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Filtered Tailings in Indonesia

The Catastrophic Failure of a Disruptive Technology

Technical Report: Steven H. Emerman, PhD, Malach Consulting
Summary, Analysis, and Recommendations: Ellen Moore, Jan Morrill, Vuysile Ncube, Paulina Personius, and Arianto Sangadji

www.earthworks.org

2026

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On behalf of Earthworks

March, 2026

Endorsed by: WALHI Southeast Sulawesi, WALHI South Sulawesi, WALHI North Maluku, Yayasan Tanah Merdeka (YTM), PUSPAHAM, Satya Bumi, Aksi Ekologi & Emansipasi Rakyat (AEER)

Report available at: earthworks.org/tailings-indonesia
Responses from mining companies and automakers available at: earthworks.org/tailings-indonesia

Cover photo: Filtered tailings facility, courtesy of a worker at Indonesia Morowali Industrial Park
Translation to Bahasa Indonesia: Johny Barliyanta

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Summary, Analysis, and Recommendations Based on the Report *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology*

Increasing demand for nickel and the rise of high pressure acid leach refining

Indonesia sits at the crossroads of mining, climate, and human rights. Nickel is one of the key minerals in electric vehicle batteries, and Indonesia is scaling up production to meet skyrocketing demand. Between 2023 and 2050, global demand for nickel is expected to double,[i] and in the last nine years, Indonesia has gone from 5.7% to 62.26% of world mine nickel production.[ii]

Increased nickel mining and processing in Indonesia means more mine waste. Driving the increase in mine waste is High-Pressure Acid Leaching (HPAL), a technology that takes low grade nickel ore and refines it to produce mixed hydroxide precipitate, a precursor for a key component of electric vehicle batteries. HPAL processing facilities generate massive amounts of toxic waste. Each metric ton of nickel metal processed using HPAL produces 133 metric tons of waste.[iii]

HPAL is a rapidly expanding technology in Indonesia. The amount of waste produced by these facilities is growing at a remarkable rate as well. As of June 2025, there were seven HPAL facilities operating in Indonesia, two at Harita Nickel at Obi Island, North Maluku, one at the Indonesia Weda Bay Industrial Park (IWIP) at Halmahera Island, North Maluku and four at the Indonesia Morowali Industrial Park (IMIP) in Central Sulawesi. These facilities alone are expected to produce at least 57 million metric tons of tailings per year.[iv] Two additional HPAL facilities at IMIP have come online since, potentially increasing the total tailings volume to approximately 62.6 million tons per year.[v] There are 12 additional HPAL projects that are permitted and/or are under construction and another 12 HPAL projects that are in the proposal stage, forecasting the potential for an exponential increase in the volume of toxic tailings generated in the name of meeting the demand for electric vehicle batteries. This would create 275 million metric tons of tailings per year if all operating, permitted and proposed HPAL projects were to be built.[vi]

The sheer volume of the toxic waste generated by HPAL processing facilities today and into the future presents an enormous risk to the environment and communities. HPAL tailings are highly acidic, toxic and contain heavy metals. Adding to this challenge are the particular conditions in Indonesia, notably the lack of standards for tailings storage facilities in national regulations, as well as a wet climate and geography that is prone to earthquakes and landslides.

HPAL technology and tailings safety

Initially, companies developing HPAL projects at IMIP and Obi Island planned to use the outdated practice of disposing the tailings into the ocean, which is allowed under Indonesian regulations.[vii] However, the Government of Indonesia announced that it would not issue permits for the practice, forcing the companies to instead store the waste on land.[viii] All of the HPAL processing facilities changed plans to use filtered tailings storage, commonly referred to as “dry stack tailings” by operators in Indonesia.

The amount of water in a tailings facility can directly impact its physical stability. Filtered tailings, which require reducing the water content of the tailings before depositing them in the tailings facility, are considered industry best practice for a number of reasons, including the reduced likelihood of failure and the reduced consequences of a potential failure. Also, filtered tailings facilities make closing a site easier when mining and processing ends.

In Indonesia and beyond, the use of the term “dry stack tailings” is a marketing and public relations term that provides an illusion of safety and serves to greenwash mining and processing operations. The use of the term “dry” evokes a tailings dam with little to no water present, while in reality filtered tailings are similar to a moist soil.

In Indonesia, HPAL companies are promising the use of filtered or “dry” tailings as a way to reduce potential stability risks, but in practice they are not actually meeting the technical requirements to make good on those promises.[ix] Even if the companies achieve tailings with the appropriate water content, precipitation can impact the small margin that exists between optimal or safe tailings, and saturation.[x]

In some cases, the facilities are not even consistently lowering the water content to the target levels the companies claim they will reach. For example, the target water content of the tailings from the PT Halmahera Persada Lygend HPAL refinery at Harita’s Obi Island operation is 35%, but the actual reported water content has ranged from 8-36%. This wild fluctuation indicates a lack of quality control, makes adequate compaction of the tailings impossible and greatly increases the likelihood of catastrophic failure.[xi]

An untested technology meets wet and seismic conditions

While filtered tailings are considered industry best practice, there are still risks, especially in a wet climate that is prone to earthquakes and landslides. The limited studies on the practice point to the difficulty of dewatering HPAL tailings and maintaining the necessary water content under rainy conditions.[xii]

There are five environmental factors that make the effective implementation of filtered tailings in Indonesia challenging. These include high seismicity; high precipitation; soft, volcanic soils that are weak foundations and susceptible to liquefaction; steep topography with risk of landslides; and volcanic activity. Compounding factors include weak national-level regulations regarding tailings storage facilities and a disturbing lack of enforcement of the regulations that do exist regarding tailings storage facilities.[xiii]

Analysis of operating HPAL facilities including Huafei Nickel Cobalt (HFNC) at IWIP, and PT Halmahera Persada Lygend (PT HPL) at the Harita Nickel facility on Obi Island, show that the projects are taller, and expected to process and store more waste than tailings facilities with comparable rainfall elsewhere in the world.[xiv] This means mining and processing companies are using this technology in a way that has not been tested appropriately under these particularly challenging conditions, putting the environment and the lives of workers and residents at risk. The proposed Sonic Bay HPAL processing facility at IWIP was also found to go well beyond the current technological limits for proven, safe tailings management.[xv] Due to the lack of data, this analysis was not able to definitively draw similar conclusions for other existing HPAL tailings facilities at IMIP and Harita Nickel's other operation at Obi Island, but it is likely that other HPAL tailings facilities are also operating beyond what is known to be safe.

Risks and impacts of HPAL tailings

Tailing facilities in Indonesia pose extreme risks to communities, workers, and the environment, including tailings failures, chronic water pollution, occupational health and safety concerns, deforestation, and the potential for deep sea tailings disposal.

While some of these risks may be exacerbated by the combination of HPAL processing and filtering technologies, they are not unique to this technology. Conventional slurry tailings facilities also present threats. HPAL filtered tailings facilities are already having significant impacts on surrounding communities and environments, and increased tailings production will likely increase the frequency and severity of harms.

Tailings failures

Filtered tailings facilities for HPAL waste have already failed at IMIP, and independent consultant reports made available through a data leak indicate that tailings pose an imminent risk of failure at Harita Nickel's operation on Obi Island. Proposed and existing HPAL tailings facilities at IWIP and the Harita Nickel operation on Obi Island fall well outside the current technological limitations for proven, safe tailings management.[xvi]

A 2022 technical review by consulting firm SRK of the PT Halmahera Persada Lygend (PT HPL) facility known as 'Dry-Stack Tailing Facility' or DSTF, also warned of catastrophic tailings failure. SRK described the failure of the tailings facility as an "uncontrolled risk" given the facility had been built without any quality control or standard monitoring tools and systems in place.[xvii]

Another consulting firm, PT Lapi ITB, warned that portions of the PT HPL DSTF would be unstable against seismic activity if regular operations were to continue as planned. Analysis of company correspondence and consultant reports made available through the data leak found that the PT HPL DSTF at Harita's operation is beyond repair and that even if perfect quality control were to be implemented, the tailings are still at risk of liquefaction and catastrophic failure with the potential to impact workers, the village of Kawasi, nearby waterways, and the Molucca Sea. Despite these warnings PT HPL has continued to add more tailings to these facilities.[xviii]

A 2023 internal PT HPL company report indicated that one of four smaller HPAL filtered tailings facilities on Obi Island is on the brink of catastrophic failure and is located just uphill from mining infrastructure and workers. These facilities were not analyzed in the previous report from external consultants.

At the Indonesia Morowali Industrial Park, harmful and even deadly tailings failures are already happening. According to media and worker testimony, on March 16, 2025 the PT Huayue Nickel Cobalt (PT HYNC) tailings storage facility inside IMIP was breached, and liquified tailings flowed into the Bahadopi River and eventually the ocean.[xix]

Five days later, on March 21, another tailings facility inside IMIP, owned by PT Qing Mei Bang (PT QMB) New Energy Materials, collapsed, killing three workers.[xx] According to testimony from workers represented by SPIM-KPBI, the second largest union at IMIP, the tailings facility was constructed on top of an infilled pond. Photos taken at the site of rescue efforts show a pond where the body of one of the workers was found. The PT QMB tailings facility that collapsed is located right next to the PT Huayue Nickel Cobalt (PT HYNC) tailings facility, at a location locally known as KM8. It is unclear if these two facilities actually operate as one.

On February 18, 2026, another failure reportedly killed one person and halted operations at the IMIP.[xxi] According to a report by CNBC Indonesia, the man who died was a worker from Palopo, South Sulawesi.[xxii] He did not have time to evacuate and was buried by the landslide inside an excavator. IMIP spokesperson Dedy Kurniawan said that the most recent landslide is suspected to have been triggered by the fragile soil conditions at the lower area of the tailings disposal, which were unable to support the weight of the tailings.[xxiii]

Satellite imagery shows that the March 2025 failures at IMIP were likely not the first. Images from January 3, 2025, show a clearly-defined landslide from the PT HYNC filtered tailings storage facility with channels for tailings to travel to the Bahodopi River. A video taken by a mineworker in September 2023 shows a bulldozer being engulfed by a landslide at an unidentified filtered tailings storage facility at IMIP.[xxiv]

Water contamination

Toxins in tailings can leak, polluting ground water, surface water, or the ocean. Tailings from nickel mining and HPAL processing of nickel ore can release a toxic carcinogen called hexavalent chromium, also known as chromium-6. This chromium may cause respiratory illnesses and an increased risk of cancer.[xxv]

In May of 2025, The Organized Crime and Corruption Reporting Project (OCCRP), the Gecko Project, and partners exposed that the Harita Group — one of the world's major nickel suppliers — knew for more than a decade that its operations on Obi Island were polluting water with the toxic chemical chromium-6.[xxvi] A 2022 report from SRK Consulting documented groundwater contamination from the PT Halmahera Persada Lygend (PT HPL) tailings facility on Obi Island. A 2020 report from consultant group, PT Lapi ITB, estimated that 29,326 cubic meters of potentially contaminated water will leak into the aquifer below the tailings facility with the potential to spread throughout the groundwater system.[xxvii] As recently as 2023, leaked documents reveal dangerous levels of the chemical while Harita publicly denied any danger to residents' drinking water. Chromium-6 levels in 2023 were more than three times the Indonesian legal limit for drinking water.[xxviii]

The presence of toxic heavy metals, including hexavalent chromium, have been documented at other nickel mining and refining operations throughout Indonesia. The NGO WALHI South Sulawesi has documented hexavalent chromium in the Lawewu River, in the Nuha District and in community water sources in Asuli Village, Towuti District, South Sulawesi dating back to July 2022. They have tied this pollution to the company PT Vale Indonesia's nickel mining activities.[xxix] In February 2024, WALHI Central Sulawesi and Friends of the Earth Japan found concerning levels of hexavalent chromium in the Bahodopi river,[xxx] which is heavily polluted by nickel mining and processing operations in Morowali.

These examples point to a chronic water contamination problem linked to nickel mining. While the latter examples cannot yet be directly tied to HPAL tailings facilities, the example of ongoing chromium-6 pollution at Harita's mining and tailings storage operations point to a grave problem and indicate the potential for similar pollution to take place at nickel mining and HPAL processing operations throughout the country.

Risks to workers

Mine workers risk their lives to carry out their jobs when tailings facilities are unsafe. The catastrophic tailings dam failure in Brumadinho, Brazil in 2019 killed 272 people, over 90% of whom were mine workers at the site.[xxxi] The March 21, 2025 tailings failure at IMIP killed three workers. Unsafe working conditions have led to other deaths at these nickel facilities. In January 2025, two workers were buried alive by a landslide caused by mining activities.[xxxii] Internal communication in 2023 revealed that a PT Halmahera Persada Lygend (PT HPL) tailings facility is on the brink of failure, putting the lives of mine workers at risk.[xxxiii]

Poor working conditions in Indonesian nickel mining and smelting facilities is a critical issue, and there are frequent cases of work-related accidents, including fatalities at sites throughout the country. One report documented 300 occupational accidents with 31 deaths at IMIP between 2023 and 2024.[xxxiv] From January to May 2025, eight work-related accidents killed seven workers at IMIP.[xxxv] In 2024, China Labor Watch released a video detailing the particularly harsh reality for Chinese workers at IMIP, including unsafe working conditions, grueling schedules, and restrictions of basic freedoms, like the freedom of movement.[xxxvi] The video highlights how Chinese subcontractors often suffer additional abuses because their immigration and work status does not allow them to join mineworkers' unions.

Adoption of other risky tailings storage methods

Poor construction, management, and oversight of filtered tailings, unavoidable environmental challenges, and the potential for imminent catastrophic failure and water contamination at sites across Indonesia, means that companies may turn to other tailings management practices. Unfortunately, the alternatives to filtered tailings are also dangerous.

Deep sea tailings disposal is an outdated and harmful practice that has been phased out in many parts of the world, with limited new mining projects proposing to use it in Norway and Papua New Guinea. Deep sea tailings disposal risks smothering seabed floors and coral reefs, and decimating fishing grounds, livelihoods, and the health of coastal ecosystems.[xxxvii] Disposal of tailings into oceans, rivers, and lakes is not prohibited by Indonesian regulation.

Another dangerous possibility is the construction of conventional slurry or 'wet' tailings dams. As of 2022, PT HPL at Obi Island was already pursuing the construction of three conventional tailings facilities,[xxxviii] an option the company itself had previously argued was too risky.[xxxix] In June 2025, Lygend Resources announced that it had completed construction on a first of its kind 'wet-discharge tailing pond' at Obi Island[xl], despite the existence of multiple wet tailings storage facilities in Indonesia dating back to 1992, according to the Global Tailings Portal.[xli] Lygend claims that the facility would be an improvement on the existing 'dry piling process' given dust and seismicity concerns.[xlii] However, conventional or 'wet' tailings dams are failing with increasing frequency and severity around the globe.[xliii] The rainy and seismic conditions in Indonesia, coupled with weak oversight and a spotty track record with regard to closure, present even greater risks to communities, workers and the environment.

Deforestation

Filtered and conventional tailings facilities occupy huge swaths of land, in addition to that which is swallowed up by the nickel mining and processing operations themselves.[xliv] The existing, permitted, and planned expansion of HPAL processing facilities, and the waste that goes with them, has the potential to drive increased deforestation. The dangers posed by filtered tailings in the Indonesian context could mean that instead of building upward, companies will spread the waste out, expanding the footprint of their facilities and destroying more forest in an effort to address stability risks. Deforestation exacerbates flood events posing a compounding risk for communities living near mining operations. On Obi Island, heavy rains and the partial failure of the sediment pond designed to contain runoff from Harita Nickel's mining operations, resulted in the flooding of homes and water sources in Kawasi Village.[xlv]

Another risk is the potential for new conventional tailings facilities to drive deforestation. The footprint of the three proposed conventional tailings dams on Obi Island is eight times greater than the maximum projected footprint of the PT HPL filtered tailings facility.[xlvi]

Insufficient standards and oversight

The oversight and regulatory structures that should safeguard clean air and water, workers' rights, and community safety are failing to reign in the risks from HPAL tailings facilities in Indonesia. The tailings regulations that do exist are generally non-quantitative, are spread across multiple documents, and are more focused on the necessary steps to receive permits and not on ensuring safety. There are also discrepancies between standards for dam safety that are sometimes adopted in practice and the actual regulations codified in Indonesian law. Indonesia does not have regulation or standards specific to filtered tailings.

Leaked documents from the Harita Group show how three international consulting firms brought in as independent reviewers for projects at Obi Island identified risks, discrepancies, and engineering flaws. Specifically, SRK Consulting highlighted the lack of any monitoring or regular inspections for the PT HPL tailings facility.

However, the same leaked documents show that external consultants hired by the mining companies may not be a reliable source of independent information on the risks posed by these operations. While SRK Consulting documented failings, it also omitted or minimized key information on water ponding and poor drainage observed on the PT HPL tailings facility, a cause for serious concern related to stability.[xlvii]

Need for due diligence from nickel purchasers

The adverse impacts to human rights and the environment associated with the generation and storage of toxic waste from HPAL processing facilities at IWIP and IMIP implicate automakers such as BMW, Mercedes-Benz, Tesla, and VW who, through their supply chain relationships with Huayou Cobalt or CATL, source nickel from these industrial parks.[xlviii]

By sourcing nickel through contractual relationships with GEM, Huayou Cobalt and CATL, companies such as BMW, Ford, General Motors, Honda, Mercedes-Benz, Tesla, Toyota, Volkswagen, Volvo Cars and Volvo Group AB could have nickel from Harita Nickel entering their supply chains.[xlix] These existing operations, together with the potential to nearly triple the number of HPAL processing facilities and associated rate of generation of tailings based on permitted and proposed facilities, dramatically increases downstream companies’ exposure to environmental and human rights risks.

Directly invested in this projected growth is the Ford Motor Company, which in March 2023 announced it had entered into an agreement with PT Vale and Huayou Cobalt to construct the Pomalaa Block High-Pressure Acid Leaching (HPAL) Project and associated filtered tailings facility with operations expected to begin in 2026.[l]

These, and other documented impacts of mineral supply chains has resulted in a widespread call amongst Indigenous leaders, communities, and civil society for mandatory environmental and human rights due diligence laws to require that downstream companies identify and address the impacts of their businesses regardless of where they occur.[li]

Earthworks' recommendations

The Indonesian government, operating companies, downstream buyers, and financial institutions must act swiftly to protect the environment, communities, and workers from risks posed by tailings facilities for HPAL waste and remedy the harms that have already occurred.

- The **Indonesian government** must hold existing operators to account for dangerous practices. It should enact a moratorium on the development and permitting of new facilities until it closes regulatory gaps and there are improvements to transparency, safety standards, community engagement, and oversight. It must carry out independent audits to confirm the facilities are safe.
- **Operating companies** must halt HPAL operations at sites where tailings failures have occurred or are imminent. They must take action to stop or mitigate harms, meaningfully engage impacted communities, and ensure transparency, independent monitoring and oversight.
- **Automakers** should initiate internal investigations into the tailings risks in their nickel supply chains and, where the outcomes of these investigations highlight safety concerns with tailings facilities, automakers should engage with nickel mining and processing companies about their plans to improve safety. Where suppliers fail to mitigate and remediate harmful impacts, automakers should responsibly disengage from sourcing at those sites.
- **Investors** should initiate internal investigations into the tailings risks in their nickel supply chains and, where the outcomes of these investigations highlight safety concerns with tailings facilities in the financial institution's portfolio, engage with nickel mining and processing companies about their plans to improve safety. Where there are unresolved safety concerns, investors should halt financing for these projects.

If safe tailings management cannot be consistently and transparently guaranteed, the Indonesian government should not permit new HPAL processing facilities or the expansion of existing facilities.

Appendixes

Appendix A: Recommendations for the Indonesian Government

To the Indonesian Regulatory Bodies, including the Ministry of Environment and Forestry, the Indonesian Ministry of Industry, the Indonesia Ministry of Public Works and the Governors of North Maluku and Central Sulawesi

The **Indonesian government** must hold existing operators to account for dangerous practices. It should enact a moratorium on the development and permitting of new facilities until it closes regulatory gaps and there are improvements to transparency, safety standards, community engagement, and oversight. It must carry out independent audits to confirm the facilities are safe.

Given the immediate risks posed by existing filtered tailings operations, we recommend the following immediate actions:

- For the PT HPL project on Obi Island, PT QMB New Energy Materials, and PT Huayue Nickel Cobalt in the Indonesia Morowali Industrial Park: order project owners to halt the deposition of tailings given the documented risk of catastrophic tailings failure and, in the case of operations on Obi Island, water pollution.
- For the PT Huafei Nickel Cobalt Project at Indonesia Weda Bay Industrial Park: order project owners to halt the deposition of tailings given it far exceeds proven technological limits for tailing storage volume, height, and throughput for the annual mean precipitation rates and therefore presents unmitigated risks to the environment, communities, and workers.
- Carry out safety audits at all existing filtered tailings storage facilities in Indonesia using independent consulting companies chosen by the Indonesian government but paid for by the owners of the tailings storage facilities. Mining and processing companies or other stakeholders should not be allowed to alter the results of audit reports.
    - Only reopen existing filtered tailings storage facilities that receive satisfactory safety audit and that comply with improved oversight and regulation.
- Order a pause on further development of the 12 HPAL projects that are permitted and/or are under construction, and enact a moratorium on permits for the 12 HPAL projects in the proposal stage until immediate safety concerns related to tailings storage are addressed, robust government oversight is established and regulatory gaps related to mine

waste are closed. Deny future permits for facilities in instances where safe tailings storage is not possible.

- Develop specific, stand-alone tailings regulations and close the regulatory gaps in the laws related to mine waste such as Law 32/2009 on Environmental Protection and Management, Law 32/2014 on Industry, Law 24/2007 on Disaster Management, Mineral and Coal Mining Law 3/2020 that Amended 4/2009, Law 6/2023 on Stipulating Government Regulation in Lieu of Law 2/2022 on Job Creating into Law, Government Regulation (GR) 37/2010 on Dams, GR 27/2020 on Specific Waste Management, GR 22/2021 on the Implementation of Environmental Protection and Management, GR 28/2021 on the Implementation of the Industrial Sector, and Ministerial Regulation of Environment and Forestry 6/2021 on Procedures and Requirements for Managing Hazardous and Toxic Materials. Some remaining gaps can be addressed by implementing the guidance set out in *Safety First: Guidelines for Responsible Mine Tailings Management*, including
    - Require the proponents of potential projects provide overwhelming evidence that the project will not have unacceptable adverse consequences on the environment, neighboring communities, or workers.
    - Increase the capacity of environmental officials to conduct regular inspections to ensure the safe management of existing tailing facilities and to assess social and environmental impacts and operational governance of the facilities.
        a. Regularly publish the outcome of these inspections and assessments of facilities' social and environmental impacts.
        b. Increase the capacity of relevant agencies to enforce fines and other penalties for non-compliance with regulations, in accordance with sanctions established in the Indonesia Constitution.
- Require the project owners for all tailings facilities to actively engage all potentially impacted downstream communities and workers in a process to co-design emergency management and response plans that prioritize safety, while respecting community rights and preferences regarding relocation.
    - The design process should include communities, workers, local unions, and local organizations.
    - The design process should be developed based on worst case failure scenarios.

