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Review of the Environmental Impact Study for a New Facility for Co-Disposal of Tailings and Waste Rock at the Barrick Gold Pueblo Viejo Mine, Dominican Republic

REPORT AUTHOR
Steven H. Emerman, Ph.D., Malach Consulting

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REPORT AUTHOR
Steven H. Emerman, Ph.D., Malach Consulting, LLC
785 N 200 W, Spanish Fork, Utah 84660, USA
Tel: 1-801-921-1228,
E-mail: SHEmerman@gmail.com

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COVER PHOTO
The existing El Llagal tailings impoundment at the Pueblo Viejo mine is nearly full.
Source: Jan Morrill, Earthworks

Communities living within the Reserva Fiscal Montenegro – located in the District of Zambrana in the municipality of Cotuí and province of Sánchez Ramírez – have been living through a continuous drama that has been unfolding for over a decade. Daily, over 450 families experience significant risks to human life and environmental disaster, living either within the boundaries of Barrick Gold's PVDC mining lease or within the immediate vicinity of the El Llagal tailings dam, with some families living barely 100 metres from the dam's wall.

Within a context of systematic protest and community conflict, the National Space for Transparency in the Extractive Industry (ENTRE) has accompanied communities in La Piñita, La Laguna, La Cerca, El Naranjo, Jurungo and Jobo Claro, responding to the calls for solidarity by the Comité Nuevo Renacer in providing technical and scientific support to study the reality they face – in particular, to review the mining company's plans to build a new tailings impoundment ("El Naranjo TSF") very close to the existing dam.

It was this relationship of solidarity with ENTRE, the Dominican Observatory of Public Policy - UASD, as well as MiningWatch and Earthworks – institutions specialized in monitoring extractivism, mining, tailings, and the environment – that made possible a contract with Dr. Steven H. Emerman. Over the course of his career, Dr. Emerman has produced over a hundred reviews of impact studies related to tailings on all continents, providing testimony before multilateral and international organizations, as well as governments.

This initiative by the Comité Nuevo Renacer and affected communities has helped facilitate the production of the following expert review of the Environmental Impact Study [for the Naranjo TSF]. We now put this publication into the hands of the public in an effort to spark critical reflection and encourage citizen empowerment, to ensure science and the law can avert danger and ultimately avoid disaster.

The above text was written by the Comité Nuevo Renacer to provide important context to the rest of the report, written by Dr. Steven H. Emerman.

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Lighting Summary

Barrick Gold has proposed the construction of a new facility for the co-disposal of 344.7 million metric tons of combined tailings and 452.7 million metric tons of potentially acid generating (PAG) waste rock behind a dam with a height of 157 meters at the open-pit Pueblo Viejo gold-silver mine in the Dominican Republic. The Environmental Impact Study (EIS) does not consider the alternative of backfill of the exhausted open pits and quarries, although such consideration is required by the Global Industry Standard on Tailings Management (GISTM) and backfill could be carried out at less than 35% of the cost of a new aboveground facility.

Executive Summary

Barrick Gold has proposed the construction of a new facility called Naranjo for the co-disposal of 344.7 million metric tons of combined tailings (tailings plus precipitation products and water treatment sludge) and 452.7 million metric tons of potentially acid generating (PAG) waste rock from the Monte Negro and Moore open pits at the Pueblo Viejo gold-silver mine in the Dominican Republic. The new facility would supplement the existing El Llagal tailings storage facility (TSF), which will fill with mine waste in 2027, while the new facility would maintain production through 2049. The mine waste at the Naranjo facility would be confined by an earth-core rockfill dam with a height of 157 meters (one of the largest earth-core rockfill dams in the world) with the tailings on the downstream side next to the dam and the waste rock on the upstream side. The consequences of dam failure have been rated as Extreme for both the El Llagal and Naranjo facilities, meaning that more than 100 fatalities are expected in the event of dam failure. A permanent water cover would be maintained on the waste rock in order to prevent acid generation through contact with oxygen.

The Environmental Impact Study (EIS) for the new facility was finalized in October 2022 and released to the public on June 25, 2023. According to the EIS, the site and technology for the Naranjo facility was chosen after an initial screening of 26 alternatives followed by scoring of eight alternatives through a multiple accounts analysis that involved environmental, socioeconomic, technical and cost accounts. The purpose of this report is to determine whether the EIS selected the safest alternative and whether the preferred alternative provides adequate protection for people and the environment. To facilitate reading by non-specialists, this report includes a review of key topics in mine waste management, including the differences between tailings dams and water-retention dams, acid mine drainage, co-disposal of tailings and waste rock, the backfill of mine waste into exhausted open pits, and the Global Industry Standard on Tailings Management (GISTM). The GISTM is particularly relevant since, as a Member Company of the International Council on Mining & Metals (ICMM), Barrick Gold is obligated to fully implement the GISTM by August 5, 2023, for tailings dams with failure consequences rated as Very High or Extreme.

The EIS is incomplete in ways that hinder review by either the Dominican government or the Dominican public. Some key documents that are cited in the EIS are listed in the bibliography as still “in progress.” Some key sections, such as the analysis of the consequences of dam failure, are written only in English with no translation into Spanish. The multiple accounts analysis states only the total scores for the eight alternatives and has removed the appendices that should state the scores with their justifications for the four accounts and the numerous subaccounts. According to the GISTM, the purpose of a multiple accounts analysis is to select the alternative that (1) minimizes risks to people and the environment and (2) minimizes the volume of tailings placed in aboveground facilities. Since elements of risk (including both the consequences of failure and the probability of failure) are scattered in subaccounts within the environmental, socioeconomic, and technical accounts, it is impossible to determine whether priority has been given to the minimization of risk. Moreover, the GISTM clarifies that the multiple accounts analysis should not include cost as a factor in the selection of the preferred alternative. It is a standard feature of many international guidance documents on dams that safety must be the determining factor and that there must not be any trade-off between safety and other factors. The various subaccounts related to the protection of human life constitute only 7.5% of the weighting of the final scores.

Although, according to the GISTM, the minimization of the permanent aboveground storage of tailings is one of the two purposes of a multiple accounts analysis, the EIS does not include any serious consideration of the alternative of backfill of mine waste into the exhausted open pits or quarries. Many jurisdictions either require open-pit backfill (California (USA), Pennsylvania (USA), New Caledonia) or the maximization of open-pit backfill (British Columbia (Canada)) or a feasibility study for open-pit backfill prior to the consideration of a new or expanded aboveground tailings storage facility (Quebec (Canada)). There are numerous examples of mining projects that have carried out simultaneous backfill and exploitation in the same open pit. Open-pit backfill is regarded as a best practice under almost all circumstances, except when the likelihood of groundwater contamination could be reduced by moving the tailings to an aboveground location. For the avoidance of groundwater contamination, the site for an aboveground tailings facility that is preferred in the EIS cannot be regarded as ideal since the EIS expresses concerns regarding the high permeability of the foundation, the potential for excessive seepage from the tailings storage facility, and the need for mitigative measures. Barrick Gold has at least eight open-pit backfill projects, including two completed, three in progress, and three planned. The backfill of the open pit at the Bullfrog mine even won the Nevada (USA) Excellence in Mine Reclamation Award for 2019. In fact, the Technical Report provided to investors by Barrick Gold states that there is a plan to backfill 163 million metric tons of PAG waste rock into the open pits, although this is not stated in the EIS.

This report estimated the mass of mine waste that could be backfilled into the open pits, as well as the cost of open-pit backfill. Based on the in situ densities of ore and waste rock (2.8 metric tons per cubic meter) and the projected extraction of ore and waste rock (196.174 and 516.922 million metric tons, respectively) over the life of the mine, the final pit volume was calculated as 254.6771 million cubic meters. Based on the density of waste rock after extraction (2.1 metric tons per cubic meter), all waste rock could be backfilled into the open pits. Out of the 344.7 million metric tons of combined tailings that are planned for disposal in the new Naranjo facility, based on the density (1.24 metric tons per cubic meter), sufficient space in the open pits would remain for all but 246.0886 million metric tons if the waste rock and tailings were co-mingled (so that the tailings occupied 75% of the pore space of the waste rock), and all but 296.2089 million metric tons if the waste rock and tailings were completely separated. The ore processing includes mixing with limestone, so that the project includes the extraction of 474.225 million metric tons of limestone from on-site quarries, corresponding to a total quarry volume of 316.15-175.6389 million cubic meters, based on limestone densities in the range 1.5-2.7 metric tons per cubic meter (limestone density not stated in available documents). Thus, there is sufficient capacity in the open pits and quarries for all of the waste rock and combined tailings, except in the extreme case of no co-mingling of waste rock and tailings and maximum limestone density. Even if all of the tailings could not be backfilled, the maximization of open-pit and quarry backfill would vastly reduce the volume of tailings that would need to be stored aboveground, in accordance with the requirements of the GISTM.
This report compiled 15 open-pit backfill projects (13 in Canada and one each in Australia and Germany) for which the costs and quantity of backfilled material are known, resulting in a geometric mean backfill cost of USD 1.20 per

metric ton of mine waste. On that basis, the cost of backfilling all 797.4 million metric tons of mine waste that are designated for disposal in the new Naranjo facility would be USD 957 million. By contrast, according to the EIS, the cost of construction of the new Naranjo facility would be USD 2695 million or USD 3.38 per metric ton of mine waste, so that the cost of backfill would be less than 35% of the cost of construction of a new aboveground facility. Even the projected cost is underestimated because it does not include the costs of operation or of long-term monitoring, inspections, maintenance and reviews of the Naranjo facility following mine closure. The cost of the new facility is unusually high based on an average mining industry-wide cost for conventional tailings management of USD 1.20 per metric ton (nearly identical to the cost of backfill) with a range of USD 0.5-2.50 per metric ton.

The co-disposal of tailings and waste rock into the same facility with a water cover on the waste rock and no mixing of the two types of mine waste is an unusual design. According to the EIS, the design is proven because the existing El Llagal facility has successfully used the same design. The EIS does not provide any evidence for the success of the El Llagal facility, such as annual dam safety inspection reports, dam safety reviews, or reports by an Independent Tailings Review Board (ITRB), although, according to the GISTM, such types of reports should be made available to the public, at least in summary form. The three-sentence summary in the public disclosure of August 5, 2023, cannot be regarded as adequate proof of success by any standard. However, although the 2005 EIS for the El Llagal tailings facility by Placer Dome stated that the facility would store both tailings and waste rock, the Technical Report by Barrick Gold to its investors clarifies that the waste rock has been stored in the Hondo waste dump, where it awaits transfer to either the open pit or the Naranjo facility, and lacks clarity as to how much, if any, waste rock is actually stored in the El Llagal facility. The El Llagal facility possibly uses a different design and is thus not analogous to the proposed Naranjo facility. To the knowledge of the author, the only mine waste storage facility with a similar design to the Naranjo facility is the tailings storage facility at the Phu Kham Copper Gold Operation in Laos. The avoidance of such a design on a worldwide basis is probably due to the very large dam needed to confine both the tailings and the waste rock, which could account for the high cost of the proposed Naranjo facility. Among other significant discrepancies between the EIS and the Technical Report, the EIS analyzes a much larger facility than is contemplated in the Technical Report, which is related to why only particular sites for the facility were considered in the EIS.

According to the analysis of the consequences of dam failure in the EIS, the spilled tailings will flow northward along the Maguaca River to the confluence with the Yuna River and then continue flowing northward along the Yuna River. The analysis calculates only the tailings flood arrival times, peak flow rates (up to 38,700 cubic meters per second), and the depths of the tailings flood (up to 22.4 meters), but not the environmental or socioeconomic consequences, such as fatalities, contamination of rivers, or impacts on human health, aquatic life, agriculture, or infrastructure. Moreover, the analysis is limited by the computer model, which calculated the tailings flood arrival times, peak flow rates, and depths only to the eastward turn of the Yuna River, a distance of 30 kilometers downstream from the Naranjo tailings facility. However, based on a statistical model developed from past tailings dam failures, with a height of 157 meters and storage of 278 million cubic meters of combined tailings, a failure of the proposed Naranjo tailings facility will result in transport of the tailings flood for 227 kilometers during the initial event. Since the distance to the ocean (Samaná Bay) is only 101 kilometers, the initial event will result in deposition of tailings along the entire reach between the tailings dam and the ocean, which will occur in less than five hours. Finally, although the El Llagal and Naranjo facilities would be only 840 meters apart and in the same watershed in the headwaters of the Maguaca River, the analysis of the consequences of dam failure did not consider the consequences of the simultaneous failure of both tailings storage facilities, although such an outcome is certainly credible considering that the same earthquake or precipitation event could cause the failure of both facilities.

The plan for closure of the mine includes a plan for the treatment and release of the water captured behind the dam until the water behind the dam reaches national water quality standards without treatment. The estimated post-closure treatment period is ten years and there is no plan nor financing for long-term water treatment. Although the PAG waste rock requires a water cover, there is no plan for the maintenance of a water cover in perpetuity. It is most important that, although the dam can never be dismantled, there is no plan nor financing for the perpetual inspection, monitoring, maintenance, and review of the dam. Without perpetual maintenance of the dam, the eventual collapse of the dam with numerous fatalities and with contamination of the Maguaca and Yuna Rivers to Samaná Bay should be regarded as inevitable.

The recommendation of this report is that the EIS should be rewritten with particular attention paid to the following:

1. All relevant specifications should be available in the EIS without references to documents that have not been written.
2. The entire EIS should be available in Spanish.
3. The appendices that state and justify the scoring of the accounts and subaccounts for each of the alternatives should be included.
4. Open-pit backfill should be fully considered as one of the alternatives.
5. A complete, accurate, and consistent mass balance should be provided for ore, tailings, waste rock, and limestone, from the beginning to the planned cessation of mining.
6. The selection of the preferred site should be based upon a more thorough knowledge of the foundation at each site.
7. Cost should not be a factor in the selection of the preferred alternative.
8. The reports (such as dam safety inspections, dam safety reviews, and ITRB reports) that justify the success of the existing El Llagal facility should be included.
9. The industry-wide past experience with the design of the proposed facility should be analyzed.
10. The analysis of the consequences of dam failure should consider the simultaneous failure of both the existing and proposed facilities.
11. The analysis of the consequences of dam failure should consider the environmental and socioeconomic consequences of failure.
12. The analysis of the consequences of dam failure should consider all impacts that will occur between the facilities and the ocean.
13. There should be plans and discussion of financing for long-term water treatment and long-term monitoring, inspection, maintenance and review of the tailings dams.
14. The revised EIS should be fully consistent with the Technical Report provided to investors.

Overview

Pueblo Viejo Dominicana Jersey 2 Limited, a joint venture with majority ownership by the Canadian company Barrick Gold (60%) and minority ownership by the American company Newmont (40%), has proposed the construction of a new facility called Naranjo for the permanent storage of additional mine waste generated by the Pueblo Viejo gold-silver mine in the Dominican Republic, where ore is extracted from two open pits called Monte Negro and Moore (Knight-Piésold Consulting, 2022; Barrick Gold, 2023a) (see Figs. 1-3). Mine waste consists largely of waste rock, which is the rock that must be removed to reach the ore body, and tailings, which are the wet and crushed rock particles from the ore body that remain after the commodity of value has been removed. At the present time, waste rock is stored at the Hondo waste rock dump, while tailings and possibly some waste rock are stored at the El Llagal tailings storage facility (TSF) (Barrick Gold, 2023a). The existing El Llagal facility will fill with tailings in 2027, while the new Naranjo facility would maintain production through 2049. The proposal is for Naranjo to store both tailings and waste rock in the same facility (Knight-Piésold Consulting, 2022).

The management or storage or disposal of mine waste is a critical component of any modern, large-scale mining project. On a global basis, for gold mining, 2.86 metric tons of waste rock are removed for every metric ton of gold ore. Considering a typical ore grade of 0.00008% and typical concentrator and smelter/refinery recovery rates, 3,046,349 metric tons of mine waste (both tailings and waste rock) are generated for every metric ton of refined gold, which is the largest rock-to-metal ratio for any common mined commodity. On a global basis, silver mining generates considerably less waste, with 2.13 metric tons of waste rock removed for every metric ton of ore, and 22,378 metric tons of mine waste generated for every metric ton of refined silver (Nassar et al., 2022a-b).

The current El Llagal facility is upslope from the communities of La Cerca, Las Lagunas, and Rayo (see Fig. 3). Fig. 4a shows a view of the tailings dam at the El Llagal facility taken from Las Lagunas at a distance of 1135 meters north of the toe of the dam (compare with Fig. 3). Fig. 4b shows a view of the tailings dam from the east, which shows the community of Rayo in the foreground at a distance of 293 meters from the toe of the dam (compare with Fig. 3). The western edge of the new Naranjo facility would be 840 meters east of the El Llagal facility and would occupy a similar upslope position (see Fig. 3). The consequences of tailings dam failure for both the existing El Llagal facility (Barrick Gold, 2022a; UNEP et al., 2023) and the proposed Naranjo facility (Knight-Piésold Consulting, 2022) have been rated as Extreme, meaning that more than 100 fatalities are expected in the event of dam failure (Canadian Dam Association, 2013, 2019; ICMM-UNEP-PRI, 2020).

Knight-Piésold Consulting (2022) has produced an Environmental Impact Study (EIS) for the Naranjo mine waste facility that was finalized and released to the Dominican government in October 2022. In turn, the Dominican government released the EIS to the public on June 25, 2023. The EIS includes a consideration of 26 combinations of possible sites and technologies for the new mine waste storage facility. Out of the 26 alternatives, 14 were eliminated by initial screening, after which the remaining eight alternatives were subjected to a multiple accounts analysis that finally ended with Alternative C (a facility for co-disposal of tailings and waste rock at Site 14 as shown in Fig. 3) as the preferred alternative.

The purpose of this report is to answer the following questions:

1. **Did the EIS select the alternative that was safest for people and the environment?**
2. **Does the preferred alternative provide adequate protection for people and the environment?**

To facilitate reading by non-specialists, this report includes a review of key topics in mine waste management, including the differences between tailings dams and water-retention dams, acid mine drainage, co-disposal of tailings and waste rock, the backfill of mine waste into exhausted open pits, and the Global Industry Standard on Tailings Management (GISTM). The GISTM is particularly relevant since, as a Member Company of the International Council on Mining & Metals (ICMM), Barrick Gold is obligated to fully implement the GISTM by August 5, 2023, for tailings dams with failure consequences rated as Very High or Extreme (ICMM, 2021, 2023).

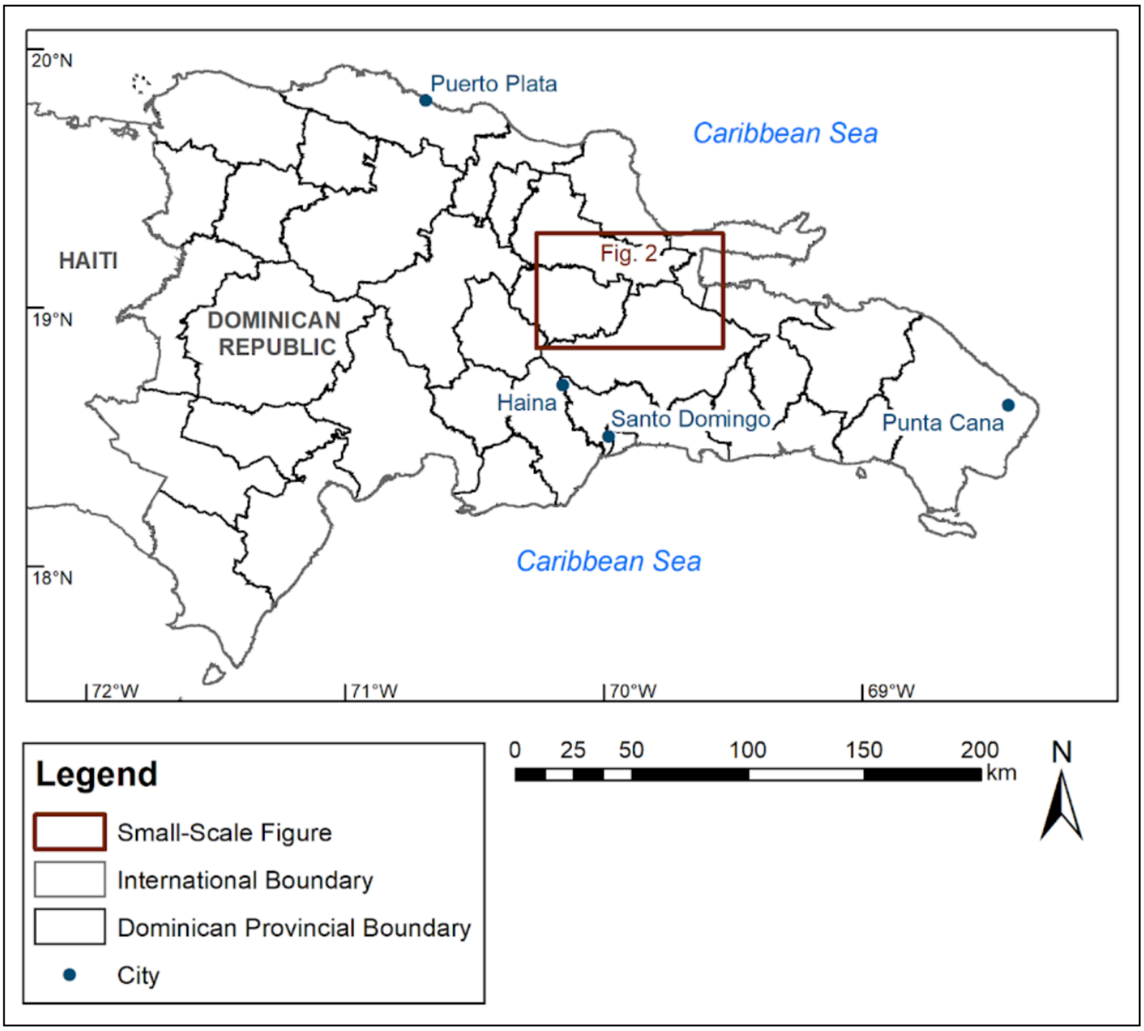


FIGURE 1. Barrick Gold has proposed the construction of a new facility for the co-disposal of mine tailings and waste rock at the open-pit Pueblo Viejo gold mine in the Dominican Republic.

