, 2013. Dam safety guidelines 2007 (2013 edition), 88 p.

Canadian Dam Association, 2019. Application of dam safety guidelines to mining dams (2019 edition), 61 p.

Cardno, 2014a. Update of the Impact Study and Environmental Management Plan, for the Metallic Minerals (copper) Beneficiation Phase, Expansion from 30 kt per day to 60 kt per day of the

Proyecto Minero Mirador, Concesión Minera "Mirador 1 (acumulada)" [Update of the Environmental Impact Study and Environmental Management Plan, for the Beneficiation Phase of Metallic Minerals (copper), Extension from 30 kt per day to 60 kt per day of the Mirador Mining Project, Mining Concession "Mirador 1 (accumulated)"]: Report to EcuaCorriente S.A., 1206 p. with 6 appendices (1125 p.).

Cardno, 2014b. Update of the Environmental Impact Study and Environmental Management Plan, for the Open-Pit Exploitation Phase of Metallic Minerals (copper), Expansion from 30 kt per day to 60 kt per day of the Mirador Mining Project, Concesión Minera "Mirador 1 (acumulada)" [Update of the Environmental Impact Study and Environmental Management Plan, for the Open-Pit Exploitation Phase of Metallic Minerals (copper), Extension from 30 kt per day to 60 kt per day of the Mirador Mining Project, Mining Concession "Mirador 1 (accumulated)"]: Report to EcuaCorriente S.A., 1130 p. with 6 appendices (1182 p.).

State Comptroller's Office (Contraloria del Estado), 2012. Report on the management of the Ministries of the Environment, Non-Renewable Natural Resources and other institutions related to the Mirador and Pananza - San Carlos mining projects in the provinces of Zamora Chinchipe and Morona Santiago; and the analysis of responsibilities for environmental damage caused at the Kenkuim (Conguime) site in Paquisha Canton, Zamora Chinchipe Province, due to illegal mining activities. DIAPA-0027-2012. P. 27.

Contraloria General del Estado (Comptroller General's Office), 2020. Special Examination of the Mirador Project, in the province of Zamora Chinchipe, in charge of the Ministry of Mining, currently the Ministry of Energy and Non-Renewable Natural Resources and related entities, for the period from 3 July 2013 to 30 September 2019. DNA6-0020-2020. 79pp.

Corriente Resources, Inc. 2008. Mirador Copper-Gold Project. 30,000 TPD Feasibility Study. Zamora-Chinchipe Province, Ecuador. April 3. 160pp.

Earthworks, 2019. U.S. Operating Copper Mines: Failure to Capture & Treat Wastewater. By Bonnie Gestring, May. 9pp. Available online at: https://earthworks.org/resources/u-s-operating-copper-mines-failure-to-capture-treat-wastewater/

Garbarino, E., G. Orveillon, H.G.M. Saveyn, P. Barthe, and P. Eder, 2018. Best Available Techniques (BAT) Reference Document for the management of waste from extractive industries in accordance with Directive 2006/21/EC: European Commission Joint Research Centre Science for Policy Report, EUR 28963 EN, 722 pp. Available online at: https://ec.europa.eu/environment/pdf/waste/mining/MWEI%20BREF.pdf

GRID-Arendal, 2022. Global Tailings Portal. Available online at: https://www.grida.no/activities/461

Holtz, R.D., W.D. Kovacs, and T.C. Sheahan, 2011. An introduction to geotechnical engineering, 2nd ed.: Pearson, 863 p.

Hull, A., J. Fraser, and M. Martinez, 2022. Chapter 19-Seismic hazard assessment: In K.F. Morrison (Ed.), Tailings management handbook-A life-cycle approach (pp. 345-360), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.

ICMM (International Council on Mining & Metals), 2020. New Global Industry Standard on Tailings Management aims to improve the safety of tailings facilities in the mining industry. Available online at: https://www.icmm.com/en-gb/news/2020/new-global-industry-standard-on-tailings-management

ICMM (International Council on Mining & Metals), 2022. Our Members. Available online at https://www.icmm.com/en-gb/our-story/our-members

ICMM-UNEP-PRI (International Council on Mining & Metals-United Nations Environment Programme-Principles for Responsible Investment), 2020. Global industry standard on tailings management-August 2020, 40 p, Available online at: https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard-on-tailings-management.pdf

IGF (Intergovernmental forum on Mining, Minerals, Metals and Sustainable Development), 2019. Evaluation of the Mining Policy Framework: Ecuador. March. Winnipeg: IISD. 72pp. Available online at: https://www.iisd.org/system/files/publications/ecuador-mining-policy-framework-assessment-en.pdf

Independent Expert Engineering Investigation and Review Panel, 2015. Report on Mount Polley Tailings Storage Facility breach: Report to Ministry of Energy and Mines and Soda Creek Indian Band, 156 p. Available online at: https://www.mountpolleyreviewpanel.ca/sites/default/files/report/ReportonMountPolleyTailingsStorageFacilityBreach.pdf

International Copper Study Group (ICSG), 2021. ICSG Directory of Copper Mines and Plants. Available by subscription: https://icsg.org/publications-list/

International Network for Acid Prevention (INAP), 2009. Global Acid Rock Drainage Guide (GARD Guide). Available online at: http://www.gardguide.com

Instituto de Investigación Geológico y Energético (IIGE), 2018. ANALYSIS AND TECHNICAL VALIDATION REPORT ON THE "HISTORICAL STUDY OF BACKGROUND CONCENTRATIONS - BASELINE - WATER RESOURCE - ECUACORRIENTE S.A., MIRADOR MINING PROJECT - SEPTEMBER 2018. 18 October.

Knight-Pièsold, 2007. Rio Quimi Tailings Management Facility Feasibility Study for 27,000 tpd mine production. Ref. No. VA201-78/09-2, 111 p.

Larrauri, P.C. and U. Lall, 2018. Tailings dams failures-Updated statistical model for discharge volume and runout: Environments, v. 5. Available online at: doi:10.3390/environments5020028

Le Poudre, D.C. (SNC Lavalin), 2015. Examples, statistics and failure modes of tailings dams and consequence of failure, Power Point Presentation, 42 slides. Available online at: https://www.esaa.org/wp-content/uploads/2015/10/15-LePoudre.pdf

Maest, A.S. and J.R. Kuipers (primary), C.L. Travers, and D.A. Atkins (contributing). 2005. Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State-of-the-Art. Earthworks, Washington, DC. Available online at: https://earthworks.org/publications/predicting_water_quality_at_hardrock_mines/.

Martin, T.E., E.C. McRoberts, and M.P. Davies, 2002. A tale of four upstream tailings dams: Tailings Dams 2002, Association of State Dam Safety Officials, 25 p. Available online at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.532.7955&rep=rep1&type=pdf

Ministry of Environment, 2015. Memorandum No. MAE-SCA-2015-0132 and Environmental Quality Administrative Process No. Z-03-2015.

Ministry of Energy and Non Renewable Natural Resources (Ecuador), 2020. Appendix II-Technical guide for the presentation of tailings deposit design projects [Anexo II-Guía técnica para la presentación de proyectos de diseño de los depósitos de tailings [Anexo II-Guía técnica para la presentación de proyectos de diseño de los depósitos de tailings [Anexo II-Tuía técnica para la presentación de depósitos de tailings], 31 p. Available online at: https://www.mingaservice.com/web/index.php/documento/categoria/legislacion-minera

Ministry of Mining (Chile), 2007. Decreto Supremo nº 248-Reglamento para la aprobación de proyectos de diseño, construcción, operación y cierre de los depósitos de tailings-published in the Official Gazette of April 11, 2007 [Regulation for the approval of projects of design, construction, operation and closure of tailings reservoirs-published in the Official Gazette of April 11, 2007], 24 p. Available online at: https://www.sernageomin.cl/wp-content/uploads/2018/01/DS248_Reglamento_DepositosRelave.pdf

Ministry of Energy and Mines (British Columbia), 2016. Guidance document- Health, safety and reclamation code for mines in British Columbia, Version 1.0: Victoria, British Columbia, updated July 2016, 37 p. Available online at: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/documents/health-and-safety/part_10_guidance_doc_10_20july_2016.pdf

Ministry of Environment and Climate Change Strategy, 2018. Technical Guidance 9: Environmental Management Act. Guidance on Preparing Nitrogen Management Plans for Mines using Ammonium Nitrate Fuel Oil Products for Blasting. Version 1.0. British Columbia, Canada.

February. 13pp. https://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-

waste/industrial-waste/ Available online at: mining-smelt-energy/guidance-documents/guidance_for_developing_nitrogen_management_plans.pdf
Morgenstern, N.R., S.G. Vick, C.B. Viotti, and B.D. Watts, 2016. Fundão tailings dam review-Panel report on the immediate causes of the failure of the Fundão dam: Report prepared for Cleary Gottlieb Steen and Hamilton LLP, 88 p. Available online at: https://pedlowski.files.wordpress.com/2016/08/fundao-finalreport.pdf
Morrill, J., D. Chambers, S. Emerman, R. Harkinson, J. Kneen. U. Lapointe, A. Maest, B. Milanez, P. Personius, P. Sampat, and R. Turgeon, 2022. Safety first-Guidelines for responsible mine tailings management: Earthworks, MiningWatch Canada, and London Mining Network: Version 2.0, May 2022, 55 p. Available online at: https://41p14t2a856b1gs8ii2wv4k4-wpengine.netdna-ssl.com/assets/uploads/2020/06/Safety-First-Safe-Tailings-Management-V2.0-final.pdf
Muñoz, V. and D. Hoekstra, 2022. Chapter 20-Climate and hydrology: In K.F. Morrison (Ed.), Tailings management handbook-A life-cycle approach (pp. 361-385), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.
Pascoe, D., Evans, S.A. & Woodworth, J., 1986. Heavy metal toxicity to fish and the influence of water hardness. *Arch. Environ. Contam. Toxicol.* **15,** 481-487. https://doi.org/10.1007/BF01056559
Plumlee, G.S., 1999. The environmental geology of mineral deposits. In: Plumlee, G.S., Logsdon, M.J. (Eds.), The Environmental Geochemistry of Mineral Deposits. Part A: Processes, Techniques, and Health Issues, Soc. Econ. Geol., Littleton, Colorado, p. 71-116. Available online at: https://eclass.uoa.gr/modules/document/file.php/GEOL455/THE%20ENVIRONMENTAL%20GEOCHEMISTRY%20OF%20MINERAL%20DEPOSITS.pdf
Plumlee, G.S., Smith, K.S., Montour, M.R., Ficklin, W.H., and Mosier, E.L., 1999a. Geologic controls on the composition of natural waters and mine waters draining diverse mineral-deposit types. In: Plumlee, G.S., Logsdon, M.J. (Eds.), The Environmental Geochemistry of Mineral Deposits. Part A: Processes, Techniques, and Health Issues, Soc. Econ. Geol., Littleton, Colorado, p. 373-432. Available online at: https://clu-in.org/conf/tio/r10hardrock3/CH19Plumlee_etal_SEG1999.pdf
Price WA, 2009. Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials. MEND Report 1.20.1. December. 570pp. Available online at: http://mend-nedem.org/mend-report/prediction-manual-for-drainage-chemistry-from-sulphidic-geologic-materials/
Robertson, P.K., L. de Melo, D.J. Williams, and G.W. Wilson, 2019. Report of the expert panel on the technical causes of the failure of Feijão Dam I-December 12, 2019: Report prepared for Vale S.A., 81 p. Available online at: https://bdrb1investigationstacc.z15.web.core.windows.net/assets/Feijao-Dam-I-Expert-Panel-Report-ENG.pdf
Quishpe Lozano, S., E.G. Peña Otaneda, M.R. Vargas Santi, and M. Santi Gualinga, 2018. Complaint against EcuaCorriente S.A. [Denuncia contra EcuaCorriente S.A.]: Fiscalía General del Estado - Ecuador, Document No. FGE-GD-2018-005305-EXT, 13 p.
Sistema Nacional de Información Ambiental (Perú) [National System of Environmental Information (Peru)], 2014. Decreto Supremo N° 040-2014-EM .- Reglamento de protección y gestión ambiental para las actividades de explotación, beneficio, labor general, transporte y almacenamiento minero [Supreme Decree No. 040-2014-EM .- Regulation of protection and environmental management for the activities of exploitation, beneficiation, general labor, transport and mineral storage], 30 p. Available online at: https://sinia.minam.gob.pe/normas/reglamento-proteccion-gestion-ambiental-las-actividades-explotacion
USACE (U.S. Army Corps of Engineers), 2000. Design and construction of levees: Manual No. 1110-2-1913, 164 p. Available online at: https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1913.pdf

USACE-HEC (U.S. Army Corps of Engineers - Hydrologic Engineering Center), 2003. Application of paleohydrology to Corps flood frequency analysis: RD-47, 34 p. Available online at: http://www.hec.usace.army.mil/publications/ResearchDocuments/RD-47.pdf

USGS (U.S. Geological Survey, 2019). 20 Largest Earthquakes in the World. Available online at: https://www.usgs.gov/programs/earthquake-hazards/science/20-largest-earthquakes-world

USGS (U.S. Geological Survey, 2022a). ShakeMap Scientific Background. Available online at: https://web.archive.org/web/20110623092131/http://earthquake.usgs.gov/earthquakes/shakemap/background.php#intmaps

USGS (U. S. Geological Survey, 2022b). Search Earthquake Catalog. Available online at: https://earthquake.usgs.gov/earthquakes/search/

Vick, S.G., 1990. Planning, design, and analysis of tailings dams: BiTech Publishers, Vancouver, Canada, 369 p. Available online at: https://open.library.ubc.ca/soa/cIRcle/collections/ubccommunityandpartnerspublicati/52387/items/1.0394902

Walsh Scientists and Engineers, 2010a. Environmental Impact Study for the Open-Pit Exploitation Phase of the Mirador Copper Mining Project-Mining areas Mirador 1 - Mirador 2 -EcuaCorriente S.A. (ECSA) [Estudio de Impacto Ambiental para la Fase de Explotación a Cielo Abierto del Proyecto minero de cobre Mirador-Áreas mineras Mirador 1 - Mirador 2 -EcuaCorriente S.A. (ECSA)]: Walsh Project Number EC155-13, 748 p.

Walsh Scientists and Engineers, 2010b. Environmental Impact Study for the Beneficiation Phase of the Mirador Copper Mining Project-Mining areas Mirador 1 - Mirador 2-EcuaCorriente S.A. (ECSA) [Estudio de Impacto Ambiental para la Fase de Beneficio del Proyecto minero de cobre Mirador-Áreas mineras Mirador 1 - Mirador 2-EcuaCorriente S.A. (ECSA)]: Walsh Project Number EC155-14, 772 p.

Walsh Scientists and Engineers, 2011. Response to Observations on the Environmental Impact Study for the Beneficiation Phase of the Mirador Copper Mining Project [Response to Observations on the Environmental Impact Study for the Beneficiation Phase of the Mirador Copper Mining Project]: Walsh Project Number EC155-14, 110 p.

Annexes

Annex 1: Tailings Dam Design and Construction Assessment for the Mirador Mine, Zamora Chinchipe, Ecuador. Report prepared by Steven Emerman, PhD, 2019, for E-Tech International.

Annex 2: Preliminary list of communities affected by the environmental, safety, and other social impacts of the Mirador Mine.

Annex 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.

Annex 4: Letter from the National Assembly to the Ministry of Energy and Non-Renewable Natural Resources. Subject: Request for Information. Oficio No. AN-QLS-2022-0030-O. 2022.

Annex 1: Tailings Dam Design and Construction Assessment for the Mirador Mine, Zamora Chinchipe, Ecuador. Report prepared by Steven Emerman, PhD, 2019, for E-Tech International.