- Improve transparency and access to information on tailings facilities by:
    - Making all documents related to tailings facilities and their impacts publicly available, including Environmental Impact Assessments.
    - Require mining and processing companies to publicly disclose the location of all tailing facilities and all information related to their safety and stability. In the case of tailings failures, require companies immediately make the location, date, amount of tailings released, and environmental/social impacts publicly available.
    - Create a nationwide registry of tailings dams that includes the name, location, size, volume, age, construction type, and hazard classification of all active, inactive and closed tailings facilities.
- Develop and implement a standard for relocation/resettlement in line with international guidance that prioritizes the protection of communities from forced relocation or land grabbing. This standard should require companies to prove relocation is the only viable option and ensures communities are only relocated if they are consulted and given the option to decline relocation.
    - In cases where communities agree to relocation, the standard should establish a participatory process to determine adequate compensation, where the community to be relocated has the final decision-making power to accept or decline the terms. The standard should ensure that relocation:
        a. Improves livelihoods and standards of living for those who are resettled. Compensation should account not just for land value, but also lost crop and production value.
        b. Accounts for time to rebuild agricultural land, local economies, etc.
        c. Does not put communities in a location that is an at-risk area.
        d. Is only carried out once communities' full compensation requirements have been met.
- Engage with labor unions to improve Health & Safety standards for mine workers including regulations to improve infrastructure and emergency evacuation routes.
- Codify a ban of aqueous tailings disposal.

Appendix B: Recommendations for Operating Companies

To the mining and processing companies operating at the Indonesia Morowali Industrial Park, the Indonesia Weda Bay Industrial Park, and within the Harita Nickel complex on Obi Island, and those companies with proposed or permitted HPAL facilities

Operating companies must halt HPAL operations at sites where tailings failures have occurred or are imminent. They must take action to stop or mitigate harms, meaningfully engage impacted communities, and ensure transparency, independent monitoring and oversight.

- Provide transparent access to information about tailings facility risks and impacts that ensure the implementation of internationally recognized frameworks and norms.
    - Publicly disclose accurate, detailed, high-quality data to demonstrate the safety and stability of all tailings facilities, based on best practices outlined in *Safety First: Guidelines for Responsible Mine Tailings Management* and any forthcoming guidance documents developed by the Indonesian government including but not limited to:
        a. The name, location, size, volume, age, construction type, and hazard classification of all active, inactive and closed tailings facilities.
        b. Facility-level Environmental Impact Assessments (EIAs) that include environmental risks, management plans, and mitigation activities.
        c. Dam Breach Analyses and any relevant updates.
        d. Emergency Management and Response Plans, and details on how the plans were developed.
        e. Closure plans and amount of financial bonding committed, annual costs to restore land, and changes to financial plan.
        f. The location, date, amount of tailings released, and environmental/social impacts of all tailings failures. This information should be updated over time.
    - Provide access to independent technical experts for community members to assess all relevant data and reports outlining risks posed by tailings facilities. Communities must be able to choose or approve the independent experts, but the cost must be covered by the responsible company.
- Meaningfully engage in local languages and in an accessible manner with communities impacted by tailings facilities to provide accurate, transparent and timely information on the risks, impacts, and safety and stability of tailing facilities.
    - Actively engage all potentially impacted downstream communities in a process to co-design emergency management and response plans that prioritize safety, while respecting community rights and preferences regarding relocation.
        a. The design process should include communities, workers, local unions, and local organizations, and

b. Be developed based on worst case failure scenarios.

- Recognize the cultural, territorial, and self-governance rights of Indigenous Peoples in terms of the UN Declaration on the Rights of Indigenous Peoples and ILO 169 by ensuring protocols are in place to obtain Free, Prior and Informed Consent (FPIC)[lii] for all tailings facilities.
- Implement site-level, independent, grievance mechanisms based on the UNGP of Business and Human Rights and ensure remedy for complaints is adequate, effective, and prompt.[liii]
- Voluntarily and transparently participate in all oversight, management and compliance activities required by the Indonesian government, including but not limited to:
    - Stopping operations at filtered tailing facilities, if ordered to do so.
    - Complying with all relevant legislation.
- Implement policies that only relocate communities with their full consent and via a participatory process where the community to be relocated has the final decision-making power design and accept or decline the terms. Companies must prove that there is no option to avoid relocation, never involuntarily relocate communities, and follow any relevant government standards for relocation.
- Develop and implement robust water quality monitoring programs downstream from all tailings facilities which:
    - Identify and test all water sources subject to potential water pollution.
    - Include community participation in the program design, and train and incorporate community as water monitors. Communities must be able to choose their own representatives in the programs.
    - Monitor water quality frequently enough to detect pollution in a timely manner.
    - Publicly disclose the results, including parameters and raw data, in all relevant local languages.
    - Where water quality has been impacted, improve and restore degraded water quality.
- Implement policies that prohibit the use of deep-sea tailings disposal.

Given the documented risk of catastrophic tailings failure and, in the case of operations on Obi Island, water pollution, we recommend that PT Halmahera Persada Lygend on Obi Island, as well as PT QMB New Energy Materials, and PT Huayue Nickel Cobalt operating in the Indonesia Morowali Industrial Park:

- Halt the deposition of tailings and immediately engage all potentially impacted downstream communities in a process to co-design emergency management and response plans that prioritize safety, while respecting community rights and preferences regarding relocation.
- Fully remediate areas where tailings spills and dam collapses have already occurred and provide compensation for communities and victims.

Given the PT Huafei Nickel Cobalt at Indonesia Weda Bay Industrial Park tailings facility far exceeds proven technological limits for tailing storage volume, height, and throughput for the annual mean precipitation rates and therefore presents unmitigated risks to the environment, communities, and workers, we recommend the company:

- Halt the deposition of tailings and immediately engage all potentially impacted downstream communities in a process to co-design Emergency Management and Response Plans that prioritizes safety, while respecting community rights and preferences regarding relocation.

Appendix C: Recommendations for Automakers and Downstream Purchasers

To automakers sourcing nickel from companies with operations at the Indonesia Morowali Industrial Park, the Indonesia Weda Bay Industrial Park, and Harita Nickel

Automakers should initiate internal investigations into the tailings risks in their nickel supply chains. Where these investigations highlight safety concerns with tailings facilities, automakers should engage with nickel mining and processing companies about their plans to improve safety. Where suppliers fail to mitigate and remediate harmful impacts, automakers should responsibly disengage from sourcing at those sites.

- Automakers should initiate an internal investigation into the tailings risks in their nickel supply chains, with careful attention to the specific risks associated with HPAL filtered tailings and publish the timebound commitments, developed with their suppliers, on how they will ensure their suppliers implement corrective action. This corrective action should conform to international best practices such as *Safety First: Guidelines for Responsible Mine Tailings Management* and this process should require nickel mining and processing companies to:
    - Publicly disclose detailed and high-quality data on their tailings facilities through their sustainability reports, through the Global Tailings Portal or on their websites, including for example: Accurate, detailed, high-quality data to demonstrate the safety and stability of all tailings facilities, based on best practices outlined in *Safety First: Guidelines for Responsible Mine Tailings Management* and any forthcoming guidance documents developed by the Indonesian government
    - Publicly disclose accurate, detailed, high-quality data to demonstrate the safety and stability of all tailings facilities, based on best practices outlined in *Safety First: Guidelines for Responsible Mine Tailings Management.*

    - Take all necessary steps to increase transparency, stop and remedy harms caused to communities, workers and the environment by operating filtered tailings facilities, ensure that future operations avoid unacceptable harms, and comply with government regulations.
    - Implement policies that prohibit sourcing from mines or processing facilities that use deep sea tailings disposal.
- If automakers find that the facilities in their supply chain persist in not mitigating and remediating their harmful impacts, then automakers should end the business relationship in line with the UN Guiding Principles of Business and Human Rights and the OECD Guidelines for Multinational Enterprises.
- Automakers should request from the Government of Indonesia the results of the safety audits on all existing filtered tailings storage facilities.

To Ford Motor Company

In addition to the points set out above, undertake due diligence to ensure the construction of the Pomalaa HPAL Project and associated tailings facilities aligns with the UNGP on Business and Human Rights and Ford's policy commitments to respect human rights and the environment. This includes implementing best practices as outlined in *Safety First: Guidelines for Responsible Mine Tailings Management.*

Appendix D: Recommendations for Investors

To investors and financiers in HPAL processing facilities at the Indonesia Morowali Industrial Park, the Indonesia Weda Bay Industrial Park, and Harita Nickel, as well as permitted or planned facilities, and the national banking and financial services regulatory authorities

Investors should initiate internal investigations into the tailings risks in their nickel supply chains and, where these investigations highlight safety concerns with tailings facilities in the financial institution's portfolio, engage with nickel mining and processing companies about their plans to improve safety. Where there are unresolved safety concerns, investors should halt financing for these projects.

- Where invested in mining and processing facilities in Indonesia, initiate an internal investigation into the tailings risks in their nickel supply chains, with careful attention to the specific risks associated with HPAL filtered tailings and require facilities to conform to international best practices such as *Safety First: Guidelines for Responsible Mine Tailings Management* as part of this, require nickel mining and processing companies to:

    - Publicly disclose detailed and high-quality data on their tailings facilities through their sustainability reports, through the Global Tailings Portal or on their websites, including for example: Accurate, detailed, high-quality data to demonstrate the safety and stability of all tailings facilities, based on best practices outlined in *Safety First: Guidelines for Responsible Mine Tailings Management* and any forthcoming guidance documents developed by the Indonesian government;
    - Take all necessary steps to stop and remedy harms caused to communities, workers and the environment, ensure that future operations avoid unacceptable harms, and that companies comply with government regulations;
    - Commit to ensuring the independence of these audits and accepting their results;
    - Implement policies that commit to not source from mines that use deep sea tailings disposal.

- Where the outcome of these audits highlight safety concerns with tailings facilities in the financial institution's portfolio, engage with nickel mining and processing companies about their plans to improve safety and, where they persist in not mitigating and remediating their harmful impacts, halt financing.

- Investors and financiers should request from the Government of Indonesia the results of safety audits using credible independent consulting companies chosen by the Indonesian government, for all existing filtered tailings storage facilities in a portfolio.

References

[i] IEA (2024), Global Critical Minerals Outlook 2024, IEA, Paris https://www.iea.org/reports/global-critical-minerals-outlook-2024, License: CC BY 4.0.
[ii] USGS (U.S. Geological Survey), 2025a. Nickel Statistics and Information. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/nickel-statistics-and-information.
These numbers differ from those in Dr. Emerman's technical report, *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.* Dr. Emerman's report cites USGS projections of 2024 data. This summary cites the actual production total, which was not available at time of the drafting of Dr. Emerman's report.
[iii] Emerman, Steven (2025, June 29). Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.
[iv] Emerman, Steven (2025, June 29). Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.
[v] Labiro, Richard (2025). *Sisi Gelap Transisi Energi: Bank-bank Pelat Merah di Balik Proyek-Proyek Nikel untuk Bahan Baku Baterai Kendaraan Listrik di Sulawesi Tengah*. Palu: Yayasan Tanah Merdeka.
[vi] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[vii] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[viii] Nangoy, Fransiska and Unguku, Fathin (2021, February 5). "Facing green pressure, Indonesia halts deep-sea mining disposal." *Reuters.* https://www.reuters.com/article/world/exclusivefacing-green-pressure-indonesia-halts-deep-sea-mining-disposal-idUSKBN2A50VG/.
[ix] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[x] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology*
[xi] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xii] Bodley, A.J. and C. Vaguener (2022, November). "Learnings from dry stacking fine grained nickel residue in the tropics." *Tailings and Mine Waste 2022*, 9 p. Available at: https://www.researchgate.net/publication/366093867_Learnings_from_Dry_Stacking_Fine_Grained_Nickel_Residue_in_the_Tropics.
[xiii] Baker, E., K. Thygesen, and B. Haworth, 2025. "Mining and mine tailings in Asia—Moving towards adoption of the Global Industry Standard on Tailings Management." *GRIDArenda*l, 68 p. Available at: https://www.researchgate.net/publication/391739738_MINING_AND_MINE_TAILINGS_IN_ASIA_Moving_towards_adoption_of_the_Global_Industry_Standard_on_Tailings_Management.
[xiv] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xv] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xvi] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xvii] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xviii] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xix] Yayasan Tanah Merdeka. (2025, March 23). "Tentang Kecelakaan Kerja di Fasilitas Penyimpanan Limbah (Tailing) di PT Indonesia Morowali Industrial Park." *Pernyataan Pers*; Yayasan Tanah Merdeka. (2025, April 8). "Morowali Dibawah Ancaman Tailing Industri Nikel." *Pernyataan Pers*. Reny Sri Ayu.

(2025, March 24). "Pekerja IMIP Tertimbun Longsor, 1 Tewas, 2 Hilang." *Kompas*. Available at: https://www.kompas.id/artikel/pekerja-imip-tertimbun-longsor-1-tewas-2-hilang.

[xx] Yayasan Tanah Merdeka (2025, March 24); Yayasan Tanah Merdeka (2025, April 8); Kabar Sulteng (2025, March 23) "3 Pekerja Tertimbun Longsor di Kawasan PT IMIP, YTM Desak Evaluasi Menyeluruh." *Kabar Sulteng.* Available at: https://www.kabarsulteng.id/2025/03/24/3-pekerja-tertimbun-longsor-di-kawasan-pt-imip-ytm-desak-evaluasi-menyeluruh/. Aryo Bhawono. (2025, April 22). "11,5 Juta Ton Limbah Tailing IMIP Ancam Sungai Bahodopi". *Betahita.* Available at: https://betahita.id/news/detail/11026/11-5-juta-ton-limbah-tailing-imip-ancam-sungai-bahodopi.html?v=1745280966. Riza Salman. (2025, April 8). "Kolam Limbah Nikel IMIP Jebol Tewaskan Tiga Pekerja". *Mongabay.* Available at: https://www.mongabay.co.id/2025/04/08/kolam-limbah-nikel-imip-jebol-dan-tewaskan-tiga-pekerja/.

[xxi] Spence, Eddy and Annie Lee (2026, February 18). "Landslide at Morowaili Nickel Hub Kills One Worker" *Bloomberg*. Available at: https://www.bloomberg.com/news/articles/2026-02-19/landslide-hits-indonesia-s-morowali-nickel-smelting-complex; Reuters (2026, February 19). "Landslide in Indonesia's Morowali nickel hub kills one, halts operations." *Reuters*. Available at: https://www.reuters.com/world/asia-pacific/landslide-indonesias-morowali-nickel-hub-kills-one-halts-operations-2026-02-19/.

[xxii] Setiawan, Nano Verda (2026, February 19). "Ada Longsor di Area Penimbunan Limbah IMIP, Manajemen Buka Suara." *CNBC Indonesia*. Available at: https://www.cnbcindonesia.com/news/20260219191337-4-712254/ada-longsor-di-area-penimbunan-limbah-imip-manajemen-buka-suara.

[xxiii] Setiawan, Nano Verda (2026, February 19). "Ada Longsor di Area Penimbunan Limbah IMIP, Manajemen Buka Suara." *CNBC Indonesia*. Available at: https://www.cnbcindonesia.com/news/20260219191337-4-712254/ada-longsor-di-area-penimbunan-limbah-imip-manajemen-buka-suara.

[xxiv] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology*.

[xxv] Tan, Rebecca, Dera Menra Sijabat and Joshua Irwandi (2023, May 10). "To meet EV demand, industry turns to technology long deemed hazardous." *The Washington Post.* Available at: https://www.washingtonpost.com/world/interactive/2023/ev-nickel-refinery-dangers/

[xxvi] Moskowitz, Eli, Alon Aviram, Serdar Vardar and Kiyo Dörrer (2025, April 30). "Major Nickel Supplier Harita Knew About Water Contamination at Indonesian Operation for a Decade." *Organized Crime and Corruption Reporting Project.* Available at: https://www.occrp.org/en/investigation/major-nickel-supplier-harita-knew-about-water-contamination-at-indonesian-operation-for-a-decade

[xxvii] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*

[xxviii] Moskowitz, Eli, Alon Aviram, Serdar Vardar and Kiyo Dörrer (2025, April 30) "Major Nickel Supplier Harita Knew About Water Contamination at Indonesian Operation for a Decade"Organized Crime and Corruption Reporting Project. Available at: https://www.occrp.org/en/investigation/major-nickel-supplier-harita-knew-about-water-contamination-at-indonesian-operation-for-a-decade.

[xxix] WALHI South Sulawesi (2023, February 24). "Submission for Special Rapporteur's thematic report on detoxification/decarbonization: Report on Heavy Metal Pollution in Rivers and Community Water Sources Due to PT Vale Indonesia's Nickel Mining and Smelters in the Context of Higher Demand of Battery Material." Available at: https://www.ohchr.org/sites/default/files/documents/issues/toxicwastes/cfis/detoxdecarb/submission-detoxification-of-climate-solutions-ngo-walhi-2.docx.

[xxx] Friends of the Earth Japan and Walhi Central Sulawesi (2024, January/February). "Water Quality Tests Surrounding Nickel Smelters and Mining Development Projects in Morowali, Indonesia."

[xxxi] Milanez, B. et al. (2019) Minas não há mais: Avaliação dos aspectos econômicos e institucionais do desastre da Vale na bacia do rio Paraopeba. Versos - Textos para Discussão PoEMAS, 3(1), 1-114. Available at: https://www2.ufjf.br/poemas//files/2017/04/Milanez-2019-Minas-n%c3%a3o-h%c3%a1-mais-versos.pdf.

[xxxii] Didi, Faisal (2025, January 30) "Dua Karyawan Meninggal Dunia, Polres Halmahera Tengah Lidik Kecelakaan Kerja di Perusahaan Tambang". *TribunTernate.com*. Available at: https://ternate.tribunnews.com/2025/01/30/dua-karyawan-meninggal-dunia-polres-halmahera-tengah-lidik-kecelakaan-kerja-di-perusahaan-tambang.

[xxxiii] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology*.
[xxxiv] Sarjan Lahay and Dedi. (2024, 1 November). "Kecelakaan Kerja Berulang di Kawasan Industri PT IMIP, Desak Pemerintah Tindak Tegas". *Mongabay.* Available at:https://www.mongabay.co.id/2024/11/01/kecelakaan-kerja-berulang-di-kawasan-industri-imip-desak-pemerintah-tindak-tegas/.
[xxxv] Supriyanto Ucok. (2025, 16 May). "7 Pekerja Tewas, YTM Soroti Buruknya SMK3 di Kawasan Industri Tambang Sulteng". *Tribun News*. Available at: https://palu.tribunnews.com/2025/05/16/7-pekerja-tewas-ytm-soroti-buruknya-smk3-di-kawasan-industri-tambang. Jeis Montesori. (2025, 16 May). "Sepanjang Januari–Mei 2025: Delapan Kecelakaan Kerja di Kawasan PT IMIP, Tujuh Pekerja Tewas". *Indotren*. Available at: https://www.indotren.com/nasional/32215162646/sepanjang-januarimei-2025delapan-kecelakaan-kerja-di-kawasan-pt-imip-tujuh-pekerja-tewas.
[xxxvi] China Labor Watch (2024, June 28). "Forged in Silence - The Untold Stories of Chinese Workers at Indonesia's Nickel Plants." Available at: https://www.youtube.com/watch?v=x0W1hotmIYs.
[xxxvii] Earthworks. Ditch Ocean Dumping. Available at: https://earthworks.org/campaigns/ditch-ocean-dumping/.
[xxxviii] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xxxix] Morese, I. (2020, May 18) "Indonesian miners eyeing EV nickel boom seek to dump waste into the sea." *Mongabay.* Available at: https://news.mongabay.com/2020/05/indonesian-miners-eyeing-ev-nickel-boom-seek-to-dump-waste-into-the-sea/.
Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xl] Lygend Resources (2025, June 17). "First wet-discharge pond in Indonesia's nickel industry completed as green benchmark." Available at https://www.lygend.com/en/news/detail/1145.
[xli] Global Tailings Portal. Accessed July 28, 2025. Available at https://tailing.grida.no/.
[xlii] Lygend Resources (2025, June 17). "First wet-discharge pond in Indonesia's nickel industry completed as green benchmark." Available at https://www.lygend.com/en/news/detail/1145.
[xliii] Bowker, Lindsay Newland and David Chambers, (2015, July 21). "The Risk, Public Liability, & Economics of Tailings Storage Facility Failures." Available at: https://earthworks.org/assets/uploads/2018/12/44-Bowker-Chambers.-2015.-Risk-Public-Liability-Economics-of-Tailings-Storage-Facility-Failures.pdf.
[xliv] Giljum, S, et. al (2025, May). "Driving Change, Not Deforestation: How Europe Could Mitigate the Negative Impacts of Its Transport Transition." FERN, Rainforest Foundation of Norway, The négaWatt Association, and Institute for Ecological Economics at WU Vienna University of Economics and Business. P. 13. Available at: https://www.fern.org/fileadmin/uploads/fern/Documents/2025/2025_Driving-change-not-deforestation-Report.pdf
[xlv] Moore, Ellen (2025, June 27). "Nickel Waste Floods Homes in Indonesia Sparking Protests." Available at: https://earthworks.org/blog/nickel-waste-floods-homes-in-indonesia-sparking-protests/.
[xlvi] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology.*
[xlvii] Emerman, Steven (2025, June 29). *Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology*.
[xlviii] Business and Human Rights Resource Center (July 2024). "Powering Electrical Vehicles: Human Rights Impacts of Indonesia's Nickel Rush" at pg 14. Available at https://media.business-humanrights.org/media/documents/2024_EV_supply_chains.pdf.
[xlix] See note 41; Aviram, Alon, Eli Moskowitz, and anonymous (30 May, 2025). "Clean Cars Poisoned Water: A Nickel Titan's Toxic Secret." *The Gecko Project.* Available at https://thegeckoproject.org/articles/clean-cars-poisoned-water/.
[l] Ford Motor Company (2023, March 30). "PT Vale Indonesia and Huayou sign nickel agreement with Ford Motor Co. supporting growth of the global sustainable EV industry", Available at: https://www.fromtheroad.ford.com/us/en/articles/2023/pt-vale-indonesia-and-huayou-sign-nickel-agreement-with-ford-mot. (last accessed 19 May 2025).