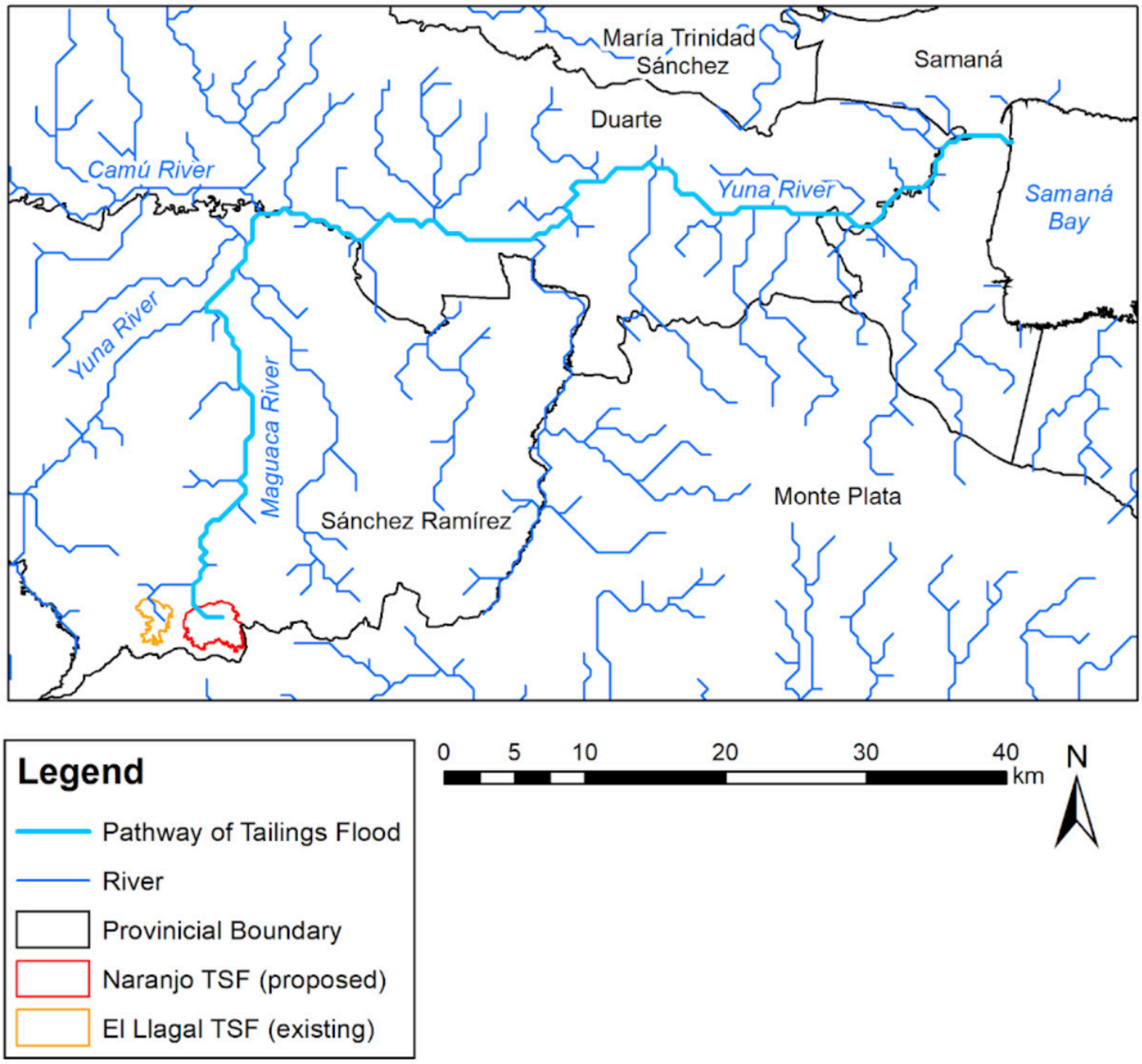


FIGURE 2. Based on a statistical model developed from past tailings dam failures, with a height of 157 meters and storage of 278 million cubic meters of tailings, a failure of the proposed Naranjo TSF (Tailings Storage Facility) at the Pueblo Viejo mine will result in transport of the tailings flood for 227 kilometers during the initial event. However, since the distance to the ocean (Samaná Bay) is only 101 kilometers, the initial event will result in deposition of tailings along the entire reach between the tailings dam and the ocean. Rivers from HydroSHEDS (2023), provincial boundaries from ESRI (2021), and perimeters of TSFs traced from Knight-Piésold Consulting (2022). See larger-scale map in Fig. 1.

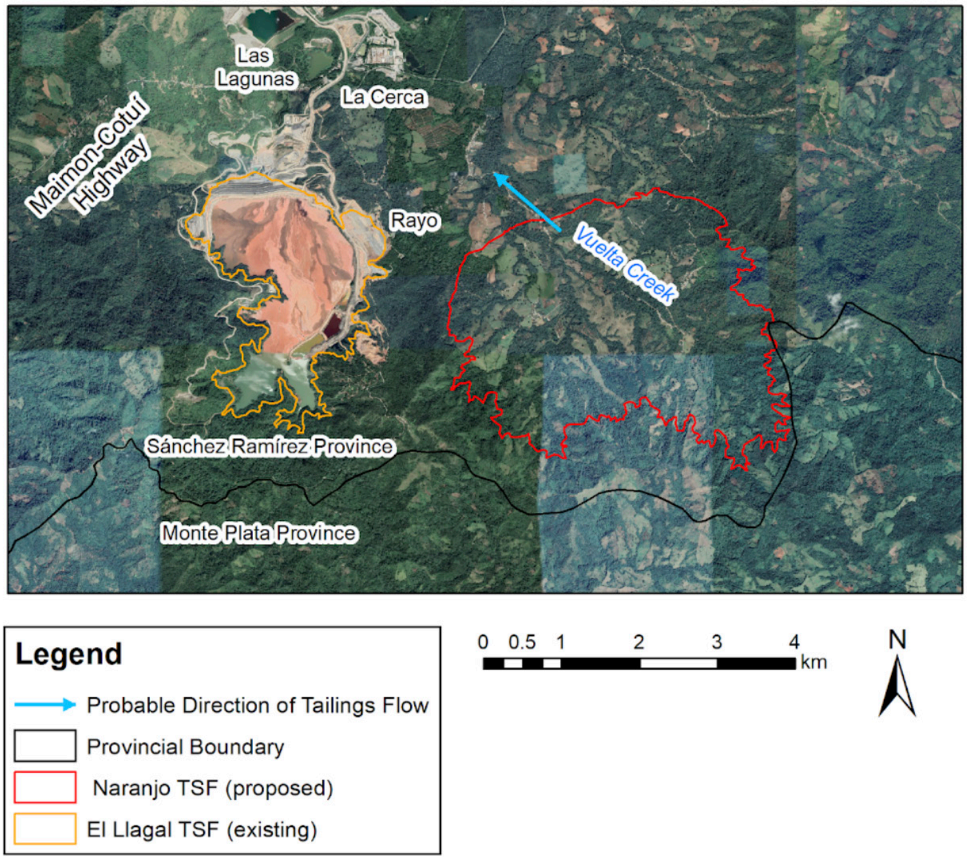


FIGURE 3. The probable pathway for the flow of tailings following the failure of the proposed Naranjo TSF (Tailings Storage Facility) is Vuelta Creek, which would flow underneath the tailings storage facility. The probable pathway will carry the tailings onto the communities of Las Lagunas and La Cerca, as well as much of the mine infrastructure. In a similar way, a failure of the existing El Llagal TSF will carry the tailings onto the communities of Las Lagunas and La Cerca, in addition to much of the mine infrastructure. For both the existing and the proposed tailings storage facilities, the consequences have been classified as Extreme, meaning that more than 100 fatalities are expected as a result of dam failure. Provincial boundaries from ESRI (2021) and perimeters of TSFs traced from Knight-Piésold Consulting (2022). See larger-scale map in Fig. 2.

FIGURE 4a. View of the existing El Llagal tailings dam from the community of Las Lagunas, 1135 meters to the north (see Fig. 3). Photo taken by the author on July 12, 2023.

Review of Mine Waste Management

Tailings Dams vs. Water-Retention Dams

Waste rock is often deposited as a free-standing waste rock dump. By contrast, because they are wet and fine-grained, tailings require confinement behind a dam. In conventional tailings management, the wet tailings are piped to the tailings storage facility with no dewatering, so that water contents are in the range 150-400%, where the water content is the ratio of the mass of water to the mass of dry solid particles. The mixture of tailings and water is then discharged into the tailings pond from the crest of the dam through spigots that connect to a pipe that comes from the ore processing plant (see Fig. 5). Tailings can be divided into two sizes with very different physical properties, which are the coarse tailings or sands (larger than 0.075 mm) and the fine tailings or slimes (smaller than 0.075 mm). The hydraulic discharge results in the separation of the sizes of tailings by gravity. The larger sands settle closer to the dam to form a beach. The smaller slimes and water travel farther from the dam to form a settling pond where the slimes slowly settle out of suspension. Typically, water is reclaimed from the settling pond and pumped back into the mining operation.

FIGURE 4b (right). The community of Rayo (houses in foreground) is only 293 meters from the existing El Llagal tailings dam (see Fig. 3). Photo taken by author on July 13, 2023.

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

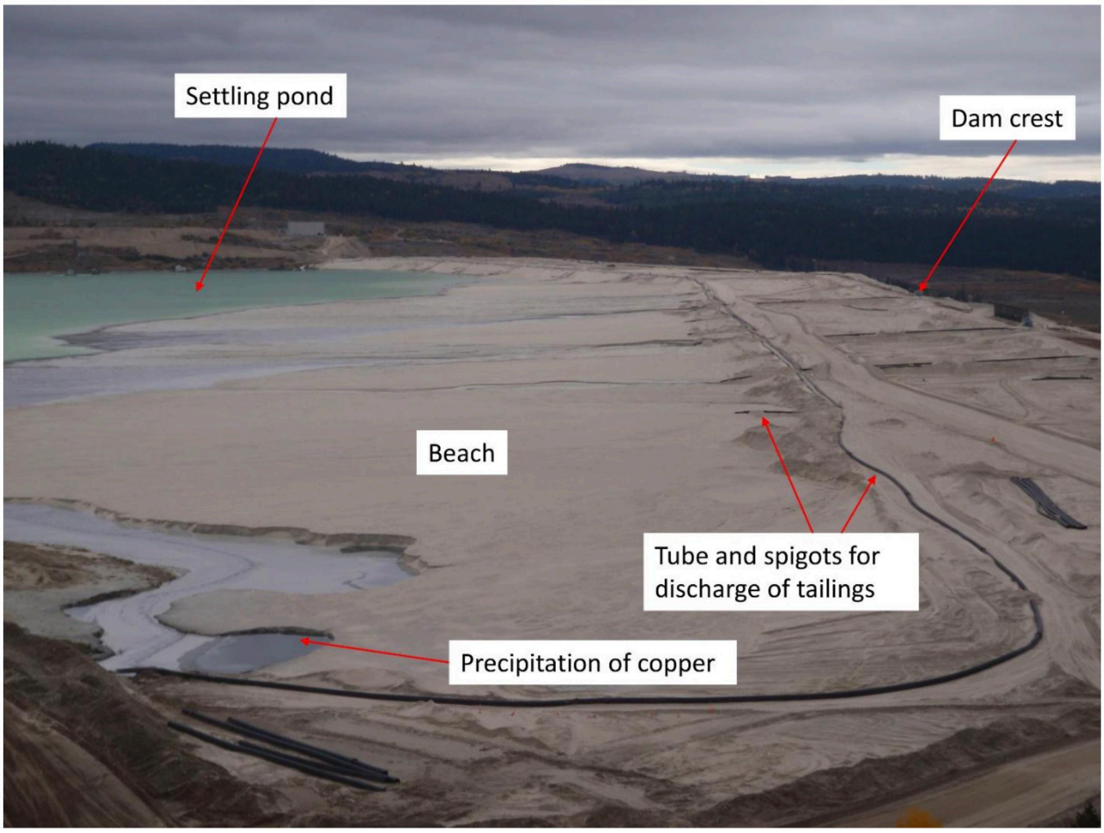


FIGURE 5. In conventional tailings management, tailings and water from the ore processing plant are hydraulically discharged in the upstream direction from spigots along the dam crest. The coarser tailings settle closer to the dam crest to form a beach. The finer tailings and water travel farther upstream where the fine tailings settle out of suspension in the settling pond. The photo is a tailings dam at the Highland Valley Copper mine in British Columbia, Canada. Photo by the author taken on September 27, 2018.

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

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

The preceding discussion largely contrasts tailings dams and water-retention dams that are in active operation. At the end of its useful life, or when it is no longer possible to inspect and maintain the dam, a water-retention dam is completely dismantled. A water-retention dam cannot simply be abandoned or it will eventually fail at an unpredictable time with consequences that are difficult to predict. On the other hand, a tailings dam cannot be dismantled unless the tailings can be moved to another location, such as an exhausted open pit. Typically, a tailings dam is expected to confine the often toxic tailings in perpetuity, although normally the inspection, monitoring, maintenance, and review of the dam cease at some point after the end of the mining project.

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

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

Acid Mine Drainage

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

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^+$$

or in words as

$$\text{pyrite + oxygen + water} \longrightarrow \text{dissolved iron + sulfuric acid}$$

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

Acid mine drainage (AMD) results when the dissolved metals and sulfuric acid are introduced into surface water or groundwater, which can have detrimental impacts on public water supply and aquatic life. Although Barrick Gold (2023a) uses the expression "acid rock drainage" (ARD), it is more common to refer to AMD when the environmental acidity results from mining activity and to refer to ARD when the environmental acidity results from natural processes or from human activity that is not related to mining, such as highway construction.

Acid mine drainage can induce a positive feedback in that the downstream load of dissolved metals can greatly exceed the dissolved metals that result from the oxidation of the exposed sulfide minerals. Stream sediments typically include clay minerals, whose surfaces have negatively-charged sites that bind cations (positively-charged ions). Most dissolved metals are cations, although there are some exceptions, such as arsenic (actually a metalloid), molybdenum and uranium, which occur in dissolved form as oxyanions (polyatomic negatively-charged ions that include oxygen). When acidic water interacts with these stream sediments, the hydrogen cations in the water displace other cations (such as metallic cations) from the negatively-charged sites on stream sediments, so that metals are no longer fixed onto sediment, but are mobilized in the stream column as dissolved metals. Stream beds can also include tailings from previous episodes of mining that have heavy metals attached to surface sites. As above, these heavy metals can be mobilized by the introduction of new acid mine drainage into streams or by other anthropogenic increases in stream acidity. For this reason, mine tailings in stream beds are often referred to as a "chemical time bomb." The literature on acid mine drainage and its impacts on human health and the environment is vast and a good starting point is Maest et al. (2005).

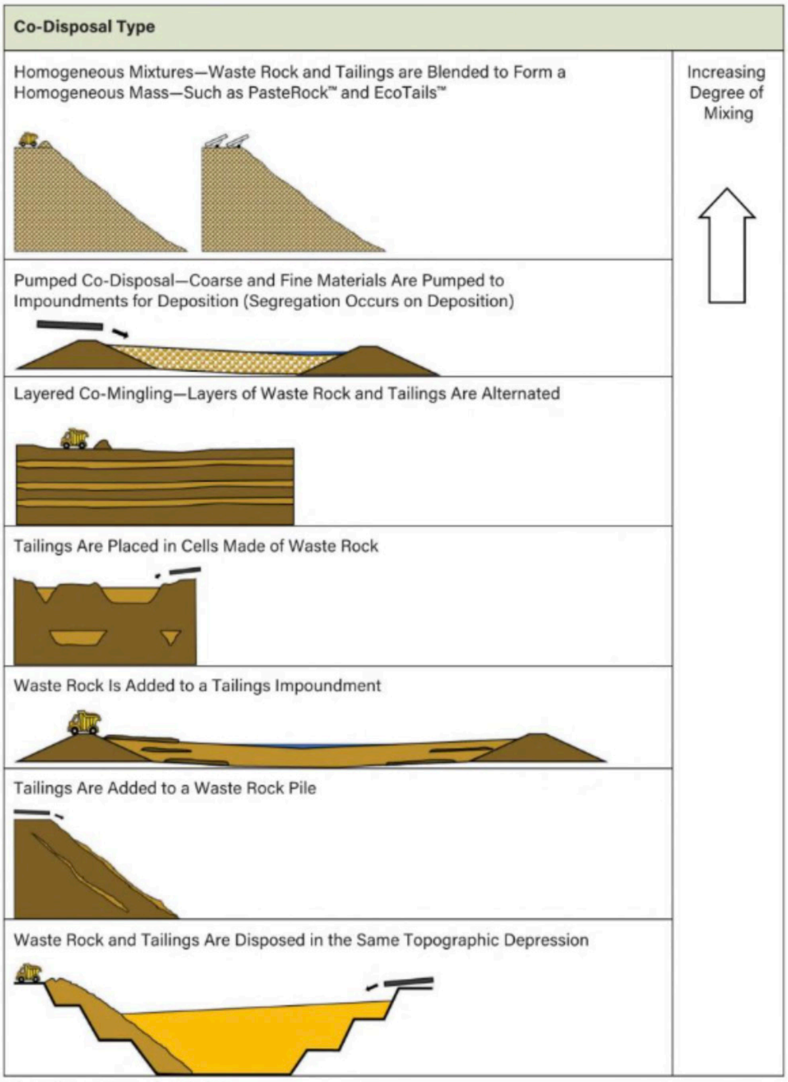
A wide range of tools have been developed for the mitigation of acid mine drainage from mining that involves the excavation of sulfide minerals. For example, soil or clay covers on tailings storage facilities can minimize the contact of tailings with oxygen and rainfall, while stormwater diversion channels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

It should be noted that, although a water cover over PAG mine waste can prevent the reaction of the sulfide minerals with oxygen, water covers on aboveground tailings storage facilities are no longer regarded as a best practice because of their detrimental impact on the physical stability of the facility. The panel that investigated the failure of the Mount Polley tailings storage facility in British Columbia (Canada) in 2014 concluded that "The goal of BAT [Best Available Technology] for tailings management is to assure physical stability of the tailings deposit. This is achieved by preventing release of impoundment contents, independent of the integrity of any containment structures. In accomplishing this objective, BAT has three components that derive from first principles of soil mechanics: 1. Eliminate surface water from the impoundment ... In short, the most serious chemical stability problem concerns tailings that contain sulfide minerals, particularly in metal and coal mining. In the presence of oxygen, these sulfides react to produce acid that then mobilizes a variety of metals in solution. There are a number of ways to arrest this reaction, and one is to saturate the tailings so that water replaces oxygen in the void spaces. This saturation is most conveniently achieved by maintaining water over the surface of the tailings. Hence, so-called water covers have sometimes been adopted for reactive tailings during operation and for closure. It can be quickly recognized that water covers run counter to the BAT principles ... But the Mount Polley failure shows why physical stability must remain foremost and cannot be compromised. Although the tailings released at Mount Polley were not highly reactive, it is sobering to contemplate the chemical effects had they been. No method for achieving chemical stability can succeed without first ensuring physical stability: chemical stability requires above all else that the tailings stay in one place" (Independent Expert Engineering Investigation and Review Panel, 2015a). The subsequent revisions to the mining legislation in British Columbia concurred in writing, "Physical stability is of paramount importance, and options that require a compromise to physical stability should be discarded" (Ministry of Energy and Mines, 2016).

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

Co-Disposal of Waste Rock and Tailings

Although waste rock and tailings are typically stored in separate facilities, the co-disposal of waste rock and tailings can be another technology for the reduction of acid mine drainage (Wilson, 2001; Wickland et al., 2006; Ulrich and Coffin, 2015; Wickland and Longo, 2017; Painchaud et al., 2022). Since tailings are usually much finer-grained than waste rock, the tailings can fill the pore spaces between the particles of waste rock. The fine-grained tailings normally have a much lower permeability than waste rock, so that the inability of water to drain from the mixture can keep it in a saturated state, thus preventing contact between rock particles and oxygen. Even when the mixture is unsaturated, oxygen will have a lower diffusion rate through the fine-grained tailings than through air. The prevention of acid generation can also occur if the NAG waste can be used to encapsulate the PAG waste (in which case, either the tailings or the waste rock could be either NAG or PAG). Other advantages of co-disposal are the greater shear strength that waste rock can add to tailings and the smaller volume and footprint of a mixture of tailings and waste rock.



Adapted from Wickland et al. 2006

FIGURE 6. The design of the proposed Naranjo TSF is most similar to the lowermost diagram in which the wall of the topographic depression is replaced by a constructed dam on the right-hand side (see Fig. 8). The only other example known to the author is the Phu Kham Copper Gold Operation in Laos (see Fig. 15). Figure from Wickland (2022).

Fig. 6 shows a classification system for co-disposal of tailings and waste rock from the SME Tailings Management Handbook (Wickland, 2022). The various technologies for co-disposal are ranked in order from top to bottom from the greatest to the least degree of mixing. The greatest mixing occurs when the waste rock and tailings are completely blended to form a homogenous mass, which should minimize the mine waste volume and maximize the protection against acid generation through contact with oxygen (see Fig. 6). Somewhat less mixing occurs when waste rock and tailings are pumped together to a storage facility. Some degree of segregation by particle size (thus, separating the waste rock and tailings) will occur at the point of deposition (see Fig. 6). Less mixing, but maintaining in some ways the additional shear strength from the waste rock, occurs when tailings and waste rock are deposited in alternating layers, or when tailings are deposited into cells constructed from waste rock (see Fig. 6). Even less mixing occurs when waste rock is added to a tailings storage facility or when tailings are added to a waste rock dump (see Fig. 6). The final category shows waste rock and tailings being added from opposite sides of a topographic depression (see bottom of Fig. 6). The topographic depression could be an exhausted open pit with the Kidston gold mine in Australia (Gowan et al., 2010) being an example. Whether any mixing occurs when two waste streams are discharged from opposite sides of a depression depends upon the mechanics of interaction of the waste streams. However, the discharge of two waste streams from opposite sides of a depression still retains the possibility of final, complete encapsulation of one type of mine waste by another. The real advantage of the deposition of potentially reactive mine waste into a topographic depression or exhausted open pit is that, if the waste is deposited below the water table, a water cover could permanently prevent contact with oxygen without a detrimental impact on physical stability, as would occur for an aboveground facility for storage of mine waste. This advantage is developed more fully in the next subsection.

Open-Pit Backfill

The worst possible outcome for any aboveground tailings storage facility is the catastrophic failure of the facility, often with fatalities and with the large-scale release of toxic materials into the environment. The typically permanent nature of these facilities means that the threat of the worst possible outcome never ends. This outcome can be avoided completely by backfilling the mine waste into exhausted open pits or underground mine workings, instead of constructing permanent aboveground facilities. Waste rock and water treatment sludges can also be backfilled into either open pits or underground mine workings (Johnson and Carroll, 2007), although with a lower priority (due to the lower risk of catastrophic failure).

The second worst possible outcome for any aboveground storage facility for either tailings or waste rock is the release of acid mine drainage into the environment. As mentioned above, in open-pit backfill projects, the mine waste is typically placed below the water table, which, if covered within an appropriate time frame, prevents oxidation of the sulfides. An impermeable dry cover placed onto backfilled mine waste (without the risk of erosion of the cover of an aboveground facility) can also prevent oxidation of sulfides (Arcadis, 2015). In the case of the Marlin gold-silver mine in Guatemala, filtered non-sulfidic tailings were backfilled into the open pit, which prevented the oxidation of the sulfidic pit walls (Montana Exploradora de Guatemala, S.A., 2012).

In addition to the prevention of catastrophic failures of aboveground tailings facilities and the long-term costs of preventing such failures, as well as the risks and costs of prevention of acid mine drainage, open-pit backfilling can facilitate the return of the surface to its pre-mining state with less risk of permanent alienation of the land from a useful or natural purpose. Open-pit backfilling also reduces the risk of seepage of contaminated mine water to surface water bodies or aquatic ecosystems. Along the same lines, open-pit backfilling has more and safer options for the permanent physical and chemical isolation of hazardous materials. Open-pit backfilling can even improve the physical and chemical stability of the pit and stabilize the pit walls.

For the above reasons, the maximum backfilling of mine tailings into either open pit or underground mine workings is currently regarded as a best practice (Mudd et al., 2011; Independent Expert Engineering Investigation and Review Panel, 2015a; Morrill et al., 2022). According to Independent Expert Engineering Investigation and Review Panel (2015a), "The overarching goal of BAT is to reduce the number of tailings dams subject to failure. This can be achieved most directly by storing the majority of the tailings below ground—in mined-out pits for surface mining operations or as backfill for underground mines." In fact, Barrick Gold has been an industry leader in open-pit backfill with two completed projects, three projects in progress, and three more projects planned (see Table 1). The backfill of the open pit at the Bullfrog mine in Nevada (USA) received the Nevada Excellence in Mine Reclamation Award in 2019 (Nevada Division of Minerals, 2021).