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

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Report prepared at the request of E-Tech International
Submitted 19 February 2019
Revised 26 February 2019

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

QUICK SUMMARY

A previous design of the tailings dam for the Mirador mine, Zamora Chinchipe, Ecuador, included a height of 63 metres, an outer slope inclination of 1V:2H, centreline construction, and the ability to withstand the probable maximum Flood. A stability analysis determined that the tailings and foundation would liquefy during the earthquake expected during the life of the project. The tailings dam currently under construction includes an outer slope inclination of 1V:1H, upstream construction (more susceptible to failure by both seismic liquefaction and flooding), the ability to withstand only a 500-year flood and a projected height of 260 metres (the highest ever built). Failure by earthquake, flooding or internal erosion is 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.

CONTENTS

SUMMARY

A previous dam design for the tailings management facility (called the Quimi tailings dam) at the Mirador copper mine, Zamora Chinchipe, Ecuador, included a height of 63 metres, an outside slope inclination of 1V:2H (vertical to horizontal ratio), centreline construction, and the ability to withstand the probable maximum Flood (significantly rarer than even a 10,000-year flood). A stability analysis conducted by consultants hired by the mining company (EcuaCorriente S.A.) determined that the full depth of the tailings, as well as the foundation, would liquefy during the earthquake expected during the life of the project. An independent assessment criticised the excessive amount of water that would be stored with the tailings and the lack of a geosynthetic liner to prevent groundwater contamination. The subsequent Environmental Impact Assessment (EIA) included two alternatives for the proposed production expansion from 30,000 tonnes per day to 60,000 tonnes per day: Quimi tailings dam (previous design with tailings dewatering) and Tundayme tailings dam (preferred by the mining company) with a height of 260 metres (the highest ever built), an outside slope gradient of 1V:1.5H, centreline construction, and the ability to withstand only a 500-year flood.
Both alternatives included the use of non-sulphide (non-acid generating) tailings for the construction of the dams with no uncertainty in the estimation of the amount of available non-sulphide tailings and no plan on what to do if there are not enough non-sulphide tailings. Contrary to the EIA, both alternatives (Quimi tailings dam and Tundayme tailings dam) are currently under construction, although only Quimi tailings dam has the initial dam for the dam. The location of the initial dam requires the upstream method of construction (more susceptible to failure by both seismic liquefaction and flooding) and has an outer slope inclination of 1V:1H (considered the maximum critical angle for prevention of internal erosion with no margin for error). The provincial government has denounced EcuaCorriente for extracting rocks from the rivers for construction material in violation of permits, suggesting that there is a lack of material for proper construction of the dams. Based on the above, failure of any of the tailings dams due to earthquakes, flooding or internal erosion should be considered 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 Zamora Chinchipe province, Ecuador (see Figs. 1 and 2). At full production, this mine will process 60,000 tonnes 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, processing the ore will result in almost 60,000 tonnes per day of waste after crushing and floating of the ore, called mine tailings or simply tailings. Tailings are toxic because of the toxic elements that tend to be associated with the 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 the tailings into the environment and liners that prevent groundwater contamination from confined tailings. The objective of this report is to answer the following question: Is the design and construction of tailings dams consistent with widely recognised safety guidelines? Before addressing this question, I will review tailings dam construction methods, common causes of tailings dam failure, and methods to prevent tailings dam failure. Much of this information is available in the standard textbook on tailings dams by Vick (1990). This report discusses only dam failure prevention based on dam construction and other aspects of the tailings management facility. Methods to prevent failure by altering the nature of the tailings, such as converting tailings to a paste, are discussed elsewhere (Klohn Crippen Berger, 2017).

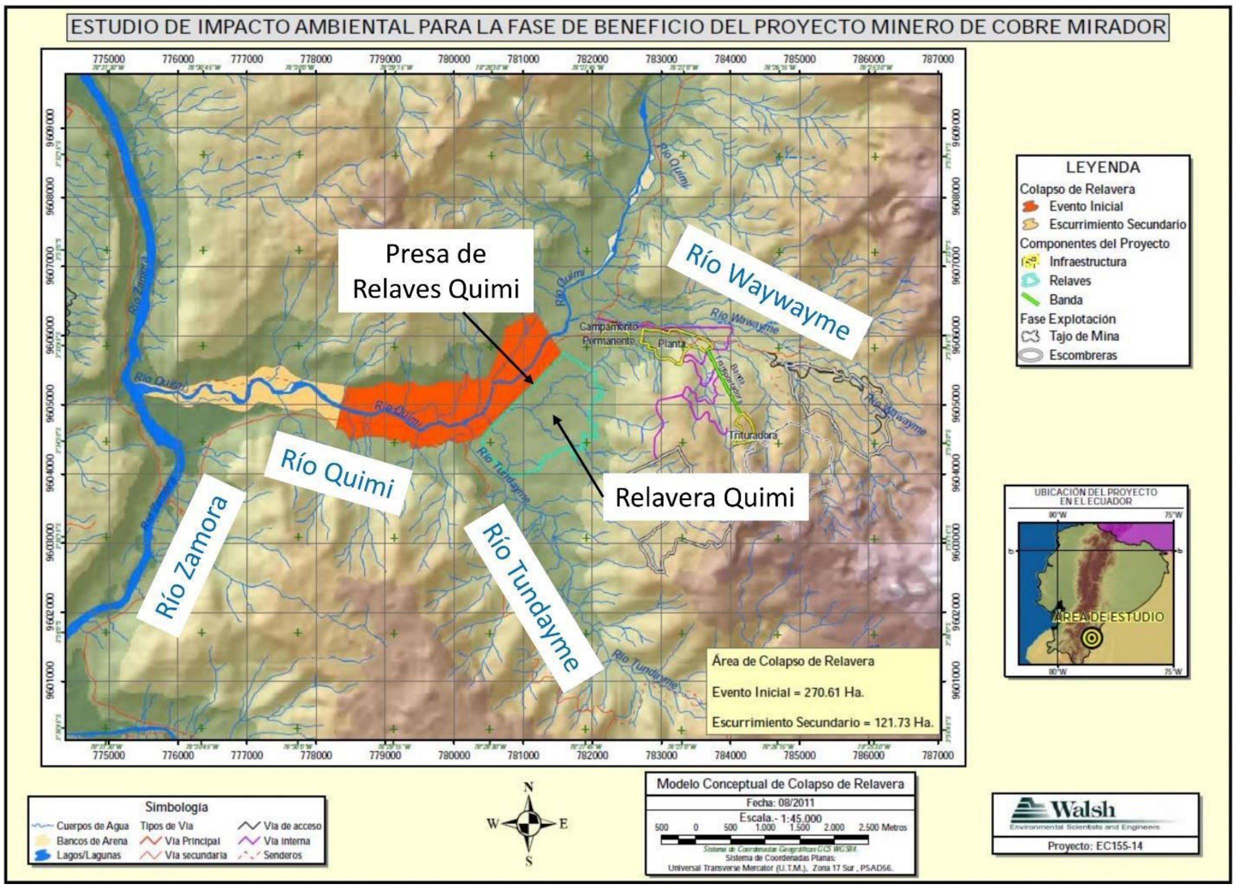


Figure 2. The Mirador copper mine is currently under construction by EcuaCorriente S.A. in Zamora Chinchipe, Ecuador. A previous Environmental Impact Assessment (EIA) in 2010 proposed a single tailings dam (called the Quimi tailings dam) and calculated the extent of tailings spillage after dam failure. 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 down the Zamora River to the headwaters of the Amazon River. Figure modified from Walsh Scientists and Engineers (2011b).

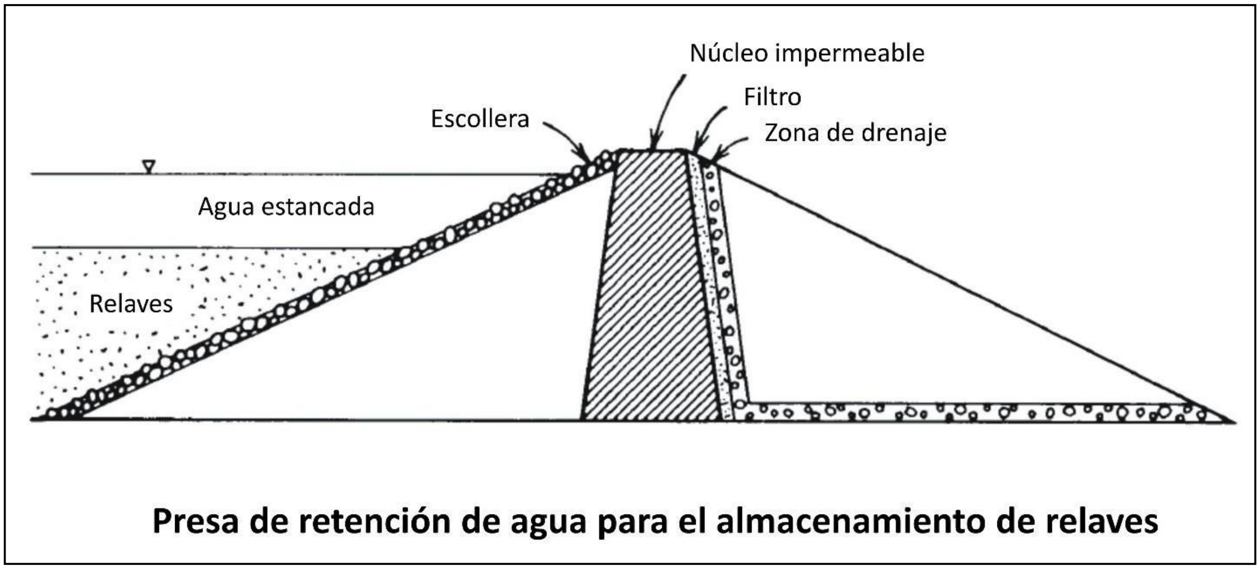


Figure 3. Tailings dams and earth dams for water retention are civil engineering structures. fundamentally different. Vick (1990) showed how a tailings dam could be constructed in the same way as a water retention dam and would be as safe as a typical water retention dam. The design includes an impermeable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

REVIEW OF TAILINGS DAMS

Tailings Dams and Water Retention Dams

Although tailings dams and water-retention dams are constructed for the purpose of restricting material flow, they are fundamentally different types of civil engineering structures. This important point was emphasised 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 projects 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*" [A recurring theme throughout the book is that there are significant differences between tailings embankment dams 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 mining projects as a whole. While water retention dams produce economic benefits that presumably outweigh their cost, tailings dams are economic handicaps to the mining operation from start to finish. As a result, it is not always economically feasible to reach the distances sometimes taken to obtain backfill for conventional water dams]. Vick (1990) gave an example of how a tailings dam could be constructed in the same way as a tailings dam, although he emphasised the economic unfeasibility of such a construction (see Figure 3). (The importance of features in Fig. 3, such as the waterproof core, the filter and the drainage area will be discussed later).

In addition to the economic infeasibility of reaching distances that are sometimes ideal for obtaining suitable fill, Vick (1990) gives many other examples of ways in which it is not economically feasible to construct a tailings dam in the same way as a water retention dam. A water retention dam (one that is constructed of earth) is constructed of rock and soil that is chosen for its suitability for dam construction. However, a tailings dam is normally constructed from construction material that is created by the mining operation, such as spoil, waste rock that is removed before reaching the ore, or from the mine tailings themselves after appropriate compaction. In addition, a water retention dam is constructed completely at the beginning before its reservoir is filled with water, whereas a tailings dam is constructed in stages as more tailings requiring storage are produced and as material from the mining operation (such as spoil) 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 toxic tailings in perpetuity, although normally inspection and maintenance of the dam ceases after the end of the mining project.

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 quoted article 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 favourable comparison with the less than 1 in 10,000 that appears representative for conventional dams. The comparison is even more unfavourable 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)"* [It can be concluded that, over the past 30 years, there have been approximately 2 to 5 'major' tailings dam failure incidents per year... If a world-wide inventory of 3.500 tailings dams, then 2 to 5 failures per year equates to an annual probability of between 1 in 700 to 1 in 1,750. This failure rate does not compare favourably with less than 1 in 10,000 which appears to be representative of conventional dams. The comparison is even more unfavourable if less 'spectacular' tailings dam failures are considered. Furthermore, these failure statistics are only for physical failures. Tailings impoundments can have environmental 'failure' while maintaining sufficient structural integrity (e.g., impacts to surface and groundwater)]. Both the total number of tailings dams and the number of tailings dam 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 at
1 in 600 per year during the period 1969-2015 in British Columbia. (See World Mine Tailings Failures (2018) for the most up-to-date information on mine tailings failures).

Tailings Dam Construction Methods

All tailings dam construction methods are means to take advantage of the very different physical properties of the two tailings sizes, which are sands (larger than 0.075 mm) and silts (smaller than 0.075 mm). These two sizes are separated by gravity at the tailings management facility. Typically, a mixture of tailings and water is discharged into the tailings pond from the dam crest through spigots that connect to a pipeline coming from the ore processing plant (see Fig. 4). Larger sands settle closer to the dam to form a beach. The smaller silts and water travel further away from the dam to form a settling pond where the silts slowly settle out of suspension. It should be noted that the beach is essential to prevent the pond from reaching the crest of the dam.

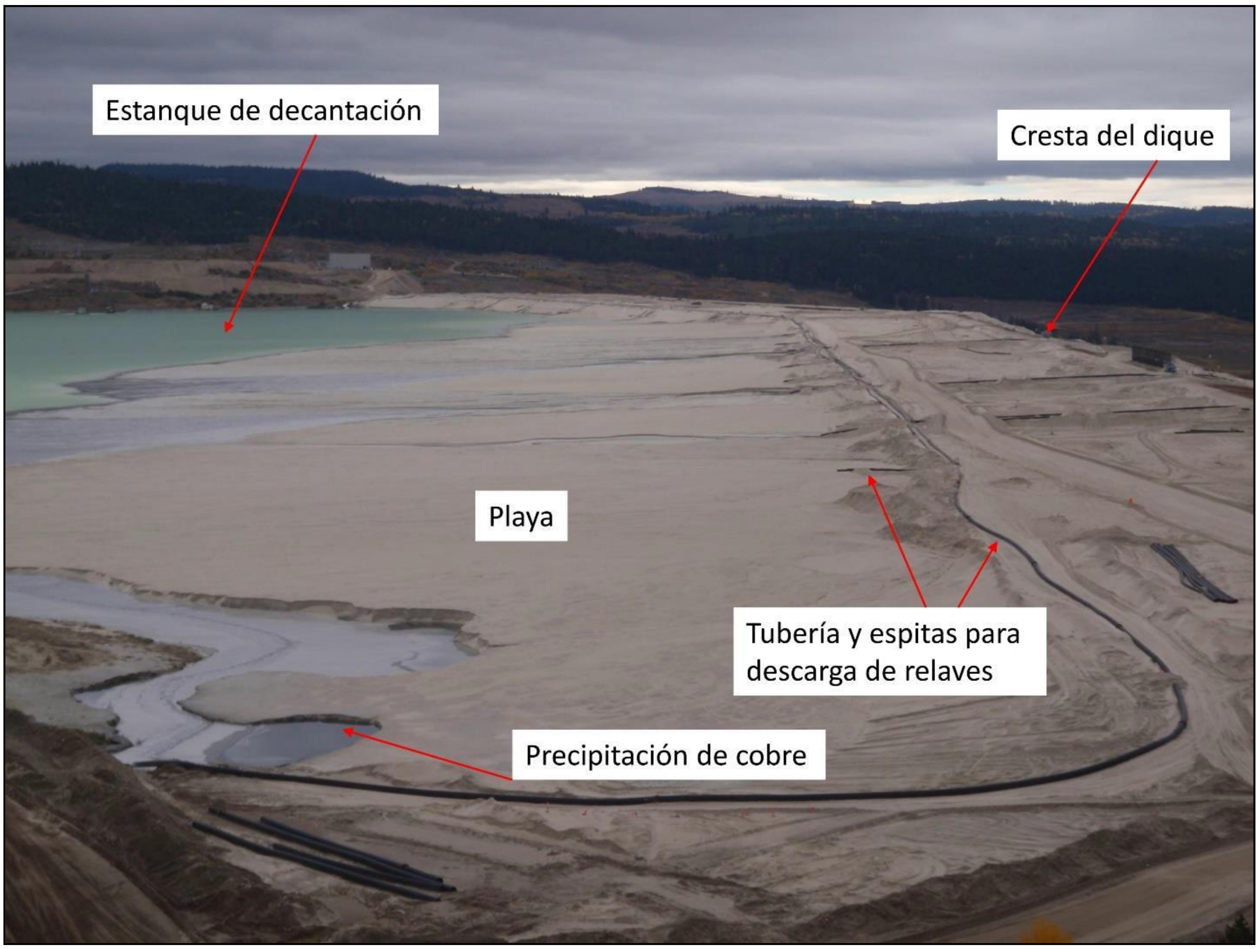


Figure 4. At the Highland Valley copper mine tailings storage facility in British Columbia, wet tailings are discharged in the upstream direction from a pipe and spigots along the dam crest. Larger particles (sands) are deposited near the dam to form a beach. Smaller particles (silts) are transported further away from the dam to form a settling pond. Copper precipitation in the tailings pond indicates 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 flood failure. Photo taken by the author on 27 September 2018.