[li] *See more* at the Business and Human Rights Resource Center's "Mandatory Due Diligence portal."
[lii] United National Declaration on the Rights of Indigenous Peoples. Available at: https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf.
[liii] Federal Institute for Sustainable Development. (2018). "Toolbox for Operational-Level Grievance Mechanisms." Available at: https://business-humanrights.be/remedy-mechanisms?tab=grievance#olgm.

Filtered Tailings in Indonesia:

The Catastrophic Failure of a Disruptive Technology

Technical Report by Dr. Steven H. Emerman, Malach Consulting

Prepared at the request of Earthworks, June 29, 2025

Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology

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Report prepared at the request of Earthworks, Submitted June 8, 2025, Revised June 29, 2025

DISCLAIMER

Some analysis in this report relies on leaked data sources. Earthworks determined that the use of these documents meets the requirements for use in the public interest, including the need to address issues of potential human rights violations, environmental damage, and resource governance gaps.

ABSTRACT

From 2015 to 2024, annual mine production of nickel in Indonesia rose from 130,000 to 2,200,000 metric tons, increasing from 5.7% to 59.5% of world production. This dramatic increase was partially accomplished through the opening, from 2021 to 2025, of seven high-pressure acid leaching (HPAL) projects for the extraction of mixed hydroxide precipitates of nickel and cobalt from laterite ores, including PT Halmahera Persada Lygend (HPL) and PT Obi Nickel Cobalt (ONC) on Obi Island, PT Qing Mei Bang (QMB) New Energy Materials, PT Huayue Nickel Cobalt (HYNC), PT ESG New Energy Material, and PT Meiming New Energy Material in the Indonesia Morowali Industrial Park on Sulawesi Island, and PT Huafei Nickel Cobalt (HFNC) in the Weda Bay Industrial Park on Halmahera Island. The innovative aspect of the explosion in HPAL projects in Indonesia is the combination of HPAL with filtered tailings. All previous HPAL projects have used conventional tailings storage facilities with the exception of the Ramu project in Papua New Guinea, which uses deep sea tailings disposal. The motivation for the combination is the need for nickel for electric vehicles plus the less environmentally destructive alternative of filtered tailings to create the complete "green" package. Disruptive technologies are innovations that are initially inferior, but which rapidly replace existing technologies. The motto "Move fast and break things" has been attributed to various promoters of disruptive technologies, which captures the dual nature of creativity and acting without regard to consequences. The thesis of this report is that the rapid explosion of HPAL and filtered tailings in Indonesia is both a disruptive technology and a catastrophic failure.

The annual capacity for the seven existing HPAL projects is 405,000 and 26,500 metric tons of nickel and cobalt, respectively. There are 14 HPAL projects that are permitted and/or under construction, including eight new projects in the Indonesia Morowali Industrial Park, with combined annual capacity of 850,900 metric tons of nickel and cobalt, respectively. Another 12 HPAL projects are in the proposal stage with a combined annual capacity of 745,900 metric tons of nickel. Based on the production of 50,000, 6500, and 7,496,050 metric tons of nickel, cobalt, and tailings, respectively, at the PT HPL project in 2023, the ratio of HPAL tailings to metal is 133. Thus, the annual production rates of HPAL tailings by all operating projects, all operating plus permitted projects, and all operating plus permitted plus proposed projects are 57, 176, and 275 million metric tons per year, respectively. Target geotechnical water contents for HPAL

tailings are 30-35%, so that the use of the name “Dry Stack Tailings Facility” (DSTF) for the filtered tailings storage facility at the PT HPL project is a marketing term. Because of the tendency for high precipitation to re-saturate filtered tailings, the precipitation rate is the primary constraint on the height, storage volume, and throughput of filtered tailings storage facilities. Based on mean annual precipitations of 2252, 2241, and 1754 mm, storage capacities of 67, 33, and 25.8 million cubic meters, and throughputs of 28,356, 49,041, and 20,537 metric tons per day for the Sonic Bay, PT HFNC, and PT HPL projects, respectively, as well as a height of 57 meters for the PT HPL project, all three projects are far beyond current technological limits.

A 2022 report by SRK Consulting for the PT HPL project on Obi Island documented groundwater contamination due to seepage from the DSTF. Although the facility had been operational for 1.5 years, part of the drainage infrastructure had not been constructed and it was unclear as to how the drainage infrastructure was supposed to operate even as designed. Groundwater contamination is built into the design of the DSTF and no available report has mentioned the existence of a liner. A 2020 report by PT Lapi ITB calculated that 29,326 cubic meters of contaminated water will leak into the underlying aquifer each year and simulated the spread of contaminants over the next 100 years. PT Lapi ITB further predicted the rise in the water table in the DSTF that would occur due to the inability of the seepage to flow away into the groundwater system fast enough and a 2020 report by Hatch predicted that the DSTF would be unstable if the water table rose to within 30 meters of the top of the stack. PT Lapi ITB and Hatch both showed that the filtered tailings would be moderately susceptible to liquefaction. PT Lapi ITB further predicted that, in response to seismic activity, the foundation would be unstable and the rockfill buttresses would be unstable if they were taller than 15 meters, which could be the reason as to why the design requires stacking the tailings much higher than the tops of the buttresses. Finally, PT Lapi ITB predicted that sections of the DSTF itself would be unstable against seismic activity at the anticipated rate of tailings production.

SRK Consulting provided all of the information necessary to come to the conclusion that, as of December 2022, the DSTF was in imminent danger of catastrophic failure. The DSTF had been constructed without any quality control on the tailings geotechnical water content or compacted density. Although the target geotechnical water content was 35%, actual geotechnical water contents ranged from 8 to 36% and compacted densities ranged from 0.93 to 2.20 metric tons per cubic meter. Because of the low tailings densities, the DSTF would reach full capacity by mid-2027, even though the closure plan was only at the conceptual stage. SRK Consulting further noted the lack of any monitoring data and described the failure of the DSTF as an “uncontrolled risk.” Even if perfect quality control were implemented beginning in 2023, the addition of more tailings increases the likelihood that the lower levels of the DSTF will undergo a sudden compaction that could lead to liquefaction and catastrophic failure.

The consulting reports included a deterministic model of the consequences of failure of the DSTF, according to which the tailings would travel only 2200 meters, even if the tailings were fully liquefied. By contrast, a statistical model predicts that the tailings will travel 47 kilometers under the most-likely scenario, so that the tailings should be expected to reach the sea under any circumstances. The deterministic model shows a flooded area with irregular ponding that stops less than a kilometer from the Molucca Sea, which usually indicates an incorrect topographic model. The flooded area intersects a westward-flowing river about 570 meters from the toe of the DSTF, so that the tailings will most likely flow westward along the river 1600 meters to the sea with considerable impacts on infrastructure and workers, as well as the village of Kawasi. Based on recent failures of two filtered tailings stacks in Brazil, the tailings could travel 20 times the height of the stack by solid slumping alone, so that, once the tailings reach the river, a fully liquefied mass will develop even if there were no initial liquefaction of the filtered tailings.

Despite the dire warnings in the report by SRK Consulting, the sequence of revisions shows that the warnings were, in fact, progressively softened and key information was removed. Revision 1 included a large photo with the heading "View of DSTF area **with significant water ponding**" (emphasis added). Revision 1 also stated, "**During the site visit, some issues with water ponding and poor drainage appeared to be present** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, further study is required" (emphasis added). By the final Revision 9, the photo had been made much smaller, the caption had become "View of dry stack tailings facility area," and in the key quote, both the sentence "During the site visit, some issues with water ponding and drainage appeared to be present" and the phrase "and the observed surface water issues" were removed. Surface ponding is a very serious problem because it raises the possibility that the entire stack might be saturated. According to PT Lapi ITB, if the DSTF were saturated to 80% of its height, the facility should be placed into Emergency Level 3, corresponding to "Immediate or actual failure that requires partial or complete evacuation, emergency communication and response measures."

The catastrophic failure of these facilities is ongoing on Sulawesi Island. On March 16, 2025, the PT HYNC filtered tailings storage facility failed by liquefaction and the released tailings flowed down the Bahodopi River to the Banda Sea. On March 21, 2025, a landslide occurred at the adjoining PT QMB filtered tailings storage facility, resulting in the deaths of three mineworkers. On March 27, 2025, an ore stockpile collapsed at the PT QMB project, resulting in the burial of heavy equipment, but no fatalities. The most recent landslide at the PT QMB filtered tailings storage facility took place on April 30, 2025, with no reports of fatalities. There is evidence that even more failures have occurred at the filtered tailings storage facilities since satellite imagery from January 3, 2025, shows a clearly-defined landslide from the PT HYNC filtered tailings storage facility with clearly-defined channels for tailings to travel to the Bahodopi River. The response from PT QMB was that the rainfall that triggered the fatal landslide was a 50-year event and, thus, "beyond human control," although tailings facilities for which failure could result in loss of life should be designed to withstand the 10,000-year event.

The various pathways ahead are filled with dangers. The first pathway is that mining companies will transition from filtered tailings to conventional tailings storage facilities. In fact, as of December 2022, PT HPL had already applied for a permit to construct three conventional tailings dams on Obi Island with a combined footprint of 1556 hectares, compared to the 195 hectares occupied by the DSTF. The second pathway is that mining companies will insist on the right to dispose of HPAL tailings directly into the sea. The third pathway is that filtered tailings storage facilities will be constructed with a large footprint and low height in order to minimize the likelihood of catastrophic failure. According to workers at PT ONC, the plan is to store 132 million metric tons of filtered tailings on 2344 hectares, with a calculated height of less than 3 meters, so that collapse would be avoided by maximizing the destruction of forest.

Despite the dangers ahead, there is an alternative pathway. The conclusion that the combination of HPAL technology and filtered tailings does not work in Indonesia is superficial ecause it is not obvious that anyone has really tried to make the disruptive technology work. In particular, lack of any quality control or monitoring would not work even for a short filtered tailings stack in the most arid climate. The immediate recommendation of this report is that measures must be taken to protect the safety of mineworkers and community residents downstream from the DSTF of the PT HPL project on Obi Island. The longer-term recommendation is that the combination of HPAL technology and filtered tailings be continued, but with proper attention to principles of safety. In particular, Indonesia must develop a manual for the safe construction of filtered tailings storage facilities in the Indonesian context and that commitment to adherence to the manual must be a pre-condition for the further operation of filtered tailings storage facilities.

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EXECUTIVE SUMMARY

From 2015 to 2024, annual mine production of nickel in Indonesia rose from 130,000 to 2,200,000 metric tons, increasing from 5.7% to 59.5% of world mine production. In a similar way, from 2020 to 2024, annual mine production of cobalt in Indonesia rose from 1100 to 28,000 metric tons, increasing from 1.1% to 9.7% of world mine production. These dramatic increases were partially accomplished through the opening, from 2021 to 2024, of five high-pressure acid leaching (HPAL) projects for the extraction of mixed hydroxide precipitates of nickel and cobalt from laterite ores (deeply weathered and cemented soils). The five HPAL projects include PT Halmahera Persada Lygend (HPL) and PT Obi Nickel Cobalt (ONC) on Obi Island in the province of North Malaku, PT Qing Mei Bang (QMB) New Energy Materials and PT Huayue Nickel Cobalt (HYNC) in the Indonesia Morowali Industrial Park on Sulawesi Island in the province of Central Sulawesi, and PT Huafei Nickel Cobalt (HFNC) in the Weda Bay Industrial Park on Halmahera Island in the province of North Malaku. The sixth and seventh HPAL projects, PT ESG New Energy Material and PT Meiming New Energy Material in the Indonesia Morowali Industrial Park on Sulawesi Island, started production in January 2025 and the first quarter of 2025, respectively. The PT Halmahera Persada Lygend (HPL) project, the first HPAL project in Indonesia, which was opened in 2021, carries out the additional step of converting the mixed hydroxide precipitates into nickel sulfate and cobalt sulfate.

The use of HPAL to process laterite ores is not a new technology, even in tropical climates with high precipitation. A total of 11 HPAL projects were opened before the first project in Indonesia, including the Coral Bay project (2005) and the Taganito project (2013) in the Philippines, the Goro project (2009) in New Caledonia, and the Ramu project (2012) in Papua New Guinea. The principal innovative aspect of the current explosion in HPAL projects in Indonesia is the combination of HPAL technology with filtered tailings technology, which is the practice at all HPAL projects in Indonesia. Tailings are the wet and crushed rock particles that remain after the commodity of value, such as mixed hydroxide precipitates of nickel and cobalt, have been extracted from the ore. In filtered tailings technology, the tailings are filtered to reduce the geotechnical water content to a level at which the tailings can be compacted in a filtered tailings storage facility. Filtered tailings technology is regarded as a best practice because it decreases the likelihood of liquefaction and collapse of the tailings storage facility, reduces the consequences if a collapse does occur, reduces the footprint of the tailings storage facility, facilitates the safe closure of a tailings storage facility, and reduces the overall water consumption of a mining operation.

The alternative to the use of filtered tailings technology is the aboveground storage of wet tailings in conventional tailings storage facilities. All previous HPAL projects have used conventional tailings storage facilities with the exception of the Ramu project in Papua New Guinea, which uses deep sea tailings disposal. The disposal of tailings into the ocean is not recommended under any circumstances and the government of Indonesia has announced that no new permits will be issued for deep sea tailings disposal, even though the practice is still allowed according to Indonesian regulations. In a similar way, the disposal of tailings directly into rivers or any natural water bodies is not recommended under any circumstances.

No study has suggested that HPAL tailings are ideal for the application of filtered tailings technology, especially not in the tropical climate and high seismicity of Indonesia. In fact, previous studies have shown the difficulty of dewatering the fine-grained HPAL tailings to the optimum water content for maximum compaction. Other studies have discussed the tendency of high precipitation to erode the filtered tailings stacks or to re-saturate the filtered tailings with the possibility of seismic impacts on re-saturated tailings. In general, the motivation for the combination of HPAL technology with filtered tailings technology is that the rapid expansion of nickel and cobalt production is needed for the global conversion from internal combustion to electric vehicles and that filtered tailings technology is less environmentally destructive than the alternatives. Thus, the combination of HPAL technology with filtered tailings technology represents the complete "green" package.

A feature of late capitalism has been the appearance of disruptive technologies, which are innovations that are initially inferior or which target an underserved niche, but which rapidly replace existing technologies, often by offering some other advantage, such as convenience, affordability, or accessibility. An example is generative artificial intelligence, which is replacing original writing through advantages in speed and convenience, despite the inferior products that it produces. The motto "Move fast and break things" has been attributed to various disruptive technologies and their promoters, which captures the dual nature of creativity and acting without regard to consequences. The thesis of this report is that the rapid explosion of high-pressure acid leaching and filtered tailings in Indonesia is both a disruptive technology and a catastrophic failure. To facilitate reading by non-specialists, this report includes a tutorial on essential aspects of mining in the Indonesian context, including laterite ores and high-pressure acid leaching, alternatives for mine tailings disposal, liquefaction, filtered tailings technology, the limit equilibrium method and factor of safety, deterministic and statistical models for tailings facility failure analysis, acid mine drainage and metal leaching, Indonesian tailings regulations, and the guidance document Safety First: Guidelines for Responsible Mine Tailings Management.

Information about existing and proposed HPAL projects and filtered tailings storage facilities is filled with contradictions, even within single company documents. In general, the 2024 review by IndoPremier was used as a base case, although this report attempted to document every possible value in the literature for parameters such as annual capacities for HPAL projects. Thus, the annual capacity for the seven existing HPAL projects is 405,000 metric tons of nickel and 26,500 metric tons of cobalt. There are 14 HPAL projects that are permitted and/or are under construction, including eight new projects in the Indonesia Morowali Industrial Park, with combined annual capacity of 850,900 metric tons of nickel and 38,800 metric tons of cobalt. The distinction between permitted and proposed projects is not always clear, but another 12 HPAL projects are in the proposal stage, including three more on Obi Island, with a combined annual capacity of 745,900 metric tons of nickel. The annual capacity of all operating and permitted projects would be 1,255,900 metric tons of nickel and 65,300 metric tons of cobalt, while the annual capacity of all operating, permitted, and proposed projects would be 2,001,800 metric tons of nickel and 65,300 metric tons of cobalt. Two HPAL projects in the Weda Bay Industrial Park with a combined annual capacity of 183,000 metric tons of nickel and 15,000 metric tons of cobalt have been paused or cancelled. As of August 2023, Obi Island was divided among 21 mining concessions, representing 18.5% of the surface area of the island.

The only filtered tailings storage facility for which detailed information is available is the facility at the PT HPL project on Obi Island, even if much of the information from the company is contradictory. Based on the production of 50,000 metric tons of nickel, 6500 metric tons of cobalt, and 7,496,050 metric tons of tailings in 2023, the ratio of HPAL tailings to metal (nickel or cobalt) is 133, which is somewhat higher than the ratio of 100 that has been commonly assumed. Based on the above, the annual production rates of HPAL tailings by all operating projects, all operating plus permitted projects, and all operating plus permitted plus proposed projects are 57 million metric tons per year, 176 million metric tons per year, and 275 million metric tons per year, respectively. The filtered tailings storage facility at the PT HPL project has a maximum height of 57 meters, footprint of 195 hectares, and capacity of 25.8 million cubic meters. The tailings facility at the PT HPL project includes buttresses constructed out of rockfill. However, the filtered tailings are stacked far higher than the buttresses, so that, if the tailings liquefied, they could easily flow over the tops of the buttresses. The capacity of the filtered tailings storage facility at the PT HFNC project in the Weda Bay Industrial Park is 66 million metric tons, corresponding to 33 million cubic meters, assuming a typical filtered tailings dry density of 2.0 metric tons per cubic meter, while the intended capacity for the paused or cancelled Sonic Bay project in the Weda Bay Industrial Park was 67 million cubic meters. The total footprint of all filtered tailings storage facilities for the Indonesia Morowali Industrial Park is 600 hectares. It is not known how many facilities exist and, thus far, only two adjoining filtered tailings storage facilities for PT HYNC and PT QMB, covering much less than 600 hectares, have been identified. Target geotechnical water contents for HPAL tailings are in the range 30-35% with a target of 35% at the PT HPL project. Thus, the use of the name "Dry Stack Tailings Facility" (DSTF) for the filtered tailings storage facility at the PT HPL project should be understood primarily as a marketing or public relations term.

Because of the tendency for high precipitation to re-saturate filtered tailings, the precipitation rate is the primary constraint on the height, storage volume, and throughput (tailings production rate) of filtered tailings storage facilities. The current technological limit for filtered tailings storage facilities was determined by collecting data on 84 filtered tailings facilities with known heights and storage volumes, as well as 23 facilities with known throughputs. The current technological limit on storage volume was constrained by a line connecting the filtered tailings storage facility at the La Coipa mine in Chile with tailings storage of 71 million cubic meters and mean annual precipitation of 43 mm and the filtered tailings storage facility at the COMILOG mine in Gabon with tailings storage of 8.6 million cubic meters and mean annual precipitation of 1779 mm, while the current technological limit on height was constrained by a line connecting the La Coipa filtered tailings storage facility with a height of 200 meters and the COMILOG filtered tailings storage facility with a height of 30 meters. Finally, the current technological limit on throughput was constrained by a line connecting the Karara filtered tailings stack in Australia with a tailings production rate of 50,000 metric tons per day and mean annual precipitation of 310 mm and the Escobal filtered tailings stack in Guatemala with a tailings production rate of 1528 metric tons per day and mean annual precipitation of 1689 mm. Based on mean annual precipitations of 2252, 2241, and 1754 mm, and throughputs of 28,356, 49,041, and 20,537 metric tons per day for the Sonic Bay, PT HFNC, and PT HPL projects, all three projects are clearly beyond current technological limits for storage volume, height, and throughput for a given precipitation rate.

A 2022 consulting report by SRK Consulting for the PT HPL project on Obi Island documented groundwater contamination with boron, chromium-6, and nickel. According to SRK Consulting, even though the facility had been operational for 1.5 years, part of the drainage infrastructure had not been constructed and, even so, it was unclear as to how the drainage infrastructure as designed was supposed to drain excess water away from the filtered tailings storage facility. The only mitigation measure proposed by SRK Consulting was to investigate the metal leaching potential of the water in the filtered tailings stack, which, of course, was not a measure that would prevent groundwater contamination if the water were enriched in toxic metals. An earlier revision of the report by SRK Consulting recommended investigation of the acid-generating potential of the filtered tailings. That recommendation was later removed, although the final version still indicated that the acid-generating potential of the tailings was unknown.

In a sense, groundwater contamination is built into the design of the filtered tailings storage facility at the PT HPL project. No available consulting report has mentioned the existence of a liner at the base of the facility, which is the typical means for preventing seepage into groundwater. A 2020 consulting report by PT Lapi ITB calculated that 29,326 cubic meters of potentially contaminated water will leak into the underlying aquifer each year and simulated the spread of contaminants through the groundwater system after 10, 50, and 100 years. The consulting report by PT Lapi ITB further predicted the rise in the water table in the filtered tailings stack that would occur due to the inability of the seepage to flow away into the groundwater system fast enough.

The report by PT Lapi ITB and another 2020 consulting report by Hatch used different methodologies to show that the filtered tailings would be moderately susceptible to liquefaction. The report by Hatch further expressed concern regarding the possible instability and liquefaction that could result from the rise in the water table within the filtered tailings stack that was predicted by PT Lapi ITB, especially in response to seismic activity. According to Hatch, the filtered tailings stack would be unstable if the water table rose to within 30 meters of the top of the stack. The report by PT Lapi ITB further predicted that the foundation of the filtered tailings stack would be unstable against seismic activity and that the rockfill buttresses would be unstable against seismic activity if they were taller than 15 meters. Although it has not been mentioned, the potential instability of tall buttresses could be the reason as to why the design requires stacking the tailings much higher than the tops of the buttresses. Finally, PT Lapi ITB predicted that sections of the filtered tailings storage facility would be unstable against seismic activity at the anticipated rate of stacking tailings.

The 2022 report by SRK Consulting provided all of the information necessary to come to the conclusion that, as of December 2022, the filtered tailings storage facility was in imminent danger of catastrophic failure. According to SRK Consulting, the tailings facility had been constructed without any quality control on the geotechnical water content or compacted density of the tailings. Although the target geotechnical water content for tailings leaving the filter presses was 35%, actual geotechnical water contents ranged from 8 to 36% with a mean of 24.5%. Although the design compacted dry density was 2.22 metric tons per cubic meter, the tailings were consistently too dry for adequate compaction, so that actual compacted densities were as low as 0.93 metric tons per cubic meter (less dense than water) and as high as 2.20 metric tons per cubic meter, with a mean in the range 1.287 to 1.355 metric tons per cubic meter. The 2020 Hatch report had measured a maximum compacted dry density of 1.6 metric tons per cubic meter, which was rejected as not credible by the 2020 PT Lapi ITB report, which proposed the alternative of 1.76 metric tons per cubic meter, suggesting confusion in the proper way to measure dry density. Because of the lower than anticipated tailings densities, SRK Consulting predicted that the filtered tailings storage facility would reach full capacity in only another 4.5 years, or by mid-2027. Despite the approaching closure date, SRK Consulting reported that the closure plan was only at the conceptual stage. SRK Consulting further noted the lack of any monitoring data, including the lack of groundwater monitoring, toe seepage measurements, regular surveys, inclinometers, CPT (Cone Penetration Test) investigations, water quality monitoring, meteorological monitoring, piezometers, V-notch weirs, or regular inspections.