TABLE 1. Open-pit backfill projects by Barrick Gold

MINE	LOCATION	COMPLETION DATE
Richmond Hills[1]	South Dakota (USA)	1995
Bullfrog[2]	Nevada (USA)	2000[3]
Cortez Hills[4]	Nevada (USA)	In progress
Phoenix[4]	Nevada (USA)	In progress
Turquoise Ridge[4]	Nevada (USA)	In progress
Golden Sunlight[5]	Montana (USA)	Planned
Kibali Gold[6]	Democratic Republic of Congo	Planned
Pueblo Viejo[7]	Dominican Republic	Planned

[1] MEND (1995)
[2] Barrick Gold (2018)
[3] Additional backfill was carried out in 2017.
[4] Barrick Gold (2021a)
[5] Barrick Gold (2021b)
[6] Barrick Gold (2022b)
[7] Barrick Gold (2023a)

MEND (1995) reviewed the practice of open-pit backfilling with 12 detailed case studies. Twenty years later, the review was updated by Arcadis (2015) with 12 additional case studies (including three case studies that were updated from the earlier review). The SME Tailings Management Handbook added three additional detailed case studies (Aparicio, 2022; Esford and Donald, 2022; McCann, 2022), including two that had not been considered in the earlier reviews. The preceding reviews considered only case studies in which mine waste was backfilled into an exhausted open pit. However, there are also cases in which the backfill of mine waste into an open pit has occurred concurrently with continued mining in another portion of the pit. In fact, concurrent open-pit backfilling is quite common in aggregate mining and in surface coal mining in the midwestern USA, as well as increasingly common in gold and base metal mining. Concurrent backfilling and mining is facilitated in the aggregates industry due to the much higher ratio of ore to waste rock than is common in base metals mining (D. Bieber, pers. comm). Concurrent backfilling and mining in surface coal mines reduces costs by reducing haulage distances. In addition, reclaiming coal mine pits within 2-3 pit widths from the active excavation face reduces reclamation time and facilitates incremental reclamation bond releases (J. Petrea, pers. comm.). Regulations for anthracite mining in Pennsylvania (USA) have encouraged concurrent backfilling and mining for over 75 years. According to the Anthracite Strip Mining and Conservation Act, "Whenever reasonable and practicable, the department shall require backfilling as the open pit mining progresses" (Pennsylvania Legislature, 1947). Concurrent backfilling and mining is also common in mineral sands mines in

Western Australia and South Africa (International Institute for Environment and Development, 2002), as well as oil sands mines of Alberta (Canada), in which tailings storage facilities with tailings dams are constructed inside working open pits (with much reduced consequences in the event of tailings dam failure) (K. Chovan, pers. comm.). Examples of base metal mines with concurrent open-pit backfilling and mining include the Old Tintaya copper mine in Peru (X. Ochoa, pers. comm.) and nearly all nickel mines in New Caledonia (Dufayard et al., 2020).

Open-pit backfilling is contraindicated under only three circumstances (Arcadis, 2015). Sometimes the exhaustion of an open pit is followed by the opening of underground mine workings below the pit. In that case, open-pit backfilling can be too hazardous for the stability of the underground mine. On the other hand, the Marlin gold-silver mine was able to backfill the open pit with filtered, compacted tailings by sealing the contact between the open pit and the underlying underground mine with a grout barrier (Montana Exploradora de Guatemala, S.A., 2012). The second contraindication is that, under some circumstances, greater physical and chemical stability could be achieved through aboveground storage of mine waste. For example, the base and walls of an open pit could be heavily fractured (perhaps as a result of blasting), so that groundwater contamination could be less likely if the mine waste were stored on the surface above a low-permeability soil. Another example is that, without backfilling, the exhausted pit could develop a pit lake. One advantage of a pit lake is that it acts as a hydraulic sink with all groundwater flowing toward the pit, thus preventing the seepage of contaminated water out of the pit. In that case, if there were a strong pre-existing hydraulic gradient, the complete backfilling of the pit could result in a rapid flow of groundwater through the pit, thus facilitating the seepage of contaminants out of the pit. Even under those circumstances, the partial backfill of the pit to just above the water table can retain the pit as a hydraulic sink without the detrimental impacts (such as impacts on wildlife) of a potentially contaminated pit lake (Johnson and Carroll, 2007). From a financial standpoint, the third contraindication is that backfilling the pit could prevent the future mining of additional ore that might be present below the pit. However, the mere possibility of additional ore (that might be economically mineable at some future time) would have to be balanced against all of the previously mentioned benefits of open-pit backfilling. Those benefits can be social, environmental and economic.

While backfilling can be cheaper than the alternatives in some cases, there can be a high cost associated with open-pit backfilling. Even so, the cost of open-pit backfilling must be balanced against the cost of construction, operation, and closure of a tailings storage facility. The cost of long-term maintenance of a tailings storage facility after the cessation of a mining project must also be considered and should not be transferred to the government or downstream communities. The least expensive backfill projects have allowed a tailings slurry to flow by gravity directly from the ore processing plant into an exhausted open pit, such as at the Marymia gold mine in Western Australia (Arcadis, 2015). The haulage of material always comes at a cost, but significant savings can arise through never removing the waste rock from the open pit, which is common at nickel mines in New Caledonia (Dufayard et al., 2020). Depending upon the properties of the pit and the mine waste, significant engineering can be required to obtain appropriate physical and chemical isolation of mine waste within the pit. Finally, it may be necessary to construct temporary waste storage facilities on the surface before the mine waste can be backfilled into the pit.

There are apparently only three jurisdictions that have mandated the backfilling of open pits, which are California and Pennsylvania in the USA, as well as New Caledonia. California (USA) has required backfill of open-pit metallic mines to the maximum extent possible since 2003 (Department of Conservation, 2003, 2007). California Code of Regulations (CCR) §3704.1(a) states, “An open pit excavation created by surface mining activities for the production of metallic minerals shall be backfilled to achieve not less than the original surface elevation, unless the circumstances under subsection (h) are determined by the lead agency to exist” (Department of Conservation, 2003). CCR §3704.1(h) then explains, “The requirement to backfill an open pit excavation to the surface pursuant to this section using materials mined on site shall not apply if there remains on the mined lands at the conclusion of mining activities, in the form of overburden piles, waste rock piles, and processed or leached ore piles, an insufficient volume of materials to completely backfill the open pit excavation to the surface, and where, in addition, none of the mined materials has been removed from the mined lands in violation of the approved reclamation plan. In such case, the open pit excavation shall be backfilled … to an elevation that utilizes all of the available material remaining as overburden, waste rock, and processed or leached ore" (Department of Conservation, 2003).

The emphasis in the New Caledonian legislation is not on filling the open pit, but on not leaving waste materials outside of the pit. According to Dufayard et al. (2020), "The mines of New Caledonia are subject to the highest environmental standards and regulations … The disturbance area is restricted to the ultimate pit limits, and all mining activity must stay in this confined area." Finally, the state of Pennsylvania (USA) requires open-pit backfill for anthracite mines (Pennsylvania Legislature, 1947). In addition, there is currently pending legislation that would require open-pit backfill in the state of Nevada (USA). According to the proposed bill AB313, "If an open pit will be excavated below the pre-mining water table, a plan for reclamation must, except as otherwise provided in subsection 2, provide for the backfilling of the open pit to a level where no pit lake will form and no seasonal or permanent wetland will exist" (Nevada Legislature, 2023). The two exceptions are "clear and convincing evidence that backfilling the open pit is technically not possible without indefinite long-term management to avoid groundwater degradation" or "a preponderance of the evidence, that backfilling the open pit would result in undue hardship on the operator because the plan for the mining operation would be unprofitable" (Nevada Legislature, 2023). In some cases, open-pit backfilling has been required by a regulatory agency for a particular mine, such as at the Ranger uranium mine in Northern Territory, Australia (Mudd et al., 2011). In other cases, open-pit backfilling has become a standard practice that has been expected by regulatory agencies, for example, at uranium mines in Saskatchewan, Canada (Arcadis, 2015), or, as already mentioned, at aggregate mines, at surface coal mines in the midwestern USA, at mineral sand mines in Western Australia and South Africa, and at oil sands mines in Alberta, Canada. Besides expectations for open-pit backfill at certain types of mines in the provinces of Alberta and Saskatchewan, the emphasis in Canada has been on the serious consideration of open-pit backfill prior to the consideration of the expansion of an existing tailings storage facility or the construction of a new tailings storage facility. According to the mining legislation in British Columbia, "In-pit or underground backfill should be maximized" (Ministry of Energy and Mines, 2016).

Section 232.3 of the 2013 Quebec (Canada) Mining Act requires that "the rehabilitation and restoration plan shall contain … in the case of an open-pit mine, a backfill feasibility study" (LégisQuébec, 2020). The *Guide de préparation du plan de réaménagement et de restauration des sites miniers au Québec* [Preparation Guide for the Redevelopment and Restoration Plan for Mining Sites in Quebec] further explains that "*Dans le cas d'une exploitation à ciel ouvert, le plan de restauration doit comporter une analyse coûts-avantages sur la possibilité de remblaiement de la fosse. Les fosses peuvent être remblayées avec des matériaux meubles, des substances minérales, des résidus miniers ou des stériles miniers. Cependant, pour être acceptable au point de vue environnemental, des validations quant à la stabilité chimique et physique à court et à long terme sont alors requises … Dans certains cas, lorsque le MERN juge que les conditions s'y prêtent et si l'analyse démontre l'impossibilité de procéder au remblayage de la fosse, toutes les voies d'accès doivent être condamnées …* " [In the case of surface mining, the restoration plan must include a cost-benefit analysis of the possibility of backfilling the pit. Pits can be backfilled with loose materials, minerals, mine tailings or mine waste rock. However, to be acceptable from an environmental point of view, validations as to the chemical and physical stability in the short and long term are then required … In certain cases, when the MERN judges that the conditions are suitable and if the analysis shows the impossibility of proceeding to the backfilling of the pit, all the access roads must be condemned…] (Ministère de l'Énergie et des Ressources naturelles [Ministry of Energy and Natural Resources], 2017). In other words, the government of Quebec does not mandate the backfilling of open pits, but does mandate a feasibility study, including an analysis of costs and benefits.

Since the passage of the 2013 Quebec Mining Act, a number of plans for large open-pit mining projects in Quebec have included at least partial backfilling. The proposed expansion of the Canadian Malartic gold mine would involve backfilling 165-200 million metric tons of waste rock and about 100 million metric tons of tailings produced during 2022-2028 (Ministère de l'Énergie et des Ressources naturelles, 2018), or approximately all of the waste rock and tailings that would be generated after 2021 (BAPE, 2016). The proposed Nouveau Monde Matawinie graphite mine would backfill 43 million metric tons or 40% of all mine waste (Nouveau Monde Graphite, 2018; BAPE, 2020). The proposed Royal Nickel Dumont mine would backfill 114 million metric tons of waste rock (Royal Nickel Corporation, 2013a-b; Canadian Environmental Assessment Agency, 2015). It is important that each of the above projects would involve some degree of concurrent backfilling and mining in the same pit. In each case, the discussion between the mining companies and provincial regulatory agencies has been the Province's urging of the companies to consider backfilling a greater proportion of the mine waste (BAPE, 2009, 2014, 2016, 2020). Part of the significance of the many open-pit backfill projects in Quebec is that the publicly available discussions between the Province and the mining companies have opened a window into the cost of open-pit backfill, which will be discussed further in the "Methodology" section.

Global Industry Standard on Tailings Management

The Global Industry Standard on Tailings Management (GISTM) was released on August 5, 2020, in response to the catastrophic failure of a tailings dam at Brumadinho, Brazil, in January 2019, which resulted in 270 deaths, including 258 mineworkers (ICMM-UNEP-PRI, 2020). Although the three official authors were the International Council on Mining & Metals (ICMM), the United Nations Environment Programme (UNEP), and Principles for Responsible Investment (PRI), a book by two of the authors of the draft standard (Hopkins and Kemp, 2021) clarified that the contributions of UNEP and PRI to the GISTM were minimal. In addition, the various follow-up documents (such as ICMM (2021)) were written by ICMM alone, with no participation by UNEP or PRI. Thus, the GISTM should be regarded as the official position of the mining industry. It has already been mentioned that Member Companies of ICMM, which include the Canadian company Barrick Gold, as well as the American company Newmont, the minority owner of the Pueblo Viejo mine, are obligated to fully implement the GISTM by August 5, 2023, for tailings dams with failure consequences rated as Very High or Extreme (ICMM, 2021, 2023). Relevant Association Members of ICMM include Canada Mining Innovation Council, Mining Association of Canada, the US-based National Mining Association, Prospectors and Developers Association of Canada, the US-based Society for Mining, Metallurgy, and Exploration, and the World Gold Council (ICMM, 2023).

The key aspects of the GISTM are the emphasis on safety and transparency. The first paragraph of the Preamble of the GISTM states, "The Global Industry Standard on Tailings Management (herein 'the Standard') strives to achieve the ultimate goal of zero harm to people and the environment with zero tolerance for human fatality. It requires Operators to take responsibility and prioritise the safety of tailings facilities, through all phases of a facility's lifecycle, including closure and post-closure. It also requires the disclosure of relevant information to support public accountability."

Safety is promoted through the rigorous application of a multiple accounts analysis (called a multi-criteria alternatives analysis in the GISTM) that has only two purposes, minimizing the risk to people and the environment and minimizing the volume of tailings and water stored in aboveground facilities. Requirement 3.2 of the GISTM states, "For new tailings facilities, the Operator shall use the knowledge base and undertake a multi-criteria alternatives analysis of all feasible sites, technologies and strategies for tailings management. The goal of this analysis shall be to: (i) select an alternative that minimises risks to people and the environment throughout the tailings facility lifecycle; and (ii) minimise the volume of tailings and water placed in external tailings facilities" (ICMM-UNEP-PRI, 2020).

The SME Tailings Management Handbook clarifies that Requirement 3.2, as well as other requirements, unequivocally require the serious consideration of either open-pit or underground backfill. According to the SME Tailings Management Handbook, "[Requirement 3.2] inherently indicates that operators should be seeking to place tailings in mined-out pits or underground workings. Further, Requirement 6.6 … indicates that operators should 'include new and emerging technologies and approaches and use the evolving knowledge in the refinement of the design, construction and operation of the tailings facility.' Recognition is growing that for certain geologic and hydrogeologic conditions, in-pit TSFs represent best available technologies (BATs), and the inherent geotechnical stability of the tailings solids below grade is a major motivator for greater consideration of the in-pit tailings management design option" (Gabora and Fuller, 2022). It should be noted that Requirement 3.2, which requires a multiple accounts analysis in order to "minimize the volume of … water placed in external tailings facilities" also argues for the avoidance of permanent water covers in tailings storage facilities.

The GISTM further explains that the alternatives analysis "should objectively and rigorously consider all available options and sites for mine waste disposal. It should assess all aspects of each mine waste disposal alternative throughout the project life cycle (i.e. from construction through operation, closure and ultimately long-term monitoring and maintenance). The alternatives analysis should also include all aspects of the project that may contribute to the impacts associated with each potential alternative. The assessment should address environmental, technical and socio-economic aspects for each alternative throughout the project life cycle" (ICMM-UNEP-PRI, 2020). The important point is that cost is not one of the "aspects" (also called one of the "accounts" in a multiple accounts analysis) that should be considered, which is consistent with the primacy of safety in the GISTM. The usage of the word "economic" throughout the GISTM clarifies that it refers to the local economy, not to the economics of the mining company. For example, Requirement 2.1 states that operators should "develop and document knowledge about the social, environmental and local economic context of the tailings facility, using approaches aligned with international best practices" (ICMM-UNEP-PRI, 2020).

The elements of transparency are compiled in Principle 15 of the GISTM, which requires companies to "publicly disclose and provide access to information about the tailings facility to support public accountability" (ICMM-UNEP-PRI, 2020). According to Requirement 15.1, "For each existing tailings facility and in accordance with Principle 21 of the UNGP [United Nations Guiding Principles on Business and Human Rights], the Operator shall publish and update at least on an annual basis, the following information: … 6. A summary of material findings of annual performance reviews and DSR [Dam Safety Reviews] … Such disclosures shall be made directly, unless subject to limitations imposed by regulatory authorities" (ICMM-UNEP-PRI, 2020). Requirement 15.2 is broader and calls for operators to "respond in a systematic and timely manner to requests from interested and affected stakeholders for additional information material to the public safety and integrity of a tailings facility" (ICMM-UNEP-PRI, 2020).

The final component of the GISTM that is particularly relevant to this report is the concept of a "credible failure mode." According to the GISTM, "The term 'credible failure mode' is not associated with a probability of this event occurring" (ICMM-UNEP-PRI, 2020). Thus, a credible failure mode is "a physically possible sequence of events that could potentially end in tailings dam failure" (Morrill et al., 2022), no matter how unlikely. One of the requirements of Safety First: Guidelines for Responsible Mine Tailings Management is that "tailings facilities must be monitored, inspected, maintained and reviewed in perpetuity, or until there are no credible (physically possible) failure modes" (Morrill et al., 2022). There are not many ways to eliminate all physically possible failure modes from an aboveground facility, aside from moving the tailings to a belowground location, such as an exhausted open pit.

Proposal for New Mine Waste Facility at Pueblo Viejo Mine

Although all of the waste rock that is extracted from the open pits is potentially acid generating (PAG), the tailings are non-acid generating (NAG) because the sulfide minerals are oxidized during the ore processing. The combined tailings (also called the mixed tailings) include the crushed particles of ore remaining after ore processing, the precipitation products that are produced during processing, and the water treatment sludge. Even after extraction of the commodity of value, the mass of combined tailings greatly exceeds the mass of ore with a ratio of 1.47 metric tons of combined tailings for every metric ton of ore. Limestone is extracted from on-site quarries for use in the ore processing. The only NAG waste rock is the limestone that is deemed unsuitable for ore processing (Knight-Piésold Consulting, 2022; Barrick Gold, 2023a).

Over the life of the mine, 196.174 million metric tons of ore and 516.922 million metric tons of waste rock will be extracted from the open pits (see Fig. 7a). The limestone extracted from quarries will include 292.798 million metric tons of quality limestone (suitable for ore processing) and 181.427 million metric tons of waste limestone for a total of 474.225 million metric tons of limestone (see Fig. 7a). The proposal for mine expansion calls for permanent storage of 344.7 million metric tons of combined tailings and 452.7 million metric tons of PAG waste rock in a new facility (see Fig. 7b). The waste rock that has already been extracted is currently stored in the Hondo waste rock dump. An unspecified quantity of waste rock from the Hondo dump will be transferred to the new Naranjo facility. There is no plan to move any of the tailings that are currently stored in the El Llagal facility (Knight-Piésold Consulting, 2022; Barrick Gold, 2023a). The question as to how much, if any, waste rock is also stored in the El Llagal facility will be discussed in the "Responses" section.

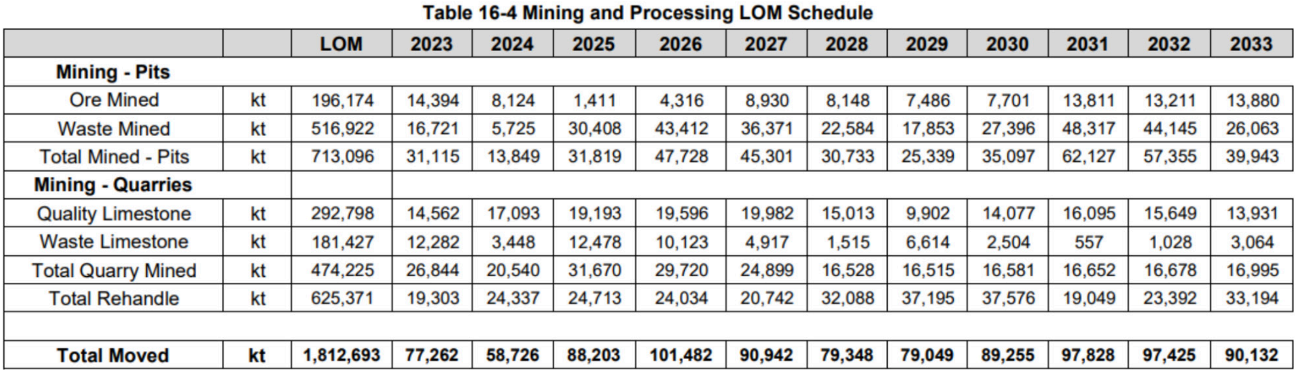


Table 16-4 Mining and Processing LOM Schedule

		LOM	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Mining - Pits													
Ore Mined	kt	196,174	14,394	8,124	1,411	4,316	8,930	8,148	7,486	7,701	13,811	13,211	13,880
Waste Mined	kt	516,922	16,721	5,725	30,408	43,412	36,371	22,584	17,853	27,396	48,317	44,145	26,063
Total Mined - Pits	kt	713,096	31,115	13,849	31,819	47,728	45,301	30,733	25,339	35,097	62,127	57,355	39,943
Mining - Quarries													
Quality Limestone	kt	292,798	14,562	17,093	19,193	19,596	19,982	15,013	9,902	14,077	16,095	15,649	13,931
Waste Limestone	kt	181,427	12,282	3,448	12,478	10,123	4,917	1,515	6,614	2,504	557	1,028	3,064
Total Quarry Mined	kt	474,225	26,844	20,540	31,670	29,720	24,899	16,528	16,515	16,581	16,652	16,678	16,995
Total Rehandle	kt	625,371	19,303	24,337	24,713	24,034	20,742	32,088	37,195	37,576	19,049	23,392	33,194
Total Moved	**kt**	**1,812,693**	**77,262**	**58,726**	**88,203**	**101,482**	**90,942**	**79,348**	**79,049**	**89,255**	**97,828**	**97,425**	**90,132**

FIGURE 7a. Over the life of the mine (LOM), 196.174 million metric tons of ore and 516.922 million metric tons of potentially acid generating (PAG) waste rock will be extracted from the open pits of the Pueblo Viejo mine. The mining operation will include the extraction of 474.225 million metric tons of limestone from quarries on the mine site (see Table 2). Portion of figure from Barrick Gold (2023a).

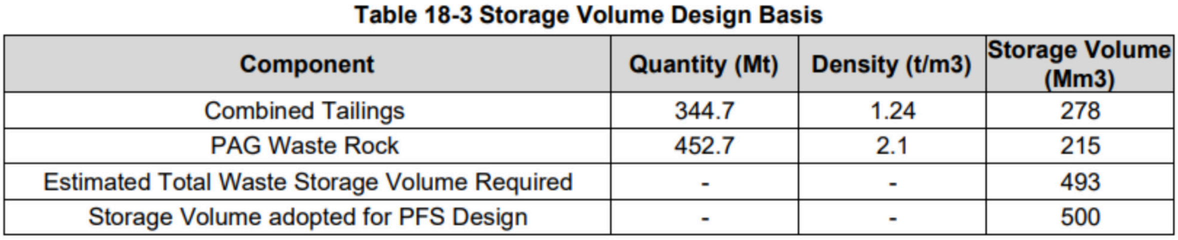


Table 18-3 Storage Volume Design Basis

Component	Quantity (Mt)	Density (t/m3)	Storage Volume (Mm3)
Combined Tailings	344.7	1.24	278
PAG Waste Rock	452.7	2.1	215
Estimated Total Waste Storage Volume Required	-	-	493
Storage Volume adopted for PFS Design	-	-	500

FIGURE 7b. The proposed Naranjo tailings storage facility (TSF) is designed to store 344.7 million metric tons of combined tailings and 452.7 million metric tons of potentially acid generating (PAG) waste rock. Figure from Barrick Gold (2023a).