Each of the three common methods of tailings dam construction (upstream, downstream and centreline) begins with an initial dam, which is constructed from natural soil, rubble or tailings from a previous episode of ore processing (see Figs. 5a-c). In the upstream construction method, successive dams are constructed in the upstream direction as the level of stored tailings increases. As mentioned above, it is more common to construct the successive dams from rubble or the coarser tailings fraction (with appropriate compaction). The advantage of the method is its low cost because very little material is required for dam construction (see Fig. 5a).

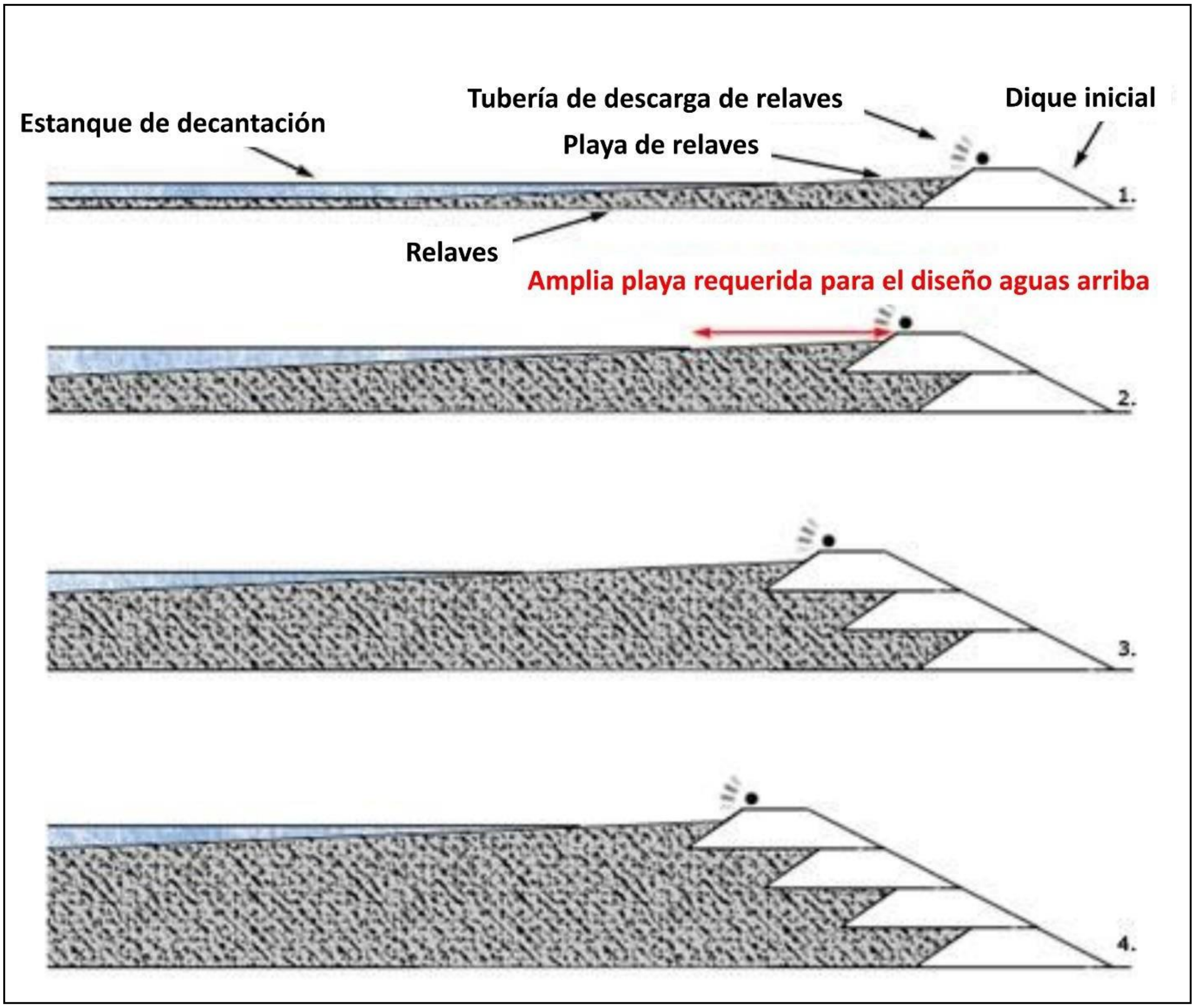


Figure 5a. In the upstream construction method, successive dams are constructed in the upstream direction as the level of stored tailings increases. The dams can be constructed from mine waste, natural soil or the coarser tailings fraction (with appropriate compaction). The advantage of the method is its low cost because very little material is required for dam construction. The disadvantage is that the dam is susceptible to seismic liquefaction failure because the uncompacted wet tailings are underneath the dam. For this reason, the upstream construction method is illegal in some seismically active countries, such as Chile.

Dams constructed by this method are also susceptible to flood failure when the beach is too narrow due to insufficient sand in the discharged tailings or excess water in the settling pond. Figure modified from TailPro Consulting (2018).

The downstream construction method is the most expensive because it requires the largest amount of construction material (compare Figs. 5a and 5b). In this method, successive dams 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 earth dam for water retention (compare Figs. 3 and 5b). The differences are that a water retention dam would be constructed entirely from suitable natural soil (rather than tailings or rubble) and would be fully constructed prior to filling the reservoir with water.

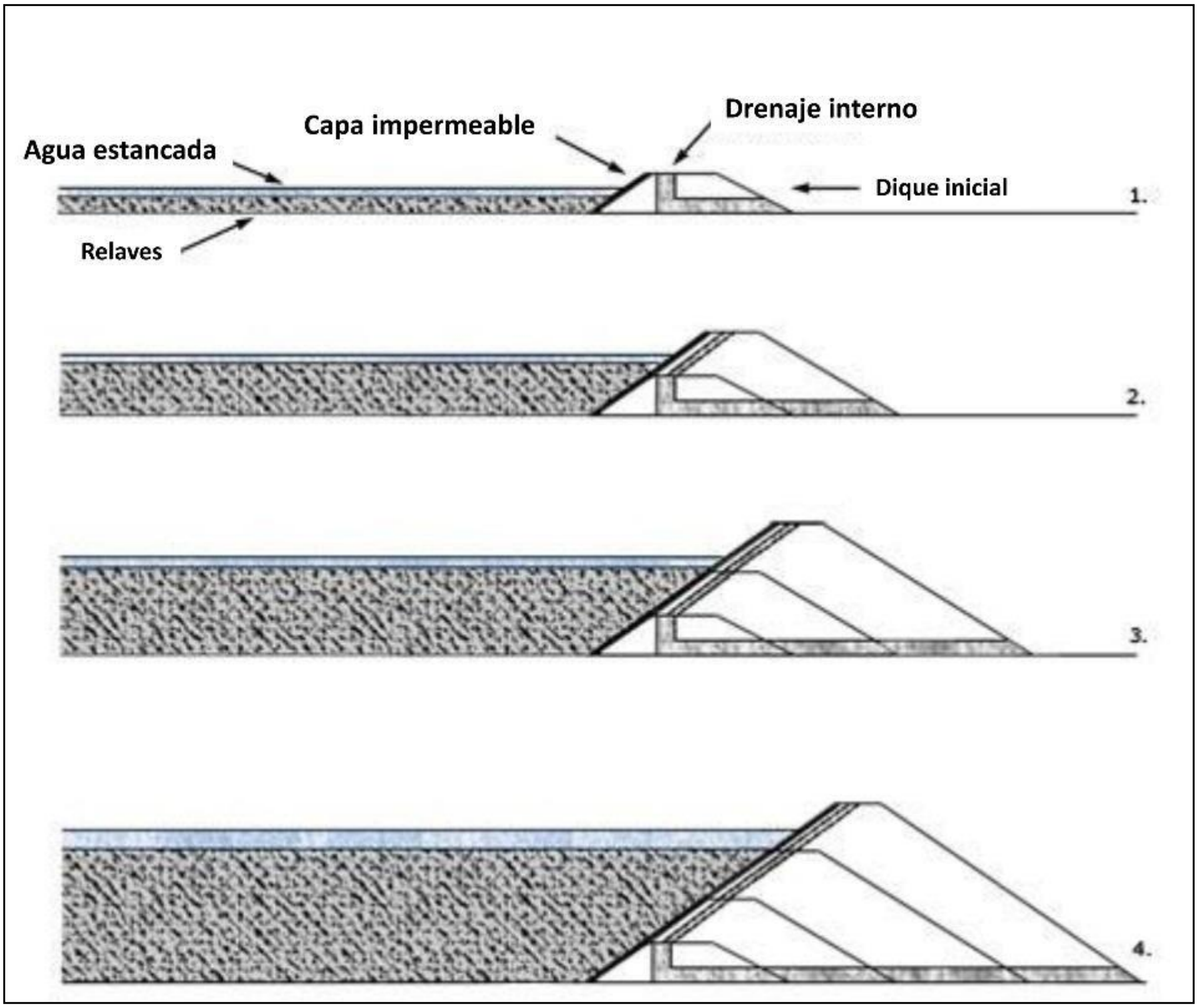


Figure 5b. In the downstream construction method, successive dams are constructed in the downstream direction as the level of stored tailings increases. The dams can be constructed from mine waste, natural soil or the coarser tailings fraction (with appropriate compaction). The ability to install impermeable layers and internal drains decreases the danger of dam failure from flooding, internal erosion, static liquefaction and foundation failure, all of which can result from excess water. Seismic resistance is high because there are no uncompacted tailings beneath the dam. The disadvantage of the method is its high cost due to the amount of material required to construct the dams (compare the dam volumes in Figs. 5a and 5b). In fact, this construction method is not very different from the construction of an earth dam for water retention (see Fig. 3). The differences are that a water retention dam would be constructed entirely from suitable natural soil (rather than tailings) and would be fully constructed before filling the reservoir with water.

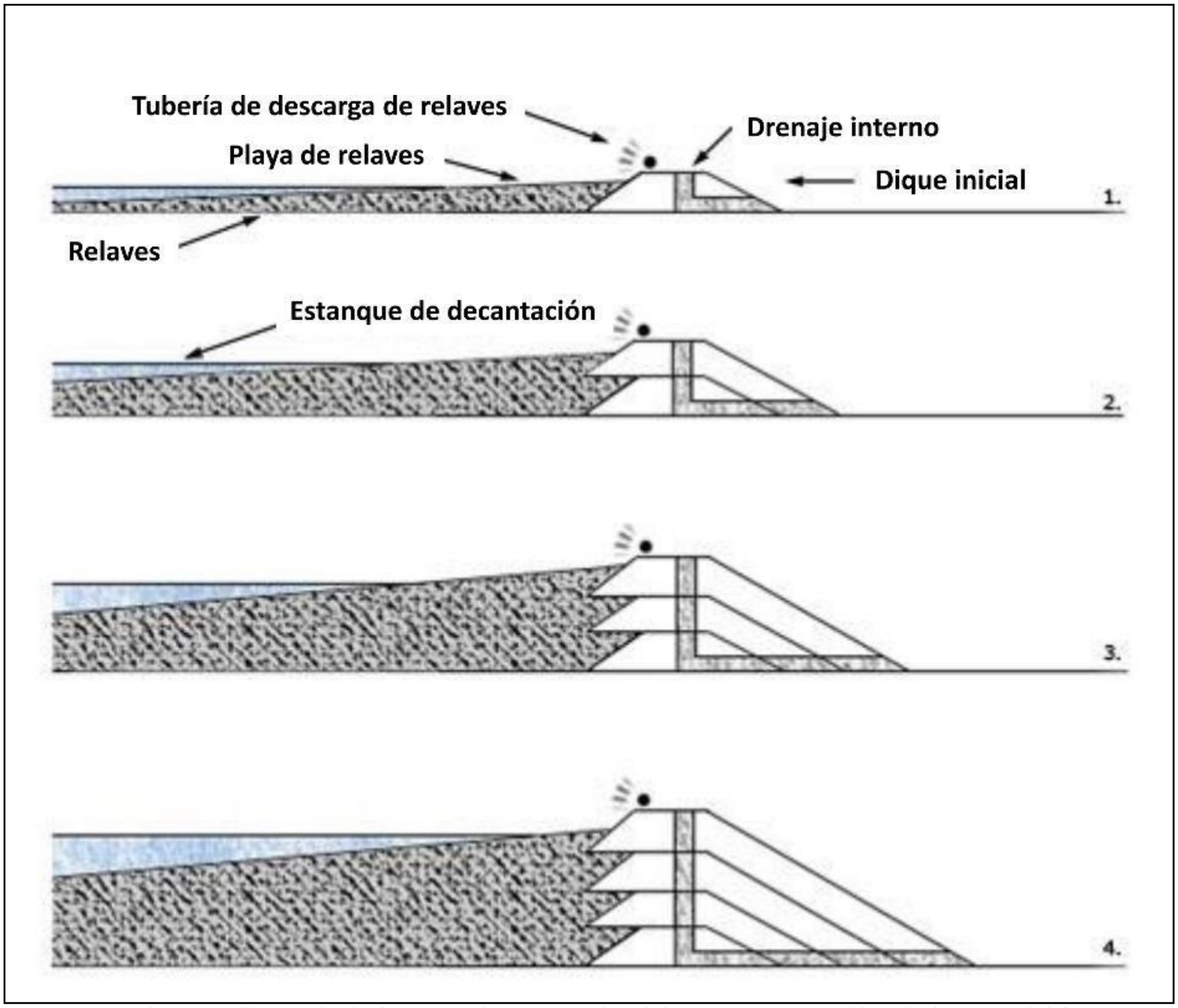


Figure 5c. In the centreline method of construction, successive dykes are constructed by placing material from construction on the beach and on the downstream slope of the previous weir. The centrelines of the rises coincide as the dam is constructed upstream. The dams can be constructed of mine waste, natural soil or the coarser fraction of tailings (with appropriate compaction). The ability to install impermeable layers (see Figure 8) and internal drains decreases the danger of dam failure from flooding, internal erosion, static liquefaction and foundation failure, all of which can result from excess water. The centreline method is intermediate between the upstream and downstream methods (see Figures 5a-b) in terms of cost and risk of failure. Seismic resistance is moderate because there are still some uncompacted tailings below the dams. It is still necessary to maintain an adequate beach to prevent flooding of the dam. Therefore, dams constructed by this method are suitable for temporary, but not permanent, water storage (Vick, 1990). Currently, the centreline construction method is the most common method of constructing tailings dams in the world.

The centreline construction method is a balance between the advantages and disadvantages of downstream and upstream construction (compare Figs. 5a-c). In this method, successive embankments are constructed by placing construction material on the beach and on the downstream slope of the previous embankment. The centrelines of the upslopes coincide as the weir is constructed upstream (see Fig. 5c). Although data on the frequency of different types of tailings dam construction are scarce (World

Mine Tailings Failures, 2018) the centreline construction method is probably the most common method of constructing tailings dams in the world. The advantages and disadvantages of the different types of construction in terms of ability to withstand catastrophic failure will be discussed after reviewing the common causes of tailings dam failures.