SRK Consulting described the failure of the filtered tailings storage facility as an "uncontrolled risk." It is important to note that the lack of quality control in the construction of the lower levels of the filtered tailings storage facility is not a problem that can be repaired. Throughout 2023 and 2024, PT HPL has continued to add more tailings on top of the tailings that had been inadequately compacted in 2021 and 2022. Even if perfect quality control were implemented beginning in 2023, the addition of more tailings increases the likelihood that the lower levels of the filtered tailings stack will undergo a sudden compaction that could lead to liquefaction and a catastrophic failure of the entire facility.

The report by SRK Consulting, as well as reports from PT Lapi ITB, included an analysis of the consequences of catastrophic failure of the filtered tailings storage facility (called the dam break analysis). According to those reports, a deterministic model predicted that the tailings would travel only 2200 meters even if the tailings were fully liquefied. Deterministic models depend upon a large range of parameters, many of which can be poorly known, so that the models are susceptible to intentional or unintentional manipulation. In particular, the model should depend upon the residual (or post-liquefaction) strength of the tailings, which SRK Consulting said was never measured. By contrast, based upon the height and storage volume of the facility at the PT HPL project, a statistical model developed from past failures of tailings storage facilities predicts that the tailings would travel 47 kilometers under the most-likely scenario (release of 33% of the stored tailings) and 161 kilometers under the worst-case scenario (release of 100% of the stored tailings), so that the tailings should be expected to reach the sea under any circumstances. The deterministic model shows a flooded area with irregular ponding that stops less than a kilometer from the Molucca Sea, which usually indicates an incorrect topographic model (non-existent barriers to flow). However, the predicted flooded area actually intersects a westward-flowing river about 570 meters from the toe of the filtered tailings storage facility along the tailings flow path. Thus, the more likely prediction is that the tailings will reach the river and then flow westward 1600 meters to the Molucca Sea with considerable impacts on the mining infrastructure and mineworkers of the PT HPL project, as well as the village of Kawasi at the outlet to the sea. Based on recent failures of two filtered tailings stacks in Brazil, the tailings will travel 20 times the height of the stack (1140 meters in the case of the PT HPL stack) by solid slumping alone, even without liquefaction. Thus, once the tailings reach the river, a fully liquefied mass will develop even if there were no initial liquefaction of the filtered tailings.

Despite the dire warnings in the report by SRK Consulting, the sequence of revisions shows that the warnings were, in fact, progressively softened and key information was removed.. The report went through nine major revisions, along with numerous minor revisions (such as Revisions 7A, 7B, 7C, 7D, and 7E). Revision 1 included a large photo with the heading "View of DSTF [Dry Stack Tailings Facility] area **with significant water ponding**" (emphasis added). Revision 1 also stated, "**During the site visit, some issues with water ponding and poor drainage appeared to be present** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the**

observed surface water issues, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing" (emphasis added).

Surface ponding is a very serious problem for a filtered tailings storage facility because the ponded water can lead to erosion and washouts (gully formation) of the filtered tailings stack and because the ponded areas are not trafficable. Surface ponding typically results from some combination of improper filtering of the tailings, stacking of the tailings during high rainfall, insufficient drainage infrastructure within the filtered tailings stack, and insufficient sloping of the surfaces to promote runoff. Moreover, ponding raises the possibility that the entire stack might be saturated and liquefiable, while the surface water would promote flow behavior if a collapse did occur. In fact, according to the 2020 report by PT Lapi ITB, if the filtered tailings stack were saturated to 80% of its height, the facility should be placed into Emergency Level 3, corresponding to "Immediate or actual failure that requires partial or complete evacuation, emergency communication and response measures." The level of saturation of the filtered tailings stack could have been determined from piezometer data, except that, as noted by SRK Consulting, piezometer data did not exist. A simple way to assess whether the entire stack might be saturated would have been to inquire as to the persistence of surface ponding after the cessation of rainfall. The report from SRK Consulting did not answer the question of how long water ponding persists after rainfall.

In the first minor follow-up to Revision 1, the photo was made much smaller and the caption was changed to "View of DSTF area **with water ponding issues**" (emphasis added). The key quote remained: "**During the site visit, some issues with water ponding and poor drainage appeared to be present** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction, however it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, further study is required to assess the risk for the tailings to have contractive behaviour during undrained shearing" (emphasis added). Up through Revision 8, the photo, caption, and key quote remained unchanged, except that "DSTF" was changed to "dry stack tailings facility" in the photo caption and "poor drainage" was changed to "drainage" in the quote. The significant change occurred in Revision 8A when the caption became simply "View of dry stack tailings facility area." In the key quote, both the sentence "During the site visit, some issues with water ponding and drainage appeared to be present" and the phrase "and the observed surface water issues" were removed, which actually left the last sentence being grammatically incorrect. The only change through the final Revision 9 was that the key quote was grammatically corrected to read: "The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m) and the lack of quality control in the placement of tailings, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing." Thus, the alarming information about surface ponding was entirely absent from the final version of the SRK Consulting report, except for the retention of a small photo with an irrelevant caption.

Another example of the imminence of catastrophic failure on Obi Island is that an internal PT HPL company report from January 2023 revealed the existence of four smaller filtered tailings storage facilities. According to the report, one of the facilities, called "Karo Disposal Tailings Dump" had a factor of safety of only 1.045, indicating that the facility was on the cusp of catastrophic failure. The recommendation of the report was that the deposition of tailings should cease in “Karo Disposal Tailings Dump.” However, the report made no recommendations regarding the safety of mineworkers, even though the unstable facility is only several hundred meters upslope from considerable mining infrastructure.

Although the catastrophic failure of filtered tailings storage facilities is imminent on Obi Island, the catastrophic failure of these facilities is ongoing in the Indonesia Morowali Industrial Park on Sulawesi Island. On March 16, 2025, the PT HYNC filtered tailings storage facility failed by liquefaction and the released tailings flowed down the Bahodopi River with overflow onto various industrial sites on the way to the Banda Sea. On March 21, 2025, a landslide occurred at the adjoining PT QMB filtered tailings storage facility, resulting in the deaths of three mineworkers. The excavation of the buried workers revealed the existence of a pond that had been infilled to construct the filtered tailings storage facility. Construction on an infilled pond is a questionable practice because it could result in a high water table within the filtered tailings storage facility. Presumably, as the excavators dug below the water table, the pond re-formed at its previous location. One of the dead workers was found at the bottom of the pond, while the bodies of the other two workers were never found. Thus, the filtered tailings storage facility apparently collapsed at its weakest spot where the water table was highest. The response from PT QMB was that the rainfall that triggered the fatal landslide was an event with a return period of 50 years and, thus, “beyond human control.” However, tailings storage facilities for which failure could result in the loss of human life should be designed to withstand either the precipitation event with a return period of 10,000 years or the Probable Maximum Flood (PMF).

On March 27, 2025, an ore stockpile collapsed at the PT QMB project, resulting in the burial of heavy equipment, but no fatalities. The location of the ore stockpile is not known and an ore stockpile is not the same as a tailings facility, but it draws into question the quality of construction of mining infrastructure at the PT QMB project. The most recent landslide at the PT QMB filtered tailings storage facility took place on April 30, 2025, with no reports of fatalities. There is evidence that even more failures have occurred at the filtered tailings storage facilities for the Indonesia Morowali Industrial Park. Satellite imagery from January 3, 2025, shows a clearly-defined landslide from the PT HYNC filtered tailings storage facility with clearly-defined channels for tailings to travel to the Bahodopi River. Finally, a video taken by a mineworker shows a bulldozer being engulfed by a landslide at an unidentified filtered tailings storage facility of the Indonesia Morowali Industrial Park in September 2023.

The various pathways ahead are filled with dangers. The obvious and superficial conclusion is that the combination of HPAL technology and filtered tailings does not work, especially given the high precipitation and seismic activity in Indonesia. The first dangerous pathway is that mining companies will transition from filtered tailings to conventional tailings storage facilities. In fact, as of December 2022, PT HPL had already applied for a permit to construct three conventional tailings dams on Obi Island for use after the “Dry Stack Tailings Facility” (DSTF) reaches full capacity (predicted to be mid-2027). With a combined footprint of 1556 hectares, the three conventional tailings storage facilities would cover eight times the area of the existing DSTF. The presence of two of the conventional tailings storage facilities at the headwaters of the Akelamo River indicates that a tailings dam failure could contaminate the entire Akelamo River Basin. The second dangerous pathway is that mining companies will insist on the right to dispose of HPAL tailings directly into the sea.

The third dangerous pathway is that filtered tailings storage facilities will be constructed with a large footprint and low height in order to minimize the likelihood of catastrophic failure.

According to workers at PT Obi Nickel Cobalt (ONC), the plan is to store 132 million metric tons of filtered tailings on 2344 hectares. Assuming a compacted dry density of 2.0 metric tons per cubic meter, the volume of the filtered tailings storage facility would be 66 million cubic meters. If the facility were modeled as a rectangular prism on a flat surface, the height would be only 2.8 meters. Thus, collapse would be avoided by maximizing the destruction of forest, in other words, by constructing the tailings facility in a pre-collapsed state. There is no other information available regarding the plans for tailings storage at PT ONC

Despite the dangers ahead, there is an alternative pathway. The obvious conclusion that the combination of HPAL technology and filtered tailings does not work in Indonesia is superficial because it is not obvious that anyone has really tried to make the disruptive technology work. In particular, lack of any quality control or monitoring would not work even for a short filtered tailings stack in the most arid climate. The general recommendation of this report is that the combination of HPAL technology and filtered tailings be continued, but with proper attention to principles of safety.

This report makes the following specific recommendations to the Indonesian government to be carried out in the following order:

1) Immediate measures must be taken to protect the safety of mineworkers and community residents downstream from the Dry Stack Tailings Facility (DSTF) of the PT HPL project on Obi Island.
2) Deposition of tailings must cease at all filtered tailings storage facilities in Indonesia.
3) There must be a moratorium on permits for new filtered tailings storage facilities in Indonesia.
4) Existing permits for filtered tailings storage facilities that have not yet been constructed must be revoked.
5) Safety audits must be carried out on all filtered tailings storage facilities in Indonesia by independent consulting companies to be chosen by the Indonesian government, but paid by the owners of the filtered tailings storage facilities.
6) Indonesia must develop a manual for the safe construction of filtered tailings storage facilities in the Indonesian context. Useful starting points are the manual developed by the BHP Rio Tinto Tailings Management Consortium for the mining industry, the manual developed by AECOM for the Office of the Public Prosecutor in Minas Gerais (Brazil), and the relevant sections of the FEMA ((U.S.) Federal Emergency Management Agency)) Tailings Dam Best Safety Practices. Particular attention should be paid to past shortcomings in the construction of filtered tailings storage facilities in Indonesia, such as the need for monitoring, the need for a closure plan prior to permitting, and the need for quality control in tailings geotechnical water contents and compacted densities.
7) Existing filtered tailings storage facilities that receive satisfactory safety audits may be re-opened with a commitment to follow the requirements of the Indonesian filtered tailings manual.
8) Filtered tailings storage facilities that were previously permitted may be constructed with a commitment to follow the requirements of the Indonesian filtered tailings manual.
9) Permits may be issued for new filtered tailings storage facilities with a commitment to follow the requirements of the Indonesian filtered tailings manual.
10) Indonesia must pass legislation prohibiting deep sea tailings disposal.

11) Indonesia must fully adopt the guidance document Safety First: Guidelines for Responsible Mine Tailings Management.

OVERVIEW

From 2015 to 2024, annual mine production of nickel in Indonesia rose from 130,000 to 2,200,000 metric tons, increasing from 5.7% to 59.5% of world mine production (USGS, 2025a; see Figs. 1 and 2a). In a similar way, from 2020 to 2024, annual mine production of cobalt in Indonesia rose from 1100 to 28,000 metric tons, increasing from 1.1% to 9.7% of world mine production (USGS, 2025b; see Fig. 2b). These dramatic increases were partially accomplished through the opening, from June 2021 (PT Halmahera Persada Lygend, 2022) through April 2024 (PT Obi Nickel Cobalt, 2025), of five high-pressure acid leaching (HPAL) projects for the extraction of mixed hydroxide precipitates of nickel and cobalt from laterite ores (deeply weathered and cemented soils). The five HPAL projects include PT Halmahera Persada Lygend (HPL) and PT Obi Nickel Cobalt (ONC) on Obi Island in the province of North Malaku, PT Qing Mei Bang (QMB) New Energy Materials and PT Huayue Nickel Cobalt (HYNC) in the Indonesia Morowali Industrial Park on Sulawesi Island in the province of Central Sulawesi, and PT Huafei Nickel Cobalt (HFNC) in the Weda Bay Industrial Park on Halmahera Island in the province of North Malaku (see Fig. 3 and Tables 1a-d). The sixth and seventh HPAL projects, PT ESG New Energy Material and PT Meiming New Energy Material in the Indonesia Morowali Industrial Park on Sulawesi Island, started production in January 2025 and during the first quarter of 2025 (Merdeka Battery Materials, 2024), respectively. The PT Halmahera Persada Lygend (HPL) project, the first HPAL project in Indonesia, which was opened in June 2021, carries out the additional step of converting the mixed hydroxide precipitates into nickel sulfate and cobalt sulfate (PT Halmahera Persada Lygend, 2024).

The use of HPAL to process laterite ores is not a new technology, even in tropical climates with high precipitation. A total of 11 HPAL projects were opened before the first project in Indonesia, including the Coral Bay project (2005) and the Taganito project (2013) in the Philippines, the Goro project (2009) in New Caledonia, and the Ramu project (2012) in Papua New Guinea (see Table 2). A distinguishing feature of the introduction of HPAL technology into Indonesia is the speed at which new HPAL projects are commissioned. While the first HPAL project opened in Cuba in 1959, worldwide, only 10 new HPAL projects became operational during the 18 years from 1998 to 2015 (see Table 2). By contrast, seven HPAL projects began operation in Indonesia over the 46-month period from June 2021 through March 2025, an average of one new HPAL project every six and a half months (see Table 1a). Another 14 HPAL projects are permitted and/or are under construction, including eight new projects in the Indonesia Morowali Industrial Park (see Table 1b). The distinction between permitted and proposed projects is not always clear, but another 12 HPAL projects are in the proposal stage, including three more on Obi Island (see Table 1c). Two HPAL projects in the Weda Bay Industrial Park have been paused or cancelled (see Table 1d). A second distinguishing feature of the introduction of HPAL technology into Indonesia is the speed with which HPAL plants have reached their “nameplate capacities.” The first HPAL in Indonesia, PT HPL, reached its nameplate capacity of 50,000 metric tons of nickel and 6500 metric tons of cobalt per year in only 12 months and was only the second HPAL plant in the world to ever reach nameplate capacity (PT Halmahera Persada Lygend, 2023a), the first being the Taganito HPAL project in the Philippines (Shibayama, 2016). As a second example, PT Huayue Nickel Cobalt (HYNC) began production in January 2022 and had achieved nameplate capacity by the time that the article by Fisher and Grossl (2023) was written in July 2023, so that the attainment of nameplate capacity in 12-18 months seems to have become the standard practice for HPAL projects in Indonesia.

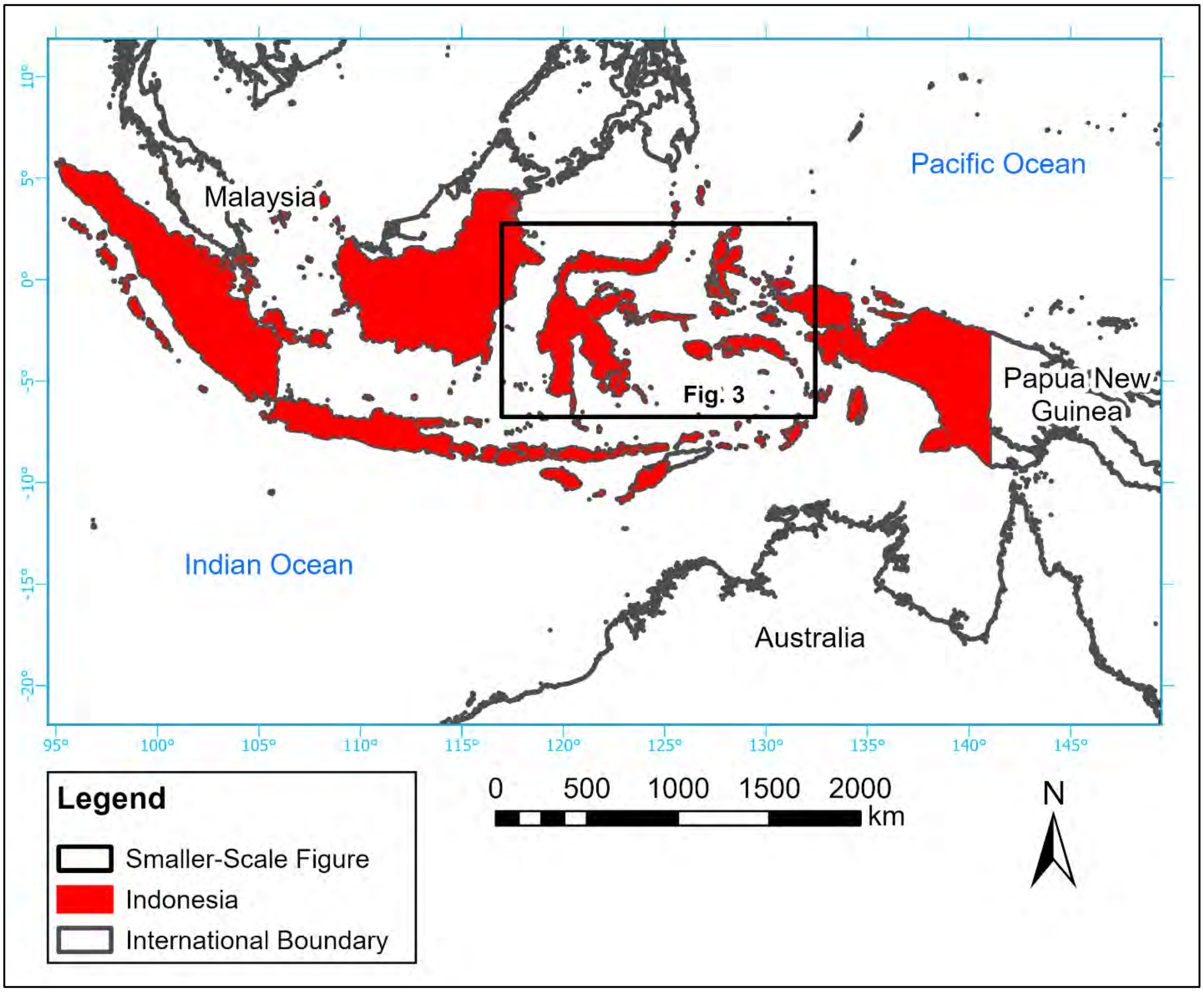

Figure 1. The objective of this report is to evaluate the performance of filtered tailings storage facilities in Indonesia. Thus far, all filtered tailings projects have been constructed on either Halmahera Island, Obi Island, or Sulawesi Island (see Fig. 3).

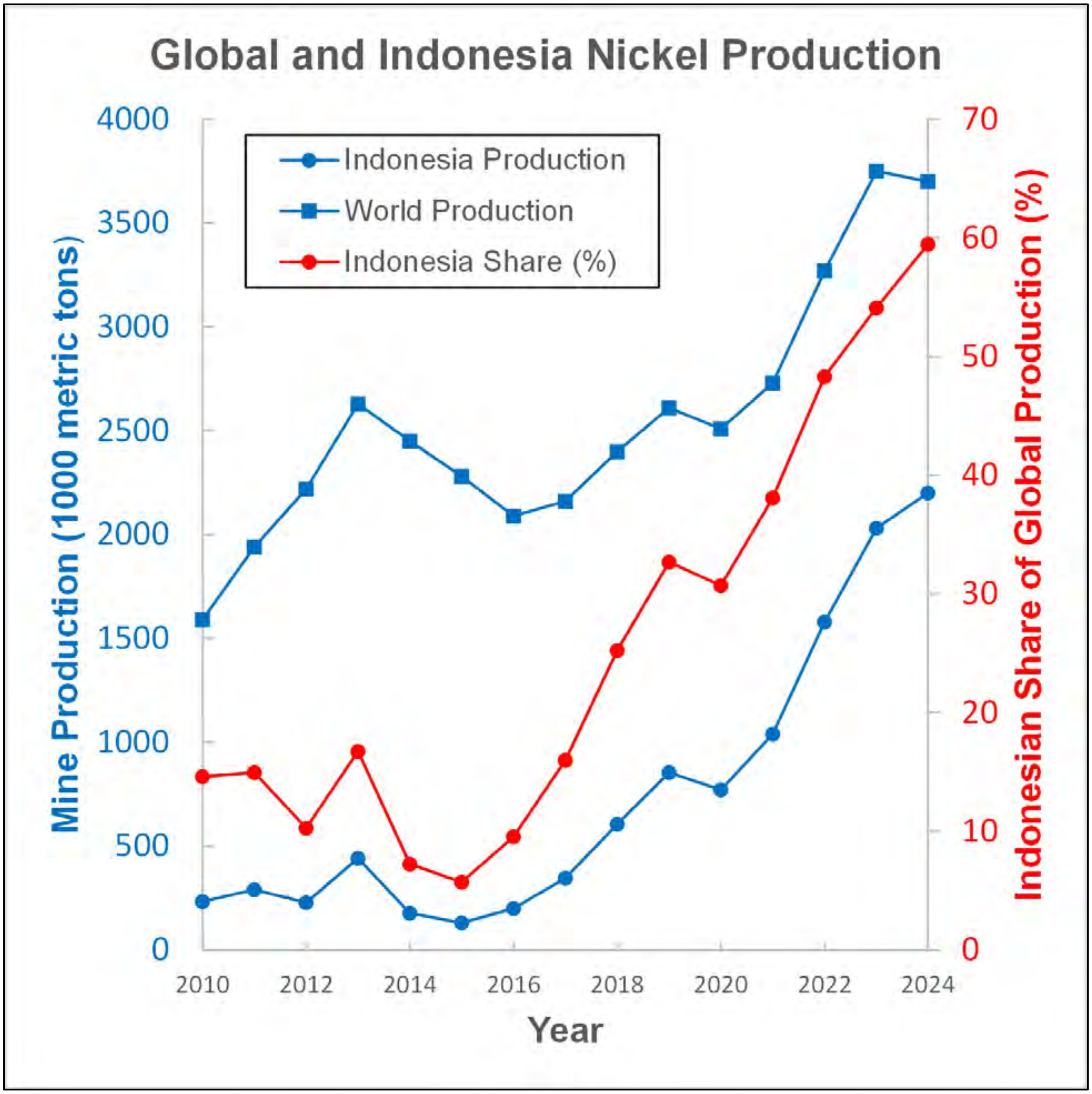

Figure 2a. From 2015 to 2024, annual mine production of nickel in Indonesia rose from 130,000 to 2,200,000 metric tons, increasing from 5.7% to 59.5% of world mine production. Data from USGS (2025a).