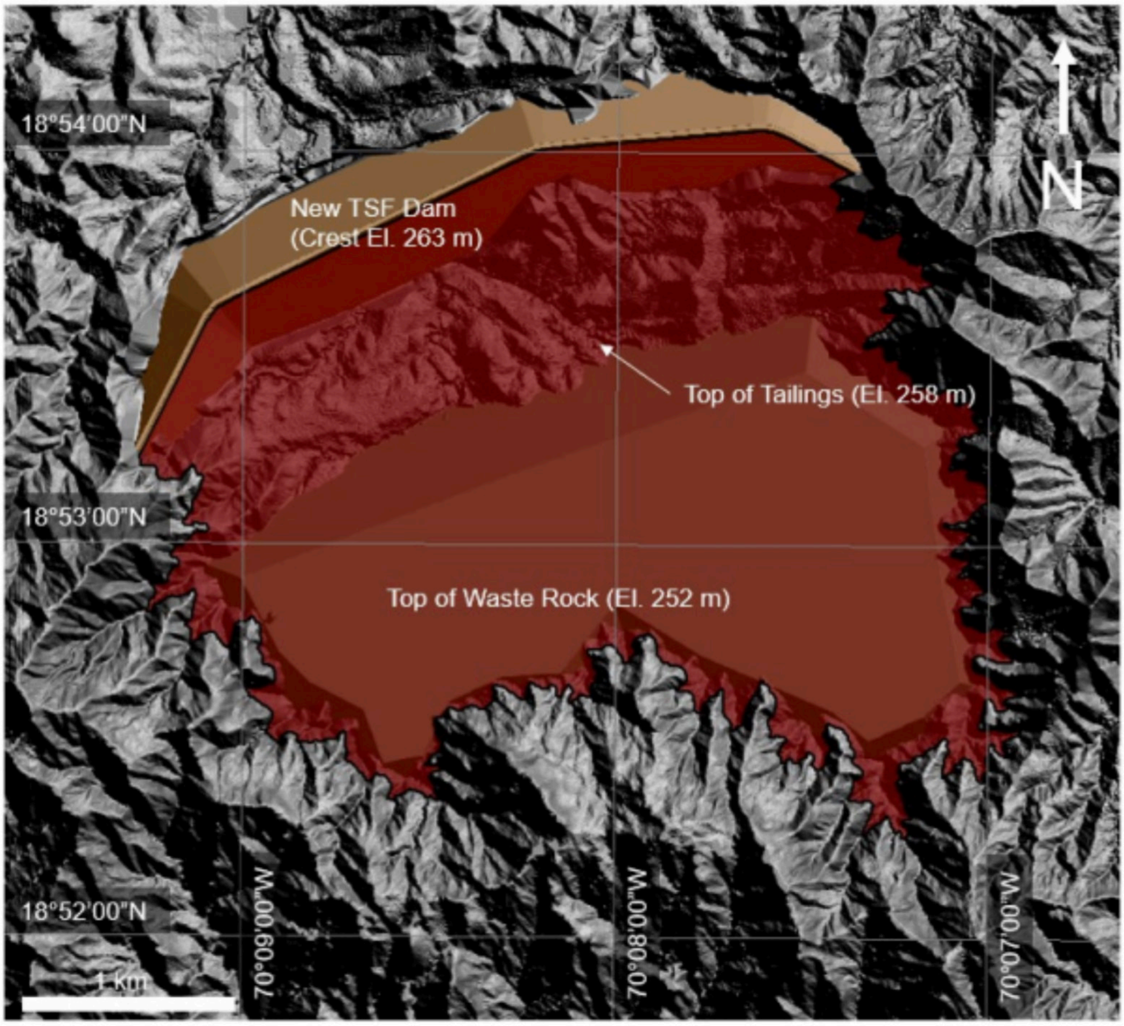


Figure 3-1. Layout of the proposed New TSF showing the ultimate dam crest elevation of 263 m, the location of the waste rock and the final elevation of the tailings surface.

FIGURE 8. The design of the proposed Naranjo TSF includes the storage of tailings on the downstream side (next to the dam) and potentially acid generating (PAG) waste rock on the upstream side. The waste rock would have a permanent water cover in order to prevent contact of the waste rock with oxygen. As a type of facility with co-disposal of tailings and waste rock, the design is most similar to the lowermost diagram in Fig. 6 in which the wall of the topographic depression is replaced by a constructed dam on the right-hand side. The only other example known to the author is the Phu Kham Copper Gold Operation in Laos (see Fig. 15). Although the EIS states that the existing El Llagal TSF is another example of the same design, the Technical Report to investors clarifies that the waste rock has been stored in the Hondo waste dump, where it awaits transfer to either the open pit or the Naranjo facility, and lacks clarity as to how much, if any, waste rock is actually stored in the El Llagal facility. Figure from Barrick Gold (2023a).

The proposed Naranjo facility would store both combined tailings and waste rock behind an earth-core rockfill dam with a height of 157 meters and crest length of 3800 meters. According to Barrick Gold (2023a), this would be one of the largest earth-core rockfill dams ever constructed. The tailings would be stored on the downstream side against the dam, while the waste rock would be stored on the upstream side (see Fig. 8). Thus, there would be no mixing of tailings and waste rock, except for mixing that occurred incidentally at the interface between the two types of mine waste. According to the EIS, *"La roca estéril PAG será almacenada en un estado permanentemente sumergido para mitigar la producción de drenaje ácido de roca a partir de la roca estéril alta en sulfuro* [PAG waste rock will be stored in a permanently submerged state to mitigate the production of acid rock drainage from the high sulfide waste rock] (Knight-Piésold Consulting, 2022). The EIS further emphasizes the permanence of the water cover in writing, "*El nivel freático se debe mantener por encima de la roca estéril contenida en la TSF luego del cierre*" [The water table must be maintained above the waste rock contained in the TSF after closure]. The permanent water cover will arise from precipitation, surface runoff onto the facility, and water that is shipped from the ore processing plant with the tailings. The plan is to maintain the top of the tailings at a higher elevation than the top of the waste rock, so that excess water flows onto the waste rock (see Fig. 8). The Technical Report to investors states, "Permanent pond covering of the facility will be minimized" (Barrick Gold, 2023a), which acknowledges both the plan for a permanent water cover and the risk involved in a permanent water cover.

The eight alternatives that were considered in the EIS include six alternatives (A-F) that involve storing both tailings and waste rock in the same facility, but at different sites (see Fig. 9). Alternative F involves the use of multiple sites with no single site large enough to accommodate all of the mine waste (see Fig. 9). Alternatives G and H involve filtering the tailings to a water content typically about 15% and storing the filtered tailings and waste rock in separate facilities (see Fig. 9). In Alternative H, the PAG waste rock would be stored in a drained state, while, in Alternative G, it would be stored in a permanently submerged state at a different site (see Fig. 9).

The analysis of alternatives in the EIS acknowledged the risk involved in a permanent water cover. With regard to Alternatives G and H, the EIS wrote, "*El objetivo del cierre de la pila de relaves filtrados y la WRSF drenada sería crear depósitos de residuos mineros permanentemente drenados y geotécnicamente estables que viertan escorrentía limpia de tormenta. Esto proporcionaría un menor nivel de riesgo (en comparación con relaves y roca estéril inundados permanentemente detrás de grandes presas)*" [The goal of the closure of the filtered tailings pile and the drained WRSF [Waste Rock Storage Facility] would be to create geotechnically stable, permanently drained mine waste deposits that discharge clean storm runoff. This would provide a lower level of risk (compared to permanently flooded tailings and waste rock behind large dams)] (Knight-Piésold Consulting, 2022). In comparing Alternatives G and H, the EIS wrote, "*Una instalación de roca estéril PAG inundada, como se incluye en la Alternativa H, ofrecería un mejor control de la generación de ácido que la instalación drenada en la Alternativa G. Por otro lado, la Alternativa H requiere de un espejo de agua permanente de agua detrás de las presas, lo que compensa el beneficio potencial de seguridad aguas abajo de la Alternativa G*" [A flooded PAG waste rock facility, as included in Alternative H, would offer better control of acid generation than the drained facility in Alternative G. On the other hand, Alternative H requires a permanent pool of water behind the dams, offsetting the potential downstream safety benefit of Alternative G] (Knight-Piésold Consulting, 2022).

The multiple accounts analysis in the EIS included environmental, socioeconomic, and technical accounts, as well as an account related to the cost of the project (see Fig. 9). Each of the accounts was composed of subaccounts, with 15 subaccounts for the environmental account, 15 subaccounts for the socioeconomic account, 14 subaccounts for the technical account, and eight subaccounts for the cost account. Two additional subaccounts were not assigned to any account. Although Alternative B received the highest score (3.65) as weighted across all accounts, Alternative C with a slightly lower score was chosen as the preferred alternative (see Fig. 9). Further information about the multiple accounts analysis and other aspects of the proposal for a new mine waste facility will be provided in the "Responses" section.

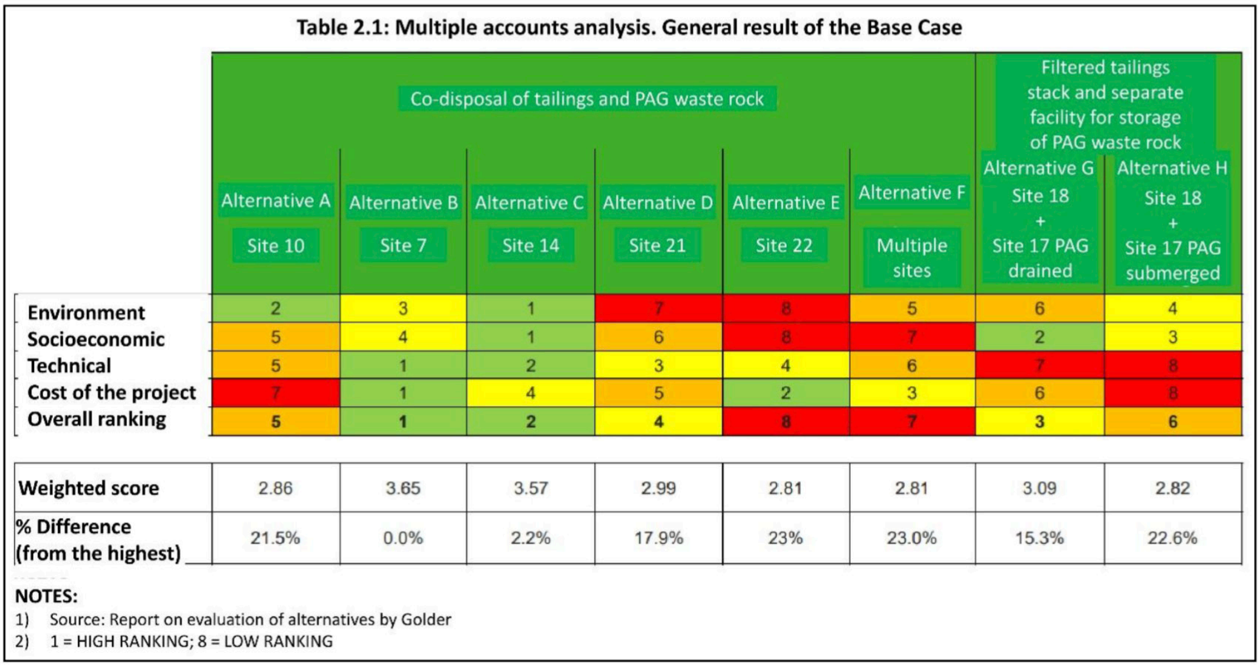


Table 2.1: Multiple accounts analysis. General result of the Base Case

	Co-disposal of tailings and PAG waste rock						Filtered tailings stack and separate facility for storage of PAG waste rock	
	Alternative A Site 10	Alternative B Site 7	Alternative C Site 14	Alternative D Site 21	Alternative E Site 22	Alternative F Multiple sites	Alternative G Site 18 + Site 17 PAG drained	Alternative H Site 18 + Site 17 PAG submerged
Environment	2	3	1	7	8	5	6	4
Socioeconomic	5	4	1	6	8	7	2	3
Technical	5	1	2	3	4	6	7	8
Cost of the project	7	1	4	5	2	3	6	8
Overall ranking	**5**	**1**	**2**	**4**	**8**	**7**	**3**	**6**

Weighted score	2.86	3.65	3.57	2.99	2.81	2.81	3.09	2.82
% Difference (from the highest)	21.5%	0.0%	2.2%	17.9%	23%	23.0%	15.3%	22.6%

NOTES:
1) Source: Report on evaluation of alternatives by Golder
2) 1 = HIGH RANKING; 8 = LOW RANKING

FIGURE 9. The EIS includes a multiple accounts analysis that evaluates eight alternatives for storage of tailings and waste rock in terms of environmental, socioeconomic, technical and cost factors, which finally resulted in the selection of the preferred Alternative C. According to the Global Industry Standard on Tailings Management (GISTM), the purpose of a multiple accounts analysis is to minimize risks to people and the environment and to minimize the volume of tailings and water placed in aboveground tailings facilities. By contrast, the minimization of the aboveground storage of tailings through backfill of the tailings into the exhausted open pits and quarries was not seriously considered as an alternative. In addition, the costs of the alternatives should not have been a factor in the choice of the preferred alternative. The appendices that would show how each alternative was scored in terms of environmental, socioeconomic, technical and cost factors was removed from the EIS, so that the scoring of the alternatives cannot be evaluated by the Dominican government or the Dominican public. Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

Methodology

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

1. **Is the EIS complete with sufficient information for full evaluation by the Dominican government and Dominican public?**
2. **Did the EIS give adequate consideration to the alternative of backfill of the exhausted open pits and quarries?**
3. **Did the analysis of alternatives in the EIS result in the choice of the safest alternative?**
4. **Has the design for the proposed Naranjo facility been adequately tested?**
5. **Does the EIS include an adequate analysis of the consequences of dam failure?**
6. **Does the EIS include an adequate plan for the long-term maintenance of the Naranjo facility after the closure of the mine?**

The questions were addressed largely by comparison of the EIS (Knight-Piésold Consulting, 2022) and the Technical Report (Barrick Gold, 2023a) that was provided to investors with internationally-recognized guidance documents, especially the Global Industry Standard on Tailings Management (GISTM) (ICMM-UNEP-PRI, 2020). There were some discrepancies in the information provided in the EIS and the Technical Report. In each case, the values given in the Technical Report were used for the analysis of this report under the assumption that they were more up-to-date. Significant discrepancies, both qualitative and quantitative, are discussed in the "Responses" section. Although the EIS is actually a compilation by Knight-Piésold Consulting of many reports written by many consulting companies, for simplicity, all references to the EIS are made to Knight-Piésold Consulting without specifying the actual author of each section. The author visited the sites of the existing El Llagal facility and the proposed Naranjo facility, as well as the surrounding communities and downstream rivers, on July 12-13, 2023.

With regard to the second question, this report includes a high-level plan for backfill of exhausted open pits and quarries in the absence of such a plan in either the EIS or the Technical Report. The main considerations were the mass of mine waste that could be backfilled into the open pits and quarries, as well as the cost of backfill for comparison with the cost of construction, operation and closure of a new aboveground mine waste storage facility. The final volume of the open pits was determined based upon the masses of ore and waste rock extracted over the life of the project (see Fig. 7a) together with the in situ ore density (see Fig. 10a) and the in situ density of the waste rock (see Fig. 10b). Although Fig. 10a taken from the Technical Report (Barrick Gold, 2023a) states the "specific gravity of ore" as 2.80 with units of t/m^3 (metric tons per cubic meter), specific gravity is the ratio of the density of the ore to the density of water, so that it is a dimensionless number. However, it should be clear from Fig. 10a that the ore density is 2.8 metric tons per cubic meter. In a similar way, Fig. 10b from the EIS (Knight-Piésold Consulting, 2022) states the specific gravity of the waste rock as 2.80 (a dimensionless number) and the density of the waste rock as 2.1 metric tons per cubic meter, which is a confusing use of the words "specific gravity" and "density." The best interpretation of Fig. 10b is that the in situ density of waste rock is 2.8 metric tons per cubic meter, while the excavated density is 2.1 metric tons per cubic meter, which would be typical values. Based on the in situ and excavated densities, the porosity of the excavated waste rock is 0.25. The range of volumes of the exhausted quarries was determined from the mass of limestone excavated over the life of the project (see Fig. 7a). The in situ limestone density was not stated, but it can range from 1.5 to 2.71 metric tons per cubic meter, depending upon the in situ porosity (Oates, 2010). Although not stated, the distinction between "quality limestone" and "waste limestone" (see Fig. 7a) probably reflects the clay content, not the porosity of the limestone.

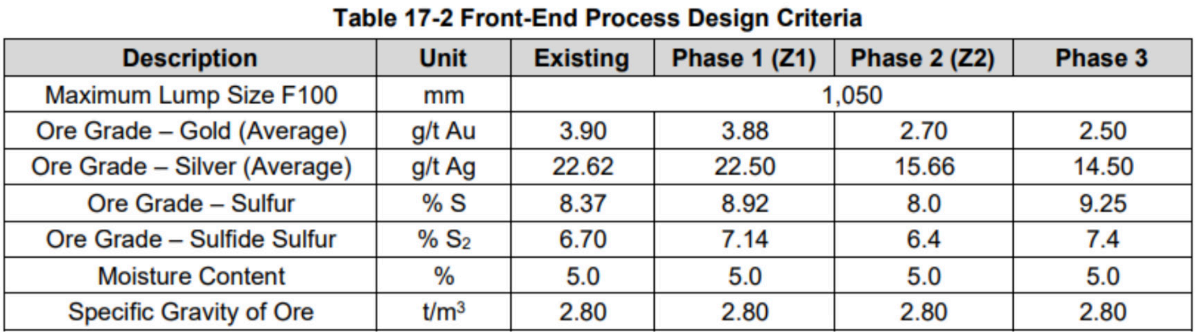


Table 17-2 Front-End Process Design Criteria

Description	Unit	Existing	Phase 1 (Z1)	Phase 2 (Z2)	Phase 3
Maximum Lump Size F100	mm	1,050			
Ore Grade – Gold (Average)	g/t Au	3.90	3.88	2.70	2.50
Ore Grade – Silver (Average)	g/t Ag	22.62	22.50	15.66	14.50
Ore Grade – Sulfur	% S	8.37	8.92	8.0	9.25
Ore Grade – Sulfide Sulfur	% S_2	6.70	7.14	6.4	7.4
Moisture Content	%	5.0	5.0	5.0	5.0
Specific Gravity of Ore	t/m^3	2.80	2.80	2.80	2.80

FIGURE 10a. The ore density is 2.80 metric tons per cubic meter (see Table 2). The specific gravity of the ore has the same numerical value, but specific gravity is the ratio of the density of the ore to the density of water, so that it is a dimensionless number. Portion of figure from Barrick Gold (2023a).

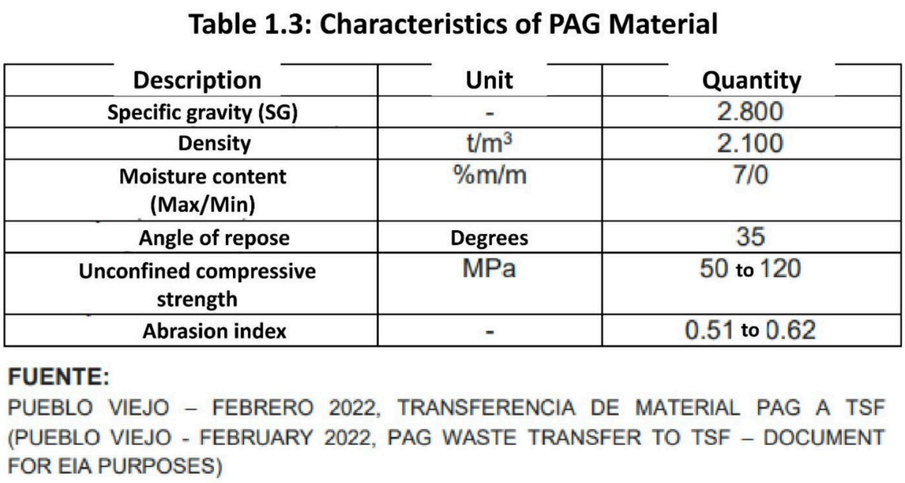


Table 1.3: Characteristics of PAG Material

Description	Unit	Quantity
Specific gravity (SG)	-	2.800
Density	t/m^3	2.100
Moisture content (Max/Min)	%m/m	7/0
Angle of repose	Degrees	35
Unconfined compressive strength	MPa	50 to 120
Abrasion index	-	0.51 to 0.62

FUENTE:

PUEBLO VIEJO – FEBRERO 2022, TRANSFERENCIA DE MATERIAL PAG A TSF (PUEBLO VIEJO - FEBRUARY 2022, PAG WASTE TRANSFER TO TSF – DOCUMENT FOR EIA PURPOSES)

FIGURE 10b. The best interpretation of the above figure is that the density of the potentially acid generating (PAG) waste rock is 2.8 metric tons per cubic meter in situ and 2.1 metric tons per cubic meter after extraction (compare with Fig. 7b and see Table 2). Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

TABLE 2. Parameters for open-pit and quarry backfill calculations

	Mass (Mt)	Density (t/m^3)	Volume (Mm^3)
In-Situ Materials			
Ore (pit)	196.174[1]	2.8[2]	70.06214
PAG waste rock (pit)	516.922[1]	2.8[3]	184.615
Limestone (quarry)	474.225[1]	1.5 – 2.7[4]	316.15 – 175.6389
Pit volume = 254.6771 Mm^3			
Pit volume + quarry volume = 430.316 – 570.8271 Mm^3			
Processed Materials[5]			
Combined tailings	344.7	1.24	277.9839
PAG waste rock	452.7	2.1	215.5714
Total mine waste volume = 493.5553 Mm^3			

[1] See Fig 7a.

[2] See Fig 10a.

[3] See Fig 10b.

[4] Oates (2010)

[5] See Fig 7b.

The masses of combined tailings and waste rock that could be potentially backfilled was assumed to be the same as the masses that are designated for permanent storage in the Naranjo facility (see Fig. 7b). Thus, the volume of mine waste was compared with the open-pit and quarry volumes based upon the masses and densities of combined tailings and excavated waste rock (see Fig. 7b). The parameters for the open-pit and quarry backfill calculations are summarized in Table 2. The volumes of mine waste and available space were compared assuming that there was either no co-mingling of the tailings and waste rock or complete co-mingling. No co-mingling meant that no tailings filled in the pore spaces between the particles of waste rock. Complete co-mingling meant that tailings filled in 75% of the porosity of the waste rock, which was assumed in a open-pit backfill project detailed in BAPE (2016).