Causes of Tailings Dam Failure

The immediate cause of most catastrophic tailings dam failures is the liquefaction phenomenon (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 carries the entire load. As a result, the mass of solid particles and water behaves like a liquid with no shear strength.

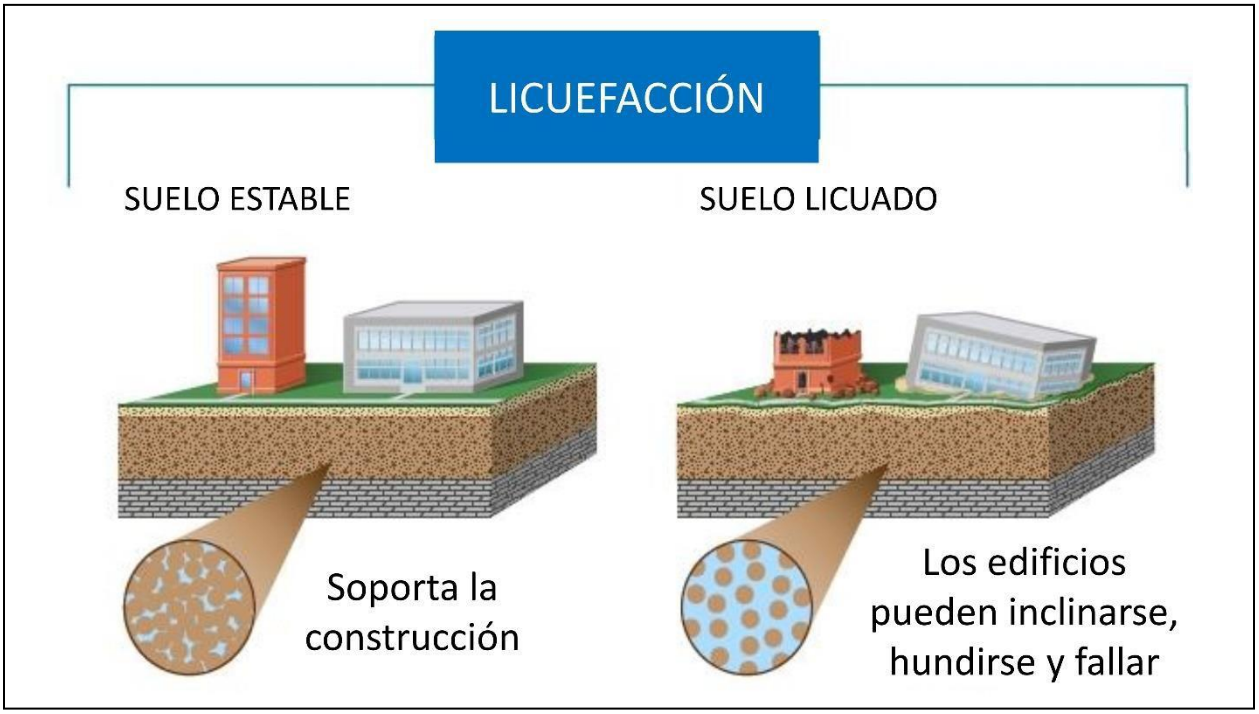


Figure 6. In a tailings deposit or natural soil, although there is interstitial water in the pores between the solid particles, the particles touch each other, so that the load is carried by the solid particles (and partially by the water). In the static liquefaction phenomenon, a combination of excessive water and excessive load causes the particles to separate, so that the interstitial water carries all the 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 were to occur slowly, the water between the particles would be forced upwards and out of the spaces between the particles. However, because the seismic shaking occurs so quickly, the water does not have time to move out 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 loose due to discharge into the pond without compaction (see Fig. 4).

The five most important causes of tailings dam failure are floods, earthquakes, static liquefaction, foundation failure and internal erosion. Each of these five causes can be understood in terms of the liquefaction phenomenon. The shaking that occurs during earthquakes causes tailings to settle to a state of increased density. This settling is much more common in tailings than in a natural soil because the tailings are very loose due to discharge into the pond without compaction (see Fig. 4). If settling occurred slowly, the water between the particles would be forced up and out of the spaces between the particles. However, because the seismic shaking occurs so quickly, the water does not have time to move out 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.

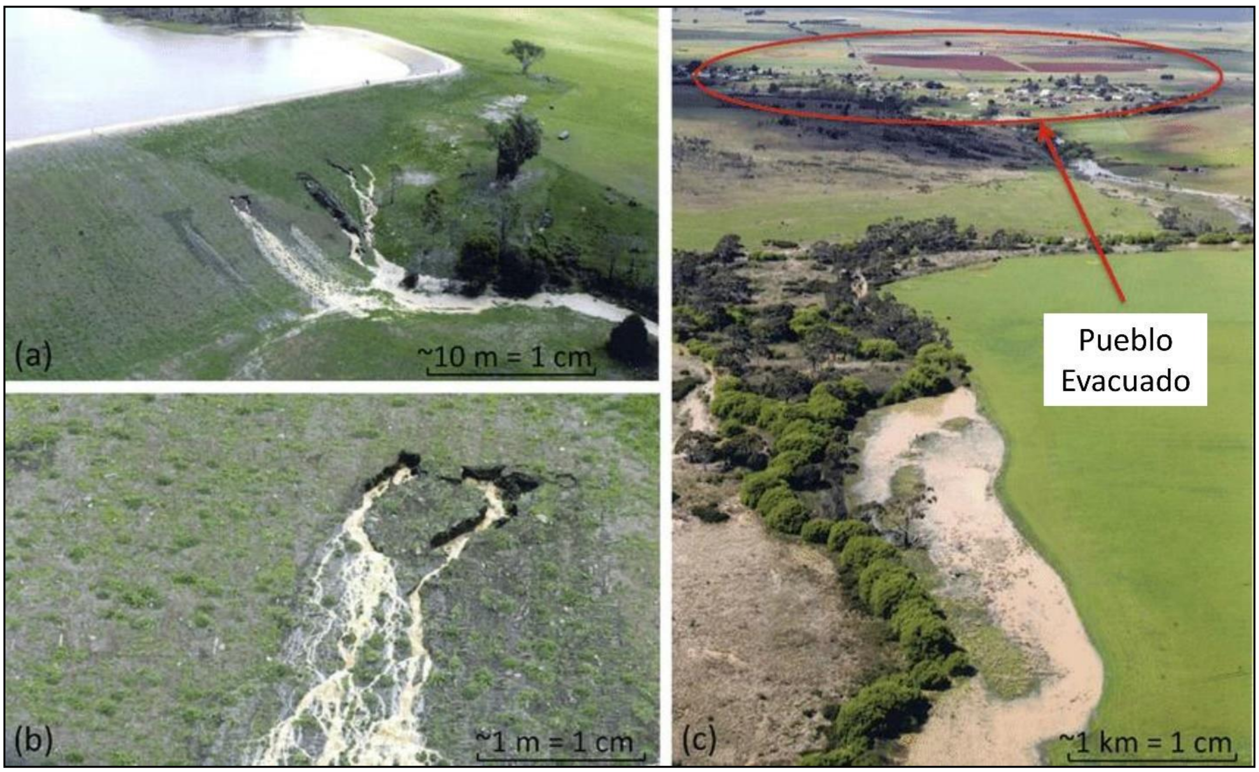


Figure 7. Internal erosion (also called channelisation) caused the failure of an earth dam in Tunbridge, Australia, in 2005. During internal erosion, seepage transports solid particles out of the dam so that the dam loses structural integrity. Internal erosion can be considered a type of liquefaction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

In addition to dynamic liquefaction that occurs during earthquakes, static liquefaction can occur simply due to consolidation (settling) of tailings. Static liquefaction can result from a combination of excessive loading, excessive water and an excessive rate of tailings accretion. If the permeability of the tailings mass is low enough, then the tailings may consolidate without sufficient time for water to escape. Instead, the water is compressed and the elevated 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 loose state of the tailings. The failure of the

Foundation failure (the soil beneath the tailings management facility or the dam itself) is usually also a type of static liquefaction. Foundation failure can occur when excessive loading or excessive water in the tailings mass forces water into a foundation that has insufficient permeability for water to pass through the foundation.

Floods that cause water to overtop earth dams almost always result in complete failure of the dam. Water overtopping the dam crest causes saturation of the dam and the excess weight of the overtopping can force solid particles apart, which is a type of liquefaction. Floods can also destroy dams by removing the tops of the dam. In addition to spilling the contents behind the dam, removing the tops of the dam reduces the overall weight of the dam and thus the dam's ability to withstand the pressure of the material behind the dam. In addition, tailings dams may simply fall due to water flowing down the embankment, causing erosion of the dam.

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

Construction Methods and Causes of Failure

Common tailings dam construction methods can now be analysed in terms of their vulnerability to common causes of dam failure. Not surprisingly, 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 over uncompacted tailings (see Fig. 5a), liquefaction of those tailings will result in the inevitable collapse of the dam, as the dam will be unsupported. 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 Press], 2018). In addition, the upstream construction method is the most susceptible to flood failure because the only feature that prevents the pond from reaching the dam is the presence of the beach. The beach can be overtopped by the pond if there is heavy rainfall in the tailings management facility basin or even if there is not enough sand in the tailings to form an adequate beach. For example, the tailings pond at the Highland Valley copper mine has a very narrow beach, which is almost non-existent on the far side of the tailings pond (see Fig. 4). This narrow beach is probably the result of insufficient coarser particles in the tailings stream from the ore processing plant. (The tailings dam at the Highland Valley copper mine was actually constructed by the centreline method. Although a suitable beach is still

Importantly, tailings dams constructed by the centreline method have other means of reducing the risk of flooding, as explained below).

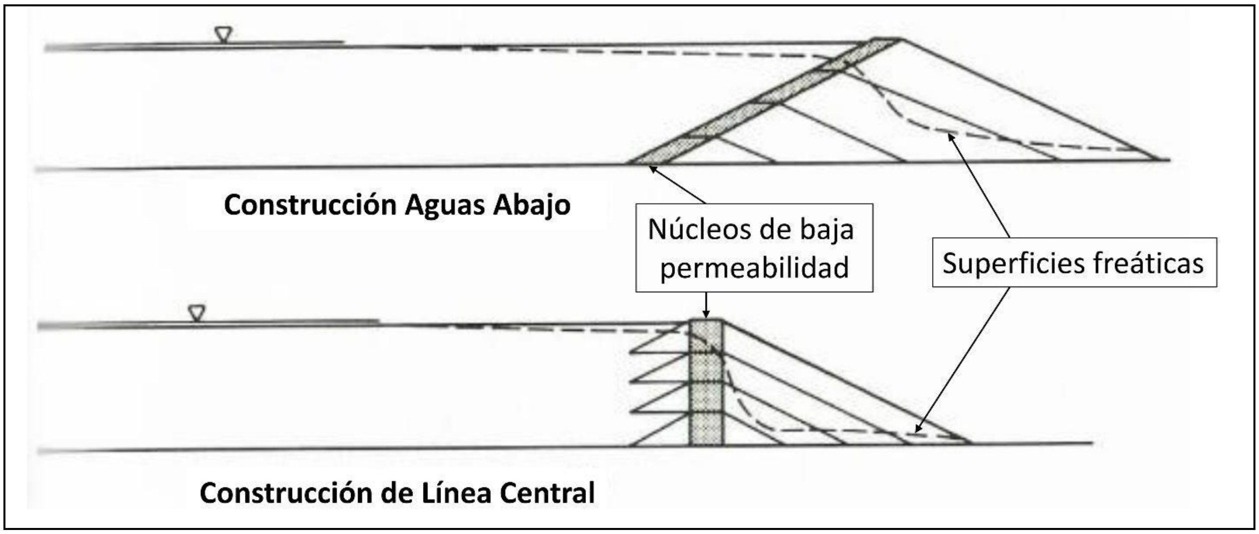


Figure 8. One of the advantages of the downstream and centreline construction methods is that it is possible to install low permeability cores to lower the water table at the foot of the dam. This lowering of the water table reduces the likelihood of internal erosion of the dam (see Figure 7), static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

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 centreline 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 nowhere to place a low permeability core or an impermeable layer, so any mention of an impermeable layer should indicate that the upstream construction method is not being used. Both the downstream and centreline methods of construction allow for 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 accommodate anywhere to install a stack drain (see Fig. 5a), although blanket drains are possible (see Fig. 9).

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 should be designed in such a way that they trap fine particles, allow water to pass through (so that the water table is kept low) and are not 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, a slope of 1V:1H (a vertical drop of one metre for a horizontal distance of one metre, equivalent to 45°), is considered to be the maximum critical angle for internal erosion prevention (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 embankment slopes should not be steeper than 1V:3H for any dam that stores base metal tailings (which include 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, it is the author's experience that a slope of 1V:2H (equivalent to 26.6° to the horizontal) is the most common.

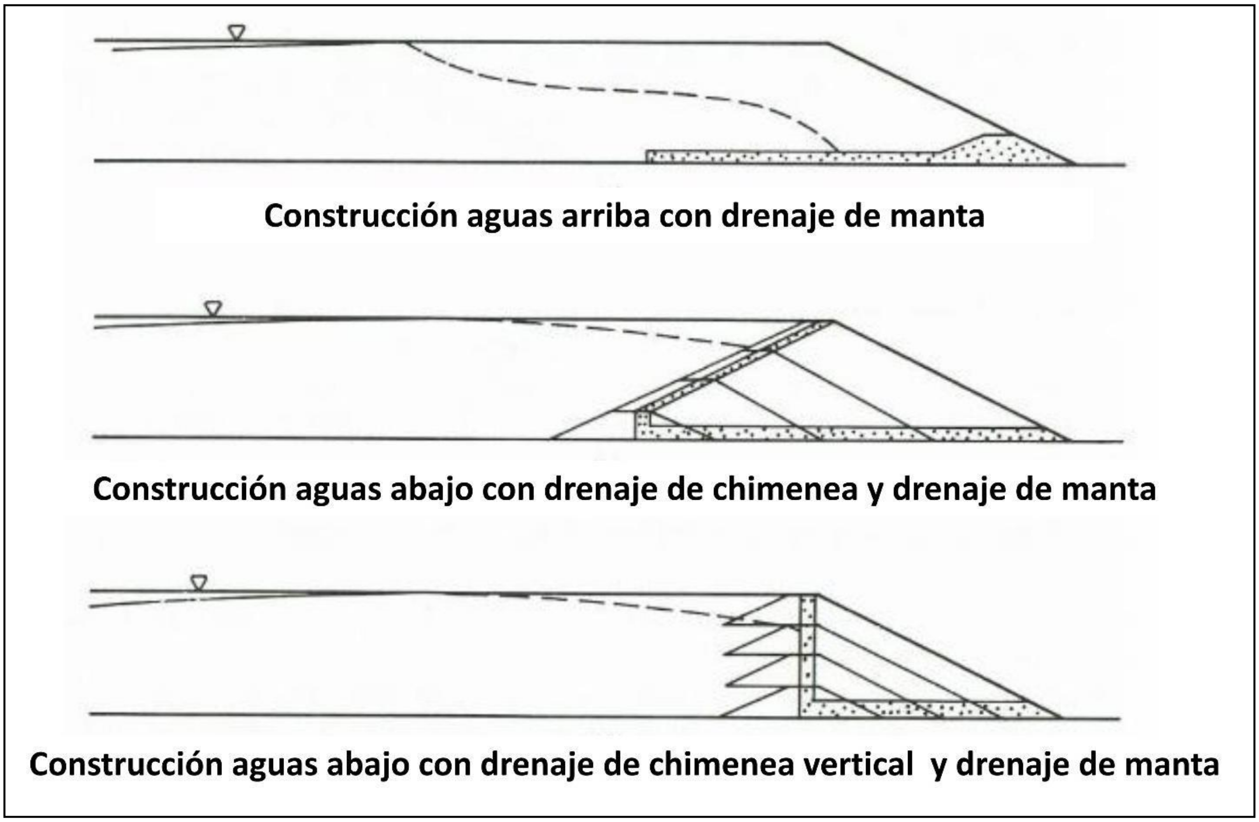


Figure 9. It is possible to install blanket drains using all three construction methods, although stack drains can be installed using only the downstream and centreline construction methods. These drains lower the water table and reduce the likelihood of internal dam erosion (see Figure 7), seismic liquefaction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

On the subject of internal erosion prevention, 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*" [For practical problems, especially where there is a danger that *i* [the hydraulic gradient] may 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. On the one hand, failure is usually catastrophic and occurs quickly and with little warning. On the other hand, 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 the flow, for example, where you may not want it and are not prepared for it... Since the failure of cofferdams is often catastrophic, it is extremely important that large safety factors are used, especially when people's lives are at stake. Failures of earth structures resulting from canalisation 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 your design".