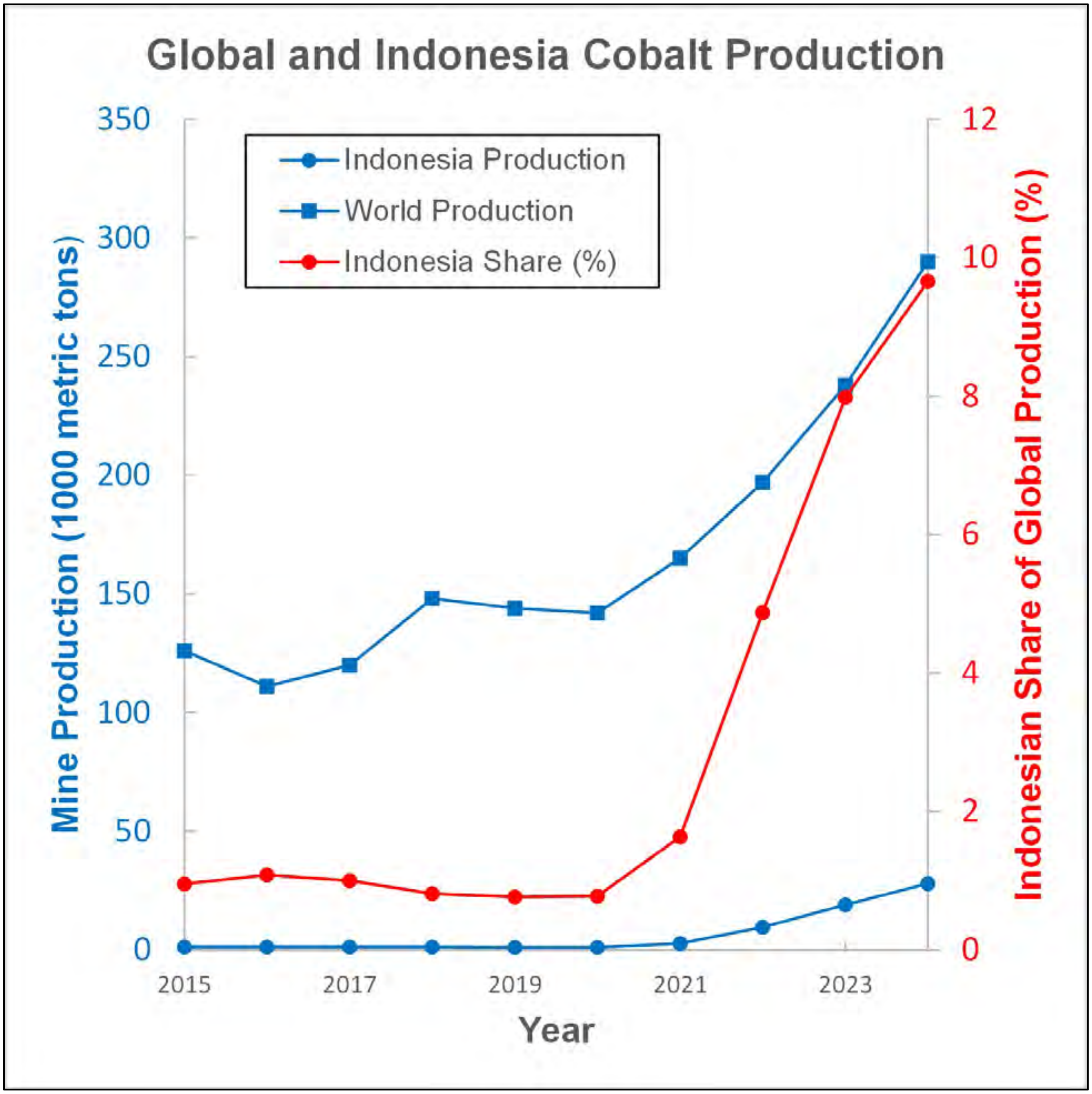

Figure 2b. From 2020 to 2024, annual mine production of cobalt in Indonesia rose from 1100 to 28,000 metric tons, increasing from 1.1% to 9.7% of world mine production. Data from USGS (2025b).

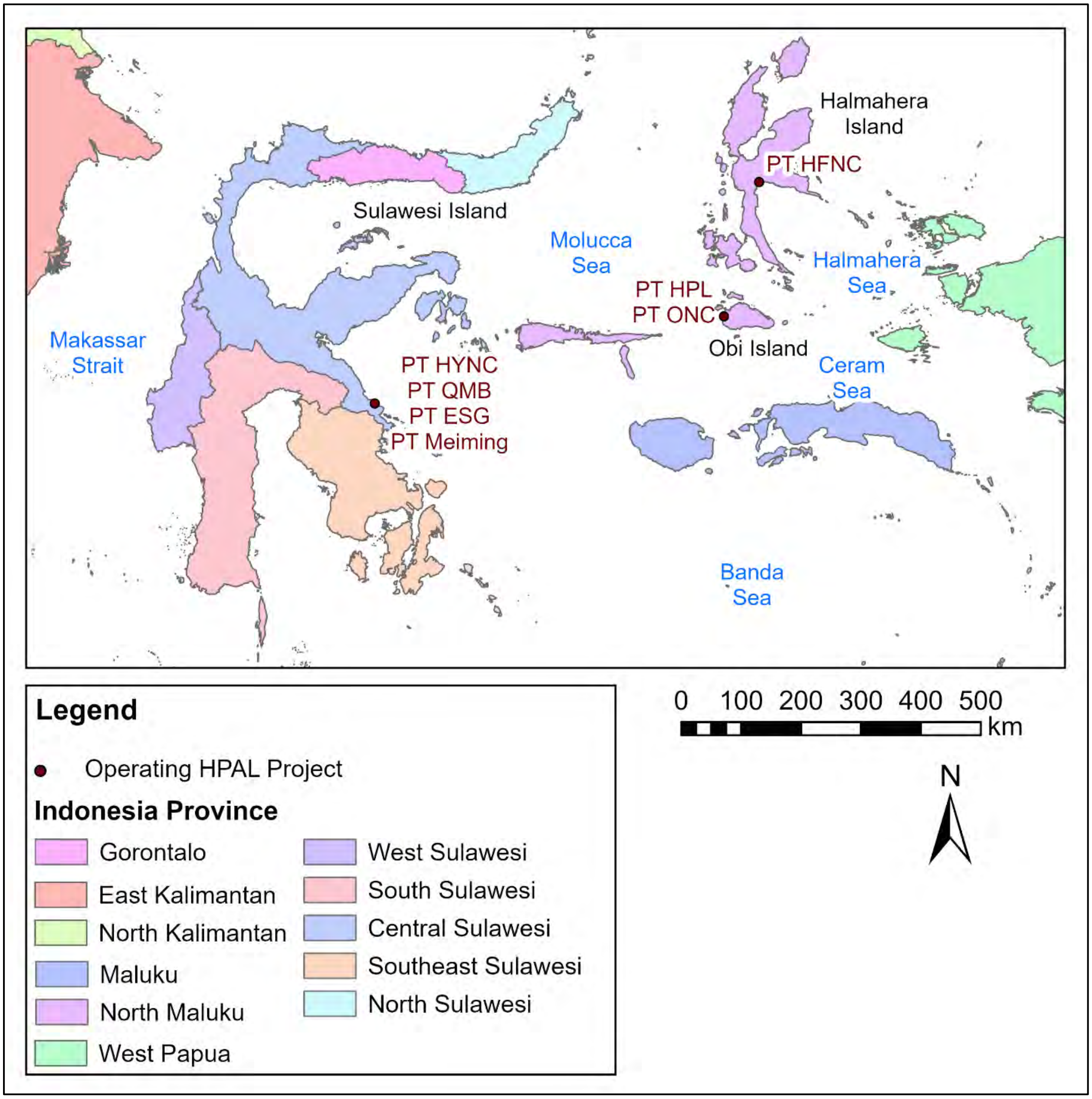

Figure 3. The seven operating HPAL projects in Indonesia are PT Halmahera Persada Lygend (HPL) and PT Obi Nickel Cobalt (ONC) on Obi Island in the province of North Malaku, PT Huayue Nickel Cobalt (HYNC), PT Qing Mei Bang (QMB) New Energy Materials, PT ESG New Energy Material, and PT Meiming New Energy Material in the Indonesia Morowali Industrial Park on Sulawesi Island in the province of Central Sulawesi, and PT Huafei Nickel Cobalt (HFNC) in the Weda Bay Industrial Park on Halmahera Island in the province of North Malaku (see Table 1a). The locations of PT HYNC, PT QMB, PT ESG, and PT Meiming, and the locations of PT HPL and PT ONC are indistinguishable at the scale of this map. See larger-scale map in Fig. 1.

Table 1a. HPAL projects in Indonesia: Operating[1]

Name	Location	Ownership	Annual Capacity (metric tons)	Operational Year
PT Halmahera Persada Lygend (HPL)[2]	Obi Island, North Malaku	Trimegah Bangun Persada (45.1%), Ningbo Lygend Mining (54.9%)	55,000 Ni[3,4] 50,000 Ni[5] 6500 Co[5]	2021[6]
PT Huayue Nickel Cobalt (HYNC)	Indonesia Morowali Industrial Park, Central Sulawesi	Zhejiang Huayou Cobalt (57%)[6], China Molybdenum (30%)[6], Nickel Industries (10%), Other (3%)	60,000 Ni[7,8] 5000 Co[9] 70,000 Ni+Co[10]	2021[11,12]
PT Qing Mei Bang (QMB) New Energy Materials	Indonesia Morowali Industrial Park, Central Sulawesi	Jingmen GEM New Material (36%), Brunp (35%), New Horizon International Holding (21%), Tsingshan Holding Group (10%) Hanwa (8%)[6,13]	50,000 Ni[14,15] 50,000 Ni+Co[16]	2022[6]
PT Huafei Nickel Cobalt (HFNC)	Weda Bay Industrial Park, Halmahera Island, North Malaku	Zhejiang Huayou Cobalt (51%), EVE Battery (17%), Glaucous International (30%), Lindo Investment (2%)[17]	120,000 Ni 15,000 Co[18]	2023[18]
PT Obi Nickel Cobalt (ONC)	Obi Island, North Malaku	Trimegah Bangun Persada (10%), Lygend (60%), Harita Group (30%)	65,000 Ni	2024
PT ESG New Energy Material	Indonesia Morowali Industrial Park, Central Sulawesi	MBMA (55%), GEM (45%; option for Ecopro (21%))	30,000 Ni[19]	2025
PT Meiming New Energy Material[20]	Indonesia Morowali Industrial Park, Central Sulawesi	MBMA, GEM[21]	25,000 Ni[21]	2025[22]

[1]Data from IndoPremier (2024) and products are mixed hydroxide precipitate unless otherwise indicated.
[2]Products are mixed hydroxide precipitate plus nickel sulfate and copper sulfate (PT Halmahera Persada Lygend, 2023a).
[3]Stated as 54,000 metric tons Ni per year by Durrant (2023)

[4]Stated as 55,875 metric tons Ni per year by Hidayat et al. (2024)
[5] PT Halmahera Persada Lygend (2023a)
[6]Durrant (2023). Ownership stated by Durrant (2023) adds to 110%.
[7]Stated as 55,655 metric tons Ni per year by Hidayat et al. (2024)
[8]Stated as 65,000 metric tons Ni per year by Fisher and Grossl (2023)
[9]Stated as 6000 metric tons Co per year by Fisher and Grossl (2023)
[10]IMIP (2025a)
[11]Nickel Industries (2025)
[12]Stated as 2022 by Fisher and Grossl (2023)
[13]Also stated as Jingmen GEM New Material (63%), Brunp (10%), EcoPro Global (9%), Tsingshan Holding Group (10%), Hanwa (8%) by Sangadji (2024)
[14]Stated as 30,000 metric tons Ni per year with an additional 30-60,000 metric tons under construction by Fisher and Grossl (2023)
[15]Stated as 65,000 metric tons Ni per year by GEM Co. (2024)
[16]IMIP (2025b)
[17]Sangadji and Pinting (2023)
[18]Nangoy (2023)
[19]Stated as 22,000 metric tons Ni by IMIP (2025i)
[20]Merdeka Battery Materials (2025)
[21]Stated as full ownership by GEM Co. and with annual capacity of 22,000 metric tons Ni by IMIP (2025k).
[22]Stated as Q1 2025 by Merdeka Battery Materials (2024).

Table 1b. HPAL projects in Indonesia: Permitted and/or under construction[1]

Name	Location	Ownership	Annual Capacity (metric tons)	Operational Year
MBMA-CATL	Indonesia Konawe Industrial Park (IKIP), Southeast Sulawesi	MBMA (66%), Ningbo Brunp Contemporary Amperex (affiliate of CATL) (34%)	60,000 Ni	2025[2]
PT Blue Sparkling Energy (BSE)	Weda Bay Industrial Park, Halmahera Island, North Malaku[3]	Harum Energy (51%)[4], Tsingshan, Holding Group	67,000 Ni 7500 Co[4]	2026
Pomalaa/PT Kolaka Nickel Indonesia (KNI)	Indonesia Pomalaa Industrial Park, Southeast Sulawesi	Zhejiang Huayou Cobalt (53%), Vale Indonesia (30%), Ford (17%)[5,6]	120,000 Ni 15,000 Co[7]	2026
PT Excelsior Nickel Cobalt (ENC)[8]	Indonesia Morowali Industrial Park, Central Sulawesi	Nickel Industries (55%)[10], United Tractors (UNTR)	67,000 Ni[9]	2026
Sorowako/PT Huali Nickel Indonesia (HNI)	South Sulawesi	Zhejiang Huayou, Cobalt, Vale Indonesia[11]	60,000 Ni 5000 Co[12]	2027
PT Ceria Nugraha Indotama[13,14]	Southeast Sulawesi	—	146,0000 Ni+Co 110,900 Ni[15] 11,300 Co[15]	2028-2030
PT Green AGCO New Energy Materials[16]	—	Gem Co.	22,000 Ni	—
PT Sulawesi Nickel Cobalt (SNC)[17]	Indonesia Morowali Industrial Park, Central Sulawesi	Zhejiang Huayou Cobalt, Tsingshan Holding Group	60,000 Ni 80,000 Ni+Co[17] 80,000 Ni[18]	—
PT Green Eco Nickel[19,20]	Indonesia Morowali Industrial Park, Central Sulawesi	—	22,000 Ni	—
PT Seawing New Energy[21]	Indonesia Morowali Industrial Park, Central Sulawesi	Tsingshan Holding Group	60,000 Ni	—
PT Honch New Energy[22]	Indonesia Morowali Industrial Park, Central Sulawesi	Tsingshan Holding Group	60,000 Ni	—

PT Decho New Energy[23]	Indonesia Morowali Industrial Park, Central Sulawesi	Tsingshan Holding Group	60,000 Ni	—
PT Chengseng New Energy[24]	Indonesia Morowali Industrial Park, Central Sulawesi	Tsingshan Holding Group	60,000 Ni	—
PT Indonesia Qingmei Energy Materials[25]	Indonesia Morowali Industrial Park, Central Sulawesi	GEM Co.	22,000 Ni	—

[1]Data from IndoPremier (2024) and products are mixed hydroxide precipitate unless otherwise indicated.
[2]Stated as end of 2027 by Merdeka Copper Gold (2024)
[3]Spence (2024)
[4]Argus (2024)
[5]Sangadji and Ginting (2023)
[6]Stated as Zhejiang Huayou Cobalt (73.2%), Vale Indonesia (18.3%), Ford (8.5%) by Sangadji (2024)
[7]Vale (2025)
[8]Products are mixed hydroxide precipitate plus nickel sulfate and nickel cathode (Nickel Industries, 2025).
[9]Stated as 72,000 metric tons Ni per year by Nickel Industries (2025)
[10]Nickel Industries (2025)
[11]PT Vale Indonesia (2023)
[12]Argus (2023)
[13]All data from Nangoy and Nguyen (2024) except as indicated.
[14]Products are mixed hydroxide precipitate plus nickel sulfate and copper sulfate (Nangoy and Nguyen, 2024).
[15]Ceria Nugraha Indotama (2025)
[16]Sangadji (2024)
[17]Stated as 80,000 metric tons Ni + Co by IMIP (2025c)
[18]Stated as 80,000 metric tons Ni per year by Nangoy (2023)
[19]IMIP (2025d)
[20]Formerly known as GEM Indonesia New Energy Materials (IMIP, 2025d)
[21]IMIP (2025e)
[22]IMIP (2025f)
[23]IMIP (2025g)
[24]IMIP (2025h)
[25]MIP (2025j)

Table 1c. HPAL projects in Indonesia: Proposed[1]

Name	Location	Ownership	Annual Capacity (metric tons)
IKIP 2	Indonesia Konawe Industrial Park (IKIP), Southeast Sulawesi	MBMA	120,000 Ni
LG Energy - ANTM	—	LG Energy Solutions, Aneka Tambang	40,000-60,000 Ni
CATL - ANTM	—	CATL, Aneka Tambang	40,000-60,000 Ni
PT Ceria Kobalt Indotama	—	Ceria Nugraha Indotama	110,900 Ni
ANEM - Gotion	Sulawesi[2]	Anugrah New Energy Materials, Gotion	120,000 Ni
PT Halmahera Persada Lygend – Phase 3[3,4]	Obi Island, North Malaku	Trimegah Bangun Persada (45.1%), Ningbo Lygend Mining (54.9%)	60,000 Ni
Ningbo Contemporary Brunp Lygend (CBL)[5]	Halmahera Island, North Malaku	Ningbo Brunp Contemporary Amperex, Ningbo Lygend New Energy, Ningbo Meishan Free Trade Port Ruiting Investment Co.[5]	40,000 Ni[3]
Huabao[3]	Indonesia Huabao Industrial Park, Central Sulawesi	Nanjing Hanrui Cobalt[4]	60,000 Ni[3]
PT Ceria Nugraha Indotama[3]	Obi Island, North Malaku	—	40,000 Ni
Jinchuan[3]	Obi Island, North Malaku	—	20,000 Ni
PT Antam[3,6]	East Halmahera Island, North Malaku	—	75,000 Ni
Indonesia Huali Industrial Park (IHIP)[7]	Malili, South Sulawesi	Zhejiang Huayou Cobalt	

[1]Data from IndoPremier (2024) and products are mixed hydroxide precipitate unless otherwise indicated.
[2]World Construction Network (2023)
[3]Durrant (2023)
[4]Asian Metal (2022)
[5]CBL (2025)
[6] Product is nickel sulfate (Durrant, 2023).
[7]Products are mixed hydroxide precipitate plus nickel sulfate (Durrant, 2023).

Table 1d. HPAL projects in Indonesia: Paused or cancelled[1]

Name	Location	Ownership	Annual Capacity (metric tons)
Sonic Bay	Weda Bay Industrial Park, Halmahera Island, North Malaku[2]	Eramet (51%), BASF (49%)	60,000 Ni
Huashan	Weda Bay Industrial Park, Halmahera Island, North Malaku[2]	Zhejiang Huayou Cobalt (68%), Glaucous (32%)[3]	123,000 Ni[4,5] 15,000 Co[6]

[1]Data from IndoPremier (2024) and products are mixed hydroxide precipitate unless otherwise indicated.
[2]Sangadji et al. (2019)
[3]SMM (2022)
[4]Stated as 120,000 metric tons Ni per year by Argus (2023)
[5]Stated as 120,000 metric tons Ni per year by SMM (2022)
[6]Argus (2023)

Table 2. HPAL projects prior to first Indonesian project[1]

Operational Year	Country	Project	Annual Capacity (metric tons)	Tailings Disposal Method
1959	Cuba	MOA	32,000 Ni 2000 Co	Conventional tailings dam[2]
1998	Australia	Bulong	9000 Ni 700 Co	Conventional tailings dam[3]
1998	Australia	Murin Murin	45,000 Ni 3000 Co	Conventional tailings dam[4]
2000	Australia	Cawse	9000 Ni 1300 Co	Conventional tailings dam[5]
2005	Philippines	Coral Bay	18,000 Ni 1500 Co	Conventional tailings dam[6]
2008	Australia	Ravensthorpe	50,000 Ni 1400 Co	Conventional tailings dam[6]
2009	New Caledonia	Goro	60,000 Ni 5000 Co	Conventional tailings dam[7]
2012	Papua New Guinea	Ramu	30,000 Ni 3000 Co	Deep sea disposal[8]
2012	Madagascar	Ambatovy	60,000 Ni 5000 Co	Conventional tailings dam[6]
2013	Philippines	Taganito	30,000 Ni 2600 Co	Conventional tailings dam[6]
2015[9]	Turkey	Gördes	10,000 Ni 750 Co	Conventional tailings dam

[1]All data from Gultom and Sianipar (2020) unless otherwise indicated.
[2]Sherritt International Corporation (2025)
[3]Senversa (2020)
[4]Glencore (2023)
[5]Woodward-Clyde (1996)
[6]UNEP et al. (2025)
[7]Mining.com (2022)
[8]MRDC (2025)

[9]Birol (2023)

The principal innovative aspect of the current explosion in HPAL projects in Indonesia is the combination of HPAL technology with filtered tailings technology. Tailings are the wet and crushed rock and soil particles, together with chemical reagents and their reaction and degradation products, that remain after the commodity of value, such as mixed hydroxide precipitates of nickel and cobalt, have been extracted from the ore. In filtered tailings technology, the tailings are filtered to reduce the geotechnical water content to a level at which the tailings can be compacted in a filtered tailings storage facility (see Fig. 4). Filtered tailings technology is regarded as a best practice because it decreases the likelihood of liquefaction and collapse of the tailings storage facility, reduces the consequences if a collapse does occur, reduces the footprint of the tailings storage facility, facilitates the safe closure of a tailings storage facility, and reduces the overall water consumption of a mining operation (Independent Expert Engineering Investigation and Review Panel, 2015; Morrill et al., 2022). To date, all HPAL projects in Indonesia use filtered tailings technology (Fisher and Grossl, 2023; Heyokha Brothers, 2024; Hidayat et al., 2024) and many permitted HPAL projects, such as PT Kolaka Nickel Indonesia (KNI) in the planned Indonesia Pomalaa Industrial Park in the province of Southeast Sulawesi and PT Huali Nickel Indonesia (HNI) in South Sulawesi (see Table 1b and Fig. 3) have declared an intention to implement filtered tailings technology (Silva et al., 2023). Non-standard terminology for filtered tailings, such as "dry tailings" and "dry stacking" will be critiqued in the "Tutorial" section.