The masses of tailings and waste rock that could be backfilled at the Pueblo Viejo mine should be regarded as approximations (or starting points for more exact calculations) because the masses of ore, waste rock, and limestone projected for excavation over the life of the mine begin in 2023 (see Fig. 7a). It is quite difficult to determine how much pit and quarry volume has been created by mining prior to 2023. It is reported that the El Llagal facility was storing 126 million cubic meters of tailings as of October 2022 (Barrick Gold, 2022a). The mining company also reported the contradictory information that "the current tailings stored at El Llagal TSF stands at 100.1 Mm³ at end of June 2023" (Barrick Gold, 2023b). Assuming that the higher value is more accurate and that it refers to combined tailings, that the combined tailings have a density of 1.24 metric tons per cubic meter (see Fig. 7b), that 1.46 metric tons of combined tailings correspond to one metric ton of ore (Knight-Piésold Consulting, 2022), and that the ore density is 2.8 metric tons per cubic meter (see Fig. 10a), the tailings in the El Llagal facility would correspond to 107.01 million metric tons of ore or 38.22 million cubic meters of pit volume that was created by extraction of ore. It is not clear how to reconcile the preceding results with the 175.3 million metric tons of ore that were excavated from 2010-2022 or the 78.5 million metric tons of ore that were processed during the same time period (see Fig. 11). The mass of total mined material (excluding limestone) of 391.1 million metric tons should correspond to 312.6 million metric tons of waste rock (after subtracting the 78.5 million metric tons of processed ore) or 215.8 million metric tons of waste rock (after subtracting the 175.3 million metric tons of mined ore) (see Fig. 11). However, there is no available information as to how much waste rock may have already been backfilled, if any. In the same way, there is no information as to how much limestone was quarried prior to 2023 or how much waste limestone has already been backfilled into the quarries. In the end, it was decided that only the following question would be addressed: How much of the mine waste that is designated for the Naranjo facility (see Fig. 7b) could be backfilled into the pit and quarry volume created beginning in 2023? As was mentioned, with more information, the question could be refined for comparison of the final volumes of the open pits and quarries with the total mine waste generated by the mine from the beginning of mining.

An additional source of uncertainty in the backfill calculations is the discrepancy in the same document (Barrick Gold, 2023a) between the 516.922 million metric tons of waste rock that will be extracted from the open pits beginning in 2023 (see Fig. 7a) and the 452.7 million metric tons of waste rock that are designated for storage in the Naranjo facility (see Fig. 7b). Since the Naranjo facility would not be ready to receive waste rock until 2025 (Barrick Gold, 2023a), presumably at least two years of waste rock (2023-2024) would be stored in the existing Hondo waste rock dump. However, the plan is to extract only 22.446 million metric tons of waste rock over 2023-2024 (see Fig. 7a), so the delay still does not resolve the discrepancy. In any event, the plan is to eventually transfer all of the waste rock in the Hondo dump either to the Naranjo facility or back into the open pits. In the end, in the absence of any other information, it was decided to accept the 516.922 million metric tons of waste rock extracted from the open pits (see Fig. 7a) for the calculation of pit volume and the 452.7 million metric tons of waste rock designated for the Naranjo facility (see Fig. 7b) as the mass of waste rock that could potentially be backfilled (see Table 2). Again, the backfill calculation in this report should be viewed as a starting point that should be refined once a complete and consistent dataset is available.

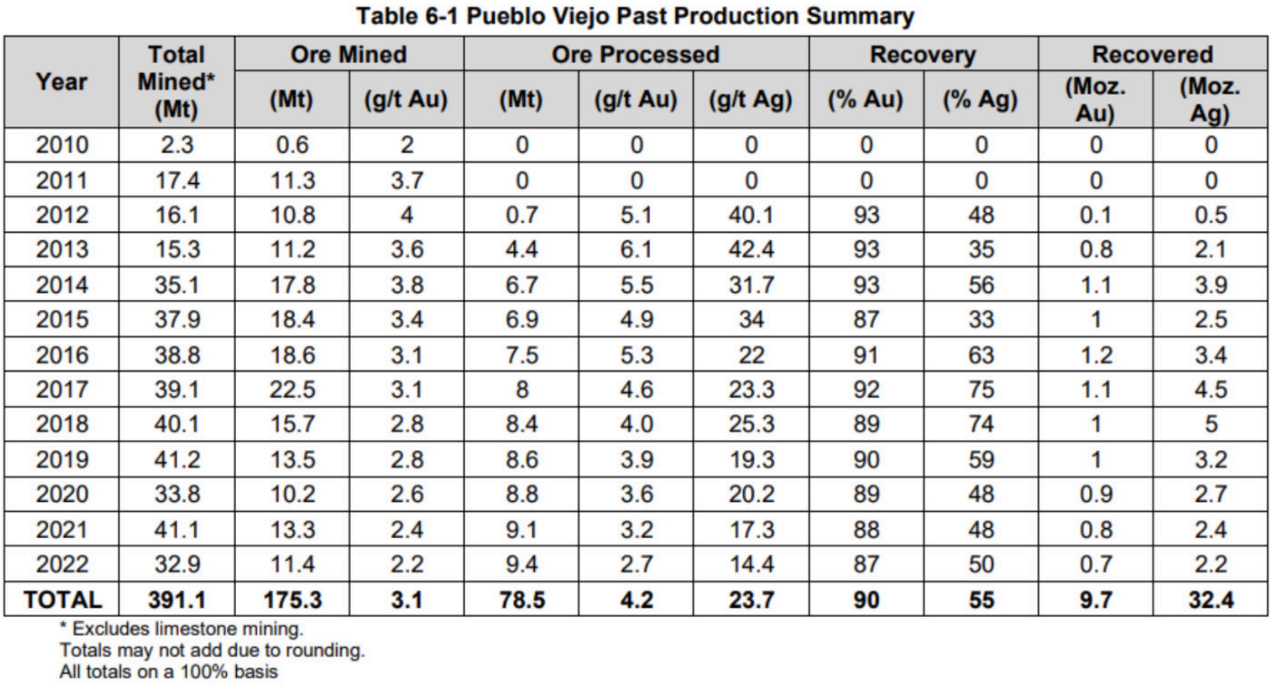


Table 6-1 Pueblo Viejo Past Production Summary

Year	Total Mined* (Mt)	Ore Mined		Ore Processed			Recovery		Recovered	
		(Mt)	(g/t Au)	(Mt)	(g/t Au)	(g/t Ag)	(% Au)	(% Ag)	(Moz. Au)	(Moz. Ag)
2010	2.3	0.6	2	0	0	0	0	0	0	0
2011	17.4	11.3	3.7	0	0	0	0	0	0	0
2012	16.1	10.8	4	0.7	5.1	40.1	93	48	0.1	0.5
2013	15.3	11.2	3.6	4.4	6.1	42.4	93	35	0.8	2.1
2014	35.1	17.8	3.8	6.7	5.5	31.7	93	56	1.1	3.9
2015	37.9	18.4	3.4	6.9	4.9	34	87	33	1	2.5
2016	38.8	18.6	3.1	7.5	5.3	22	91	63	1.2	3.4
2017	39.1	22.5	3.1	8	4.6	23.3	92	75	1.1	4.5
2018	40.1	15.7	2.8	8.4	4.0	25.3	89	74	1	5
2019	41.2	13.5	2.8	8.6	3.9	19.3	90	59	1	3.2
2020	33.8	10.2	2.6	8.8	3.6	20.2	89	48	0.9	2.7
2021	41.1	13.3	2.4	9.1	3.2	17.3	88	48	0.8	2.4
2022	32.9	11.4	2.2	9.4	2.7	14.4	87	50	0.7	2.2
TOTAL	**391.1**	**175.3**	**3.1**	**78.5**	**4.2**	**23.7**	**90**	**55**	**9.7**	**32.4**

* Excludes limestone mining.
Totals may not add due to rounding.
All totals on a 100% basis

FIGURE 11. It is reported that the El Llagal facility was storing 126 million cubic meters of tailings as of October 2022 (Barrick Gold, 2022a). Assuming that the preceding value refers to combined tailings, that the combined tailings have a density of 1.24 metric tons per cubic meter (see Fig. 7b), that 1.46 metric tons of combined tailings correspond to one metric ton of ore (Knight-Piésold Consulting, 2022), and that the ore density is 2.8 metric tons per cubic meter (see Fig. 10a), the tailings in the El Llagal facility would correspond to 107.01 million metric tons of ore or 38.22 million cubic meters of pit volume. It is not clear how to reconcile the preceding results with the 175.3 million metric tons of ore that were excavated from 2010-2022 or the 78.5 million metric tons of ore that were processed during the same time period. The mass of total mined material (excluding limestone) of 391.1 million metric tons should correspond to 312.6 million metric tons of waste rock (after subtracting the 78.5 million metric tons of processed ore) or 215.8 million metric tons of waste rock (after subtracting the 175.3 million metric tons of mined ore). A further source of confusion is that Barrick gold (2023b) also reported the contradictory information that "the current tailings stored at El Llagal TSF stands at 100.1 Mm³ at end of June 2023." Figure from Barrick Gold (2023a).

The unit cost of open-pit backfill (per metric ton of dry mine waste) was determined based on 15 open-pit backfill plans that were publicly available and which included costs. The plans were a mix of proposed, in-progress and completed backfill projects. In some cases, the cost was a pre-implementation estimate with no available information as to the actual cost. Out of the 15 backfill plans, 13 were in Canada, and eight were in Quebec. The preponderance of publicly available cost estimates from Quebec is a result of the mining legislation in Quebec that requires a feasibility study for open-pit backfill with a comparison of costs and benefits. Costs that were stated in CAD were converted to USD using 1 CAD = 0.76 USD, while prices that were stated in euros were converted using 1 euro = 1.19 USD. Plans for backfill of waste rock that were based on volume were converted to mass using a bulk density of 1.84 metric tons per cubic meter for excavated and compacted waste rock (Porter and Bleiwas, 2003). A plan for backfill of water and tailings with a stated volume and solids content was converted to mass of dry tailings using a particle density of 3.0 metric tons per cubic meter.

In a similar way, with regard to the fifth question, this report includes a high-level analysis of the consequences of dam failure in the absence of an adequate analysis in the EIS. The consequences of failure were addressed by using the most recent statistical model of past tailings dam failures (Larrauri and Lall, 2018). The statistical model predicts the initial runout of tailings following dam failure. The initial runout is the distance covered by the tailings due to the release of gravitational potential energy as the tailings fall out of the tailings deposit. After the cessation of the initial runout, normal fluvial processes could transport the tailings downstream indefinitely until the tailings reach a major lake or the ocean. When the initial runout reaches a major river, as would happen in the failure of the tailings facilities of the Pueblo Viejo mine, it can be difficult to separate the initial runout from the subsequent normal fluvial processes. For example, the failure of the tailings dam at the Samarco mine in Minas Gerais, Brazil, spilled tailings into the Doce River, so that the initial runout extended 637 kilometers to the Atlantic Ocean (Larrauri and Lall, 2018). According to Larrauri and Lall (2018), the best predictor of the initial runout of released tailings is the dam factor H_f, defined as

$$H_f = H\left(\frac{V_F}{V_T}\right)V_F \qquad (1)$$

where H is the height of the dam (meters), VT is the total volume of confined tailings and water (millions of cubic meters), and VF is the volume of the spill (millions of cubic meters). The most-likely predictions for the volume of the spill and the initial runout Dmax (kilometers) are then

$$V_F = 0.332 \times V_T^{0.95} \qquad (2)$$

$$D_{max} = 3.04 \times H_f^{0.545} \qquad (3)$$

It should be noted that Eqs. (2)-(3) express the most-likely consequences of dam failure. In particular, the most-likely consequence is that dam failure will result in the release of about one-third of the stored tailings (see Eq. (2)). However, the worst-case scenario is that dam failure will result in the release of 100% of the stored tailings, for which there are examples (Larrauri and Lall, 2018). Therefore, the worst-case runout (VF = VT) should be calculated using Eq. (3) with

$$H_f = HV_F \qquad (4)$$

Responses

The Environmental Impact Study is Incomplete

The EIS is incomplete in three significant ways that prevent adequate review by the Dominican government or the Dominican public, assuming that the government and the public have the same information. The first significant way is that many of the specifications for the proposed Naranjo facility can be found only in documents that have not been written, meaning that these specifications cannot be found anywhere. For example, according to the EIS, "*Los criterios de diseño de la TSF se discuten más adelante en la Sección 5.1, y podrán consultarse en mayor detalle en el Informe de bases de diseño (BGC, en curso [a]) … En el informe de las bases de diseño de la nueva TSF (BGC, en curso [a]) y la actualización completa de datos hidrometeorológicos (BGC, 31 de enero de 2018) se encuentran datos detallados de precipitación y evaporación, así como discusiones sobre estaciones climáticas, períodos de registro y síntesis/análisis de datos … Otros detalles referentes a los criterios de diseño del Nuevo TSF se proporcionan en un documento aparte (BGC, BGC en curso [a]) … Los criterios de diseño de estabilidad física se enumeran en un documento aparte (BGC, en curso [a]) … Durante la operación de almacenaje de colas y roca estéril, se ha contemplado almacenamiento para una PMP de 72 horas (1050 mm), asumiendo que el aliviadero de emergencia se construirá cuando lo indique el plan de respuesta ante el desencadenante de la acción (TARP, en inglés) (BGC, BGC en curso [a])*" [The TSF design criteria are discussed further in Section 5.1, and can be found in more detail in the Design Basis Report (BGC, in progress [a]) … Detailed precipitation and evaporation data, as well as discussions of climate stations, periods of record, and data synthesis/analysis, can be found in the design basis report for the new TSF (BGC, in progress [a]) and the complete hydrometeorological data update (BGC, January 31, 2018) … Other details regarding the design criteria of the New TSF are provided in a separate document (BGC, BGC in progress [a]) … Physical stability design criteria are listed in a separate document (BGC, in progress [a]) … During the tailings and waste rock storage operation, storage has been contemplated for a PMP of 72 hours (1050 mm), assuming that the emergency spillway will be constructed when indicated by the trigger action response plan (TARP, in English) (BGC, BGC in progress [a])] (Knight-Piésold Consulting, 2022).

The cited document is listed in the bibliography of the Spanish-language EIS as the following English-language document:

BGC Engineering Inc. (en curso [a]). TSF3 Expansion Design Basis Report (Borrador) [Informe]. Preparado para Pueblo Viejo Dominicana Jersey 2 Limited (PV).
For ease of reading, a complete English translation of the above reference would be:
BGC Engineering Inc. (in progress [a]). TSF3 Expansion Design Basis Report (Draft) [Report]. Prepared for Pueblo Viejo Dominicana Jersey 2 Limited (PV).

As another example, the *Tabla 5-1. Resumen de los criterios de diseño de la TSF* [Table 5-1. Summary of the design criteria for the TSF] lists "*Ataguías*" [Cofferdams] as "*en curso*" [in progress] without reference to any particular other document. The final example is that *Anexo A: Descripción del proyecto y sus fases* [Appendix A: Description of the project and its phases] includes seven drawings with the warning that "*este dibujo debe leerse en conjunto con el informe de BGC titulado 'Diseño Conceptual de la Nueva Instalacion de Almacenamiento de Colas', Borrador - en curso, de fecha 18 de mayo de 2022* [this drawing should be read in conjunction with the BGC report entitled "Conceptual Design of the New Tailings Storage Facility," draft - in progress, dated May 18, 2022] (Knight-Piésold Consulting, 2022). The two uncompleted BGC documents seem to be different documents with different titles. The EIS gives no indication as to how to find the draft report from May 18, 2022, or whether the document has since been updated. No attempt has been made in this report to document all instances of references in the EIS to documents that have not been written or are otherwise unavailable.

The second significant way in which the EIS is incomplete is that substantial sections of the EIS are written in English with no translation into Spanish. Many of the figures, tables and maps are available only in English. Some of the most important sections of all are the sections that analyze the consequences of failure of the proposed tailings dam. Two examples are the sections entitled "*Ruptura de Presa e Inundación*" [Dam Failure and Flooding] in *Anexo A: Descripción del proyecto y sus fases* [Appendix A: Description of the project and its phases] and the section entitled "*Metodología del Estudio Preliminar de Ruptura de Presas e Inundación* [Methodology of the Preliminary Study on Dam Failure and Flooding] in *Anexo B: Análisis de alternativas* [Appendix B: Analysis of alternatives]. In the previous examples, the only information available in Spanish is the section title with the remainder entirely in English. As a final example, Tables C1-C9 in *Anexo B: Análisis de alternativas* [Appendix B: Analysis of alternatives], which compile the characteristics of the various alternatives, are written only in English with no translation into Spanish. It is quite disturbing that, at a very minimum, the Dominican government has not requested the mining company to produce an EIS in the national language.

The third significant way in which the EIS is incomplete is that it provides only the total weighted scores of each of the alternatives (see Fig. 9) with no information as to how each of the accounts and subaccounts were separately scored. According to *Anexo B: Análisis de alternativas* [Appendix B: Analysis of alternatives] of the EIS, "*La Tabla 6.2-2 (Apéndice A) presenta un resumen de la evaluación de preselección realizada utilizando los criterios de la Tabla 6.2-1 … La Tabla 6.2-4 (Apéndice A) presenta un resumen de la evaluación de preselección de la Fase 2 completada utilizando los criterios de la Tabla 6.2-3 … Las tablas detalladas del MAA se presentan en el Apéndice A*" [Table 6.2-2 (Appendix A) presents a summary of the pre-screening evaluation conducted using the criteria in Table 6.2-1 … Table 6.2-4 (Appendix A) presents a summary of the completed Phase 2 pre-selection evaluation using the criteria in Table 6.2-3 … The detailed tables of the MAA [Multi-criteria Alternatives Analysis] are presented in Appendix A] (Knight-Piésold Consulting, 2022). The only information about the critical Appendix A is the title page with the title "*APENDICE A Tablas del Análisis de Alternativas Multicriterio - Apéndice A-1 – Tablas 6.2-2 y 6.2-4 - Apéndice A-2 – Tablas A-1 a A-6*" [APPENDIX A Multicriteria Alternatives Analysis Tables - Appendix A-1 – Tables 6.2-2 and 6.2-4 - Appendix A-2 – Tables A-1 to A-6] (Knight-Piésold Consulting, 2022) with the remainder of the section deleted. In fact, the table of contents of *Anexo B: Análisis de alternativas* [Appendix B: Analysis of alternatives] lists six appendices (A-F) with the caveat (in all capital letters) "*APPENDICES (NO SON INCLUIDOS EN ESTA VERSION)*" [APPENDICES (NOT INCLUDED IN THIS VERSION)] (Knight-Piésold Consulting, 2022). Without the missing appendices, it is impossible for the Dominican government and Dominican public to assess whether the accounts and subaccounts have been scored correctly. The importance of the separate scores are more fully discussed in the subsections "The Analysis of Alternatives does not Emphasize Safety" and "The Design for the New Facility is Untested" in this report.

The Alternative of Open-Pit Backfill has not been Seriously Considered

The EIS briefly considers the alternative of "*Almacenamiento de relaves en un tajo abierto*" [Tailings storage in an open pit], but dismisses the alternative with the sentence "*El Plan de la Mina Pueblo Viejo dedica los tajos abiertos a almacenar roca PAG, por lo que los tajos no están disponibles para el almacenamiento de relaves*" [The Pueblo Viejo Mine Plan dedicates the open pits to storage of PAG rock, so that the pits are not available for tailings storage] (Knight-Piésold Consulting, 2022). The EIS provides further explanation in writing, "*Se espera que los tajos se llenen con agua en el período posterior al cierre de la Mina, inundando cualquier relleno; la roca PAG es reactiva mientras que los relaves no lo son; la inmersión de PAG en los tajos llenos con agua es más efectiva para reducir el agua afectada después del cierre que el uso de los tajos para el almacenamiento de relaves*" [The pits are expected to fill with water in the period following the closure of the Mine, flooding any backfill; PAG rock is reactive while tailings are not; PAG immersion in water-filled pits is more effective in reducing affected water after closure than using the pits for tailings storage] (Knight-Piésold Consulting, 2022). There is no other consideration of the option of open-pit backfill in the entire EIS. There is also no consideration of any other means of reducing the aboveground storage of tailings, despite the fact that, according to the GISTM, the reduction of the volume of tailings stored aboveground is one of the two purposes of the multiple accounts analysis.

The above explanation in the EIS of the avoidance of tailings backfill is generally consistent with industry practice. Even so, the risk of acid mine drainage from PAG waste rock that is stored aboveground must be balanced against the risk of the collapse of wet, fine-grained tailings that are stored aboveground. The real problem with the explanation in the EIS is that the EIS is not a proposal for a tailings storage facility, but a proposal for a facility that would store both tailings and waste rock. Thus, it should be critical for the EIS to consider how to minimize the waste rock that must be stored aboveground, as well as the tailings that are stored aboveground. On the contrary, the EIS gives no explanation as to how it arrived at the mass or volume of waste rock that must be stored aboveground, even though those values are critical factors as to why only certain sites could be chosen and why the alternative of multiple sites was both considered and dismissed (see Fig. 9). The EIS and the Technical Report are not in agreement on the required volume of waste rock that must be stored in the Naranjo facility. According to the EIS (Knight-Piésold Consulting, 2022), the required volume of waste rock is 277 million cubic meters, while the Technical Report (Barrick Gold, 2023a) states a required volume of 215 million cubic meters (compare Figs. 7b and 12). In a similar way, according to the EIS (Knight-Piésold Consulting, 2022), the required volume of combined tailings is 368 million cubic meters, while the Technical Report (Barrick Gold, 2023a) states a required volume of 278 million cubic meters (compare Figs. 7b and 12). Thus, the EIS analyzes a much larger facility than is contemplated in the Technical Report. As with the missing documents and references, no attempt was made in this report to catalog all discrepancies between the EIS and the Technical Report.

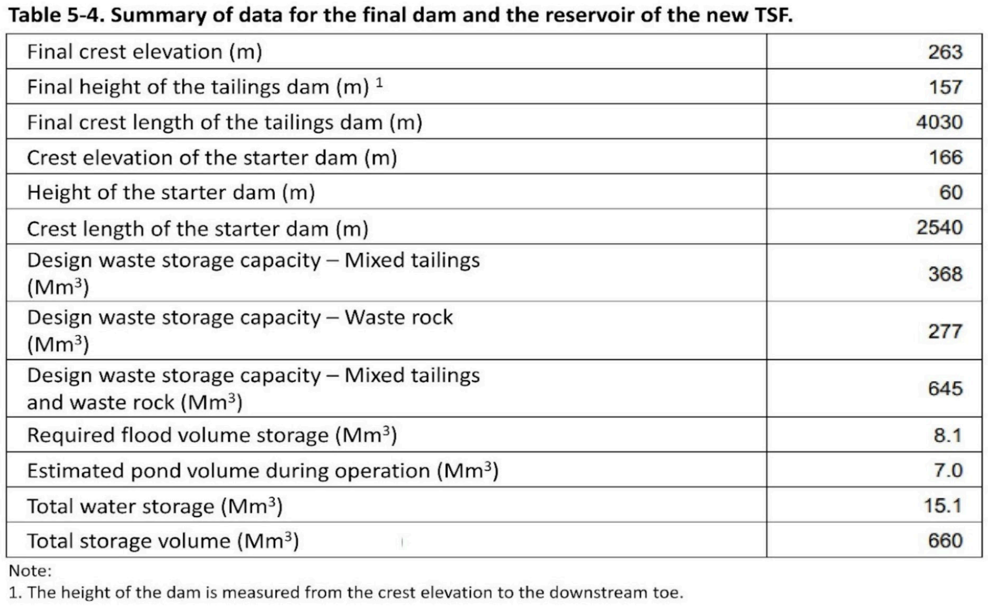


Table 5-4. Summary of data for the final dam and the reservoir of the new TSF.

Final crest elevation (m)	263
Final height of the tailings dam (m) [1]	157
Final crest length of the tailings dam (m)	4030
Crest elevation of the starter dam (m)	166
Height of the starter dam (m)	60
Crest length of the starter dam (m)	2540
Design waste storage capacity – Mixed tailings (Mm^3)	368
Design waste storage capacity – Waste rock (Mm^3)	277
Design waste storage capacity – Mixed tailings and waste rock (Mm^3)	645
Required flood volume storage (Mm^3)	8.1
Estimated pond volume during operation (Mm^3)	7.0
Total water storage (Mm^3)	15.1
Total storage volume (Mm^3)	660

Note:
1. The height of the dam is measured from the crest elevation to the downstream toe.