Safety Criteria for the Design of Tailings Dams

The most important step in designing dams to avoid catastrophic flood and earthquake failures is to choose the appropriate design flood and the appropriate design earthquake. The design earthquake is actually a design seismic acceleration, which depends on the magnitude of the design earthquake, the distance from the fault where the earthquake is expected to occur, and the nature of the material beneath the dam. These design criteria depend on the hazard potential or consequences of failure. For example, the (US) Federal Emergency Management Agency classifies dams into three categories according to 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 a design inflow flood (FEMA, 2013). A dam with a low hazard potential should be designed for a 100-year flood (flood with a 1% exceedance probability in any given year) or "*a smaller flood justified by rationale*". A dam with a significant hazard potential must be designed for a 1,000-year flood (flood with a probability of exceedance 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 IMP 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*". PMP magnitudes have been determined for most of the United States (NWS-HDSC, 2017), as well as for most of the developed world. Procedures for PMP determination 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).

Similarly, each of the hazard potentials corresponds to a design earthquake. According to the Federal Emergency Management Agency, the Maximum Credible Earthquake (MTE), 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 high hazard potential dams, "*the MDE [Maximum Design Earthquake] usually is equated with the controlling MCE*". As with 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*". Similarly, the U.S. Army Corps of Engineers has emphasised "*There is no return period for the MCE*" (USACE, 2016). However, some older non-governmental guidelines, such as the US National Fire Protection Association, defined TMC 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 recognised. These guidelines include five risk categories. The risk to any permanent population places a dam in the three highest risk categories, where the high risk, very high risk and extreme risk categories correspond to expected fatalities of ten or less, 100 or less, and more than 100, respectively. The guidelines consider the design criteria for floods and earthquakes based on both a risk-informed approach and a traditional, standards-based approach. Under the risk-informed approach, the minimum annual exceedance probability of the design flood or earthquake in the very high risk or extreme risk category 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 hazard category, the design flood should be 2/3 between the 1,000-year flood and the IMP, while the design earthquake should be halfway between the 2,475-year earthquake and either the 10,000-year earthquake or the TMC. For a dam in the extreme hazard category, the design flood should be the IMP, while the design earthquake should be the 10,000-year earthquake or the TMC. There are many other design flood guidelines in use around the world and these were comprehensively reviewed by FEMA (2012).

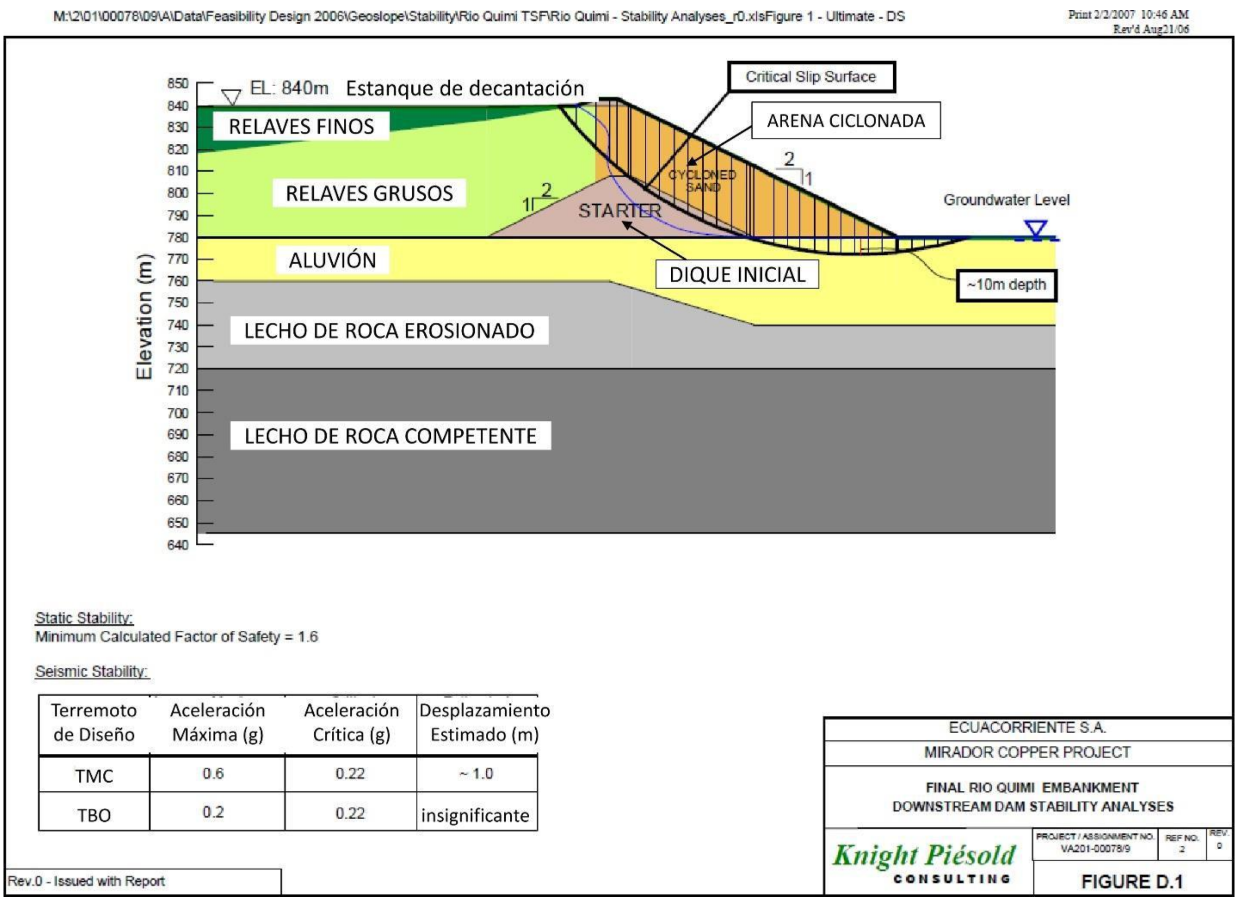
DESIGN OF TAILINGS MANAGEMENT FACILITY AT MIRADOR MINE

Previous Version and its Criticisms

Prior to the submission of the first Environmental Impact Study for the Mirador mine in 2010 (Walsh Scientists and Engineers, 2010a-b, 2011a), EcuaCorriente S.A. contracted Knight-Pièsold (2007) to review the design of the tailings management facility. The Knight-Pièsold (2007) review also contains an excellent summary of the design. The previous design included processing 27,000 tonnes of ore per day with permanent storage of the tailings in the Quimi tailings dam (see Fig. 2). The foundation of the facility would be alluvial soil with competent bedrock at a depth of 75-100 metres. The Quimi Dam would be 63 metres high after final height and would be constructed using the centreline method with an embankment slope of 1V:2H (see Fig. 10). Ore processing would result in 2% concentrate (destined for shipment for further processing), 87% coarser tailings (sands) and 11% finer tailings (silts). The water and tailings mix would be transported to the Quimi tailings dam undewatered with 66.5% water for the coarser tailings and 79% water for the finer tailings (percentage by weight). The initial dam dam would be constructed from locally available natural soil. Material for the construction of successive dams would be obtained by cyclone separation of the tailings in sand form to separate the coarser fraction, estimated at 23% of the tailings in sand form, which would be suitable for dam construction. It was emphasised 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*".

A significant part of the design involved the means by which groundwater contamination by acid mine drainage (AMD) would be avoided. The main component of AMD is sulphuric acid that results from the oxidation of sulphide minerals after they are exposed to oxygen at the surface as tailings. If DAM is allowed to enter groundwater or surface water, it can degrade public water supplies and aquatic organisms through acidification and contamination by heavy metals that were part of the crystalline structure of the sulphide minerals. Acidification of downstream rivers can also mobilise heavy metals that are stored in sediments in river beds. The possibility of AMD was addressed in the proposal by soil compaction.

to create a low permeability liner at the base of the facility. In addition, it was found that only the finer tailings would be sulphide-rich and therefore potential SAD generators. These finer tailings would be discharged below pond level at the rear of the tailings management facility to prevent oxidation. Finally, "*post-closure surface grading will ensure the cleaner tailings remain saturated in perpetuity*" (Knight-Pièsold, 2007).



Terremoto de Diseño	Aceleración Máxima (g)	Aceleración Crítica (g)	Desplazamiento Estimado (m)
TMC	0.6	0.22	~ 1.0
TBO	0.2	0.22	insignificante

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 TDE [maximum design earthquake] and TBO [operational base earthquake]. Liquefaction is also predicted for loose alluvial soils near the surface (in the upper 10 metres) for the TDE and TBO". Knight-Pièsold (2007) identified the TDE with the TMC (maximum credible earthquake). The operational base earthquake is the earthquake expected to occur during the life of the project. Note that the maximum accelerations during the TMC and OBE were predicted to 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 will be required to increase the liquefaction resistance of these loose soils within the footprint of the embankment and for a distance downstream of the embankment. Stability analyses indicate that a 100-metre wide area of ground will require treatment along the embankment alignment". However, there were no details or assurances that the "ground improvement" would eliminate the possibility of liquefaction of the foundation. The Knight-Pièsold (2007) diagram clarifies that the previous design of the Quimi tailings dam included centreline construction and an embankment slope of 1V:2H. Figure modified from Knight-Pièsold (2007).

Based on the potential for loss of life and the environmental and economic consequences that would result from tailings dam failure, Knight-Pièsold (2007) gave the tailings dam a VERY HIGH risk assessment (its capitalisation) using the Canadian Dam Association (2013) rating system. Knight-Pièsold (2007) recommended that the dam be designed using IMP as a safety criterion, which is even more stringent than recommended by the Canadian Dam Association (2013). However, Knight-Piesold (2007) admitted the difficulty of correctly estimating the IMP as '*the available regional records* [*of* precipitation*] are not particularly long, nor* are *the data considered to be of exemplary quality'*. In addition, "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 (DEM) be the MCE, which is also more stringent than recommended by the Canadian Dam Association (2013).

The critical part of the Knight-Pièsold (2007) review was the seismic stability analysis, which stated that "*the entire depth of the tailings deposit is potentially liquefiable for the MDE and OBE [Operating Base Earthquake]. Liquefaction is also predicted for the loose alluvial soils near surface (in the upper 10 meters) for the MDE and OBE"* [the entire depth of the tailings deposit is potentially liquefiable for the MDE and OBE [Operating Base Earthquake]. Liquefaction is also predicted for the loose alluvial soils near the surface (in the upper 10 meters) for the MDE and OBE] (see Fig. 10). The OBE is the earthquake 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 an exceedance probability over the 30-year life of the project of 6.13%. In other words, Knight-Piesold (2007) stated that the probability was 6.13% that the entire tailings mass, as well as the foundation, would be subject to seismic liquefaction at some point during the 30-year 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 assumed to store the 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*" [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 metre wide area of ground will require treatment along the embankment alignment]. However, there were no details or assurances that "ground improvement" would eliminate the possibility of liquefaction of the foundation. There is no evidence that this type of seismic stability analysis was ever repeated, even as the proposed height of the tailings dam increased.

The description of the project in the subsequent Environmental Impact Assessment (Walsh Scientists and Engineers, 2010a-b, 2011a) differed little from the Knight-Pièsold (2007) report, except that the ore processing rate was increased to 30,000 tonnes per day. Walsh Scientists and Engineers (2010b) clarified that "The tailings impoundment will be retained as a permanent post-closure facility" and that "a permanent water cover over the tailings will provide anoxic conditions, which will prevent the generation of acidic water, maintaining neutral lake conditions". One of the comments from the Ecuadorian Ministry of Environment was the cogent observation that "seismic stability should be the product of a local seismic study of the project area and not regional as has been lightly done in the study. Similarly with respect to landslides that could locally occur in the project area" (Walsh Scientists and Engineers, 2011b). The Walsh Scientists and Engineers (2011b) response did not address the comment at all, but simply referred to the accompanying Knight-Pièsold (2007) report, which also did not address the comment. The same response document to the Ecuadorian Ministry of Environment (2011b) included a map showing the distribution of tailings that would occur along the Quimi River after dam collapse (see Fig. 2). The initial tailings surge 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 discussed in the Discussion section.

An independent review (not contracted by the mining company) included a wide range of criticisms of the plan for the tailings management facility as it existed at the time (Kuipers, 2012). The most important criticism from a catastrophic failure prevention point of view 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. Typical industry standards require partial dewatering of tailings to no more than 50% water before sending them to tailings management facilities. Conversely, it should be noted that, in response to the Mount Polley tailings dam failure, the Independent Expert Engineering Investigation and Review Panel (2015) (2015) recommended that all tailings be fully dewatered prior to storage. The most important criticism from the point of view of preventing groundwater contamination was that Kuipers (2012) recommended a geosynthetic liner at the base of the facility, rather than relying on a low permeability soil for prevention of seepage from the facility.

Two other areas of criticism addressed design methodology and financial assurance. Kuipers (2012) criticised the explicit reliance on the "Observation 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) by stating "the Observational Method is useless without a way to respond to the observations". Finally, Kuipers (2012) criticised AMEC's (2004) estimate that a financial guarantee of $55 million would be sufficient for mine closure and reclamation, and said that $568 million would be more reasonable. It is important to note that the financial assurance estimate has not been reconsidered for the larger project currently under construction.