The alternative to the use of filtered tailings technology is the aboveground storage of wet tailings in conventional tailings storage facilities. All previous HPAL projects have used conventional tailings storage facilities with the exception of the Ramu project in Papua New Guinea, which uses deep sea tailings disposal (see Table 2). The disposal of tailings into the ocean is not recommended under any circumstances (Morrill et al., 2022). In 2021 the government of Indonesia announced that no new permits will be issued for deep sea tailings disposal (Nangoy and Ungku, 2021), even though Indonesian regulations for environmental protection released the same year included regulations for deep sea tailings disposal (Government of the Republic of Indonesia, 2021). In a similar way, the disposal of tailings directly into rivers without confinement is not recommended under any circumstances (Morrill et al., 2022).

No study has suggested that HPAL tailings are ideal for the application of filtered tailings technology, especially not in the tropical climate and high seismicity of Indonesia. The problems are that the optimum geotechnical water content for maximum compaction is typically only a few percentage points below the saturation water content, so that high precipitation can easily re-saturate the tailings. Saturated tailings can become physically unstable even under static conditions, while the combination of saturated tailings with seismic activity leads to even more potential instability. An additional problem is that high precipitation can tend to erode away the filtered tailings stacks. According to Firdau (2022), "This technology, using acid under conditions of intense heat and pressure to remove nickel from raw ore, has never been tested before in Indonesia, where the frequency of earthquakes, heavy rainfall and landslides can make it especially treacherous to transport and store hazardous waste." According to Lee (2023), "Dry-stacking is challenging in a country that has high rainfall and regular seismic activity." According to Guberman et al. (2024), "Dry stacking is considered to be the best option for Indonesia to deal with mine waste. However, the stability of the stacks and erosion issues are yet to be examined for the particular geography of the country, which could face the possible adverse impact of heavy rains and earthquakes." Sangadji (2024) summarized, "It is also concerning that these companies are operating filtered tailings facilities in a highly wet climate or high rainfall areas that are also categorized as disaster-prone areas (high frequency of earthquakes, landslides and floods)." The filtered tailings manual by the BHP Rio Tinto Tailings Management Consortium (2024) views erosion of the filtered tailings stack as the main challenge for filtered tailings in high-precipitation areas, but without specific reference to Indonesia. According to BHP Rio Tinto Tailings Management Consortium (2024), "Uncompacted stack slopes in high rainfall areas can erode quickly and form large gullies. It is recommended that these areas be rolled-compacted to minimize erosion. Sealed and compacted tailings are relatively erosion resistant except in heavy rain and/or concentrated surface water flows."

Figure 4. Panoramic view of filtered tailings storage facility in Indonesia. The precise location is not stated. Photo from Fisher and Grossl (2023).

The high precipitation and seismicity led some mining companies to conclude that deep sea disposal was the only workable option for Indonesia. In fact, only the year before PT Halmahera Persada Lygend (HPL) opened the first HPAL project in Indonesia, managerial employees of PT HPL wrote, "Tailings application for Halmahera tropical region is less suitable. Halmahera tropical region, particularly at Obi island, is an earthquake active area with 3,000 mm/year rainfall, and ±7,000 people living in the village downstream. Due to this condition, the cost of construction and water control will be very high and is not feasible for the project economically. The main composition residue will be pumped to DSTP [Deep Sea Tailings Disposal] " (Gultom and Sianipar, 2020). According to Sanderson (2022), "At the Chinese-owned Ramu nickel mine in neighbouring Papua New Guinea, mine waste is disposed of directly into the deep sea, a process that can smother the seabed, and damage marine ecosystems if the waste resurfaces. Chinese companies in Indonesia initially wanted to use the same process but after government objections it looks more likely they will store their waste on land, using a so-called 'dry-stack tailings' process. Ningbo Lygend, a Chinese company that has built a nickel-processing plant in Indonesia for the EV battery market, recently warned in its application to list on the Hong Kong stock exchange that this would be more expensive." Ningbo Lygend Mining is the majority (54.9%) owner of PT HPL (see Table 1a; IndoPremier, 2024).

An additional complicating factor with HPAL tailings is that, due to their fine-grained nature and the complex chemistry that results from the reagents that are added to neutralize the tailings after acid leaching, the optimum water contents for maximum compaction are much higher than would be typical for hard-rock tailings. While a typical target geotechnical water content for filtered tailings is 15% (Klohn Crippen Berger, 2017; Crystal et al., 2018), target geotechnical water contents for filtered HPAL tailings are in the range 30-35% (SRK Consulting, 2022a; Lu, 2023; Souisa, 2023, Heyokha Brothers, 2024; Huayou Cobalt, 2023; Zhejiang Huayou Cobalt, 2024). Although filtered tailings should have no free water when they compacted in the filtered tailings stack, the weight of additional overlying tailings will cause the release of more water from the underlying tailings, which will need to be managed in order to avoid re-saturation of the tailings. According to a consulting report by Hatch (2020) for PT Halmahera Persada Lygend (HPL), "The filtered tailings as designed [have] 30% in place moisture content. Upon consolidation of the tailings with time, this will generate substantial quantity of water … This indicates that a system of internal drainage within the tailings stack will also be required in order to lower the groundwater table and reduce the risk of slope instability and liquefaction of the tailings."

A study that was carried out by Hatch for Prony Resources New Caledonia two years later found that current filter press technology was still unable to achieve the high optimum water contents that would be required for HPAL tailings that would be produced in the New Caledonia project. According to Bodley and Vaguener (2022), "During the feasibility level studies, a target OMC [Optimum Water Content] of 33%, corresponding with a residue cake solids content of 75% was defined. The filter press struggled to produce residue cake drier than 73% solids [corresponding to geotechnical water content of 37%]. The field trial indicated that the residue OMC was lower than that which could be reasonably produced from filtration alone … Moisture contents in the filter cake were measured on discharged samples from the DWP1 plant and were determined to be generally >3 % wet of the estimated target OMC tested during feasibility studies." Because current filter press technology cannot achieve the required geotechnical water contents, the tailings would need to be dried in the field prior to compaction. Bodley and Vaguener (2022) explained the difficulty, "This suggests that filtration alone was not able to meet the field requirement and the residue will require some conditioning in the field to achieve the higher compaction specification for structural materials. Conditioning the residue during the wet season is difficult due to the frequent and intense rainfall events." For clarification, in geotechnical engineering, the geotechnical water content is the mass of water divided by the mass of dry solids, while the solids content is the mass of solids divided by the total mass (solids + water). Thus, the solids content and geotechnical water content do not sum to 100%.

Because the HPAL tailings were still nearly saturated even after filtration, it was difficult to compact the tailings without expelling more water and even driving heavy equipment on the tailings for compaction was a challenge. According to Bodley and Vaguener (2022), "The field results show saturation levels ranging from 90 % to 95 %, whereas the line of optimums corresponds to a saturation level between 80 % to 85 %. This suggests a higher level of saturation than what was determined from the feasibility study residue cake testing campaign. Many of the samples tested show very high saturation levels, hence difficulty in field compaction was observed with pumping conditions in the wetter residue fill … Trafficability to and on the stack was impacted by wet ground conditions. This was particularly noticeable where the 30 t articulated dump trucks (ADTs) fitted with standard width tires drove over previous tracks and discrete rutting was observed … Under wet conditions the largest challenge was slippery conditions … Surface water management best practices were followed during filtered residue landform construction, however heavy rain events still severely affect productivity and materials placement quality. The filtered residue could not be compacted during or following such rainfall events (i.e. with typical threshold exceeding 10 mm per 24 hours)."

The only solutions that were proposed by Bodley and Vaguener (2022) were placing excessively wet tailings in non-critical areas of the filtered tailings storage facility and stockpiling tailings during excessively wet periods with compaction during the drier periods. According to Bodley and Vaguener (2022), "It is therefore critical that any filtered residue landform in such an environment comprise a non-structural or off specification zone whereby the 'wetter' cake produced during the wet season can be stored without a requirement for unnecessary double handling. Other options such as temporary wet weather stockpiling at the plant may be considered depending on space availability." The preceding solutions are, in fact, standard practice at nearly all filtered tailings storage facilities. Other than the above, the author is not aware of any technical publication that has proposed a solution to the problems of filtered tailings in tropical climates.

A great deal has been said about the amount of mine waste that is produced by HPAL technology. According to Sangadji and Ginting (2023), "It is estimated that every ton of nickel metal processed through HPAL produces 100 tons of residue." The addition of reagents to the ore and the production of reaction products leads to an increase in the mass of ore even after the commodity of value has been extracted. According to Hidayat et al. (2024), "Around 1.3 ton of tailing (dry basis) is generated for every ton of limonite [a type of laterite ore] processed." Fisher and Grossl (2023) summarized, "HPAL is notoriously famous for the quantum of the tailings due to its processing flowsheet. It typically generates 1.25x volume of the feedstock ore in the tailings. Using Huayue as an example, it produces approximately 70Ktpa Ni. Using 1% ore it would consume approximately 7Mt of limonite ore every year and the tailings generated would be approximately 8.75Mtpa," implying a waste to metal ratio of 125. The waste to metal ratio for HPAL processing will be re-calculated in the section "Summary of Filtered Tailings Storage Facilities in Indonesia" of this report.

In all fairness, it must be pointed out that HPAL processing of nickel ores actually produces less waste than hard-rock mining of nickel. On a global basis, the grades of mined nickel ores declined from 1.55% in 2001 to 0.94% in 2020, while recovery rates remained steady in the range 68-82% (Foss and Koelsch, 2022; see Fig. 5). By contrast, for the limonite layer of a laterite ore, nickel concentrations are in the range 0.8-1.5% (Gultom and Sianipar, 2020; see Fig. 6). The other factor is that the two major types of mine waste are tailings and waste rock, which is the rock that must be removed to reach the ore body. Considerable waste rock is produced by hard-rock nickel mining, especially in surface or open-pit mining, while the extraction of laterite ores involves the production of comparatively little waste rock or overburden, since the laterite ores tend to be at or just below the surface. According to Nassar et al. (2022a-b), global averages for nickel mining are the production of 1.36 tons of waste rock for every ton of ore, ore grade of 0.82%, concentrator recovery rate of 79%, and smelter/refinery recovery rate of 90%, for a waste to metal ratio of 230, or about twice the ratio for HPAL technology. The corresponding averages for global cobalt mining are the production of 2.12 tons of waste rock for every ton of ore, ore grade of 0.12%, concentrator recovery rate of 55%, and smelter/refinery recovery rate of 90%, for a waste to metal ratio of 859 (Nassar et al., 2022a-b). Thus, typical ore grades of hard-rock cobalt ores of 0.12% are similar to typical cobalt grades of the limonite layers of laterite ores of 0.15% (Gultom and Sianipar, 2020; see Fig. 6). However, as with nickel production, HPAL processing for cobalt produces about one-third of the mine waste as hard-rock cobalt mining because of the much greater amount of waste rock that is generated by hard-rock mining.

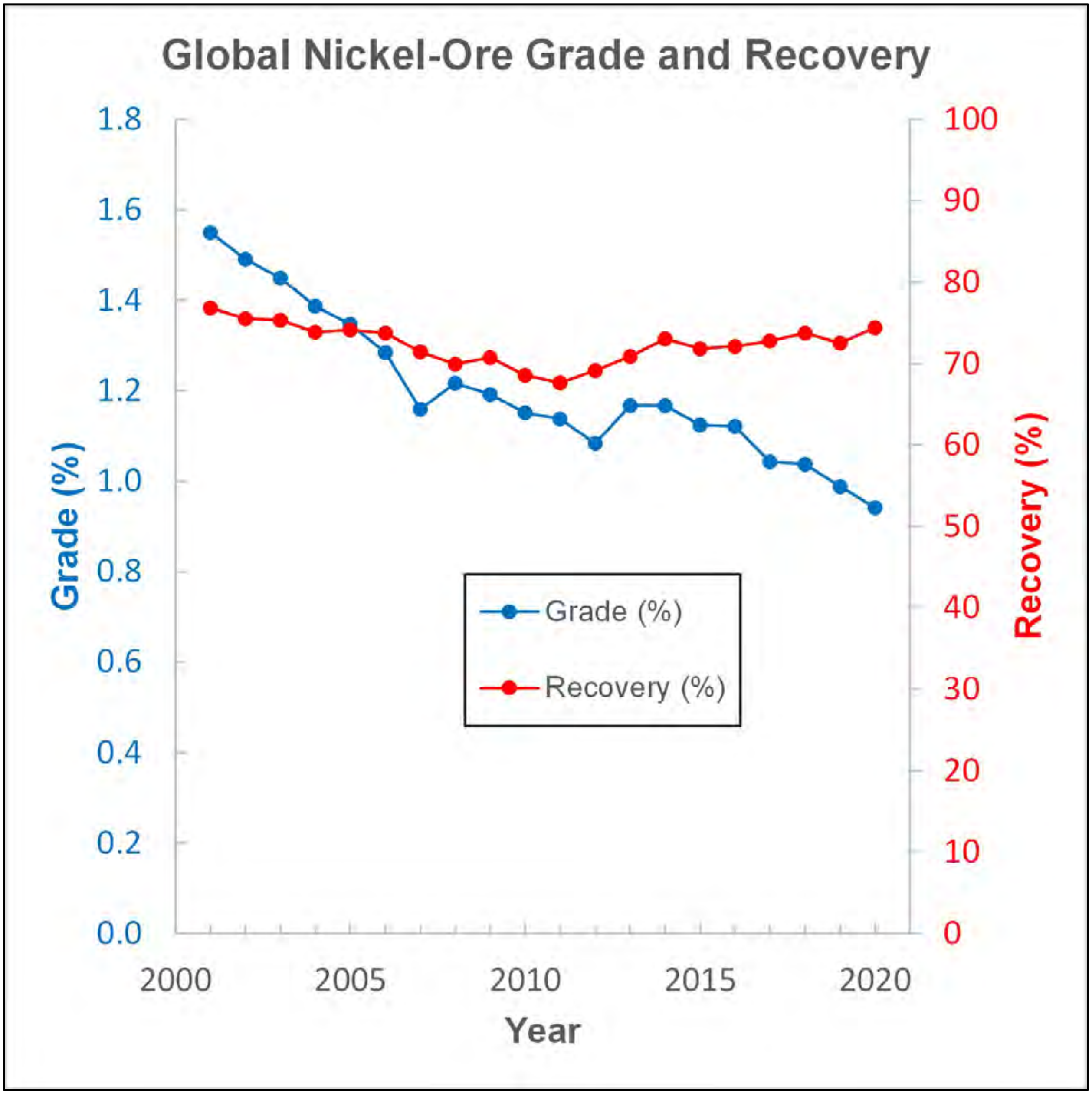

Figure 5. On a global basis, the grades of mined nickel ores declined from 1.55% in 2001 to 0.94% in 2020, while recovery rates remained steady in the range 68-82%. Data from Foss and Koelsch (2022).

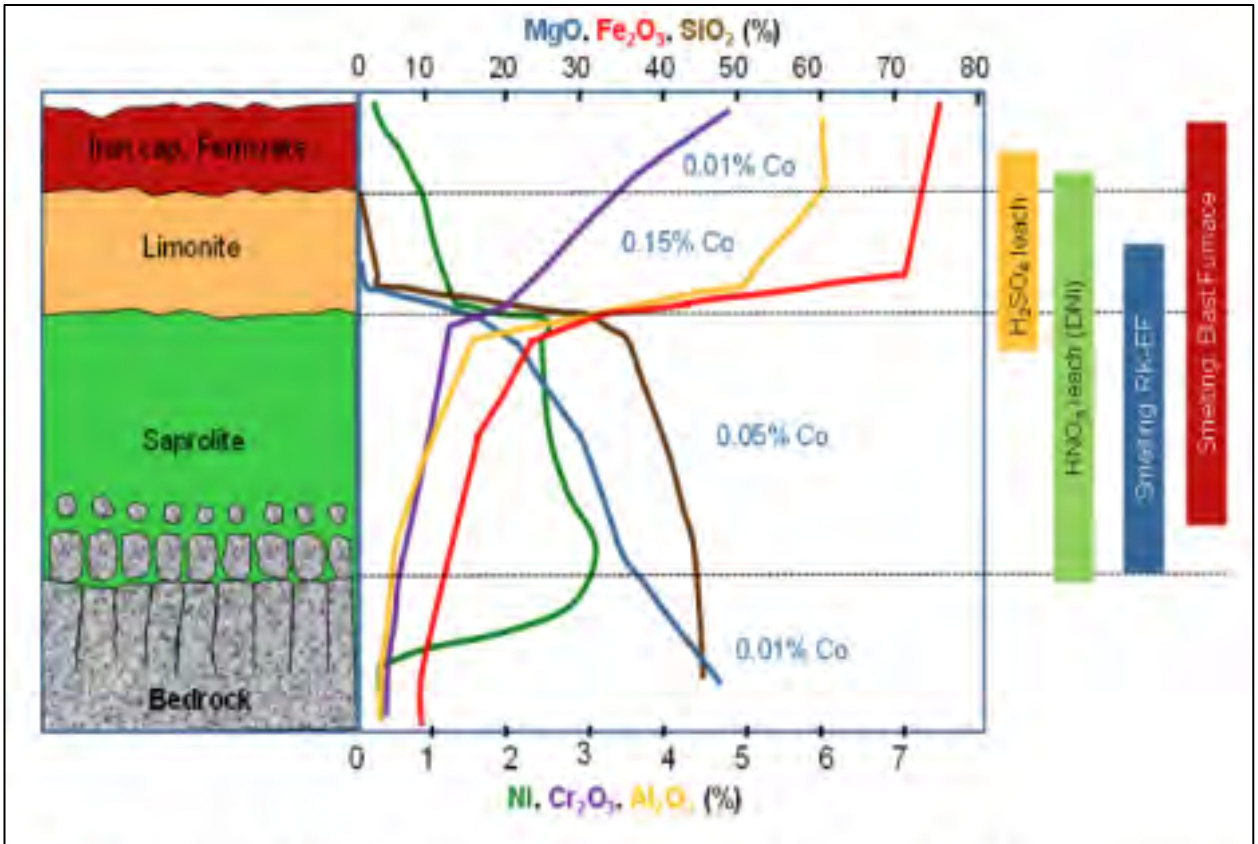

Figure 4. Nickel ore profile and character

Figure 6. For the limonite layer of a laterite ore, nickel concentrations are in the range 0.8-1.5%, while a typical cobalt concentration is 0.15%. Figure from Gultom and Sianipar (2020).

Despite the fact that no one has argued that HPAL tailings are ideal or even suitable for the application of filtered tailings technology, the combination of HPAL technology with filtered tailings technology combines two concepts:

1) A rapid expansion of nickel and cobalt production is needed for the global conversion from internal combustion to electric vehicles.
2) Filtered tailings technology is less environmentally destructive than the alternatives.

Thus, although it is rarely stated explicitly, the combination of HPAL technology with filtered tailings technology represents the complete "green" package. The connection was explicitly made by Heyokha Brothers (2024) in their article "The myths surrounding Indonesia's Nickel Revolution: Fact or fiction?" According to Heyokha Brothers (2024), "As Indonesia rises in the global nickel market, its strategic reserves and geographic advantages position it as a centre of the electric vehicle (EV) industry. By pioneering the development of an entire EV supply chain—from mines to EVs—Indonesia is embarking on an unprecedented initiative towards sustainable energy … Indonesia has taken a proactive stance in the last decade on embracing advanced technologies such as High-Pressure Acid Leach (HPAL), implementing stringent environmental regulations, and innovating greener waste management solutions … Indonesia has an abundance of limonite ores and stands to lead in greener initiatives with this method … HPAL technology has significantly enhanced waste management practices in Indonesia's nickel industry, setting new standards for environmental responsibility. The HPAL process generates tailings, which are primarily composed of iron and magnesium residues with about 35% moisture. These are treated and dry stacked to meet local government standards … Managing nickel processing waste as dry tailings rather than wet tailings offers considerable environmental benefits, as dry tailings are more stable, less risky for the environment, and use less water … Indonesia has become a stabilizing force that ensures economical and scalable battery materials, proving that economic development and environmental responsibility can indeed coexist and thrive together to achieve global energy transition targets and net zero goals."

A feature of late capitalism has been the appearance of disruptive technologies, which are innovations that are initially inferior or which target an underserved niche, but which rapidly replace existing technologies, often by offering some other advantage, such as convenience, affordability, or accessibility. An example is generative artificial intelligence, which is replacing original writing through advantages in speed and convenience, despite the inferior products that it produces. The motto "Move fast and break things" has been attributed to various disruptive technologies and their promoters, which captures the dual nature of creativity and acting without regard to consequences (Taplin, 2017). Related concepts, developed in the specific context of filtered tailings technology are "Reckless Creativity" (Emerman, 2021a-b; 2022a-b) and "Design Euphoria" (Riskope, 2022). According to Emerman (2021a, 2022b), Reckless Creativity has one or more of the following characteristics:

1) There is no scaffolding, meaning that the new innovation does not build upon previous innovations through a series of intermediate steps with proper testing and verification of each step.
2) One or more of the technologies required to carry out the innovation does not currently exist.
3) Predictions are based upon single input values or best-case scenarios without considering the range of possible inputs.
4) Although potential problems are recognized, they are quickly dismissed as irrelevant without justification.
5) Basic precautions are not taken that would be routine for previous innovations.
6) There is no consideration of the consequences of being wrong, that is, of the consequences of failure.

The thesis of this report is that the rapid explosion of the combination of high-pressure acid leaching and filtered tailings in Indonesia is both a disruptive technology and a catastrophic failure. The phrase "catastrophic failure" is used in the dual sense of the catastrophic failure of technology or a phenomenon and the catastrophic failure, that is, the physical collapse, of individual tailings storage facilities. "Failure" is also distinguished from "catastrophic failure," both in terms of the technology and an individual tailings storage facility. "Failure" is simply any non-fulfillment of the design objectives, while "catastrophic failure" refers to both the speed and the magnitude of the impacts of failure.