FIGURE 12. The EIS and the Technical Report are not in agreement on the required volume of waste rock and tailings that must be stored in the Naranjo facility. According to the EIS, the required volume of waste rock is 277 million cubic meters, while the Technical Report provided to investors states a required volume of 215 million cubic meters (compare with Fig. 7a). According to the EIS, the required volume of combined (or mixed) tailings is 368 million cubic meters, while the Technical Report states a required volume of 278 million cubic meters (compare with Fig. 7a). Thus, the EIS analyzes a much larger facility than is contemplated in the Technical Report. Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

In partial contrast to the EIS, there is considerably more discussion regarding plans for open-pit backfill in the Technical Report. For this reason, the Pueblo Viejo mine is listed as a Barrick Gold open-pit backfill project in Table 1. Currently, the waste rock extracted from the open pits is stored at the Hondo waste rock dump. The plan is to backfill part of this waste rock and to transfer the rest of the waste rock to the proposed Naranjo facility. According to the Technical Report, “The PAG waste material deposited in Hondo is intended to be rehandled into completed pit void locations when available, and the remainder will be rehandled into the PAG handling system to the Naranjo TSF after pit mining is completed … Due to sequencing of the completion of the Lower Llagal TSF and the planned commissioning of the Naranjo TSF, there has been a necessity to store PAG in above-ground dumps temporarily. The PAG will be ultimately rehandled into in-pit voids and the Naranjo TSF … PAG waste is currently being transported to temporary ex-pit waste dumps, which will be rehandled into both the Naranjo TSF facility and the mined pit voids below the water table. Pit backfilling is expected to start in 2030 and continue until the end of mine life with a planned capacity of 163Mt of PAG waste” (Barrick Gold, 2023a). The Technical Report adds, “As part of the closure requirements pertinent to environmental permitting, all PAG waste must be stored in anaerobic conditions to minimise the acid generating potential. This is typically achieved by co-disposing PAG and tailings in the TSF facilities but can also be achieved by backfilling the pits to an elevation below the natural water table level” (Barrick Gold, 2023a). The preceding statement is incorrect because there are far more open-pit backfill projects than aboveground facilities that store both tailings and waste rock. This subject will be discussed further in the subsection “The Design for the New Facility is Untested.”

The Technical Report (Barrick Gold, 2023a) does not explain why it is possible to backfill only 163 million metric tons of waste rock and no tailings, and this subject is not considered at all in the EIS. Based upon the masses and in situ densities of ore and waste rock, the final pit volume should be 254.6771 million cubic meters (see Table 2).

Based upon the excavated density and the mass of waste rock that is designated for the Naranjo facility, the volume of waste rock requiring backfill should be 215.5714 million cubic meters (see Table 2). Thus, it should be entirely feasible to backfill all of the PAG waste rock into the open pits. In other words, the mass of waste rock that could backfilled into the open pits (452.7 million metric tons) with room to spare, constituting all of the waste rock that is designated for the Naranjo facility, is far greater than the capacity of 163 million metric tons that was stated in the Technical Report (Barrick Gold, 2023a). As discussed in the "Methodology" section, the preceding calculation does not take into account any pit volume created prior to 2023, nor any plans to backfill waste rock that was extracted prior to 2023. However, it should be noted that the waste rock designated for the Naranjo facility includes an unspecified mass of waste rock that is currently stored at the Hondo waste rock dump.

The difference between the final pit volume (254.6771 million cubic meters) and the volume of backfilled waste rock (215.5714 million cubic meters) is equal to 39.10571 million cubic meters, which is the available space above the waste rock that could be filled with tailings (see Table 3). If there were no mixing of tailings and waste rock, then the available space above the waste rock could be filled with 48.49109 million metric tons of tailings at a density of 1.24 metric tons per cubic meter (see Fig. 7b), leaving 296.2089 million metric tons of tailings that could not be backfilled into the open pits (see Table 3). If the waste rock and tailings are allowed to mix, then there is 79.52536 million cubic meters of available space (the region above the waste rock plus 75% of the pore space within the waste rock), which could be filled with 98.61144 million cubic meters of tailings, leaving 246.0886 million cubic meters of tailings that could not be backfilled.

Table 3. Tailings remaining for quarry backfill after preferential backfill of waste rock into open pit followed by backfill of tailings

Co-Mingling of Waste Rock and Tailings	Available Space after Waste Rock Backfill (Mm^3)	Maximum Tailings Backfill into Open Pit (Mt)	Tailings Remaining for Quarry Backfill (Mt)
No	39.10571	48.49109	296.2089
Yes	79.52536[1]	98.61144	246.0886

[1] The available space for tailings within the waste rock is calculated as 75% of the pore volume of the waste rock.

At a minimum, it appears as if the maximization of open-pit backfill could eliminate the need for the permanent aboveground storage of waste rock and substantially reduce the volume of tailings that would require permanent aboveground storage. However, another option that has not been considered in either the EIS or the Technical Report is the possibility of backfilling tailings into the exhausted quarries. Based on possible limestone densities in the range 1.5 – 2.7 metric tons per cubic meter, the total quarry volume created beginning in 2023 would be in the range 316.15 – 175.6389 million cubic meters, with the larger volume corresponding to the lower density. Thus, all of the tailings designated for the Naranjo facility could be backfilled into the exhausted quarries, except in the circumstances of no possible mixing of tailings and waste rock in the open pits and very high limestone density. As above, even if all of the tailings could not be backfilled into either the open pits or the quarries, the maximization of both open-pit and quarry backfill could greatly reduce the volume of tailings that would require permanent aboveground storage.

It should be noted that most of the excavated limestone does not require backfill because it is consumed in the ore processing, thus being transformed into a component of the combined tailings. The waste limestone that is unsuitable for processing is the only NAG waste rock. According to the Technical Report, "NAG waste material is currently placed in-pit voids. After 2025, all NAG material resulting from the quarries and pits will be deposited in a NAG stockpile northwest of the mine or quarry voids when available" (Barrick Gold, 2023a). Thus, there is no actual need to backfill the quarries with limestone, so that the quarries could be dedicated to the storage of tailings. Possible problems associated with backfill of tailings into exhausted quarries are discussed below.

The unit costs for open-pit backfill have ranged from USD 0.28 per metric ton to USD 15.00 USD per metric ton, with 10 out of the 15 studies in the range 0.72 – 1.50 USD per metric ton (see Table 4). The very high outlier (USD 15.00 per metric ton) included the additional cost of remediation of acid mine drainage from waste rock that had been stored on the surface at the Soviet-era Lichtenberg uranium mine in former East Germany (Arcadis, 2015). As mentioned earlier, the very low outlier (USD 0.28 per metric ton) was achieved through the transport of uranium tailings as a slurry by gravity directly from the ore processing plant into an exhausted open pit (Arcadis, 2015). In no other case was it apparent why the cost was particularly high or low. Instead of removing the outliers, the expected value was calculated as the geometric mean (USD 1.20 per metric ton), which suppresses the impact of outliers. The calculation of the median would be an alternative approach, which would yield a nearly identical result (USD 1.18 per metric ton). Throughout the remainder of this report, the value of USD 1.20 per metric ton will be used as the best estimate for the unit cost of open-pit backfill.

Table 4. Unit costs for open-pit backfill for selected mining projects

Mine	Country or Canadian Province	Ore	Quantity (Mt)		Cost (million USD)	Unit Cost (USD/t)
			Waste Rock	**Tailings**		
Lichtenberg[1]	Germany	U	230[2]	—	3450[3]	15.00
Whistle[1]	Ontario	Cu-Ni	6.4	—	19	2.97
Rabbit Lake[4]	Saskatchewan	U	—	8.8	23.06	2.62
Solbec[4]	Quebec	Cu-Pb-Zn	0.508[2]	0.1	1.0691[5]	2.11
Matawinie[6]	Quebec	graphite	49.5[7]		74.0[8]	1.50
Canadian Malartic[9]	Quebec	Au	—	92[10]	119[8]	1.29
Owl Creek[1]	Ontario	Au	3.648	—	4.7[8]	1.29
Canadian Malartic[9]	Quebec	Au	242.55	—	285[8]	1.18
Dumont[11]	Quebec	Ni	1251.8[12]	—	1463.5[8]	1.17[13]
Island Copper[4]	British Columbia	Cu	90	—	100	1.11
Dumont[14]	Quebec	Ni	984.6[15]	—	748.6-1279.8[8]	0.76-1.30
Captain N Extension[4]	New Brunswick	Pb-Zn	0.1	—	0.1	1.00
East Sullivan[4]	Quebec	Cu-Zn-Ag-Cd	0.37[2]	—	0.35	0.95
Canadian Malartic[16]	Quebec	Au	625	—	449[8]	0.72
Marymia[1]	W. Australia	Au	—	1.296094	0.3595	0.28
					Geometric Mean	1.20
					Median	1.18

[1] Arcadis (2015)
[2] Volume converted to mass using 1.84 t/m³ (Porter and Bleiwas, 2003)
[3] Euros converted to USD using 1 euro = 1.19 USD
[4] MEND (1995)
[5] Cost of backfilling waste rock only
[6] BAPE (2020)
[7] The proposed plan is to backfill 40% of 107.5 Mt of waste rock and tailings. The value is the additional cost of backfilling all but 15 Mt of waste rock and tailings.
[8] CAD converted to USD using 1 CAD = 0.76 USD
[9] BAPE (2009), Golder Associés Ltée (2009)
[10] Based on backfilling 143 Mm³ of water and tailings with 45% solids content (Golder Associés Ltée, 2009) and assumed particle density of 3 t/m³
[11] Royal Nickel Corporation (2013a)
[12] 1070 Mt of waste rock and 181.8 Mt of overburden (unconsolidated deposits)
[13] 1.12 UDS/t for waste rock and 1.46 USD/t for overburden
[14] BAPE (2014), Royal Nickel Corporation (2014)
[15] 826 Mt of waste rock and 158.6 Mt of overburden (unconsolidated deposits)
[16] BAPE (2016), Mine Canadian Malartic (2016)

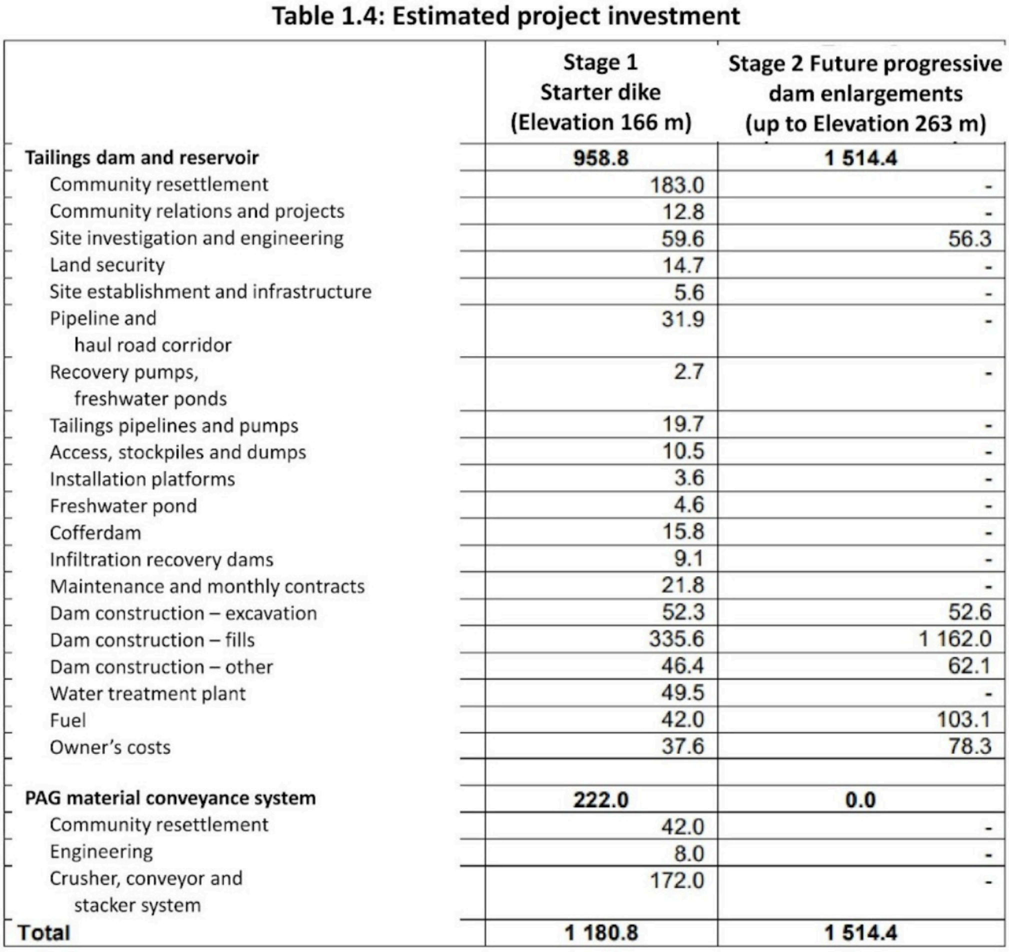


Table 1.4: Estimated project investment

	Stage 1 Starter dike (Elevation 166 m)	Stage 2 Future progressive dam enlargements (up to Elevation 263 m)
Tailings dam and reservoir	**958.8**	**1 514.4**
Community resettlement	183.0	-
Community relations and projects	12.8	-
Site investigation and engineering	59.6	56.3
Land security	14.7	-
Site establishment and infrastructure	5.6	-
Pipeline and haul road corridor	31.9	-
Recovery pumps, freshwater ponds	2.7	-
Tailings pipelines and pumps	19.7	-
Access, stockpiles and dumps	10.5	-
Installation platforms	3.6	-
Freshwater pond	4.6	-
Cofferdam	15.8	-
Infiltration recovery dams	9.1	-
Maintenance and monthly contracts	21.8	-
Dam construction – excavation	52.3	52.6
Dam construction – fills	335.6	1 162.0
Dam construction – other	46.4	62.1
Water treatment plant	49.5	-
Fuel	42.0	103.1
Owner's costs	37.6	78.3
PAG material conveyance system	**222.0**	**0.0**
Community resettlement	42.0	-
Engineering	8.0	-
Crusher, conveyor and stacker system	172.0	-
Total	**1 180.8**	**1 514.4**

FIGURE 13. The total cost for construction of the Naranjo TSF (tailings storage facility) is projected to be USD 2695 million or USD 3.38 per metric ton of mine waste. The projected cost is underestimated because it does not include the costs of operation or of long-term monitoring, inspections, maintenance and reviews of the Naranjo TSF following mine closure. By contrast, using a unit cost of USD 1.20 per metric ton based on previous open-pit backfill projects (see Table 4), the cost of backfilling 344.7 million metric tons of tailings and 452.7 million metric tons of waste rock would be USD 957 million. The projected cost of the Naranjo TSF is unusually high, since typical costs for conventional tailings management are USD 1.20 per metric ton with a range of USD 0.5 – 2.50 per metric ton. Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

Based on a cost of USD 1.20 per metric ton of mine waste, the cost of backfilling 344.7 million metric tons of tailings and 452.7 million metric tons of waste rock would be USD 957 million. On the other hand, the total cost of the Naranjo TSF (tailings storage facility) is projected to be USD 2695 million or USD 3.38 per metric ton of mine waste (Knight-Piésold Consulting, 2022; see Fig. 13). Even that projected cost is underestimated because it does not include the costs of operation or of long-term monitoring, inspections, maintenance and reviews of the Naranjo TSF following mine closure (see Fig. 13). According to the EIS, "*PVD ha estimado la inversión total del proyecto 'Nueva Instalación de Co-disposición de Relaves y Roca Estéril para la Mina Pueblo Viejo' (nuevo TSF), en base al diseño conceptual de la presa (capacidad total de almacenamiento de residuos mineros de 645 Mm^3), según se detalla en el informe de diseño de BGC. Los montos aquí presentados … no incluyen ajustes por el valor presente de los montos futuros, ni tampoco los costos de operación ni cierre*" [PVD has estimated the total investment of the "New Facility for Co-disposal of Tailings and Waste Rock for the Pueblo Viejo Mine" (new TSF) project, based on the conceptual design of the dam (total mining waste storage capacity of 645 Mm^3), as detailed in the BGC design report. The amounts presented here do not include adjustments for the present value of future amounts, nor do they include the costs of operation or closure] (Knight-Piésold Consulting, 2022). The design report by BGC Engineering mentioned in the preceding quote is apparently the same as the previously-discussed report that is still "*en curso*" [in progress]. In summary, based on the available information, the cost of backfill of the mine waste would be less than 35% of the cost of construction and operation of a new aboveground mine waste storage facility. It is noteworthy that the projected cost of the Naranjo TSF is unusually high, since typical costs for conventional tailings management are USD 1.20 per metric ton with a range of USD 0.5 - 2.50 per metric ton (Klohn Crippen Berger, 2017). The reasons for the high cost of the Naranjo facility will be discussed in the subsection "The Design for the New Facility is Untested."

It was previously mentioned that open-pit backfill is regarded as a best practice under almost all circumstances, except when the likelihood of groundwater contamination could be reduced by moving the tailings to an aboveground location. Those circumstances would not apply in the case of the Pueblo Viejo mine because the EIS expresses considerable doubts regarding the suitability of the preferred site for the prevention of groundwater contamination from the Naranjo facility. The EIS summarizes the problem in the following way: "*El Nuevo TSF está siendo planificado para almacenar solidos de relaves, rocas de desecho potencialmente generadoras de ácido (PAG) y aguas de proceso de mina y de contacto. Las presas que requieren almacenamiento de agua para la inmersión permanente de relaves o rocas de desecho reactivas deben funcionar como estructuras de retención de aguas. La cantidad de filtración que escapa de un TSF y el movimiento a través del agua subterránea de los contaminantes que estén contenidos es una función crítica y ambientalmente sensible de la instalación. La fundación de una presa de colas es un componente estructural fundamental. La fundación de una presa tiene doble función: (1) estabilidad estructural y rigidez suficiente para limitar las deformaciones dentro de patrones de comportamiento aceptables; (2) control de filtraciones con respecto a la cantidad y calidad del flujo, presiones de levante y esfuerzos erosivos*" [The New TSF is being planned to store tailings solids, potentially acid-generating (PAG) waste rock, and mine process and contact waters. Dams that require water storage for the permanent immersion of tailings or reactive waste rock must function as water retention structures. The amount of seepage that escapes from a TSF and the movement through groundwater of contained contaminants is a critical and environmentally sensitive function of the facility. The foundation of a tailings dam is a fundamental structural component. The foundation of a dam has a double function: (1) structural stability and sufficient rigidity to limit deformation within acceptable behavior patterns; (2) seepage control with respect to flow quantity and quality, uplift pressures, and erosive stresses] (Knight-Piésold Consulting, 2022).

There is still uncertainty as to whether the preferred site has a sufficiently low permeability to act as the foundation for a dam and to prevent groundwater contamination. According to the EIS, "*Las siguientes son las incertidumbres geológicas e hidrogeológicas claves para el diseño del Nuevo TSF en base a la investigación preliminar del sitio realizada hasta la fecha … Potencial de filtraciones excesivas debajo de la fundación de la presa o a través de las crestas de la cuenca … Las pruebas in-situ de las formaciones geológicas en la cuenca y la huella de la presa del Nuevo TSF completadas como parte de la investigación preliminar del sitio han encontrado conductividades hidráulicas variables que si resultan continuas podrían resultar en una filtración excesiva y requerir un tratamiento de mitigación en la fundación (por ejemplo, inyección). La filtración excesiva, si no es tratada, podría provocar la erosión de la fundación y el movimiento a través de las aguas subterráneas de contaminantes aguas abajo del Nuevo TSF*" [The following are the key geologic and hydrogeologic uncertainties for the design of the New TSF based on the preliminary site investigation conducted to date … Potential for excessive seepage below the dam foundation or through basin crests … The in-situ testing of the geological formations in the basin and the New TSF dam footprint completed as part of the preliminary site investigation have found variable hydraulic conductivities that, if continued, could result in excessive seepage and require mitigation treatment in the foundation (for example, injection). Excessive seepage, if left untreated, could lead to erosion of the foundation and movement through groundwater of contaminants downstream of the New TSF] (Knight-Piésold Consulting, 2022).

The EIS continues with uncertainty regarding the permeability of the soils and clastic sedimentary rocks at the preferred site. According to the EIS, "*Los depósitos de suelos transportados observados hasta la fecha en el sitio de la presa del Nuevo TSF son predominantemente limos y arcillas y se prevé que en general tengan una permeabilidad relativamente baja, pero estos depósitos podrían contener capas o bolsones de suelos de granos mas gruesos que podrían tener una permeabilidad comparativamente mas alta ... Al sur del estribo derecho de la presa, la Cresta Este es una cresta afilada de aproximadamente 3 km de largo ... Existe un potencial de zonas con mayor permeabilidad en rocas meteorizadas y no meteorizadas en la Cresta Este, donde se encuentran lutitas tobáceas y limolitas con intercalaciones de calizas y calizas de la Fm Hatillo*" [The transported soil deposits observed to date at the New TSF dam site are predominantly silts and clays and are generally expected to have relatively low permeability, but these deposits may contain layers or pockets of coarser-grained soils than could have comparatively higher permeability ... South of the right abutment of the dam, the East Ridge is a sharp ridge approximately 3 km long ... There is a potential for zones with higher permeability in weathered and unweathered rocks in the East Ridge, where there are tuffaceous shales and siltstones with intercalations of limestone and limestone from the Hatillo Fm] (Knight-Piésold Consulting, 2022).

The greatest concern in the EIS regarding the preferred site is reserved for the possible occurrence of karst, that is, limestone with large, open channels created by dissolution, which could result in the rapid transport into and through the subsurface of contaminated water from the Naranjo facility. According to the EIS, "*Potencial de calizas u otras unidades geológicas colapsables/solubles dentro de la cuenca del valle ... Actualmente, existe incertidumbre en cuanto a si la piedra caliza de la Fm Hatillo esta presente dentro de las áreas de la huella de la presa y del embalse de la presa ... Los tipos de roca caliza tienen potencial para el desarrollo kárstico de disolución, lo que podría resultar en zonas con mayor permeabilidad y mayor potencial de filtración y el movimiento a través de las aguas subterráneas de contaminantes más allá de la cresta de la cuenca del valle y el gradiente descendente del Nuevo TSF ... Es posible que se requieran evaluaciones hidrogeológicas y evaluaciones de filtración para cuantificar las tasas de filtración que pueden escapar del TSF y para evaluar si las ubicaciones con caliza de mayor permeabilidad pueden requerir tratamiento del subsuelo*" [Potential for limestone or other collapsible/soluble geologic units within the valley basin ... Currently, there is uncertainty as to whether limestone from the Hatillo Fm is present within the areas of the footprint of the dam footprint and of the dam reservoir ... Limestone rock types have potential for the development of dissolution karst, which could result in zones with increased permeability and greater potential for seepage and movement through groundwater of contaminants beyond the crest of the valley basin and the downgradient of the New TSF ... Hydrogeological assessments and seepage assessments may be required to quantify the seepage rates that may escape the TSF and to assess whether locations with higher permeability limestone may require treatment of the subsurface] (Knight-Piésold Consulting, 2022).