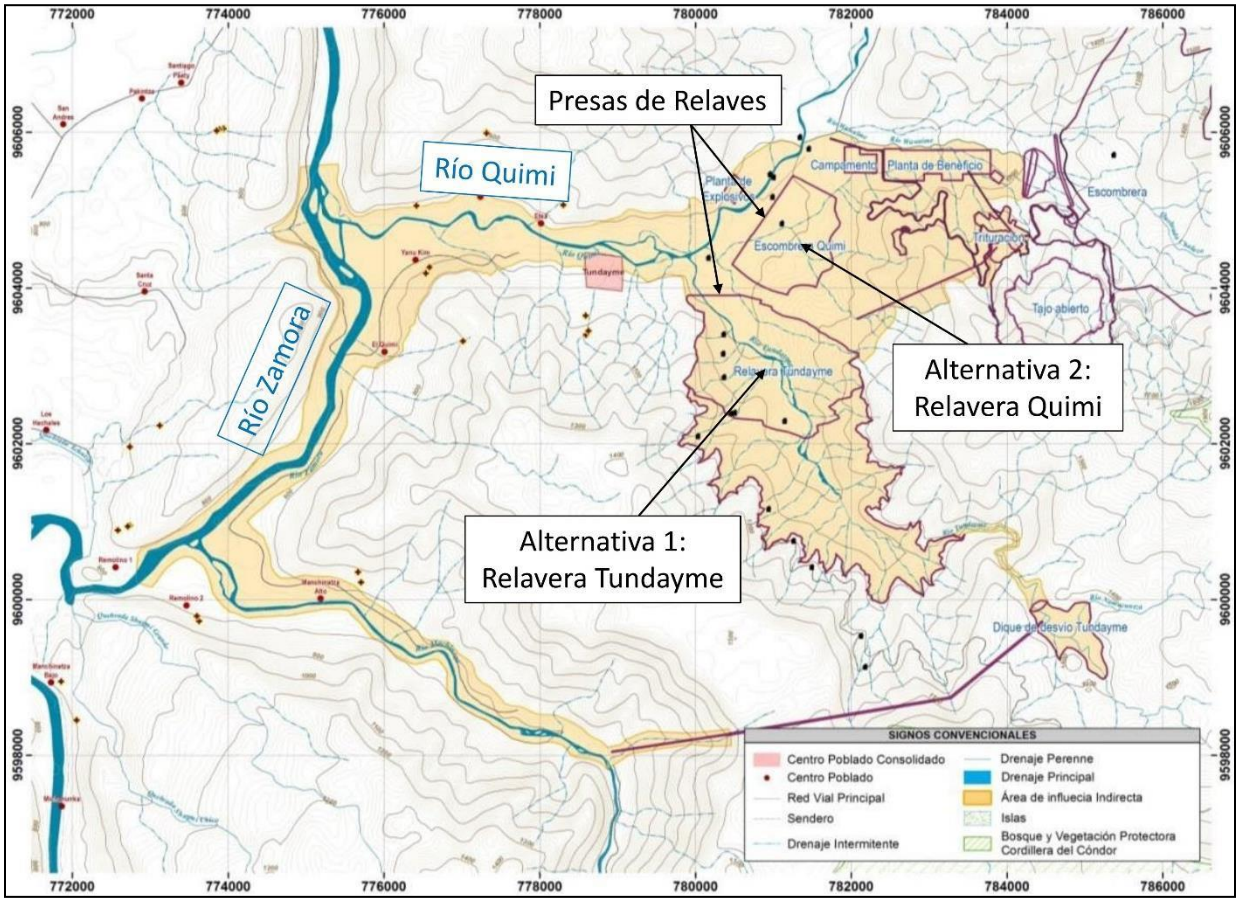


Figure 11. The second Environmental Impact Assessment (Cardno, 2014a) proposed two alternatives for increasing the copper ore production of 30,000 to 60,000 tonnes per day. Alternative 1 was to replace the Quimi tailings dam with the Tundayme tailings dam, for which the dam would be 260 metres high, the highest tailings dam ever built. Alternative 2 was to maintain the Quimi tailings dam, but increase its capacity by dewatering the tailings. Alternative 1 was preferred because of 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 Assessment (Cardno, 2014a). Figure modified from Cardno (2014a).

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

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

Final Version and its Critics

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 tonnes per day to 60,000 tonnes per day. Alternative 1 (preferred by the mining company) was to replace the Quimi tailings dam with the Tundayme tailings dam (Fig. 11-12) in the steep valley of the Tundayme River, which would have more space for tailings. Alternative 2 was to keep the tailings to minimum moisture content by turning them into a paste and adding portland cement to immobilise the 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 Quimi tailings dam and Tundayme tailings dam were discussed throughout the EIS, it is clear from Chapter 5: Alternatives Studied in Cardno (2014a) that these were two alternatives, where costs, environmental impacts and all other aspects were assessed separately for each alternative.

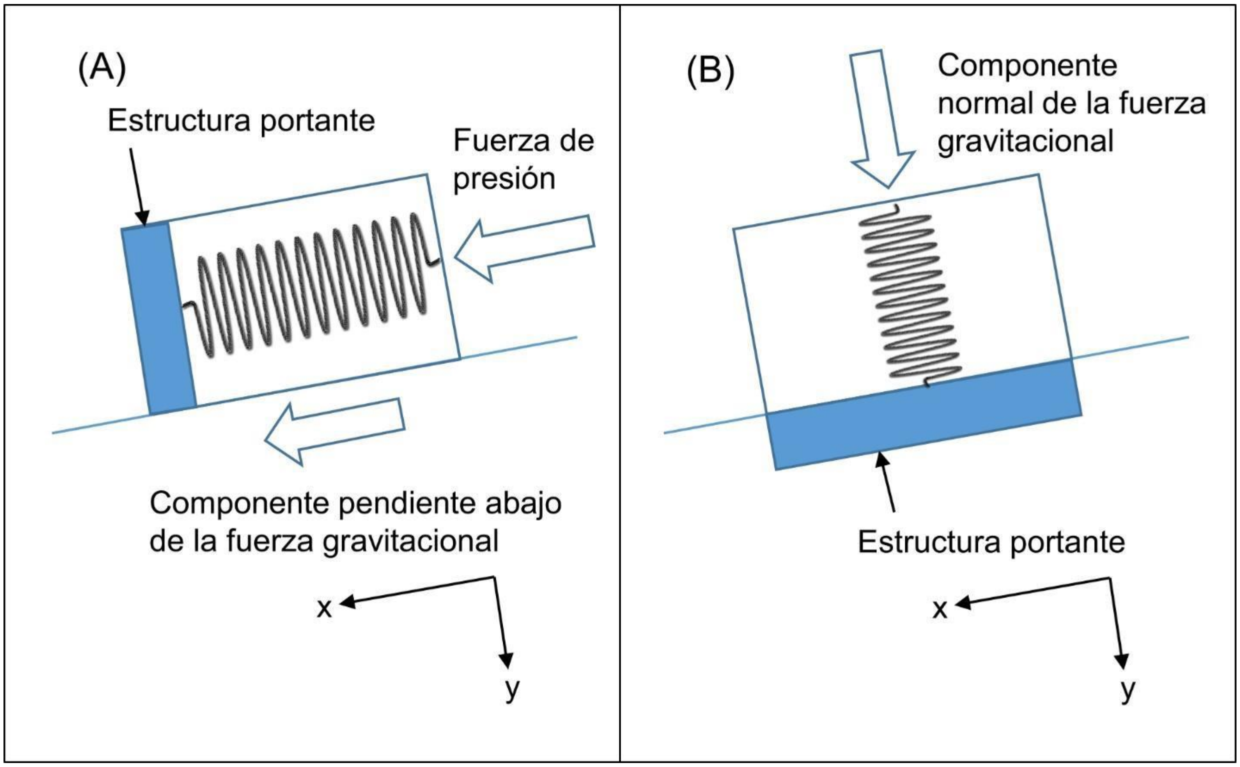


Figure 13. A loaded spring is the simplest model for any deformable solid that has not been stressed beyond its yield point. (A) In the case of a concrete dam, there are some load-bearing structures (shown here as a single reinforced column) that prevent movement of the dam in the downslope direction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

The Tundayme dam had a planned height of 260 metres, which would be the highest tailings dam in the world (the current highest 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 metres. Embankment inclinations were 1:1.5H and 1V:2H for the Tundayme dam and 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 foreseen, as discussed above. For example, with respect to the Tundayme dam, Cardno (2014a) wrote "In the upstream slope of the initial embankment, impermeable facilities (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 dam was 380,097,000 m^3 . The storage volume of Relavera Quimi could be correspondingly lower due to the removal of water from the tailings. 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.

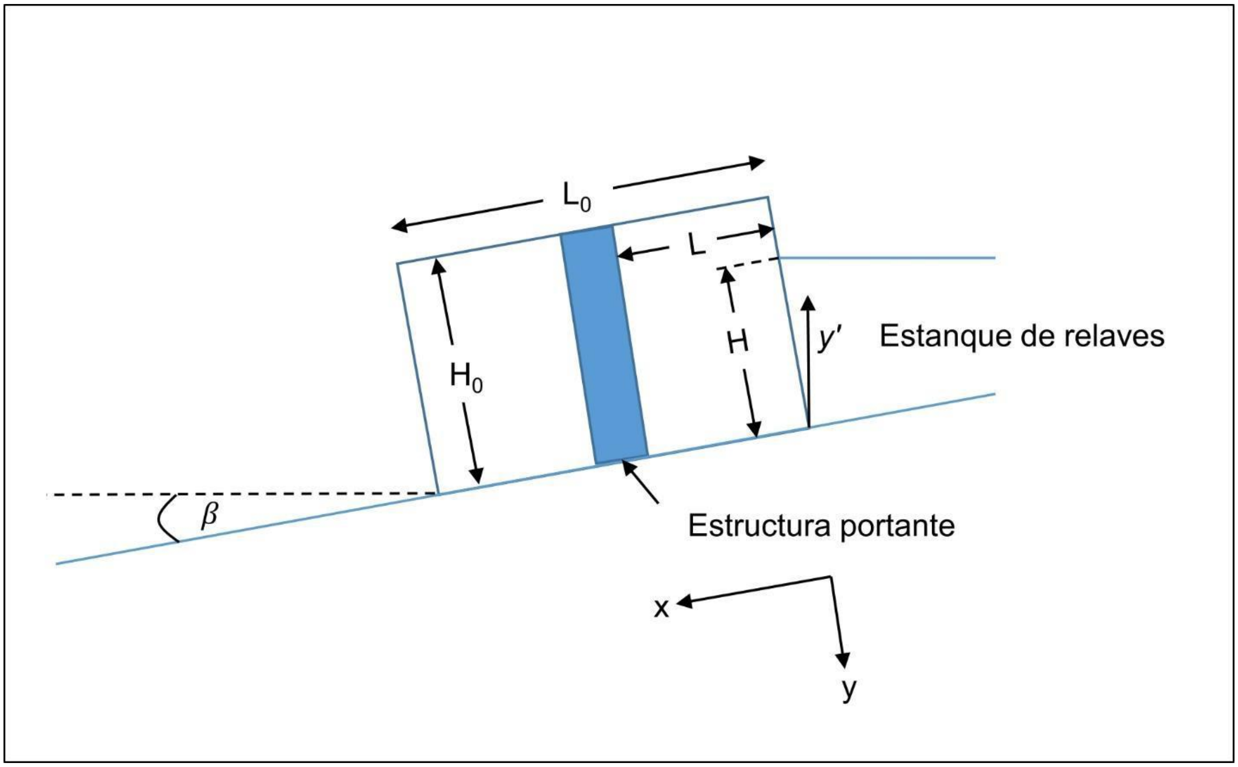


Figure 14. Although the geometry of the earth dam is greatly simplified, it still captures all the forces acting on the dam and the resistances to those forces. The variable *L* is the space in the downslope direction between reinforced columns or other supporting structures, which is shown here as the downslope distance between the upstream edge of the dam and a single supporting structure. Since tailings dams lack reinforcement columns or other defined supporting structures, the load is carried by the entire dam, so that *L* = *L0*. Figure modified from Emerman (2016).

A major change compared to the previous EIS was the reduction in the magnitude of the design flood from the previous choice of Probable Maximum Flood. The design flood for the Tundayme dam was the 500-year flood for the first five years, at which point the dam would be 90 metres high.

The design flood was the 1,000-year flood until the end of the ninth year, when the dam would be 155 metres high. After the ninth year, the design flood would rise to the IMP. The reduction in the magnitude of the design flood was presumably an inappropriate response to the higher floods that would occur in the Tundayme valley. According to Cardno (2014a), "The Tundayme tailings dam is located downstream of the Tundayme River, occupying a large area for stormwater runoff in the upper reaches of the river (52 km^2). Due to the large flows, flood control in rainy seasons is difficult". In general, much less information was available on the Quimi dam than on the Tundayme dam, as the Tundayme dam was the preferred alternative.

The new EIS (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 been increased from 63 metres to 260 metres, the embankment slope had been increased from 1V:2H to 1V:1.5H, and the dam was in a steeper valley (both along the sides and in the direction towards the Quimi River). 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 tailings-water mixture (collectively called the scale and mode of operation), with no other changes to the dam design. The calculation was carried out by modelling the tailings dam as a set of loaded springs and using the spring compressions as a measure of progress towards failure (see Fig. 13). It was found that

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

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

where R_x is the relative risk of failure in the downstream direction, R_y is the relative risk of failure in the normal direction (gravity collapse), ρ_T is the density of the tailings-water mixture, H_0 is the height of the dam, H is the height of the tailings, and subscripts "1" and "2" refer to the first and second scales and modes of operation, respectively (see Fig. 14). The valley slope β was found to be a less important factor and Eqs. (1)-(2) are simplified expressions that neglect the slope (see Fig. 14). Using parameter values available in Cardno (2014a), Emerman (2016) found that, compared to the original plan (referred to as alternative 3 in Cardno (2014a)), the risk of failure in the downstream direction increased by a factor of 17.03 for alternative 1 (Tundayme dam), while the risk of normal failure (gravity 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: Is the design and construction of the tailings dams consistent with widely recognised safety guidelines? After reviewing the construction and causes of tailings dam failure, and the design history of the tailings dams at the Mirador mine, the question can be broken down into the following questions:

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

The questions were addressed by comparing information from the most recent Environmental Impact Study (Cardno 2014a-b) with the standard textbook on tailings dams (Vick, 1990), as well as widely recognised guidelines for design flood and earthquake screening (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 supplemented with photos taken by the author on 6 November 2018, during a visit in the company of Luis Sánchez Zhiminaycela (activist in the Amazonian Community of Social Action Cordillera del Cóndor Mirador; see Fig. 1) and Ing. Evelyne Blondeel of E-Tech International. We were not allowed to enter the mine site and all photos were taken from the road bordering the mine site. It is possible that answers to my concerns can be found in other technical documents that could not be consulted. However, it should be noted that writing this report involved studying 6,384 pages of information produced by the company and its consultants.

Although the above guidelines are not legally enforceable in Ecuador, EcuaCorriente S.A. relied on compliance with the Canadian Dam Association (2013) guidelines in its Environmental Impact Assessment (Walsh Scientists and Engineers, 2010a) and in its responses to questions from the Ecuadorian Ministry of Environment (Walsh Scientists and Engineers, 2011). Therefore, it must be assumed that EcuaCorriente S.A. intends to comply with the Canadian Dam Association (2013) guidelines in all aspects of the project. Certainly, a project that was legal in Ecuador but was inconsistent with internationally recognised guidelines should be 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 inadequate. 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 judgement that failure "*would have a significant environmental impact on downstream watercourses. The economic consequences and socio-economic impact...would also be very high*" [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 higher 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 between 100 and 1,000 years. The interpretation of "significant" risk is that there is a risk only to a temporary population ("temporary use of cabin, passing transportation routes, engaging in recreational activities"), restoration of cultural and environmental values or in-kind compensation is "highly likely", and there will be economic losses only to "recreational facilities, temporary workplaces and little-used transportation routes" (Canadian Dam Association, 2013). It should be clear that the "significant" risk category is irrelevant for a dam 1000 metres upstream from the inhabited village of Tundayme.

Use of Non-Sulphide Tailings for Tailings Dam Construction

The prediction that the coarser tailings will be non-sulphide (non-acid generating) and that only the finer tailings will be sulphide (potential 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 become tailings. None of the available documents indicate the size of the rock samples. However, a published procedure states that measurements of neutralisation potential and acidity potential were performed on two gram samples (Skousen et al., 2001). On that basis, 21 x 2 grams = 42 grams represents less than 10^{-13} (less than one part in ten trillion) of the expected 657 million tonnes of mine tailings (60,000 tonnes per day for 30 years). Furthermore, none of the documents contain any measure of the uncertainty (error bounds) in the prediction that 87% of the processed ore will become coarser tailings (assumed to be non-sulphide).

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 Quimi River (see Figure 11), opposite the Quimi tailings dam. Photo taken by the author on 6 November 2018.

Figure 16. The initial dam for the Quimi tailings dam was built at the edge of the road, the other side of which is the river Quimi (see Fig. 11). Since it is not possible to advance the dam further in the downstream direction, the intention must be to construct the entire dam using the upstream method (compare Figures 5a-c). This is inconsistent with the design assessed by Knight-Pièsold (2007) and both Environmental Impact Studies (Walsh Scientists and Engineers, 2010b; Cardno, 2014a), both of which included centreline construction for the Quimi tailings dam. Tailings dams constructed by the upstream method are more susceptible to failure by both earthquakes and flooding. Due to the inability to install impermeable layers (see Figures 5a-c, 8), their higher water content also makes them more susceptible to failure by internal erosion, static liquefaction and foundation failure. Photo taken by the author on 6 November 2018.