The distinction between failure and catastrophic failure is standard in guidance documents on tailings dam safety. According to FEMA (2004), "Any malfunction or abnormality outside the design assumptions and parameters which adversely affect a dam's primary function of impounding water is properly considered a failure. Such lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure." Although FEMA (2004) primarily deals with water-retention dams, the same document clarifies that "In addition to conventional structures, this definition of 'dam' specifically includes 'tailings dams,' embankments built by waste products disposal and retaining a disposal pond." ANCOLD (2012, 2019) defines "failure" as "the occurrence of an event outside the expectation of the design or facility licence conditions, that could range from the uncontrolled release of water including seepage, to a major instability of an embankment leading to loss of tailings and/or water." According to Canadian Dam Association (2021), "a tailings dam failure can generally be defined as the inability of the dam to meet its design intent, whether in terms of management, operational, structural, or environmental function, resulting in potential loss of life, loss to the stakeholders, or adverse environmental effects. For the purposes of this Bulletin [referring to catastrophic failure], a tailings dam failure is defined as a physical breach of the dam followed by uncontrolled and typically sudden and catastrophic release of any or all stored materials (e.g., fluids, tailings, sludge, etc.)." The FEMA Tailings Dam Safety Best Practices is the most explicit in defining "failure" as "the loss of function of a component, system, or process" and defining "catastrophic failure" as "the uncontrolled release of the contents of a tailings storage facility into the downstream environment that leads to significant damage in the downstream area, including potential life loss or other harm to humans, damage to the environmental, damage to property or infrastructure, or financial harm to the owner(s) of the facility and/or other stakeholders" (FEMA, 2025). Although not explicitly stated in any guidance document, any failure of a tailings storage facility that results in at least one fatality should be regarded as a "catastrophic failure," regardless of the quantity of water or tailings that were released.

The dual nature of catastrophic failures acting at high speed and with wide-ranging detrimental impacts is exemplified in Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022). According to Safety First, "This document outlines guidelines aimed at preventing catastrophic failures, defined as failures that constitute a rapid shock, and that happen without warning (even if they could have been foreseen)" (Morrill et al., 2022). Safety First also quotes the Global Industry Standard on Tailings Management (GISTM) (ICMM-UNEP-PRI, 2020) in defining a "catastrophic failure" as "a tailings facility failure that results in material disruption to social, environmental and local economic systems" and stating that "catastrophic events typically involve numerous adverse impacts, at different scales and over different timeframes, including loss of life, damage to physical infrastructure or natural assets, and disruption to lives, livelihoods, and social order."

To facilitate reading by non-specialists, the next section of this report is a tutorial on essential aspects of mining in the Indonesian context, including laterite ores and high-pressure acid leaching, liquefaction, alternatives for mine tailings disposal, filtered tailings technology, the limit equilibrium method and factor of safety, deterministic and statistical models for tailings facility failure analysis, acid mine drainage and metal leaching, Indonesian tailings regulations, and the guidance document Safety First: Guidelines for Responsible Mine Tailings Management. The tutorial is followed by a summary of filtered tailings storage facilities in Indonesia and then a discussion of these tailings facilities within the context of the current technological limits for filtered tailings. These general sections are followed by detailed analyses of the imminent catastrophic failure on Obi Island and the ongoing catastrophic failure in the Indonesia Morowali Industrial Park on Sulawesi Island. The report concludes with a review of the dangerous pathways ahead, the alternative pathway ahead, and specific recommendations for the Indonesian government.

TUTORIAL ON ESSENTIAL ASPECTS OF MINING IN INDONESIA

Laterite Ores and High-Pressure Acid Leaching

Laterites are cemented soils that are formed through prolonged chemical weathering of ultramafic bedrock in tropical and subtropical climates. Laterites are enriched in iron and aluminum due to the relative insolubility of those elements and the leaching of most other common elements in rocks and soils. When laterites are regarded as sources of nickel and cobalt, and sometimes iron and chromium, they are called laterite ores. The two principal types of laterite ores are limonite ores and saprolite ores. Limonite ores are more deeply weathered and form the upper part of the laterite profile, while saprolite ores are less weathered, form the lower part of the laterite profile, and gradually merge into the ultramafic bedrock (see Fig. 6). Typical nickel concentrations are 0.8-1.5% for limonite ores and 1.5-3% for saprolite ores.

Saprolite ores are processed using a rotary kiln electric surface (RKEF) in which iron and nickel are melted to form a ferronickel alloy. After removal of the slag, the resulting ferronickel can be used for stainless steel production. RKEF technology tends to work poorly on limonite ores, which have relatively high iron content and low nickel content. The innovation of high-pressure acid leaching (HPAL) is the ability to process limonite ores, which were formerly regarded simply as overburden on top of the richer saprolite ore, and which were disposed as a waste product. The HPAL technology can be used to process limonite ores for the production of mixed hydroxide precipitates of nickel and cobalt. Mixed hydroxide precipitates can be further processed to form nickel sulfate and cobalt sulfate, which are essential components of batteries for electric vehicles.

The HPAL processing of limonite ores can be summarized in the following steps (Gultom and Sianipar; 2020; Ribero et al., 2021):

1) The limonite ore is mixed with water to form a slurry with removal of coarser low-grade material.
2) The slurry is fed into an autoclave in which it is leached with sulfuric acid at temperatures of about 250°C and pressures up to 5000 kiloPascals.
3) The acid leaching separates the slurry into a pregnant leach solution that is enriched in nickel and cobalt and a solid barren leach residue, consisting largely of iron compounds, aluminum oxide, silica, and clay minerals.
4) Both the pregnant leach solution and the solid barren leach residue are neutralized with limestone. The barren leach residue plus reaction products from mixing with limestone are now tailings.
5) The pregnant leach solution goes through multiple stages called counter current decantation (CCD) to remove impurities through precipitation and increase the concentration of nickel and cobalt in the solution. The precipitated impurities are also tailings.
6) Additional limestone is added to neutralize the tailings, so that the reaction products increase the mass of tailings.
7) Additional processing converts the pregnant leach solution into solid mixed hydroxide precipitates of nickel and cobalt.

8) Additional processing can convert the mixed hydroxide precipitates of nickel and cobalt into the end products nickel sulfate and cobalt sulfate.

The alternatives for disposal of the tailings (barren leach residue, precipitates from refining of the pregnant leach solution, and reaction products from neutralization with limestone) are the subject of the next subsection.

Alternatives for Mine Tailings Disposal

The non-alternatives for the disposal of mine tailings are the discharge of tailings into the ocean or rivers. The disposal of mine tailings into the sea, rivers, lakes, or any natural water bodies should not be carried out under any circumstances (Morrill et al., 2022). Sangadji et al. (2019) is an excellent review of the dangers of deep sea tailings disposal in the Indonesian context and documents the prior destruction caused by deep sea tailings disposal in Indonesia. According to Sangadji et al. (2019), “Indonesia has itself experienced the horror of tailings disposal into the sea. For eight years, (1996–2004) PT Newmont Minahasa Raya dumped a total of four million tonnes of gold mine tailings at a depth of 82 m in Buyat Bay. The tailings pipe repeatedly leaked, causing damage to marine and coastal ecosystems including coral reefs.” It is noteworthy that even the mining industry has denounced the disposal of mine tailings into rivers and, at least, the shallow sea. According to the Responsible Gold Mining Principles, “We will not develop a new mine that would involve the use of riverine or shallow submarine tailings” (World Gold Council, 2019).

Of course, the ideal would always be the conversion of tailings into marketable products, so that, essentially, there would be no tailings (which are waste products by definition). The primary obstacle is that tailings cannot be marketable products unless they are non-toxic, non-metal leaching, and non-acid generating. The preceding concepts are discussed further in the subsection “Acid Mine Drainage and Metal Leaching.” The secondary obstacle is that, even when tailings have been shown to be non-harmful to the environment, the proposed products have largely been relatively low-value products, such as road aggregate and fertilizer. Thus, tailings could be sold as road aggregate or fertilizer only if there is a close-by market, so that shipping costs would be minimal.

The second ideal would be backfilling the tailings into the exhausted pits from where the ore was extracted. Tailings backfill is regarded as best practice under nearly all circumstances, except in cases where backfill would pose a greater threat of groundwater contamination than the construction of an aboveground tailings storage facility. Such circumstances might arise, for Example, if the pit were heavily fractured or permeable, while the tailings could potentially be moved to another location on top of an impermeable foundation. However, it is nearly always the case that only a fraction of the tailings can ever be backfilled. The most important factor limiting the fraction of tailings that can be returned to a depleted pit is the expansion (also called bulking) that occurs throughout all of the processes that are involved in the conversion of an ore body into a commodity of value (such as mixed hydroxide precipitates of nickel and cobalt) and tailings. In the case of HPAL projects, these processes largely include blasting, crushing (also called comminution), and mixing with water. The addition of reagents to neutralize acidity also creates solid reaction products that increase the total volume and mass of tailings.

In summary, the permanent aboveground storage of tailings on land is often the only workable alternative at the present time (see Fig. 7). Despite the fact that it is often the only workable alternative, aboveground tailings storage facilities create the permanent threats of catastrophic collapse of the facilities, as well as the contamination of groundwater and surface water by the tailings. Tailings are typically hydraulically discharged behind a dam that is constructed out of waste rock, the coarser fraction of tailings after suitable compaction, or earthfill or rockfill that is available on the mine site (see Figs. 8a-b). Tailings can be divided into two sizes with very different physical properties, which are the coarse tailings or sands (larger than 0.075 mm) and the fine tailings or slimes (smaller than 0.075 mm). The hydraulic discharge results in the separation of the sizes of tailings by gravity. The larger sands settle closer to the dam to form a beach. The smaller slimes and water travel farther from the dam to form a settling pond where the slimes slowly settle out of suspension. Typically, water is reclaimed from the settling pond and pumped back into the mining operation. The hydraulic discharge means that the tailings are too wet to be compacted in the tailings storage facility, the significance of which is discussed in the following subsection on "Liquefaction."

Figure 7. In conventional tailings management, wet tailings are permanently stored behind a dam constructed from waste rock, the coarser fraction of the tailings, or rockfill or earthfill that is available on the mine site. Photo of the Aguzadera dam at the Atalaya Mining Riotinto mine in Andalusia, Spain, taken by the author on June 19, 2019.

Figure 8a. A mixture of water and tailings with a solids content of 35% by mass is hydraulically discharged into the tailings pond from the crest of the Cobre dam at the Atalaya Mining Riotinto mine in Andalusia, Spain (see Fig. 7). Because of the lack of compaction, the loosely-packed tailings are susceptible to liquefaction (see Fig. 10). Photo taken by the author on June 21, 2019.

Figure 8b. A mixture of water and tailings with a solids content of 35% by mass is hydraulically discharged into the tailings pond from the crest of the Cobre dam at the Atalaya Mining Riotinto mine in Andalusia, Spain (see Fig. 7). Because of the lack of compaction, the loosely-packed tailings are susceptible to liquefaction (see Fig. 10). Photo taken by the author on June 21, 2019.

In conventional tailings management, the tailings are shipped to the tailings storage facility from the ore processing plant with no dewatering, so that the geotechnical water content of the tailings is in the range 150-400%, although it can be as low as 67%. High-density thickened or paste tailings technology dewaters the tailings to geotechnical water contents in the range 33-67% prior to export to the tailings storage facility, while filtered tailings technology dewaters the tailings to geotechnical water contents less than about 20%. Conventional tailings behave like a wet slurry, while high-density thickened or paste tailings behave like a paste (as the name implies), and filtered tailings behave like a moist soil. The boundaries between the different tailings technologies depend upon the physical and chemical properties of the tailings, and is defined by physical behavior, not geotechnical water content (Klohn Crippen Berger, 2017). The advantages and risks of filtered tailings technology are reviewed following the discussion of liquefaction.

Liquefaction

A mass of mine tailings consists of solid rock particles in which the pores between the particles are filled with a combination of air and water. From an engineering perspective, a mass of mine tailings is a type of soil. Of course, from an agricultural perspective, a soil should include organic matter and organisms and be able to support the growth of higher plants. However, these biological properties are not relevant for engineering purposes. An excellent reference for more complete information on the engineering properties of soils is Holtz et al. (2011). The phrases "soil" and "mass of tailings" will be used interchangeably in this subsection, which largely follows the presentation in Holtz et al. (2011).

A normal stress means any stress that is acting perpendicular to a surface (see Fig. 9). A normal stress acting on a soil can be partially counterbalanced by the water pressure within the pores. The effective stress is defined as the normal stress minus the pore water pressure. The effective stress is a measure of the extent to which the solid particles are interacting with or "touching" each other (see Fig. 9). The normal stress without subtracting the pore water pressure is also called the total stress.

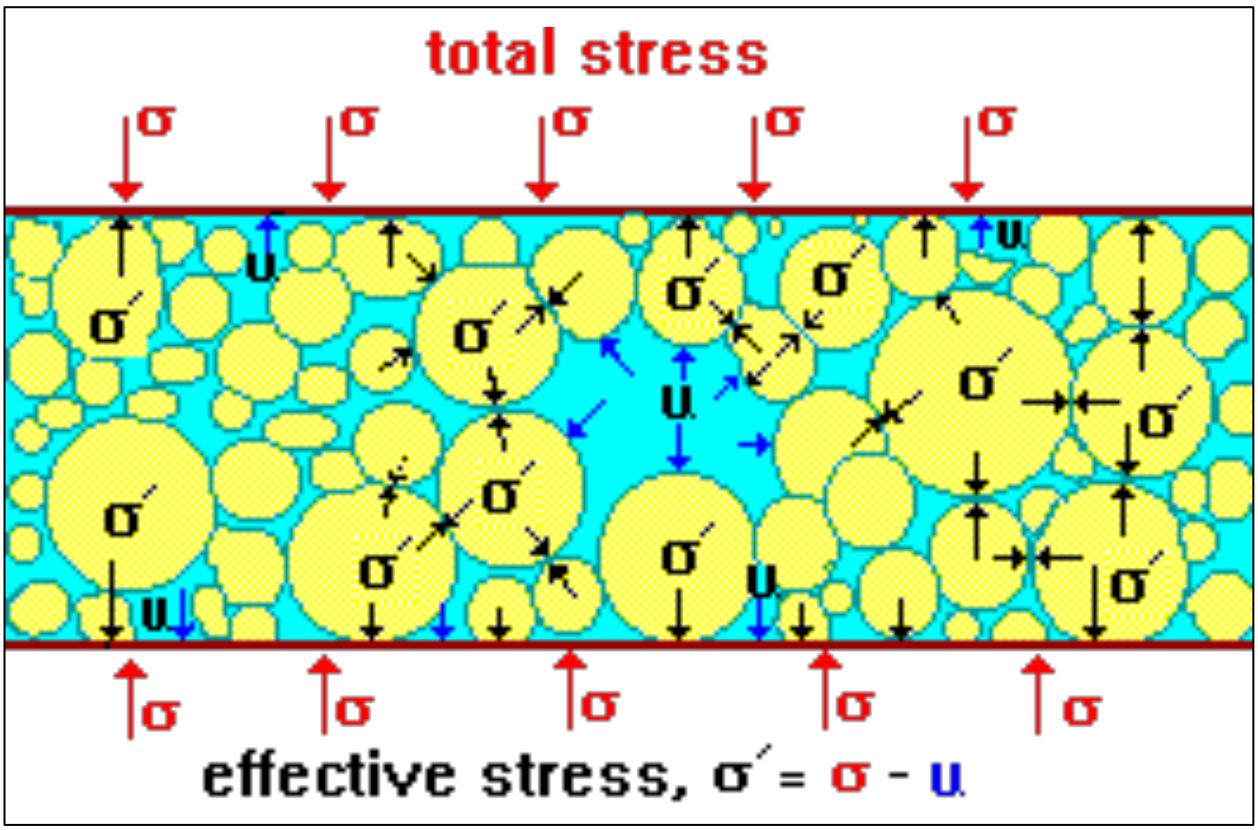

Figure 9. The effective stress in soil is equal to the total stress minus the pore water pressure. The effective stress is a measure of the extent to which the solid particles are interacting with or "touching" each other. Terzaghi's Principle states that the response of a soil mass to a change in stress is due exclusively to the change in effective stress. Figure from GeotechniCAL (2025).

Terzaghi's Principle states that the response of a soil mass to a change in stress is due exclusively to the change in effective stress (Holtz et al., 2011). For example, suppose that sediments are deposited on a river floodplain or tailings are hydraulically discharged into a tailings reservoir without compaction. The weight of the solid particles creates a normal stress, so that the particles will consolidate under their own weight. The amount and rate of consolidation is determined by the effective stress, that is, the extent to which the particles are interacting with one another. Sufficient water pressure can offset the normal stress, so that little consolidation could occur and at a slow rate.

The phenomenon of liquefaction, in which a soil loses its strength and behaves like a liquid, can be explained through an application of Terzaghi's Principle (see Fig. 10). In the diagram on the left-hand side of Fig. 10, although the solid particles are loosely packed and the pores are saturated with water, the particles touch each other. Because there is contact between the particles, the load (the weight of particles or other materials above the particles shown on the left-hand side of Fig. 10), is carried by the solid particles. The load is also partially borne by the water due to the water pressure. The term permeability refers to the ability of water to flow through the pores. A mix of coarse and fine particles will have low permeability because the finer particles will fill in the pores between the coarser particles and, thus, restrict the pore space for water flow.

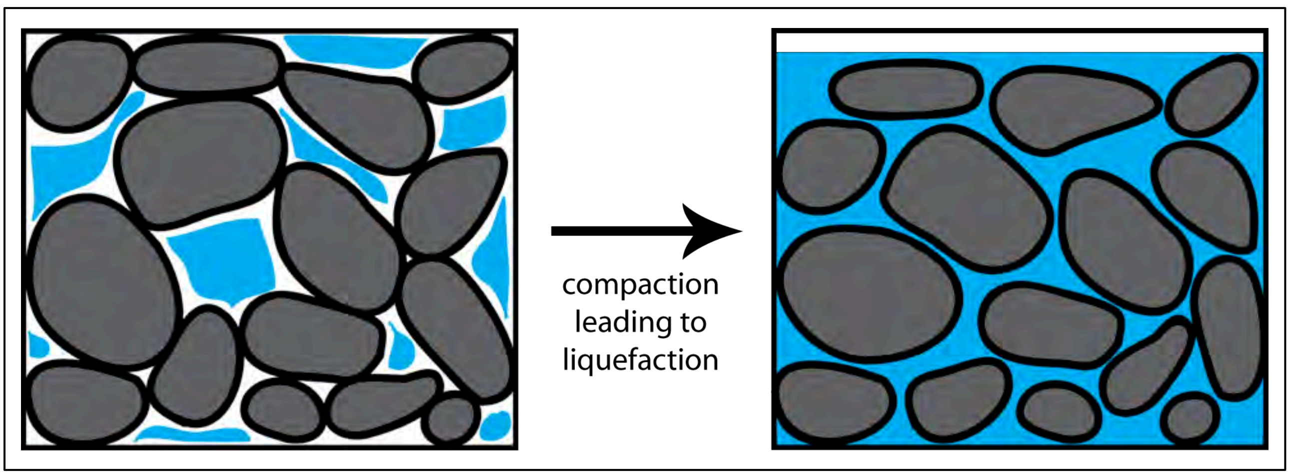

Figure 10. In the diagram on the left, although the solid particles are loosely packed and the pores are saturated with water, the particles touch each other, so that the load is supported by the particles (and partially by the water). Loose-packing means that the soil is in a contractive state, so that the solid particles will tend to compact to a more densely packed state following an increase in load or a disturbance (such as an earthquake). If the water cannot escape (due to low permeability or the speed of the disturbance), the solids cannot compact so that the additional stress is converted into an increase in pore water pressure (see the diagram on the right). The increased water pressure can decrease the effective stress almost to zero or to the point where the particles no longer "touch" each other (see Fig. 9). At this point, the soil mass has undergone liquefaction in which the water supports the entire load and the mass of particles and water behaves like a liquid. This phenomenon of liquefaction is promoted by saturated pores and loosely packed particles. Tailing deposits are especially susceptible to liquefaction because the tailings are very loosely packed due to the hydraulic discharge into the reservoir without compaction. If the pores are unsaturated prior to the disturbance, some compaction can occur (decreasing the size of the pores), so that the pores become saturated. Any further contractive behavior will then convert the additional stress into increased pore water pressure. On that basis, liquefaction is possible even if the pores are only 80% saturated. Figure from DoITPoMS (2025).

Loose-packing means that the soil is in a contractive (or contractile) state, so that the solid particles will tend to compact to a more densely packed state following an increase in load or a disturbance (such as an earthquake). If the water cannot escape (due to low permeability or the speed of the disturbance), the solids cannot compact so that the additional stress is converted into an increase in pore water pressure (see right-hand side of Fig. 10). The increased water pressure can decrease the effective stress almost to zero or to the point where the particles no longer "touch" each other (see Fig. 10). At this point, the soil mass has undergone liquefaction in which the water supports the entire load and the mass of particles and water behaves like a liquid. Another way to explain the same concept is that liquefaction is the phenomenon in which a mixture of solid particles and water undergoes a rapid and dramatic drop in shear strength from a peak strength (also called the yield strength) to a residual strength (also called the liquefied strength or the post-liquefaction strength) (see Fig. 11). Any drop in shear strength to zero is only temporary because once the mixture of solid particles and water starts flowing, there will be some interactions among the particles, which will give the mixture a small amount of shear strength.

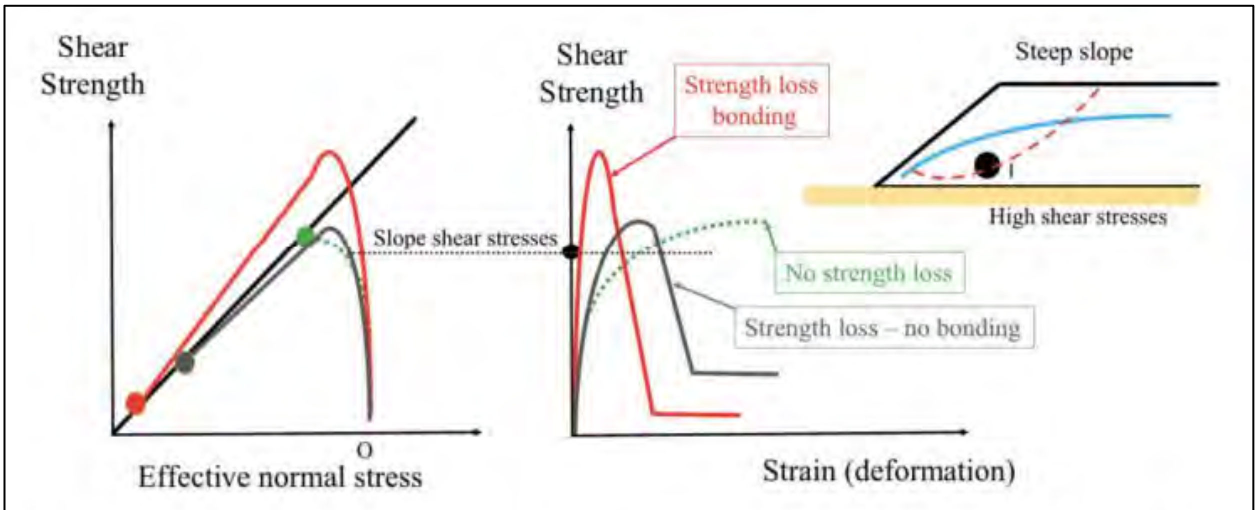

Figure 49: Schematic Comparison in Behavior Between Soil that has No Strength Loss, Soil with Strength Loss, and Either No Bonding or with Bonding

Figure 11. When a soil undergoes liquefaction, there is a dramatic drop in shear strength from a peak strength (also called a yield strength) to a residual strength (also called a liquefied strength or a post-liquefaction strength). The shear strength does not literally fall to zero (compare with Fig. 10) because, once the soil begins to flow, there will be some interactions between the solid particles, giving some shear strength to the mixture of water and solid particles. Figure from Robertson et al. (2019).