The EIS summarized the concerns regarding the permeability of the foundation at the preferred site in writing, "*En esta etapa, la consideración de que las permeabilidades de las fundaciones de las presas y los estribos serán lo bastante bajas como para evitar filtraciones excesivas debe verse como un riesgo significativo en el costo y la programación de la obra*" [At this stage, the consideration that the permeabilities of the dam foundations and abutments will be low enough to prevent excessive seepage should be seen as a significant cost and scheduling risk] (Knight-Piésold Consulting, 2022). The point of the preceding review of the concerns expressed in the EIS is that, based upon present knowledge, there is no reason to believe that groundwater contamination could be avoided by construction of a new aboveground facility for permanent storage of mine waste, as opposed to the backfill of the mine waste into the exhausted open pits or quarries. It should be noted that the EIS never argued that the alternative of open-pit backfill should be dismissed because of the possibility of groundwater contamination. Even aside from the lack of consideration of open-pit backfill, the uncertainty regarding the foundation at the preferred site indicates that the choice of the preferred site should be based upon a more thorough knowledge of the geology at all of the alternative sites, including the open pits.

This report has suggested the possibility of backfill of the tailings into the exhausted quarries. The presence of limestone has been a concern at the preferred site and certainly limestone could be present beneath the exhausted quarries. However, it still remains to be determined which quarries, if any, are underlain by karst. Even so, the solid tailings are believed to be non-acid generating, although there has been no discussion in available documents of the potential of the tailings for metal leaching under neutral or alkaline conditions. Potential problems could arise from the process water that is currently shipped to the tailings storage facility along with the tailings. In that case, the tailings could be dewatered prior to backfill, which is a common practice, for example at the Marlin gold-silver mine in Guatemala (Aparicio, 2022). Even so, the partial backfill of a quarry to just above the water table can retain the pit as a hydraulic sink, so that groundwater flows toward, rather from away from the quarry (Johnson and Carroll, 2007). The purpose of this subsection has not been to argue that backfill is the answer, but it needs to be considered as a serious alternative. Although it has been shown that backfill could be carried out at far less cost than the construction of a new aboveground facility, the significance of cost is addressed in the next subsection.

The Analysis of Alternatives does not Emphasize Safety

Aside from the lack of transparency and the lack of serious consideration of the alternative of open-pit and quarry backfill, the fundamental problem with the multiple accounts analysis (or multi-criteria alternatives analysis) in the EIS is that the cost of the project should not even be one of the accounts (or criteria). Of course, without any information regarding the scores for the separate accounts, it is impossible to determine which alternative would have been preferred if cost had not been taken into consideration. As already mentioned, the GISTM does not include the cost of the alternative as one of the accounts and states that only the environmental, technical and socioeconomic aspects of the alternatives should be considered (ICMM-UNEP-PRI, 2020). In fact, the inclusion of cost as a consideration would be inconsistent with the two purposes of a multiple accounts analysis, which are the minimization of risk to people and the environment and the minimization of the aboveground storage of tailings and water (ICMM-UNEP-PRI, 2020). The consideration of cost would certainly be inconsistent with the “ultimate goal of zero harm to people and the environment with zero tolerance for human fatality” and the obligation to “prioritise the safety of tailings facilities” (ICMM-UNEP-PRI, 2020), as stated in the first paragraph of the Preamble to the GISTM.

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

It is noteworthy that the description of multiple accounts analysis in Environment Canada (2013) explicitly includes the consideration of mine backfill as an alternative. According to Environment Canada (2013), "In some cases separation of the float tailings (which typically represents the largest fraction of the tailings volume) from the leach residue tailings would result in the larger volume of float tailings being geochemically benign, which greatly reduces any potential impacts … Mine backfill is often required as part of the mine plan. It may be advantageous to consider tailings as a backfill material to achieve two goals. Firstly, it may offer a logical rationale to separate the leach and float tailings, and secondly, by reducing the volume of tailings that needs to go to the TMF [Tailings Management Facility], the potential impacts are reduced."

It is now a well-established concept in the areas of both tailings dams and water-retention dams that safety is the priority and that there can be no trade-off between safety and any other benefits, including costs. According to the U.S. Army Corps of Engineers (USACE, 2014), "A key mission of the USACE dam safety program is to achieve an equitable and reasonably low level of risk to the public from its dams. USACE executes its project purposes guided by its commitment and responsibility to public safety. Since 'Life Safety is Paramount,' it is not appropriate to refer to balancing or trading off public safety with other project benefits. Instead, it is after tolerable risk guidelines are met that other purposes and objectives will be considered." According to the Mount Polley panel, "Safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor … Future permit applications for a new TSF [Tailings Storage Facility] should be based on a bankable feasibility that would have considered all technical, environmental, social and economic aspects of the project in sufficient detail to support an investment decision, which might have an accuracy of ±10%–15%. More explicitly, it should contain the following: … b. Detailed cost/benefit analyses of BAT [Best Available Technology] tailings and closure options so that economic effects can be understood, recognizing that the results of the cost/benefit analyses should not supersede BAT safety considerations" (Independent Expert Engineering Investigation and Review Panel, 2015a). The preceding quote should also help to clarify the purpose of a cost/benefit analysis, which is most certainly not to enable a trade-off between safety and cost. Thus, any discussion of cost in Environment Canada (2013), Ministère de l'Énergie et des Ressources naturelles [Ministry of Energy and Natural Resources], 2018) or the SME Tailings Management Handbook (Malgesini and Chapman, 2022) should be understood in light of the preceding quote.

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

The multiple accounts analysis in the EIS does include considerations of safety, but these considerations are scattered throughout the subaccounts of the environmental, socioeconomic and technical accounts (see Fig. 9). For this reason, even if the EIS provided the separate scores for each account (which it does not), it still would not tell the Dominican government or the Dominican public the extent to which safety had been prioritized in the multiple accounts analysis, which is why it is crucial for the EIS to reveal the separate scores for each subaccount. For example, there are four subaccounts that are related to the minimization of risk to people, two in the socioeconomic account and two in the technical account. Risk to human life is a combination of the consequences of tailings dam failure to the downstream population together with the likelihood of tailings dam failure. Subaccounts SE3 and SE4 within the socioeconomic account are both related to the consequences of failure (see Figs. 14a-b) and are discussed together in the EIS under the heading "*Riesgo para las Personas y la Infraestructura Comunitaria Asociado con una Falla de la Instalación de Almacenamiento de Residuos Mineros*" [Risk to People and Community Infrastructure Associated with Failure of a Mine Waste Storage Facility]. Subaccount SE3 is scored based on the number of households within the zone that will be flooded following dam failure (see Fig. 14a), while subaccount SE4 is scored based on the number of independent communities that will be flooded (see Fig. 14b). Subaccounts T2 and T3 within the technical account are both related to the likelihood of failure (see Figs. 14c-d) and are discussed together in the EIS under the heading "*Riesgo de Inestabilidad de Presa/Estructura*" [Risk of Dam/Structure Instability]. Subaccount T2 is scored based on the potential for excessive seepage through the dam foundation (see Fig. 14c), while subaccount T3 is scored based on the potential for weak, deep soils within the foundation of the dam and the remainder of the facility (see Fig. 14d).

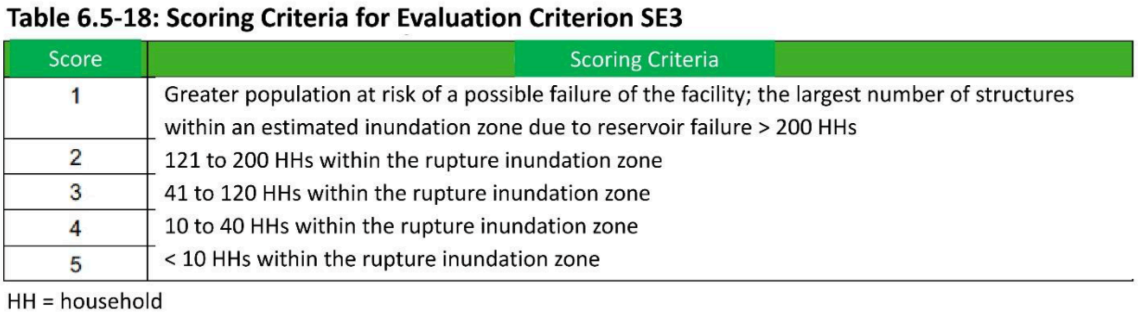


Table 6.5-18: Scoring Criteria for Evaluation Criterion SE3

Score	Scoring Criteria
1	Greater population at risk of a possible failure of the facility; the largest number of structures within an estimated inundation zone due to reservoir failure > 200 HHs
2	121 to 200 HHs within the rupture inundation zone
3	41 to 120 HHs within the rupture inundation zone
4	10 to 40 HHs within the rupture inundation zone
5	< 10 HHs within the rupture inundation zone

HH = household

FIGURE 14a. The risk of failure is a combination of the consequences of failure and the probability of failure. The consequences of failure for each of the alternatives was evaluated in subaccounts SE3 and SE4 (see Fig. 14b) of the socioeconomic account (see Fig. 9). Subaccount SE3 takes into account the number of households within the zone that will be flooded following failure of the proposed Naranjo TSF. Although not stated, the number of households probably considers only those households upstream from the eastward turn of the Yuna River (see Fig. 2), which is the only area that was considered in the dam breach analysis. The appendices that would show how each alternative was scored were removed from the EIS, so that the scoring of the alternatives cannot be evaluated by the Dominican government or the Dominican public. Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

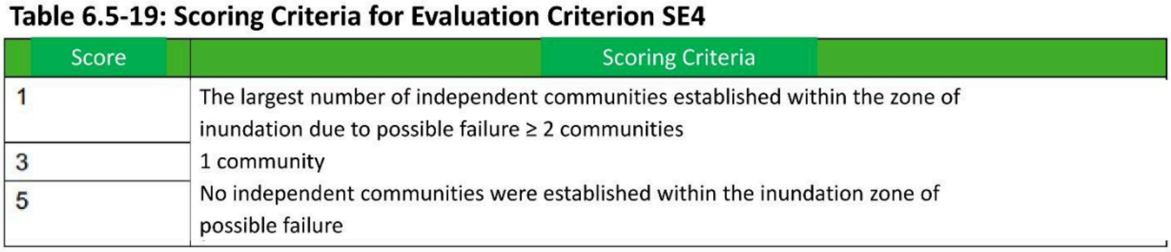


Table 6.5-19: Scoring Criteria for Evaluation Criterion SE4

Score	Scoring Criteria
1	The largest number of independent communities established within the zone of inundation due to possible failure ≥ 2 communities
3	1 community
5	No independent communities were established within the inundation zone of possible failure

FIGURE 14b. The risk of failure is a combination of the consequences of failure and the probability of failure. The consequences of failure for each of the alternatives was evaluated in subaccounts SE3 (see Fig. 14a) and SE4 of the socioeconomic account (see Fig. 9). Subaccount SE3 takes into account the number of independent communities within the zone that will be flooded following failure of the proposed Naranjo TSF. Although not stated, the number of communities probably considers only those communities upstream from the eastward turn of the Yuna River (see Fig. 2), which is the only area that was considered in the dam breach analysis. The appendices that would show how each alternative was scored were removed from the EIS, so that the scoring of the alternatives cannot be evaluated by the Dominican government or the Dominican public. Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

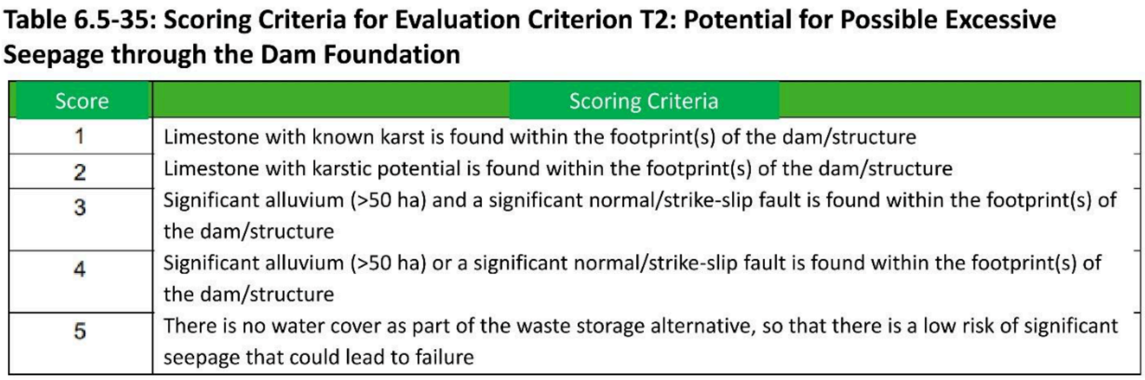


Table 6.5-35: Scoring Criteria for Evaluation Criterion T2: Potential for Possible Excessive Seepage through the Dam Foundation

Score	Scoring Criteria
1	Limestone with known karst is found within the footprint(s) of the dam/structure
2	Limestone with karstic potential is found within the footprint(s) of the dam/structure
3	Significant alluvium (>50 ha) and a significant normal/strike-slip fault is found within the footprint(s) of the dam/structure
4	Significant alluvium (>50 ha) or a significant normal/strike-slip fault is found within the footprint(s) of the dam/structure
5	There is no water cover as part of the waste storage alternative, so that there is a low risk of significant seepage that could lead to failure

FIGURE 14c. The risk of failure is a combination of the consequences of failure and the probability of failure. The probability of failure for each of the alternatives was evaluated in subaccounts T2 and T3 (see Fig. 14d) of the Technical account (see Fig. 9). Subaccount T2 takes into account the potential for excessive seepage through the foundation of the dam. The appendices that would show how each alternative was scored were removed from the EIS, so that the scoring of the alternatives cannot be evaluated by the Dominican government or the Dominican public. Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

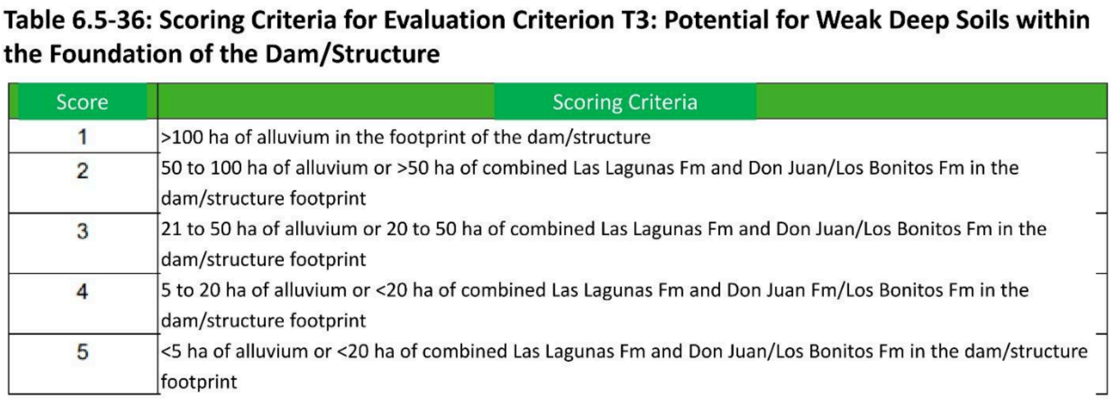


Table 6.5-36: Scoring Criteria for Evaluation Criterion T3: Potential for Weak Deep Soils within the Foundation of the Dam/Structure

Score	Scoring Criteria
1	>100 ha of alluvium in the footprint of the dam/structure
2	50 to 100 ha of alluvium or >50 ha of combined Las Lagunas Fm and Don Juan/Los Bonitos Fm in the dam/structure footprint
3	21 to 50 ha of alluvium or 20 to 50 ha of combined Las Lagunas Fm and Don Juan/Los Bonitos Fm in the dam/structure footprint
4	5 to 20 ha of alluvium or <20 ha of combined Las Lagunas Fm and Don Juan Fm/Los Bonitos Fm in the dam/structure footprint
5	<5 ha of alluvium or <20 ha of combined Las Lagunas Fm and Don Juan/Los Bonitos Fm in the dam/structure footprint

FIGURE 14d. The risk of failure is a combination of the consequences of failure and the probability of failure. The probability of failure for each of the alternatives was evaluated in subaccounts T2 (see Fig. 14c) and T3 of the Technical account (see Fig. 9). Subaccount T3 takes into account the potential for weak deep soils in the foundation of the dam and the rest of the facility. The appendices that would show how each alternative was scored were removed from the EIS, so that the scoring of the alternatives cannot be evaluated by the Dominican government or the Dominican public. Figure from Knight-Piésold Consulting (2022) with overlay of English labels.

In light of the discussion of concerns expressed in the EIS regarding the foundation at the preferred site, it is especially critical for the Dominican government and the Dominican public to know how subaccounts T2 and T3 were scored (see Figs. 14c-d). Since it is known that limestone with at least potential for karst is present at the preferred site, the preferred alternative should not receive a score any higher than “2” for subaccount T2 (see Fig. 14c). The highest score of “5” should not be possible because there is a plan for a water cover in the mine waste storage facility (see Fig. 14c). The combination of subaccounts T2 and T3 is somewhat difficult to understand. An alternative could receive scores of “3” or “4” for T2 if significant alluvium (greater than 50 hectares) is present at the site (see Fig. 14c). On the other hand, a high score for subaccount T3 would require as little alluvium as possible (see Fig. 14d). In particular, a site with 50 hectares of alluvium could receive a score for T3 no higher than “2” (see Fig. 14d). The highest score of “5” would require the presence of less than five hectares of alluvium (see Fig. 14d).

Although the EIS does not provide the scores for the separate accounts and subaccounts for each alternative, it does state the weighting that was assigned to each account and subaccount for the calculation of the total score. The socioeconomic account was assigned a weight of 30%, while the technical account was assigned a weight of 20%.

The subaccounts SE3 and SE4 had a combined weight of 15% of the socioeconomic account. In a similar way, the subaccounts T2 and T3 had a combined weight of 15% of the technical account. In summary, the four subaccounts related to risk to human life constituted only 7.5% of the total score.

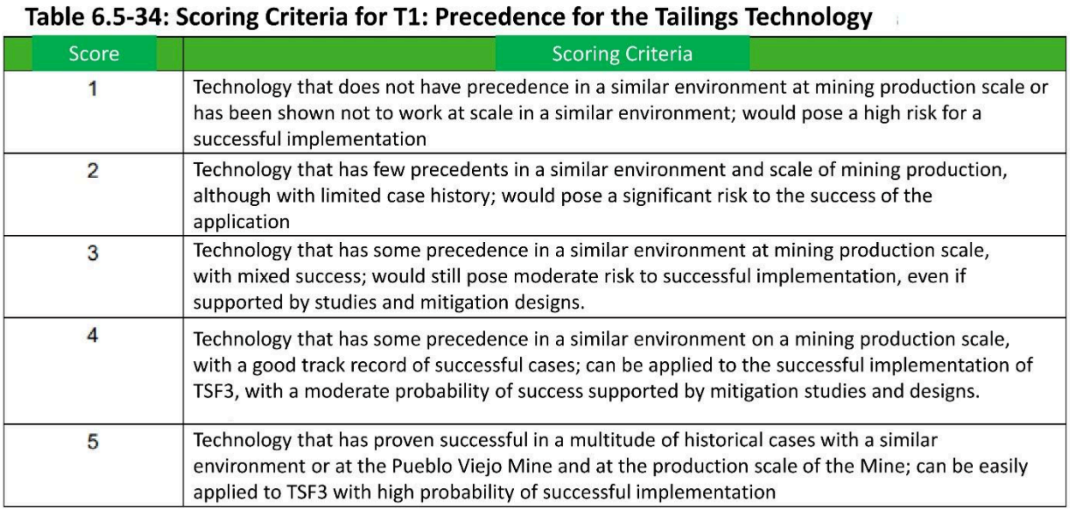


Table 6.5-34: Scoring Criteria for T1: Precedence for the Tailings Technology

Score	Scoring Criteria
1	Technology that does not have precedence in a similar environment at mining production scale or has been shown not to work at scale in a similar environment; would pose a high risk for a successful implementation
2	Technology that has few precedents in a similar environment and scale of mining production, although with limited case history; would pose a significant risk to the success of the application
3	Technology that has some precedence in a similar environment at mining production scale, with mixed success; would still pose moderate risk to successful implementation, even if supported by studies and mitigation designs.
4	Technology that has some precedence in a similar environment on a mining production scale, with a good track record of successful cases; can be applied to the successful implementation of TSF3, with a moderate probability of success supported by mitigation studies and designs.
5	Technology that has proven successful in a multitude of historical cases with a similar environment or at the Pueblo Viejo Mine and at the production scale of the Mine; can be easily applied to TSF3 with high probability of successful implementation

Figure 14e. The first subaccount T1 within the technical account is related to the precedence for the technology for tailings storage. In this way, the EIS recognizes the importance of the use of proven technologies. On the other hand, the likelihood of future success of the proposed Naranjo facility is predicted based on the past success of the El Llagal facility with no other examples presented for the use of this technology. The above table shows that the highest score can be given to "Technology that has proven successful in a multitude of historical cases with a similar environment or at the Pueblo Viejo Mine and at the production scale of the Mine …" In other words, past success at the Pueblo Viejo mine is sufficient proof of future success, even if the technology has never been used at any other mine. It should be considered as to whether this last criterion (success at the Pueblo Viejo mine) was added for the sole purpose of giving the highest score to the preferred alternative of co-disposal of tailings and waste rock at the same facility with permanent water cover over the waste rock (Alternatives A-F; see Fig. 9). Figure from Knight-Piésold Consulting, 2022) with overlay of English labels.

The Design for the New Facility is Untested

The first subaccount T1 within the technical account is related to the precedence for the technology for tailings storage (see Fig. 14e). In this way, the EIS recognizes the importance of the use of proven technologies. The lowest score would be given for "*Tecnología que no tiene precedencia en un entorno similar a escala de producción minera o que se ha demostrado que no funciona a escala en un entorno similar; supondría un alto riesgo para una implementación exitosa*" [Technology that does not have precedence in a similar environment at mining production scale or has been shown not to work at scale in a similar environment; would pose a high risk for a successful implementation] (Knight-Piésold Consulting, 2022; see Fig. 14e). As with all of the separate accounts and subaccounts, there is no indication as to how this subaccount was scored for the various alternatives.

An indication as to how subaccount T1 was scored for the preferred alternative is given in the claim in the EIS that the design of the Naranjo facility is a proven technology. Since Alternatives A-F would all use the same design at different sites (see Fig. 9), the same claim would apply to all six alternatives. According to the EIS, "*Los métodos de deposición de los relaves y roca estéril PAG considerados serán similares a los que se usan actualmente en el TSF El Llagal. El diseño del nuevo TSF se apoya en tecnologías probadas de relaves, incluyendo la deposición de relaves de lodo CIL/HDS y* *la descarga subaérea de roca estéril PAG, para luego ser cubierta con los relaves y agua del embalse dentro de un período definido. La roca estéril PAG será almacenada en un estado permanentemente sumergido para mitigar la producción de drenaje ácido de roca a partir de la roca estéril alta en sulfuro*" [The PAG waste rock and tailings deposition methods considered will be similar to those currently used at TSF El Llagal. The design of the new TSF relies on proven tailings technologies, including CIL/HDS [Carbon-in-Leach/High Density Sludge] slurry tailings deposition and PAG subaerial waste rock discharge, to then be covered with tailings and impoundment water within a defined period. PAG waste rock will be stored in a permanently submerged state to mitigate the production of acid rock drainage from high sulfide waste rock] (Knight-Piésold Consulting, 2022). The EIS further compared another untested technology with the proven technology used at the El Llagal facility. According to the EIS, "*La 'encapsulación' de PAG en una masa de relaves no saturados aún no se ha demostrado con éxito a escala de campo para minimizar el ARD. (Esto se comparó con la encapsulación comprobada de PAG en pulpa de relaves, que ha demostrado ser exitosa en el TSF existente El Llagal)*" [The 'encapsulation' of PAG in a body of unsaturated tailings has not yet been successfully demonstrated at field scale to minimize ARD. (This was compared to the proven encapsulation of PAG in tailings pulp, which has proven successful at the existing El Llagal TSF)] (Knight-Piésold Consulting, 2022).