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

1) Sulphide tailings will either be used to build the dams or there will be a change in the limiting value that defines the sulphide content that counts as "sulphide". Either 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 accommodate the lack of construction material. For example, the embankment slope will be made steeper or there will be a change from centreline construction to upstream construction, which requires less construction material.

As mentioned by Kuipers (2012) and the Independent Expert Engineering Investigation and Review Panel (2015), the "Observation Method" only makes sense if they are ways to adapt to new observations.

Figure 17. The initial embankment for the Quimi tailings dam has a slope of 1V:1H (45°). This is inconsistent with the design assessed by Knight-Pièsold (2007; see Figure 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 (factor of safety = 1,0). In contrast, according to the US Army Corps of Engineers (USACE, 2000), "for sand levees, a downstream slope of 1V at 5H [11.3°] is considered sufficiently flat to prevent seepage damage exiting the downstream slope [internal erosion]". Photo taken by the author on 6 November 2018.

Additional Tailings Dam Failure Risks

None of the documents provided by EcuaCorriente S.A. or its consultants have addressed the risk of landslides, despite being asked to provide this information by the Ecuadorian Ministry of Environment (Walsh Scientists and Engineers, 2011b). The problem is particularly acute in the steep valley of the Tundayme River (see Fig. 12).

From a cost reduction point of view, one of the advantages of this site is that it is possible to use the slopes as walls for the Tundayme tailings dam, instead of the Quimi tailings dam, which requires the construction of walls on three sides of the reservoir (Cardno, 2014a; see Fig. 1).

The

The main landslide threat is that rockfall 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 Quimi River 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 18. The sign makes it clear that both the Quimi tailings dam (see Figures 1, 16 and 17) and the Tundayme tailings dam are currently under construction. This is inconsistent with the Environmental Impact Assessment (Cardno, 2014a), which listed the two tailings ponds as alternatives. Photo taken by the author on 6 November 2018.

Contradictions between Construction and Design

There are three major contradictions between the actual construction and design of the tailings management facilities at the Mirador mine. The first is that the Quimi dam is being constructed using the upstream method. The initial dam for the Quimi tailings dam was built on the edge of the road, the other side of which is the Quimi River (see Figs. 11 and 16). Since it is not possible to advance the dam further in the downstream direction, the intention must be to construct the entire dam using the upstream method (compare Figs. 5a-c).

This is inconsistent with the design assessed by Knight-Pièsold (2007) and both the environmental impact (Walsh, 2010b; Cardno, 2014a), which included the construction of the centreline for the Quimi tailings dam. Tailings dams constructed by the upstream method are more susceptible to failure by both earthquakes and flooding. Due to the inability to install impermeable layers (see Figures 5a-c, 8), their higher water content also makes them more susceptible to failure by internal erosion, static liquefaction and foundation failure.

The second contradiction is that a simple application of trigonometry shows that the initial embankment of the Quimi dam (see Fig. 17) has a slope of 1V:1H (45°). This is inconsistent with the design assessed by Knight-Pièsold (2007; see Figure 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 the maximum critical angle to prevent internal erosion of the dam without any margin of error (safety factor = 1.0).
In other words, the initial dam was built at the point of failure, and is in danger of failing as soon as the tailings dam fills with wet tailings.

Figure 19a. Overflow from the sedimentation ponds for the Tundayme tailings dam is discharged into a pipe and flows into the Quimi River (see Figure 11). Photo taken by the author on 6 November 2018.

The most striking contradiction of all is that both tailings dams, 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 Figures 1, 11, 16, 17 and 18). There are at least three possible interpretations of the appearance of the two tailings ponds:

1) The mine will process 60,000 tonnes of ore per day using both tailings dams to store tailings.
2) The mine will process 90,000 tonnes of ore per day by storing 60,000 tonnes of wet tailings per day in the Tundayme tailings dam and 30,000 tonnes of wet tailings per day in the Quimi tailings dam.
3) The mine will process 120,000 tonnes of ore per day by storing 60,000 tonnes of wet tailings per day in the Tundayme tailings dam and 60,000 tonnes of dewatered tailings per day in the Quimi tailings dam.

It is impossible to decide which interpretation is correct when there is no apparent connection between the designs and the actual construction. Similarly, 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 internal erosion failure due to its excessively steep slope (see Fig. 17).

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

The Tundayme tailings dam is not even being built with due respect for the protection of the Quimi River. The sedimentation ponds are supposed to prevent the flow of muddy water from the construction site from entering the Quimi River. However, the overflow from the sedimentation ponds for the Tundayme tailings dam is discharged into a pipe and flows into the Quimi River (see Figs. 19a-b). The grey colour of the discharge from the sedimentation ponds shows that the sedimentation ponds are not functioning (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 fine particle sedimentation.

Figure 19c. The grey colour of the discharge from the sedimentation ponds shows that the sedimentation ponds are not functioning (Quishpe Lozano et al., 2018). Photo taken by the author on 6 November 2018.

DISCUSSION

Explanation for Contradictions between Construction and Design

A possible explanation for the change from centreline construction to upstream construction (see Fig. 16) and the excessively steep slope of the initial dam (see Fig. 17) can be found in a complaint by the provincial government of Zamora Chinchipe against EcuaCorriente S.A. According to the complaint "Here the extraction of stone material in a portion of the Tundayme River [shown above]. As in the Quimi and Waywayme rivers [see Figures 2 and 11], the extraction of stone material in this area does not take place within any mining concession for the exploitation of aggregates and stone...It should be noted that in the review of the national Mining Cadastre, no mining titles for the exploitation of stone material were registered within the Mirador project in the aforementioned area" (Quishpe Lozano et al., 2018). One 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 20. According to a complaint by the provincial government of Zamora Chinchipe (Quishpe Lozano et al., 2018), "Here the extraction of stone material was taking place in a portion of the Tundayme River [shown above]. As in the Quimi and Waywayme rivers [see Figures 2 and 11], the extraction of stone material in this area is not carried out within any mining concession for the exploitation of aggregates and stone...It is worth noting that in the review of the national Mining Cadastre, no mining titles for the exploitation of stone material within the Mirador project in the aforementioned area are registered". A possible explanation for the illegal extraction of construction material from the rivers is the lack of other sources of construction material. A shortage of construction material could also explain the change from centreline construction to upstream construction (see Figure 16) and the excessively steep embankment of the initial embankment (see Figure 17). Photo taken by the author on 6 November 2018.

These changes in construction as a result of a shortage of construction material are a repeat of the sequence of events that led to the failure of the tailings dam at the Mount Polley mine. The failure to reassess 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*" [It was planned to place the Zone C slope at an "interim" slope of 1.4H:1V, rather than the design basis 2.0H:1V, as a temporary expedient until mine waste delivery can catch up with construction ... But instead of rectifying the steep interim slopes at this time as planned, such measures were left for future stages of embankment raising...Instead of adhering to a centreline configuration, Raise 2 used a fully upstream construction...These construction conditions were never reconciled with the Stage 2 stability analyses, which had been based on the original design configuration].

Mirador Tailings Dam Failure Probability

It is now appropriate to rigorously consider the failure probabilities of the Tundayme and Quimi dams. Knight-Pièsold (2007) determined that the probability of failure of the original Quimi dam design due to seismic liquefaction was 0.21% in a given year and 6.13% over 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 were used to build the Tundayme dam with changes only to the dam and tailings heights, the annual failure probability would be 17.03 x 0.21% = 3.59%, for a probability of failure over the 30-year 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 moved from the Quimi valley (7% down slope towards the Quimi river) to the Tundayme valley (13% down slope towards the Quimi river).
3) The Tundayme tailings dam is in a larger catchment (with larger floods) and the design flood has been changed from the Probable Maximum Flood to the 500-year flood.
4) There appears to be no commitment to build according to design, especially no commitment to use the centreline construction method. It is important to note that the upstream construction method is more susceptible to all causes of dam failure.

The changes in the Quimi dam (change from centreline construction to upstream construction, steepening of the embankment slope from 1V:2H to 1V:1H) also increase the failure probability of the Quimi dam. On the above basis, the failure probabilities of both dams are so high that they must be considered as inevitable.

Consequences of Tailings Dam Failure

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

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

where *H* is the height of the dam (metres), V_T is the total confined volume of tailings and water (million cubic metres), and *VF* is the spill volume (million cubic metres). The spill volume and initial surge Dmax (kilometres) can be predicted as

$$V_F = 0.332 \times V_T^{0.95} \tag{4}$$

$$D_{max} = 3.04 \times H_f^{0.545} \tag{5}$$

Inserting *H* = 260 metres and V_T = 390.097 million cubic metres (for Tundayme Dam; Cardno (2014a)) into Eqs. (3)-(5) produces *VF* = 94 million cubic metres and a *Dmax* value of just under 350 kilometres. 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 tailings dam failure consequences. The largest tailings spill in history was due to the failure of the Fundão dam in Brazil in 2015, which spilled 32 million cubic metres of water and tailings (Larrauri and Lall, 2018). With a height of 90 metres, the Fundão dam was also the highest tailings dam to ever fail (Larrauri and Lall, 2018). Even that dam with a smaller *H* and *VF* than the Tundayme dam resulted in a measured *Dmax* of 657 kilometres (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 VERY HIGH hazard category by Knight-Pièsold (2007) should also be reconsidered. 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 Canadian Dam Association (2013) classification system, the only risk category higher than VERY HIGH is EXTREME. This risk category includes probable deaths of more than 100 people, large loss of critical fish habitat, and the impossibility of restoration or in-kind compensation. To summarise this discussion, failure of the tailings dams at the Mirador mine is inevitable and the consequences will be extreme.

CONCLUSIONS

The main findings of this report are summarised below:

1) The design criteria of capacity to withstand a 500-year flood and a 500-year earthquake are inadequate for tailings dams, whereby failure would result in loss of life and extensive environmental damage.
2) The assumption that the coarser tailings will not be sulphide bearing cannot be relied upon in the construction of tailings dams from the same tailings.
3) No assessment of the risks posed by landslides or high erosion rates in the mining project area has been carried out.
4) Contrary to design, the Quimi dam is being constructed using the upstream construction method, which is more susceptible to all causes of tailings dam failure.
5) Contrary to design, the Quimi dam has an embankment slope of 1V:1H, which is the maximum critical angle for the prevention of internal erosion failure. From this point of view, the dam is susceptible to failure as soon as the tailings dam is filled with wet tailings.
6) Contrary to the design, both the Quimi dam and the Tundayme dam alternatives are currently under construction.
7) Tailings dam failure 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 should 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 that evaluated the Mount Polley (Independent Expert Engineering Investigation and Review Panel, 2015) and Fundão (Fundão Tailings Dam Review Panel, 2016) tailings dam failures. Contrary to previous expert panels, it is recommended that this panel be convened before the disaster rather than after.

EXPRESSIONS OF GRATITUDE

I thank Ing. Evelyne Blondeel of E-Tech International for her assistance during the mine site visit.

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Dr. Steven H. Emerman holds a *B*.S. in Mathematics from The Ohio State University, an M.A. in Geophysics from Princeton University, and a Ph.D. in Geophysics from Cornell University. Dr. Emerman has 31 years of teaching experience in hydrology and geophysics and has 66 peer-reviewed publications in these areas. Dr. Emerman is the owner of Malach Consulting, which specialises in assessing the environmental impacts of mining for mining companies as well as governmental and non-governmental agencies.

REFERENCES

AMEC Earth & Environmental, 2004. Preliminary Mine Closure and Reclamation Plan, Mirador Project, Ecuador.

Canadian Dam Association, 2013. Dam safety guidelines 2007 (2013 edition) [Dam safety guidelines 2007 (2013 edition)], 88 p.

Campaña, J., L. Valenzuela, and A. Figueroa, 2015. The Quillayes sand tailings dam in Chile-design and operation: Proceedings Tailings and Mine Waste 2015 Vancouver, BC, 14 p. Available online at: https://open.library.ubc.ca/cIRcle/collections/59368/items/1.0320846

Cardno, 2014a. Update of the Impact Study and Environmental Management Plan, for the Metallic Minerals (copper) Beneficiation Phase, Expansion from 30 kt per day to 60 kt per day of the Mirador Mining Project, Mining Concession "Mirador 1 (cumulative)": Report to EcuaCorriente S.A., 1206 p. with 6 annexes (1125 p.).

Cardno, 2014b. Update of the Impact Study and Environmental Management Plan, for the Open Pit Mining Phase of Metallic Minerals (copper), Expansion from 30 kt per day to 60 kt per day of the Mirador Mining Project, Mining Concession "Mirador 1 (cumulative)": Report to EcuaCorriente S.A., 1130 p. with 6 annexes (1182 p.).

Connors, S.R., E.L. Hadley, M. Hansen, and S.H. Emerman, 2016. Reassessment of a tailings flow slide calculator: Geological Society of America Abstracts with Programs, v. 48, no. 7. Available online at: https://gsa.confex.com/gsa/2016AM/webprogram/Paper281555.html

Davies, M.P., 2002. Tailings impoundment failures-Are geotechnical engineers listening? Geotechnical News, November 2002, pp. 31-36.

Emerman, S.H., 2014. Prediction of transport of mine tailings following failure of an earthen dam on the Rio Quimi, Ecuador: Report to E-Tech International, 7 p.

Emerman, S.H., 2015. Prediction of mine tailings transport in suspended load following failure of an earthen tailings dam on the Quimi River at the Mirador mine, Ecuador: Report to E-Tech International, p. Available online at: https://static1.squarespace.com/static/52d71403e4b06286127a1d48/t/564a18c0e4b0f19eae571949/1447696576435/Espanol-Emmerman-Mine-Tailing-Transport111515.pdf.

Emerman, S.H., 2016. Effect of scaling on the safety of earthen dams-Application to a proposed expansion of the Mirador Mine, Ecuador: Report to E-Tech International, 11 p.

European Commission, 2009. Reference document on best available techniques for management of tailings and waste-rock in mining activities. 557 p. Available online at: http://eippcb.jrc.ec.europa.eu/reference/bref/mmr_adopted_0109.pdf

FEMA (Federal Emergency Management Agency), 2005. Federal guidelines for dam safety-Earthquake analyses and design of dams, 2005.

dam design]: FEMA-65, 75 p. Available online at: https://www.ferc.gov/industries/hydropower/safety/guidelines/fema-65.pdf

FEMA (Federal Emergency Management Agency), 2012. Summary of existing guidelines for hydrologic safety of dams: FEMA P-919, 474 p. Available online at: https://www.fema.gov/media-library- data/20130726-1849-25045-1538/01_hydrosafetydam_intro.pdf

FEMA (Federal Emergency Management Agency), 2013. Selecting and accommodating inflow design floods for dams: FEMA-94, 38 p. Available online at: https://www.fema.gov/media-library-data/1386108128706-02191a433d6a703f8dbdd68cde574a0a/Selecting_and_Accommodating_Inflow_Design_Floods_for_Dams.PDF.

Fisher, W.D., T.K. Camp, and V.K. Krzhizhanovskaya, 2017. Anomaly detection in earth dam and levee passive seismic data using support vector machines and automatic feature selection: Journal of Computational Science, v. 20, pp. 143-153.

Fourie, A.B., J.H. Palma, G. Villavicencio and R. Espinace, 2013. Risk minimisation in construction of upstream tailings storage facilities based on in-situ testing [Minimisation of risk based on in-situ testing during construction of tailings storage facilities using the upstream method]: Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris 2013, pp. 1471-1474.

Holtz, R.D., W.D. Kovacs, and T.C. Sheahan, 2011. An introduction to geotechnical engineering, 2nd ed.: Pearson, 863 p.

Imprensa Nacional [National Press], 2018. Resolução Nº 4, de 15 de fevereiro de 2019 [Resolution No. 4, of 15 February 2019]. Disponible en línea en: http://www.in.gov.br/materia/-/asset_publisher/kujrw0tzc2mb/content/id/63799094/do1-2019-02-18-resolucao-n-4-de-15-de-fevereiro-de-2019-63799056

Independent Expert Engineering Investigation and Review Panel, 2015. Report on Mount Polley Tailings Storage Facility breach: Report to Ministry of Energy and Mines and Soda Creek Indian Band, 156 pp. Available online at: https://www.mountpolleyreviewpanel.ca/sites/default/files/report/ReportonMountPolleyTailingsStorageFacilityBreach.pdf

Jeyapalan, J.K., J.M. Duncan, and H.B. Seed, 1983. Analyses of flow failures of mine tailings dams: Journal of Geotechnical Engineering, v. 109(2), pp. 150-171.

Klohn Crippen Berger, 2017. Study of tailings management technologies: Report to Mine Environment Neutral Drainage (MEND) Program, MEND Report 2.50.1, 164 p. Available online at: http://mend-nedem.org/wp-content/uploads/2.50.1Tailings_Management_TechnologiesL.pdf

Knight-Pièsold, 2007. Rio Quimi Tailings Management Facility Feasibility Study for 27,000 tpd mine production. Ref. No. VA201-78/09-2, 111 p.

Kuipers, J., 2012. Evaluation of the stability of the Mirador Project Tailings Management Facility and an estimation of financial assurance requirements for the Mirador Copper Project, Ecuador: Report to E-Tech International, 20 p.

Larrauri, P.C. and Lall, U., 2018. Tailings dams failures-Updated statistical model for discharge volume and runout: Environments, v. 5. Available online at: doi:10.3390/environments5020028.

Fundão Tailings Dam Review Panel, 2016. Report on the immediate causes of the failure of the Fundão Dam: Report to Cleary Gottlieb Steen & Hamilton, LLP, 88 p. Available online at: http://fundaoinvestigation.com/wp- content/uploads/general/PR/en/FinalReport.pdf

Le Poudre, D.C. (SNC Lavalin), 2015. Examples, statistics and failure modes of tailings dams and consequence of failure, Power Point Presentation, 42 slides. Available online at: https://www.esaa.org/wp-content/uploads/2015/10/15-LePoudre.pdf

NWS-HDSC (National Weather Service - Hydrometeorological Design Studies Center), 2017. Current NWS Probable Maximum Precipitation (PMP) Documents. Available online at: http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html

Quishpe Lozano, S., E.G. Peña Otaneda, M.R. Vargas Santi, and M. Santi Gualinga, 2018. Complaint against EcuaCorriente S.A.: Fiscalía General del Estado - Ecuador, Document No. FGE-GD-2018-005305-EXT, 13 p.

Skousen, J., J. Simmons, and P. Ziemkiewicz, 2001. The use of acid-base accounting to predict post-mining drainage quality: Proceedings, America Society of Mining and Reclamation, pp. 437-447. Available online at: https://www.asmr.us/Portals/0/Documents/Conference-Proceedings/2001/0437-Skousen.pdf

TailPro Consulting, 2018. Conventional Impoundment Storage - The Current Techniques. Available online at: http://tailings.info/disposal/conventional.htm

USACE (U.S. Army Corps of Engineers), 2000. Design and construction of levees: Handbook No. 1110-2-1913, 164p. Available online at: https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1913.pdf.

USACE-HEC (U.S. Army Corps of Engineers - Hydrologic Engineering Center), 2003. Application of paleohydrology to Corps flood frequency analysis.

Paleohydrology to Corps flood frequency analysis]: RD-47, 34 p. Available online at: http://www.hec.usace.army.mil/publications/ResearchDocuments/RD-47.pdf
Vick, S.G., 1990. Planning, design, and analysis of tailings dams: BiTech Publishers, Vancouver, Canada, 369 p.
WMO (World Meteorological Organization), 2009. Manual on estimation of probable maximum precipitation: WMO-No. 1045, 257 p. Available online at: http://www.wmo.int/pages/prog/hwrp/publications/PMP/WMO%201045%20en.pdf
Walsh Scientists and Engineers, 2010a. Environmental Impact Assessment for the Open Pit Mining Phase of the Mirador Copper Mining Project-Mirador 1 - Mirador 2 Mining Areas-Ecuacorriente S.A. (ECSA): Walsh Project Number EC155-13, 748 pp.
Walsh Scientists and Engineers, 2010b. Environmental Impact Assessment for the Beneficiation Phase of the Mirador Copper Mining Project-Mirador 1 - Mirador 2 Mining Areas-Ecuacorriente S.A. (ECSA): Walsh Project Number EC155-14, 772 p.
Walsh Scientists and Engineers, 2011a. Environmental Management Plan: Walsh Project Number EC155-14, 92 pp.
Walsh Scientists and Engineers, 2011b. Response comments on the Environmental Impact Assessment for the Beneficiation Phase of the Mirador Copper Mining Project: Walsh Project Number EC155-14, 110 p.
World Mine Tailings Failures Failures [World Mine Tailings Failures], 2018. World Mine Tailings Failures-from 1915. Available online at: https://worldminetailingsfailures.org/

Annex 2: Preliminary list of communities affected by the environmental, safety, and other social impacts of the Mirador Mine.

	LOCAL NAME	NAME: OPEN STREETMAP PLACES DATABASE	PROVIN-CIA	CAN-TON	PARRO-QUIA	Latitude	Length
1	Tundayme (header parish)	Tundayme	Zamora Chinchipe	El Pangui	Tundayme		
	Churuwia and Etsa		Zamora Chinchipe	The Pangui	Tundayme		
	Quimi Valley[1] 3 km south of the Mirador project		Zamora Chinchipe	El Pangui	Tundayme	-3,53794° o 3° 32' 17" south	-78,45634° o 78° 27' 23" west
	The Quimi		Zamora Chinchipe	El Pangui	Tundayme	-3,58672° o 3° 35' 12" south	-78,51496° o 78° 30' 54" west
5	Machinaza High		Zamora Chinchipe	The Pangui	Tundayme		
	Yanua Kim		Zamora Chinchipe	The Pangui	Tundayme		
	Chuchumbletz a	Chuchum-bletza	Zamora Chinchipe	The Pangui	El Güismi		
	San Carlos Numpai,		Zamora Chinchipe	The Pangui	Tundayme		
8	Whirlpool 2 Chuchumbletz a						
	Machinias (Whirlpool 1)						
	Bomboiza Gualaquiza-Morona S.		Zamora Chinchipe	Guala-mayb e	Bomboiza		
	Shiram Enta						
	Bell Entsa	Campana-ka Entsa					
	Narvaez						
	Ayantás						
	Piunts-San José						
	Procurement	Procurement					
	Union of Bomboiza Zamora	Union of the two rivers?					

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

	LOCAL NAME	NAME: OPEN STREETMAP PLACES DATABASE	PROVIN-CIA	CAN-TON	PARRO-QUIA	Latitude	Length
	Community Arenal	Arenal					
	Yantsas San Luis						
	The Tiink		Morona Santiago				
21	Yukutais						
	Asau	Asao	Morona Santiago				
	Shuar Centre Wapis						
	Fincas mestizo populations downstream of Asau to centre Pupu						
25	Pupu						
26	Tsunsuim						
	Upundios						
	Parish of San Carlos de Lemon	San Carlos de Limón	Morona Santiago	San Juan Bosco	San Carlos de Limón		
29	Nankints,						
30	Community 27 of February						
31	Akarunts						
	Mixed-race populations from Akarunts to the community La Victoria						
	La Victoria						
	Shuar Ampam						
35	Ampakai						
	Mayapis						
	Yunkumas - Tarq.						
	The Union						
	Yukiantza						
	Kuankus						
	Shuar Centre Kapisun						
42	Shuar Centre Suritiak						

	LOCAL NAME	NAME: OPEN STREETMAP PLACES DATABASE	PROVIN-CIA	CAN-TON	PARRO-QUIA	Latitude	Length
	Shuar Centre Pandam						
	Shuar Centre Nantip						
45	Shuar Centre Kim						
46	Shuar Centre Kushapuk						
	Santiago - City Tiwintza						
	Shuar Centre Mayaik						
49	Shuar Centre Kaputna						
50	Shuar Centre Peñas						
51	Jempekat Shuar Centre (Union of Yaupi Santiago						
	Peruvian Shuar Centres on the banks of the river Santiago						

Annex 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 sulphide 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 resulting 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 TMFAtotal 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 recognised 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		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%		
Total Closure Costs (rounded)			$55,000,000		$568,000,000

Annex 4: Letter from the National Assembly to the Ministry of Energy and Non-Renewable Natural Resources. Subject: Request for Information. Oficio No. AN-QLS- 2022-0030-O. 2022.

Oficio No. AN-QLS-2022-0030-O

Quito, D.M., 17 February 2022

Subject: REQUEST FOR INFORMATION

Mr. Engineer
Juan Carlos Bermeo Calderon
Minister of Energy and Non-Renewable Natural Resources
MINISTRY OF ENERGY AND NON-RENEWABLE NATURAL RESOURCES
In his office

Yours sincerely

In my capacity as National Assemblyman for the period 2021 - 2025, I extend my cordial greetings, and in accordance with the provisions of the Constitution of the Republic of Ecuador, in numeral 9 of Article 120 and Article 18 numeral 2, in accordance with Articles 74, 75 and 110 numeral 3 of the Organic Law of the Legislative Function in accordance with Articles 22 and 23 of the Organic Law of Transparency and Access to Public Information, and in response to the request made to me by my office, 75 and 110 numeral 3 of the Organic Law of the Legislative Function in accordance with articles 22 and 23 of the Organic Law of Transparency and Access to Public Information and in response to the request made to my office by Acción Ecológica, signed by its president Ivonne Yánez. I request the urgent delivery to my office of certified and paginated copies of the following documents regarding the Mirador large-scale mining project, which is being developed in the province of Zamora Chinchipe, canton El Pangui, parishes of Tundayme and El Gúismi:

1. Supporting Information of the Oficio N° ECSA-HSE-2019-104, dated 3 May 2019, by which ECSA requested to the Zonal Coordination of Mining South the scope of the feasibility issue of the Tundayme tailings dam and its optimised facilities, attaching the Report "DESCRIPTION OF TUNDAYME TAP AND OPTIMISATION OF THE FACILITIES, MIRADOR PROJECT, PRODUCTION 60000 TONS PER DAY", dated May 2019. In this way
in particular, the delivery of the following documents:

- Report with the description of the Tundayme Relay and optimisation of the installations (printed and digital).
- ANNEX l. Relavera Tundayme plans.
- ANNEX 2. Drawings of the Temporary Diversion Tunnel - Starting Dike.
- ANNEX 3. Clean Water Diversion Infrastructure Plans of the Tundayme River
- ANNEX 4. Plans of Water Drainage Infrastructure of the Tundayme Spring ANNEX
- 5. Geotechnical Studies (CD)
- APPENDIX 6. Main Dam - Tundayme Dam Plans
- ANNEX 7. Plans Interceptor Channel Access # 12 - Relavera Tundayme
- ANNEX 8. Drawings of the Tundayme River Clean Water Diversion Tunnel Overflow Dike ANNEX
- 9.

2. Supporting information of Technical Report No. 0141-CRMZ-2018, dated 21 February 2018; issued by the Regional Coordination of Zamora Mines of the Mining Regulation and Control Agency, with subject: VERIFICATION OF TECHNICAL INFORMATION ANALYSIS OF PLANS OF THE MIRADOR MINING PROJECT (Cia. ECUACORRIENTE S.A.). OF THE WORKS

Oficio No. AN-QLS-2022-0030-O

Quito, D.M., 17 February 2022

CONDITIONED IN THE ENVIRONMENTAL LICENCE FOR THE EXPLOITATION PHASE OF METALLIC MINERALS. We request the delivery of the Technical Reports in support of the Analysis of the Information Submitted on the Works Conditioned in the Environmental Licence Mineral Exploitation Phase, and the Annexes of Technical Information and Memoranda, detailed below:

WORK	OFFICE	TECHNICAL REPORT	DATE REPORT
NORTH EAST (South)	ARCOM-Z-CR-2017-0002-OF	No. 03-DTSCT-Z-2017	01 - January - 2017
WATER DIVERSION CHANNELS SLAG HEAP	ARCOM-Z-CR-2016-1694-OF	No. 855-DTSCT-Z-2016	08 - November - 2016
DIKE AND ACID DRAINAGE BASIN	ARCOM-Z-CR-2018-0222-OF	TECHNICAL REPORT No-085-CRMZ-2018	28 January of 2018
EXPLOSIVES MIXING PLANT	ARCOM-Z-CR-2017-0476-OF	MEMO: ARCOM-CGCM-2017-1381-ME	September - 2017
FLOOD CONTROL CHANNELS OF ACID WATER RESERVOIRS	THIS WORK IS INCLUDED IN ACID WATER DRAINAGE	TECHNICAL REPORT No-085-CRMZ-2018	28 January of 2018
ACID WATER TREATMENT PLANT	THIS CONSTRUCTION SITE IS PART OF THE BENEFICIATION PLANT.	TECHNICAL REPORT No-1062-DTSCT-Z-2016	27 December 2016
SEDIMENTATION PONDS	ARCOM-Z-CR-2017-1032-OF	ARCOM-CGRCM-2017-0972-MM	14 - June - 2017
RETAINING WALL OF THE HEAP	THIS CONSTRUCTION SITE IS PART OF THE WASTE DUMP	No. 03-DTSCT-Z-2017	01 - January - 2017
DYKE MONITORING WELLS	IS PART OF THE ACID DRAINAGE DYKE.	TECHNICAL REPORT No-085-CRMZ-2018	28 January of 2018
MINE AND WASTE ROCK CRUSHING PLANT PLATFORMS	ARCOM-Z-CR-2017-0002-OF	No. 01-DTSCT-Z-2017	03 - January - 2017

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Quito, D.M., 17 February 2022

ANNEXES - TECHNICAL REPORTS AND

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

3. Supporting information of Technical Report No. 0137-CRM7.-2018, dated 21 February 2018; issued by the Regional Coordination of Mines Zamora of the Mining Regulation and Control Agency, with subject: VERIFICATION OF TECHNICAL INFORMATION AND ANALYSIS OF PLANS OF THE TUNDAYME TREAP AND ITS INSTALLATIONS OF THE MINING PROJECT.
MIRADOR (Cia. ECUACORRIENTE S.A). The information supporting this report is similar to that of Technical Report No. 0141-CRMZ-2018, and we therefore ratify our express request for access to public information indicated in the previous paragraph.
4. Supporting information of Technical Report No. 0156-CGRMZ-2018, dated 27 November 2018, issued by the Regional Coordination of Minas Zamora of the Mining Regulation and Control Agency, with subject: ANALYSIS OF TECHNICAL INFORMATION OF THE TREATMENT PLANT OF AQUEID WATER FROM FILTRATION OF THE RELAVERA DAM.
TUDAYME (PROFIT). We request the delivery of the information submitted by the TUNDAYME TUNDAYME TUNDAYME DAM FILTRATION WATER TREATMENT PLANT, 3.1 PLANS SUBMITTED:

ANNEX 01

- General implementation of the Acid Drainage Treatment plant (1 piano). Process flow
- diagram.
- Implementation of the acid water treatment plant. Water
- supply and drainage pipe system (1). Water supply and
- drainage pipe system (2). Cutting of the processing
- station.
- Longitudinal section of the dyke (2 pianos).

ANNEX 02.

- General implementation of seepage water dams.

ANNEX 03.

- Tailings pond acid water treatment plant filtration calculation

Oficio No. AN-QLS-2022-0030-O

Quito, D.M., 17 February 2022

ANNEX 04.

- Environmental management plan for the beneficiation phase including contingency plan (1CD).

With kind regards. Yours sincerely

Electronically signed document

Mr. Salvador Quishpe Lozano
ASSEMBLY

Copy:

Mr Lawyer
Edy Alquímedes Jadan Sarango
Advisor Level 2

Mr. Magister
Angel Virgilio Medina Lozano
General Coordinator for Inter-Agency Relations