Thus, the likelihood of future success of the proposed Naranjo facility is predicted based on the past success of the El Llagal facility with no other examples presented for the use of this technology. Fig. 14e shows that the highest score can be given to "*Tecnología que ha demostrado ser exitosa en una multitud de casos históricos con entorno similar o en la Mina Pueblo Viejo y a la escala de producción de la Mina …*" [Technology that has proven successful in a multitude of historical cases with a similar environment or at the Pueblo Viejo Mine and at the production scale of the Mine …] (Knight-Piésold Consulting, 2022). In other words, past success at the Pueblo Viejo mine is sufficient proof of future success, even if the technology has never been used at any other mine. It should be considered as to whether this last criterion (success at the Pueblo Viejo mine) was added for the sole purpose of giving the highest score to the preferred alternative of co-disposal of tailings and waste rock at the same facility with permanent water cover over the waste rock (Alternatives A-F; see Fig. 9).

Nevertheless, the EIS does not present any evidence for the success of the El Llagal facility nor does such evidence appear to be available elsewhere. Although the EIS refers to the "*encapsulación comprobada de PAG en pulpa de relaves*" [proven encapsulation of PAG in tailings pulp], that encapsulation would occur, if it occurred at all, only after the closure of the El Llagal facility, so that there can be no present evidence for possible future success. Evidence for past and present success might be in the form of reports of annual dam safety inspections, reports of dam safety reviews, or reports from the Independent Tailings Review Board (ITRB) or the Engineer of Record. Without such reports, the past success of the El Llagal facility is only a promise from Barrick Gold, which is inconsistent with the requirements for transparency in the GISTM. The types of reports listed above should be included under Requirement 15.1 of the GISTM. Moreover, Requirement 15.2 calls for mining companies to "respond in a systematic and timely manner to requests from interested and affected stakeholders for additional information material to the public safety and integrity of a tailings facility" (ICMM-UNEP-PRI, 2020) with no stipulation that the additional material need only be in the form of summaries. It should be noted that, since the consequences of failure of the El Llagal facility have been rated as Extreme, Barrick Gold is obligated to fully meet the requirements of the GISTM with respect to that facility by the above-stated deadline of August 5, 2023. The Barrick Gold Tailings Management Policy further confirms, with no restriction to tailings storage facilities with Very High or Extreme consequences of failure that "to meet the requirements of our mission statement, we commit to: … Transparent communication and meaningful engagement with internal and external stakeholders and to respond in a systematic and timely manner to requests for additional information material to public safety and the integrity of our tailings facilities" (Barrick Gold, 2023b).

The summary of dam safety reports that was released by Barrick Gold (2023b) on August 5, 2023, states in its entirety: “The DSI [Dam Safety Inspections] and DSR [Dam Safety Reviews] conducted on the dam revealed no material findings. The comprehensive assessment confirmed that the dam has been well-constructed, meets safety regulations, and adheres to industry best practices. Furthermore, the dam is supported by robust safety documentation. The outcome instills confidence in stakeholders and regulatory authorities, assuring them of the dam’s reliability [and] rigorous safety standards” (Barrick Gold, 2023b). The fourth sentence of the summary should be regarded not as part of the summary, but as a summary of the summary. Thus, the three-sentence summary would not count as an adequate summary by any standard of dozens of reports, each of which must contain hundreds to thousands of pages. Barrick Gold (2023b) clarifies that “Material findings are findings that have a high probability of becoming or [being] actual dam safety issues that require immediate attention and are considered immediately dangerous to life, health or the environment, [or constitute] a significant regulatory enforcement.” In other words, the summary is simply stating that no issues were detected that could indicate the danger of imminent dam failure, which is far from an indication of the success of a proven technology, as was claimed in the EIS. By contrast, the GISTM defined “material” in a much broader way as “important enough to merit attention, or having an effective influence or bearing on the determination in question” (ICMM-UNEP-PRI, 2020). The preceding quotes from Barrick Gold (2023b) correct numerous spelling mistakes and missing words in the original document, which might be some indication of the haste in which the document was written.

Even so, there is some question as to the real similarity between the El Llagal and Naranjo facilities. The co-disposal of tailings and waste rock in the same facility was certainly the original plan for the El Llagal facility. According to the 2005 EIS for the Pueblo Viejo mine by Placer Dome Dominicana (2005), “*En el presente capítulo se describen las directrices para el diseño de las instalaciones de la laguna de colas, el método mediante el cual las colas y el desmonte serán depositados en la laguna, las características de las colas y el sistema de manejo de las mismas*” [This chapter describes the guidelines for the design of the tailings pond facilities, the method by which the tailings and waste rock will be deposited in the pond, the characteristics of the tailings and the system for handling them]. However, the extent to which waste rock is actually deposited in the El Llagal facility (as opposed to the Hondo waste rock dump) is quite unclear from either the Technical Report or the EIS. According to the Technical Report, “PAG waste rock from the pits is hauled to dedicated waste dump locations (currently the Hondo dump … Due to sequencing of the completion of the Lower Llagal TSF and the planned commissioning of the Naranjo TSF, there has been a necessity to store PAG in above-ground dumps temporarily” (Barrick Gold, 2023a). According to the EIS, “*La sedimentación de material potencialmente generador de ácido en El Llagal se ha limitado desde 2020 y el modelo de balance hídrico asume que no se depositará material potencialmente generador de ácido después de 2022*” [Deposition of potentially acid-generating material at El Llagal has been limited since 2020 and the water balance model assumes that no potentially acid-generating material will be deposited after 2022]. The disclosure by Barrick Gold on August 5, 2023, states, “The El Llagal TSF is the storage facility for tailings and waste rock at the Pueblo Viejo Project … The ‘El Llagal’ TSF storage capacity is generated by earth core rockfill dams, which are planned to be built to a crest elevation of 265 m, with a total waste storage volume of 225 Mm^3” (Barrick Gold, 2023c). The disclosure does not reveal what proportions of the planned volume will be tailings and waste rock, which would have been the obvious piece of additional information.

The design of the Naranjo facility is, in fact, quite unusual, and does not appear to fit into any of the seven categories for co-disposal of tailings and waste rock in the SME Tailings Management Handbook (Winkler, 2022; compare Fig. 8 with Fig. 6). The closest analogy to the design of the Naranjo facility would be the lowermost diagram in Fig. 6 in which the right-hand side of the topographic depression is replaced by a constructed dam (compare with Fig. 8). The only example known to the author in which waste rock is deposited on the upstream side of a tailings pond is the Phu Kham Copper Gold Operation in Laos (Miller et al., 2012; Hawley and Cumming, 2017; see Fig. 15). The most likely reason why such designs are rare is the very large dam (both in terms of height and length) that is required to confine both tailings and waste rock in the same facility. As has been mentioned, waste rock is typically stored separately from tailings (either as mine backfill or as an aboveground waste rock dump), since, unlike tailings, waste rock does not require a dam for confinement. The decision to store both tailings and waste rock in the same facility could very well be the reason behind the very high projected cost of the Naranjo facility (see Fig. 13).

Figure 15.3: (a) Waste rock deposition in the tailings storage facility, (b) pushing waste rock lifts into the tailing pond. Source: W Wilson

FIGURE 15. The design of the proposed Naranjo TSF includes the storage of tailings on the downstream side (next to the dam) and potentially acid generating (PAG) waste rock on the upstream side (see Fig. 8). The waste rock would have a permanent water cover in order to prevent contact of the waste rock with oxygen. As a type of facility with co-disposal of tailings and waste rock, the design is most similar to the lowermost diagram in Fig. 6 in which the wall of the topographic depression is replaced by a constructed dam on the right-hand side. The only other example known to the author is the Phu Kham Copper Gold Operation in Laos (shown above). Although the EIS states that the existing El Llagal TSF is another example of the same design, the Technical Report to investors clarifies that the waste rock has been stored in the Hondo waste dump, where it awaits transfer to either the open pit or the Naranjo facility, and lacks clarity as to how much, if any, waste rock is actually stored in the El Llagal facility. Figure from Hawley and Cunning (2017).

The Consequences of Failure have been Underestimated

The EIS summarized the results of the analysis of consequences of failure of the Naranjo tailings dam by writing, "*La evaluación de impacto preliminar valido los criterios de diseño de la presa como 'Extrema' de acuerdo con las pautas de CDA (2013) que se citan en Tabla 5.1* [The preliminary impact assessment validated the dam design criteria as 'Extreme' in accordance with the CDA [Canadian Dam Association] (2013) guidelines cited in Table 5.1] (Knight-Piésold Consulting, 2022). Nothing in the EIS explains the meaning of Extreme consequences and the Dam Safety Guidelines of the Canadian Dam Association (2013) are available only for purchase and then only in English and French. Extreme consequences means that more than 100 fatalities are expected in the event of tailings dam failure. In terms of "Environmental and cultural values," Extreme consequences means "Major loss of **critical** fish or wildlife habitat" (emphasis in original) and "Restoration or compensation in kind impossible" (Canadian Dam Association, 2013). In terms of "Infrastructure and economics," Extreme consequences means "Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)" (Canadian Dam Association, 2013). The EIS does not give any further information as to how it arrived at the assessment of Extreme consequences, but the position of the Naranjo facility (as well as the El Llagal facility) upslope from the communities of Las Lagunas and La Cerca, as well as much of the mine infrastructure (see Fig. 3) cannot be overlooked. In the case of the failure of the Naranjo facility, the probable direction of tailings flow will be along Vuelta Creek, which would flow under the Naranjo facility, and which would carry the tailings directly towards Las Lagunas and La Cerca and much of the mine infrastructure (see Fig. 3).

The analysis of the consequences of tailings dam failure in the EIS (which is also available only in English) predicts only the maximum flow depth (up to 22.4 meters), the peak flow rate (up to 38,700 cubic meters per second), the peak arrival time, and the front arrival time for various locations downstream of the proposed Naranjo facility (Knight-Piésold Consulting, 2022). There is no consideration of real environmental or socioeconomic impacts, of which only a partial list might include the following:

1. expected fatalities and seriously injured persons
2. impacts on short-term and long-term human health
3. impacts on residences, schools and health-care facilities
4. impacts on heritage, recreation, community, and cultural assets
5. impacts on economic infrastructure
6. impacts on farms and livestock
7. impacts on transportation, including roads, bridges and railroads
8. impacts on fish and wildlife, including impacts on habitat
9. impacts on long-term air and water quality
10. impacts on aquatic life and ecology in downstream water bodies, including the Maguaca and Yuna Rivers, as well as Samaná Bay (see Fig. 2)

By contrast with the EIS, the August 5, 2023, disclosure by Barrick Gold does acknowledge that, in the case of failure of the El Llagal facility, "A dam breach will result in a significant negative impact to the existing flora and fauna in the downstream environment of Maguaca and Yuna rivers … The rivers impacted by tailings release are Maguaca, this river is the fresh water source for many communities, but the main river impacted is the Yuna. This river is one of the most important rivers used for agriculture, fresh water and livestock water source … The communities directly impacted by the tailings release are Zambrana Arriba, Zambrana Abajo, La Cabirma, Maricao, Cotui. This will impact directly the access roads, churches, hospitals, commercial businesses and family houses … The economic areas impacted are agriculture and livestock. The Yuna river water is the axis of the economic market in the north-east region. This area is one of the top rice production zones of Dominican Republic" (Barrick Gold, 2023c).

A possible fallacious argument could be that the consequence classification is needed only for the determination of the design criteria. In other words, a tailings dam that is designed for Extreme consequences is designed according to the strictest standards. In fact, the Technical Report states, "The Naranjo TSF dam will be designed for 'Extreme' consequence classification which is consistent with Barrick's Tailings Management Standard (TMS, March 7, 2022) and the Global Industry Standard on Tailings Management (GISTM, August 2020). The dam design meets or exceeds design criteria associated with the "Extreme" consequence classification …" (Barrick Gold, 2023a). Thus, the preceding quote simply affirms that the strictest standards will be followed without making any predictions about the real environmental and socioeconomic consequences of tailings dam failure.

The argument is fallacious because the EIS is not simply a tool for the determination of the tailings dam design criteria. The EIS is a tool that the Dominican government and the Dominican public can use to determine whether the approval of the proposed Naranjo facility would be a wise decision. That decision requires a judicious balancing of the benefits of a new tailings facility with the risks that would be imposed by a new tailings facility. The aforementioned balancing should be understood in terms of the benefits and risks that would be experienced by the Dominican Republic, not the benefits and risks from the perspective of a foreign mining company. It should be clear that making a wise decision would require full knowledge as to the real environmental and socioeconomic risks of a new tailings facility.

The EIS systematically underestimates the consequences of tailings dam failure in two significant ways. The first is that there is no consideration of the consequences of the simultaneous failure of both the El Llagal and the Naranjo tailings dams. The EIS considered two possible scenarios for tailings dam failure, which were a "Flood-induced (Rainy-day)" scenario and a "Fair-weather (Sunny-day)" scenario. According to the EIS, "Flood-induced dam failures occur during large flood inflow conditions when the pond water level rises above normal operating levels. Given that the New TSF is planned to operate without an emergency spillway, an overtopping failure was considered a credible failure mode during a Probable Maximum Flood (PMF) event … Fair-weather dam failures are assumed to occur when the pond is at its maximum annual operating level … A release caused by a foundation failure triggered by an earthquake was assumed as the dominant credible failure mode. Given the proposed geotechnical design of the dam, this potential event has not been modelled as a sudden failure but a slumping of the dam to the New TSF pond surface elevation initiating a subsequent overtopping failure" (Knight-Piésold Consulting, 2022). In other words, it was assumed that tailings dam failure would initiate with either an extreme precipitation event or an earthquake. Given the proximity of the El Llagal and Naranjo facilities (see Fig. 3), it is certainly credible that the same extreme precipitation event or earthquake could cause the simultaneous failure of both tailings dams.

The analysis of the consequences of failure in the EIS was limited by the numerical model, not by the actual downstream area that will be impacted by tailings dam failure. Thus, the numerical model calculated the maximum flow depth, peak flow rate, peak arrival time, and front arrival time only until the eastward turn of the Yuna River where it joins with the Camú River (see Fig. 2). According to the EIS, "The modelling extent includes the area downstream of the New TSF to just upstream of the confluence with Rio Camu … The final model outflow boundary is approximately 30 km downstream of the New TSF Dam to just upstream of the confluence with Rio Camu" (Knight-Piésold Consulting, 2022). It is likely that the estimate in the EIS of the number of households and independent communities that will be impacted by tailings dam failure for each alternative (see Figs. 14a-b) also considered only the region between the Naranjo facility and just upstream of the confluence of the Yuna and Camú Rivers (see Fig. 2), but this was never clarified.

Based on Eqs. (1)-(3), a tailings dam height of 157 meters, and a tailings storage volume of 278 million cubic meters, the most-likely scenario following dam failure will be the release of 70 million cubic meters of tailings (25% of the stored volume) with a runout distance of 227 kilometers during the initial event. However, the distance from the site of the Naranjo facility to Samaná Bay is only 101 kilometers (see Fig. 2). Therefore, there is no need to consider the worst-case scenario (release of 100% of the stored tailings) or any impact of the 215 million cubic meters of stored waste rock on the runout distance. It should be assumed that the flood of tailings will reach Samaná Bay during the initial event following tailings dam failure. There have not been many measurements of the velocities of tailings floods, but they have ranged from 20 – 160 kilometers per hour (Jeyapalan, 1981). Using the most conservative value of 20 kilometers per hour, the tailings flood will arrive at Samaná Bay in five hours.

There is no Plan for Long-Term Maintenance of the Facility

From the standpoint of the downstream communities, the most important part of any plan for a tailings dam is the plan for the permanent maintenance of the tailings dam. No matter how beneficial a mine might be for the local communities and no matter how long the mine might be in operation, the closure of the mine and its tailings dams begins the long period of perpetuity during which the tailings dam remains as a permanent hazard for the downstream residents. An important feature of the closure plan is the need for a permanent water cover over the waste rock in order to prevent its oxidation and the generation of acid mine drainage. This permanent water cover would be ensured by the natural precipitation onto the waste rock and the inflow of surface water from the watershed of the Naranjo facility. Thus, the first end member of concern is that, because of an extended drought, there will be so little water cover that the waste rock will start to oxidize and acid mine drainage will develop. This possibility has not been discussed anywhere in the EIS, which is disturbing, since a very great variety of possible climatic regimes are possible when the time period of consideration is perpetuity.

The second end member of concern is that, because of an extended wet period, so much water will accumulate behind the tailings dam that water could flow over the dam with contamination of downstream waterways and with the possible erosion and failure of the dam. The plan is for a 10-year period of pumping the water from the Naranjo facility to a water treatment plant followed by release of the treated water into Naranjo Creek, from where the water will flow into the Maguaca River (see Fig. 2). After 10 years, the water from the Naranjo facility will be allowed to passively discharge into Naranjo Creek without treatment. According to the EIS, "*La planificación del cierre asume que el agua procedente de la TSF y la recuperación de filtraciones serán bombeadas y tratadas en la planta ETP por un largo período de tiempo (cierre activo), y que continuará así hasta que se demuestre que la calidad del agua es adecuada para ser vertida directamente (cierre pasivo) … Después de un período de aproximadamente 10 años o antes, sujetos a una verificación de la calidad del agua, se permitirá que el estanque descargue pasivamente al arroyo Naranjo*" [Closure planning assumes that water from the TSF and seepage recovery will be pumped and treated at the ETP [Effluent Treatment Plant] plant for an extended period of time (active closure), and that it will continue to do so until water quality is shown to be suitable for direct release (passive closure) … After a period of approximately 10 years or sooner, subject to verification of water quality, the pond will be allowed to passively discharge into Naranjo Creek] (Knight-Piésold Consulting, 2022). The 10-year period is supported by a model of chemical mass balance, but, as with many of the models used to draw conclusions in the EIS, insufficient detail is provided for evaluation of the model. However, ten years seems to be a very short period for all of the reactions between waste rock and water to come to completion. It is most important that there is no plan as to what to do if the water in the Naranjo facility has not arrived at an acceptable water quality after 10 years or 20 years or 100 years. There is certainly no plan nor financing for the perpetual treatment of the water in the Naranjo facility.

The most important shortcoming of all is that there is no plan nor financing for the permanent maintenance of the earth-core rockfill dam that is supposed to keep all of the tailings, waste rock and water in place in perpetuity. The need for permanent maintenance of any dam that has credible failure modes has been reviewed in the earlier subsection "Tailings Dams vs. Water-Retention Dams." This same need is even confirmed in the Barrick Gold Tailings Management Standard (Barrick Gold, 2012). For the closure phase, the Tailings Management Standard distinguishes between "Active Care" during which "activities primarily include regular monitoring and inspections of performance as the TSF proceeds to steady-state conditions, with routine maintenance and water management as required" and "Passive Care" during which "activities include monitoring and inspections at a reduced frequency and few maintenance requirements, reflective of the TSF being near or at steady-state conditions" (Barrick Gold, 2012). Nothing in the Tailings Management Standard (Barrick Gold, 2012) gives any indication that the phase of passive care ever ends. Based on the above discussion of the water treatment plan, the phase of passive care would seem to begin 10 years after the cessation of deposition of mine waste in the Naranjo facility and will continue in perpetuity. For tailings with failure consequences in the Extreme category, even for the indefinite period of passive care, the Tailings Management Standard requires routine inspections twice per year, dam safety inspections once per year, dam safety reviews once every 10 years, and independent third-party reviews and assurance audits "as required" (Barrick Gold, 2023c). However, the EIS provides no information as to how Barrick Gold plans to carry out these inspections and reviews in perpetuity or how they plan to take appropriate actions in perpetuity in response to these inspections and reviews. A discussion of the plans and financing of long-term monitoring, inspection, maintenance and review of the tailings dams, as well as long-term water treatment, should be a required and critical feature of the next version of the EIS.

Summary Conclusions

In this section, the questions from the “Methodology” section are repeated with very brief responses. More detailed responses can be found in the preceding “Responses” section.

1) Is the EIS complete with sufficient information for full evaluation by the Dominican government and Dominican public?

No, the EIS is not complete. Many important data are contained in documents that have not yet been written, many important sections (such as the analysis of the consequences of tailings dam failure) are available only in English, and the scoring of the various accounts and subaccounts for the multiple accounts analysis (multi-criteria alternatives analysis) is missing completely.

2) Did the EIS give adequate consideration to the alternative of backfill of the exhausted open pits and quarries?

No, the alternative of backfill of the exhausted open pits and quarries was dismissed without serious consideration, although such consideration is a requirement of the Global Industry Standard on Tailings Management (GISTM) and Barrick Gold has won an award for open-pit backfill. All of the tailings and waste rock that are designated for the new facility could be backfilled into the available open pits and quarries for less than 35% of the cost of construction of a new aboveground storage facility, not taking into the account the costs of operation and long-term maintenance of an aboveground facility.

3) Did the analysis of alternatives in the EIS result in the choice of the safest alternative?

No, there is no indication that the multiple accounts analysis resulted in the choice of the safest alternative. The four subaccounts related to risk to human life constituted only 7.5% of the total score and according to the GISTM and many guidance documents, the cost of the project should not even have been one of the accounts.

4) Has the design for the proposed Naranjo facility been adequately tested?

No, the design for the proposed Naranjo facility has not been adequately tested. It is not clear that the existing El Llagal facility is analogous to the proposed facility and there is no evidence for the success of the El Llagal facility.

5) Does the EIS include an adequate analysis of the consequences of dam failure?

No, the EIS does not include an adequate analysis of the consequences of dam failure. The analysis does not consider the simultaneous failure of the El Llagal and Naranjo facilities, considers impacts only 30 kilometers downstream, and only maximum flooding depths, peak flow rates, peak arrival times, and front arrival times, without considering the real environmental and socioeconomic impacts. Based on past failures of tailings dams, the tailings flood will arrive at Samaná Bay in less than five hours.

6) Does the EIS include an adequate plan for the long-term maintenance of the Naranjo facility after the closure of the mine?

No, the EIS does not include any plan for water treatment for more than 10 years and no plan for the long-term inspections, monitoring, maintenance and reviews of the tailings dam, despite the fact that such inspections and reviews are required by the Barrick Gold Tailings Management Standard.

Recommendations

The recommendation of this report is that the EIS should be rewritten with particular attention paid to the following:

1. All relevant specifications should be available in the EIS without references to documents that have not been written.
2. The entire EIS should be available in Spanish.
3. The appendices that state and justify the scoring of the accounts and subaccounts for each of the alternatives should be included.
4. Open-pit backfill should be fully considered as one of the alternatives.
5. A complete, accurate, and consistent mass balance should be provided for ore, tailings, waste rock, and limestone, from the beginning to the planned cessation of mining.
6. The selection of the preferred site should be based upon a more thorough knowledge of the foundation at each site.
7. Cost should not be a factor in the selection of the preferred alternative.
8. The reports (such as dam safety inspections, dam safety reviews, and ITRB reports) that justify the success of the existing El Llagal facility should be included.
9. The industry-wide past experience with the design of the proposed facility should be analyzed.
10. The analysis of the consequences of dam failure should consider the simultaneous failure of both the existing and proposed facilities.
11. The analysis of the consequences of dam failure should consider the environmental and socioeconomic consequences of failure.
12. The analysis of the consequences of dam failure should consider all impacts that will occur between the facilities and the ocean.
13. There should be plans and discussion of financing for long-term water treatment and long-term monitoring, inspection, maintenance and review of the tailings dams.
14. The revised EIS should be fully consistent with the Technical Report provided to investors.

About the Author

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

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