The phenomenon of liquefaction is promoted by saturated pores and loosely packed particles. Conventional tailings storage facilities are especially susceptible to liquefaction because the tailings are very loosely packed due to the hydraulic discharge into the tailings storage facility without compaction. If the pores are unsaturated prior to the disturbance, some compaction can occur (decreasing the size of the pores), so that the pores become saturated. Any further contractive behavior will then convert the additional stress into increased pore water pressure. On that basis, liquefaction is possible even if the pores are only 80% saturated.

There is a considerable literature on methods for evaluating the susceptibility of soil or tailings to liquefaction (Fell et al., 2015). For example, incomplete gravity separation during hydraulic discharge could lead to a mix of coarse and fine tailings, which could make the tailings more susceptible to liquefaction by reducing their permeability. On that basis, the particle-size distribution can be used as a preliminary screening tool to assess the potential for liquefaction. More sophisticated screening tools (Seed et al. 2003; Bray et al., 2004) involve empirical relationships between the plasticity index and the liquid limit or the ratio of the geotechnical water content to the liquid limit. The liquid limit is the geotechnical water content above which the mixture of water and solid particles behaves like a liquid, while the plastic limit is the geotechnical water content above which the mixture of water and solid particles behaves like a plastic. The plasticity index is the difference between the liquid limit and plastic limit, in which the limits are expressed as percentages.

Soil that is already in a densely packed state is said to be in a dilative (or dilatant) state, so that the solid particles will tend to expand following a disturbance. In this case, disturbance causes a strengthening, rather than a weakening of the soil, due to the resulting decrease in pore water pressure. A soil in which the particles will neither compact nor expand following a disturbance is said to be in the critical state. The basis of Critical State Soil Mechanics is the principle that, following a disturbance, all soils will tend to approach the critical state of packing, in which the critical void ratio (ratio of volume of pore space to volume of solid particles) depends upon the effective vertical stress.

Filtered Tailings Technology

Filtered tailings technology seeks to address two important problems in mining by partially dewatering the tailings before they are shipped to the tailings storage facility:

1) The water consumption can be reduced by recycling the water from the tailings back into the mining operation.
2) The likelihood of liquefaction of the tailings can be reduced by desaturating the tailings and then by compacting the tailings as they are stored in a filtered tailings storage facility.

Other advantages of filtered tailings technology are reducing the consequences of failure of the tailings storage facility, reducing the footprint of the tailings storage facility, and facilitating the safe closure of the facility (Klohn Crippen Berger, 2017).

Although the literature on HPAL projects in Indonesia repeatedly refer to “dry tailings,” “dry stacking,” and “dry stack tailings facilities,” this is non-standard terminology and should be avoided. The tailings are not literally dry and, if they were, it would be impossible to properly compact them for safe storage. On their website, the consulting company Knight-Piésold includes a publication by employees of Knight-Piésold that states, “Regarding terminology, the rather misleading term dry stack is generally not a good engineering term since the target moisture content coming from the filter plant is typically desired to be somewhere around the optimum moisture content based on the Proctor compaction procedure … Geotechnical engineers associate the optimum moisture content with moisture levels just below full saturation after compaction, thus terming such a facility as a dry stack is a misnomer. The present authors would encourage practitioners to abandon the use of the term dry stacking in favor of the more straightforward term, ‘filtered tailings.’ It is not desirable to unintentionally mislead the public at large with an industry term that is noticeably misused" (Ulrich and Coffin, 2017). With regard to the proposed Twin Metals mine in Minnesota (USA), for which the mineral lease has since been canceled, the Minnesota Department of Natural Resources (2021) asked, "Is characterizing the tailings filter cake as being 'dry' a common terminology for a product exhibiting a 13% to 16% moisture content?" The SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook confirms that "The term dry stacking … is somewhat of a misnomer. Stacked tailings must be sufficiently dry to allow placement in stable and trafficable piles, but not so dry as to result in dust generation from prevailing wind" (Reemeyer, 2022).

The critique of phrases such as "dry stack" is most complete in the guidance document Tailings Dam Safety Best Practices (FEMA, 2025). According to FEMA (2025), "Although frequently mislabeled as 'dry stacks,' filtered tailings usually contain a significant amount of water that may seep out of the stack over time as the height of fill and the resulting effective stress increases. If not managed correctly, including provisions for surface water control, lower portions of a filtered tailings stack can become saturated (or nearly saturated), and if the moist filter cake was not compacted to a sufficiently high density, then the materials may be subject to liquefaction and flow failure … Furthermore, most (if not all) existing filtered tailings facilities have experienced at least some difficulty achieving the target moisture contents at some time during their operation." In this report, the tailings will be referred to as "filtered" rather than "dry," except to quote from other sources or to refer to proper names.

A simple comparison of the water contents for the different categories of tailings (conventional, thickened, high-density thickened or paste, filtered) overstates the reduction in water consumption that can be achieved by the transition from conventional to filtered tailings technology. The reason is that, within the tailings storage facility, the solid tailings will settle out of suspension so that the supernatant water can be recycled back into the mining operation. For example, a typical mill will export to the tailings storage facility 70 tons of water for every 30 tons of solid tailings (see Fig. 12). In a typical conventional tailings storage facility, of those 70 tons of water, 7 tons of water will remain entrained within the tailings for a geotechnical water content of 23.3%, while 63 tons of water will be released at the tailings facility and recycled back into the mining operation (see Fig. 12). The progression from conventional to thickened to high-density thickened to paste tailings technology increases the proportion of water that is recycled through dewatering of the tailings prior to shipment to the tailings storage facility ("reclaimed during processing") and decreases the proportion of water that is recycled out of the tailings storage facility ("released at tailings facility") (see Fig. 12). However, the end result from a water consumption standpoint does not change, namely that typically, for every 30 tons of solid tailings, 7 tons of water remain permanently entrained within the tailings (see Fig. 12). The step change occurs in the transition to filtered tailings technology, in which, typically, no water can be recycled from the filtered tailings storage facility, while 5 tons of water remain entrained within the tailings for every 30 tons of solid tailings, for a geotechnical water content of 16.7% (see Fig. 12). In summary, the typical reduction in water consumption through the use of filtered tailings technology is 2 tons of water for every 30 tons of solid tailings, in comparison to any other tailings management technology (Klohn Crippen Berger, 2017).

An additional source of reduction in water consumption through filtered tailings technology is the reduction in evaporation through the elimination of a free water surface on top of the tailings. The evaporation from the tailings pond is highly variable and depends upon solar radiation, water temperature, and atmospheric factors, such as air temperature, relative humidity and wind speed, as well as the technologies that can be used to reduce evaporation. According to Spiller and Dunne (2017), “The amount of evaporation of water from the TSF [Tailings Storage Facility] may range from about 5% to more than 60% of the total water lost at a TSF.” On that basis, at the lower end of evaporation (5% of total water loss), for every 7 tons of water entrained within the tailings, another 0.4 tons of water will be lost to evaporation. At the higher end of evaporation (60% of total water loss), for every 7 tons of water entrained within the tailings, another 10.5 tons of water will be lost to evaporation. Thus, the reduction in water consumption through a conversion to filtered tailings technology could be as high as 12.5 tons of water for every 30 tons of tailings if the conversion occurred from an existing or planned facility with extremely high evaporation and no other technologies for reducing evaporation. On the other hand, the tailings pond can also be a source of water through the capture of precipitation and surface runoff (Klohn Crippen Berger, 2017). Most case studies regarding conversions to filtered tailings technology have not explicitly taken into account any reduction in water consumption through reduction in evaporation from the tailings pond (e.g., Gagnon and Lind, 2017; Moreno et al., 2018).

Figure 5.1 Comparison of Water Recovery for Tailings Technologies

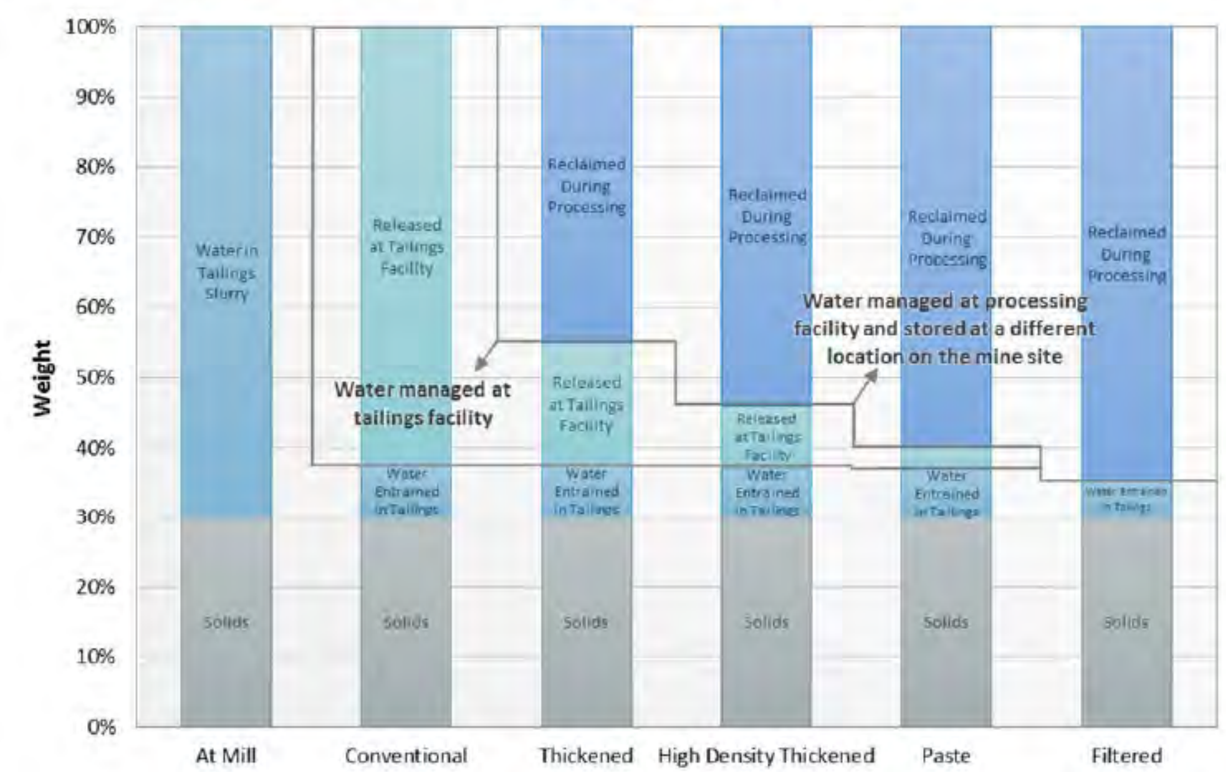

Figure 12. In conventional, thickened, high-density thickened, and paste tailings technology, for every 30 tons of solid tailings, the water entrained in the tailings has a mass of 7 tons. This entrained water is not released as the tailings settle out of suspension and is generally non-recoverable and, thus, a component of water consumption. In filtered tailings technology, for every 30 tons of solid tailings, the non-recoverable water entrained in the tailings has a mass of 5 tons. Therefore, the reduction in water consumption resulting from the use of filtered tailings technology is 2 tons of water for every 30 tons of tailings. Some additional reduction in water consumption could occur through reduction of evaporation at the tailings facility. Figure from Klohn Crippen Berger (2017).

Filtered tailings technology reduces the likelihood of liquefaction of the tailings stack through desaturating the pore spaces between the tailings, reducing the overall quantity of water in the tailings storage facility, and compacting the tailings within the tailings storage facility. This compaction reduces the likelihood of liquefaction by putting the tailings into a dilative (as opposed to contractive) state in which they will expand rather than consolidate when they are sheared or disturbed. Most typically, filtered tailings storage facilities are constructed with an outer shell of compacted tailings (sometimes called the "structural zone") surrounding an inner core of uncompacted or lightly compacted tailings (see Fig. 13). Although some recent mining project plans have claimed that filtered tailings do not require a dam, the structural zone fulfills the exact same function as a dam, that is, it is an engineered structure that prevents the flow of water or waste materials containing water. For example, with regard to its proposal for a copper mine in Minnesota, Twin Metals Minnesota (2022) wrote, "Dry stacking filtered tailings means there is no need for a dam – dam failure is impossible." The response from the Minnesota Department of Natural Resources (2021) was that a dam is a "structure that impounds water **and/or waste materials containing water**" (emphasis in the original). Klohn Crippen Berger (2017) has also emphasized that a filtered tailings facility "still requires 'structural zones' (which perform like dams), made of compacted tailings for confinement" and "if filtered tailings are placed in a stand-alone facility (pile/stack), the outer slopes must maintain structural stability (similar to a dam or a waste dump), particularly under seismic loading conditions." Finally, according to Safety First: Guidelines for Responsible Mine Tailings Management, "Because they [filtered tailings facilities] still require a structural zone (which is a type of dam) for containment, they must be treated as an engineered tailings facility (i.e. tailings dam) from a regulatory standpoint … The structural zone of a filtered tailings facility serves the same function as a dam" (Morrill et al., 2022).

Figure 3.5 Schematic of a Filtered Tailings Facility

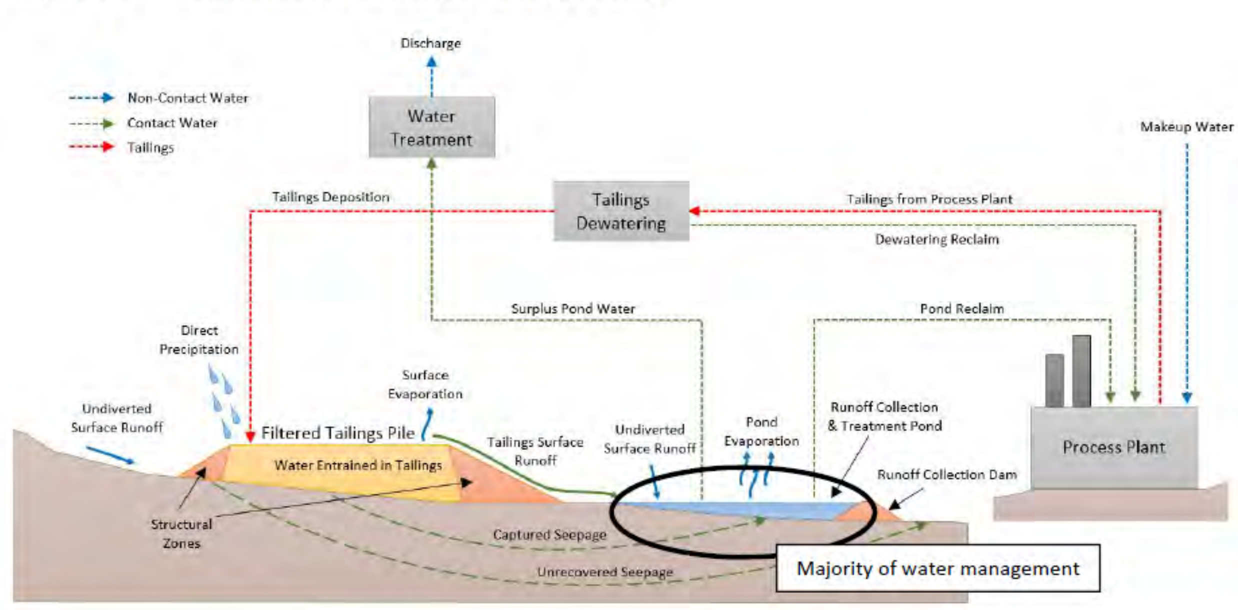

Figure 13. Current filter press technology does not consistently produce filtered tailings with the appropriate geotechnical water content for adequate compaction. Even if tailings do leave the filter presses with the appropriate water content, they can be rewetted by precipitation. The standard solution for filtered tailings stacks is to place the tailings that are too wet or too dry for adequate compaction in the center of the facility in a non-structural zone, in which the tailings are either uncompacted or lightly compacted. The tailings with the appropriate water content for adequate compaction are then placed on the periphery, where they can be compacted to form a structural zone. The structural zone serves the same function as a dam for the non-structural zone. Figure from Klohn Crippen Berger (2017).

Tailings Dam Safety Best Practices emphasized that the status of the structural zone as a dam is a function of the liquefaction potential of the filtered tailings. According to Tailings Dam Safety Best Practices, “A dam is defined herein as a constructed structure that retains contents that are potentially subject to flow. The contents may exist in a liquid, semi-solid, or solid phase but are subject to liquefaction (i.e., may revert to a liquid phase) under some type of loading condition. Thus, this guide may be applied to a filtered tailings facility if the tailings have the potential to flow” (FEMA, 2025). The document by FEMA (2025) continued, “Containment is generally achieved using outer structural zones of site borrow material, waste rock, or compacted filtered tailings (if adequate dewatering is achieved) … Filtered tailings facilities may include a containment structure that meets the definition of a dam … Inclusion of a containment structure is important to consider if the tailings have the potential to exhibit flow liquefaction due to higher moisture contents/degree of saturation resulting from wet weather conditions or inadequate dewatering from filtration, and/or if the degree of compaction is less than what is required to eliminate contractive behavior in the structural zones of the tailings stack.”

The inner core of a filtered tailings storage facility is, in fact, a requirement for the storage of tailings that left the filter presses with too much water for adequate compaction. Crystal et al. (2018) have emphasized that target water contents for filtered tailings are rarely achieved. According to Crystal et al. (2018), “Commonly, projects are specifying (or promising) a target filter-cake moisture at the limit of the filter performance (including at the limit of the thickener's ability to deliver feed at the required solids ratio). This has caused numerous examples where the operating performance does not consistently meet the target … Essentially, irrespective of site, ore body type, or filter press manufacturer, a 15% moisture content remains a typical target, while tracking of day-in and day-out moisture contents of filter cakes demonstrates that achievable moisture contents are often in the range of 17 to 18% when things are running smoothly and can be up to 20 to 23% when off-spec … 'Targets' may be cited or promised, but achievable filter cake moisture contents and the variability of the process are not generally within the tailings engineer's control." For example, Mexican gold and silver mines that use filtered tailings technology have achieved geotechnical water contents in the range 14-19% (Espinosa-Gomez et al., 2018). Cacciuttolo Vargas and Pérez Campomanes, 2022) list 28 filtered tailings storage facilities with geotechnical water contents ranging from 12 to 20%, although without clarifying whether these are target or achieved water contents. Even if the tailings leave the filter presses with the target geotechnical water content, they can still be rewetted by precipitation. Thus far, these filtered tailings storage facilities have mostly been small and mostly constructed in areas with arid climates (Klohn Crippen Berger, 2017). The partial restriction to arid regions has partly been motivated by the greater need to recycle water in regions with high water scarcity. However, an additional factor has been the challenges in achieving the appropriate water content for adequate compaction in wet climates. At the present time, the standard solution in both arid and wet climates is to set aside an inner core (a region away from the outer slopes) for placement of tailings that cannot be adequately compacted. Crystal et al. (2018) continue, "The tailings engineer can, however, specify acceptable moisture contents for different areas of the dry stack, depending on stacking strategies. For example, external structural zones may have more stringent criteria than non-structural zones, for which reduced constraints may be allowed."

It is noteworthy that the filtered tailings storage facilities in Indonesia are often referred to as "tailings dams." For example, according to Sangadji (2024), "In their official documents, both HNC [PT HYNC] and QMB state that they each generate 6.4 million tons of tailings per year … In 2023, around 12.5 million tons of waste containing iron and manganese were sent to storage facilities, which both companies refer to in their Environmental Impact Assessment documents as 'tailings dams.'" As a second example, the consulting reports for the filtered tailings storage facility at the PT HPL project on Obi Island refer to the study of the consequences of failure of the facility as a "dam break analysis" (PT Lapi ITB, 2020, 2022; SRK Consulting, 2022a).

Because of its ability to reduce both the likelihood and the consequences of failure of tailings storage facilities, filtered tailings technology is currently regarded as the best available technology. According to the expert panel report on the failure of the tailings storage facility at the Mount Polley mine, "BAT [Best Available Technology] has three components that derive from first principles of soil mechanics: 1. Eliminate surface water from the impoundment. 2. Promote unsaturated conditions in the tailings with drainage provisions. 3. Achieve dilatant conditions throughout the tailings deposit by compaction … Filtered tailings technology embodies all three BAT components … There are no overriding technical impediments to more widespread adoption of filtered tailings technology." The document Safety First: Guidelines for Responsible Mine Tailings Management also mandates "the use of Best Available Technology for tailings, in particular filtered tailings" (Morrill et al., 2022).

At the same time, it goes without saying that the use of filtered tailings technology cannot be a license for ignoring other aspects of safety. Even though Twin Metals Minnesota (2022) writes, "Dry stacking filtered tailings means there is no need for a dam – dam failure is impossible," failure is never impossible. In fact, the use of filtered tailings technology can lead to complacency from an illusion of safety. According to Oboni and Oboni (2020), "Dewatered tailings would tend to bring the probability of failure towards the bottom of the historical range, provided, of course the dewatering is effective, and does not generate excessive risk taking based on its promises." A related issue is the lack of guidance based on experience that always results from the adoption of a new technology. Again, according to Oboni and Oboni (2020), "The problem is that the possible alternatives to slurry deposition have not yet created the same body of knowledge that could support development of professional guidances and protocols of a quality equal to that for slurry deposition."

The strongest argument of all that failure of filtered tailings storage facilities is possible is that, aside from the failures in Indonesia that are documented in this report, at least three catastrophic failures of filtered tailings storage facilities occurred from 2022 to 2024. The first failure was the collapse of the 48-meter-high filtered tailings stack at the Pau Branco iron-ore mine owned by the French company Vallourec in Brazil on January 8, 2022 (see Fig. 14). The resulting slump buried Highway BR-40, but without any fatalities (see Figs. 15a-b). The second failure occurred on September 24, 2024, when the filtered tailings storage facility of the mining company Cuzcatlán SA de CV, a subsidiary of the Canadian company Fortuna Mining, in Oaxaca, Mexico, released contaminated water into the El Coyote river (Desinformémonos, 2024; EDUCA, 2024; see Fig. 16). The contamination extended to the drinking water well that supplies the communities of Magdalena Ocotlán and San Matías Chilazoa. A previous failure with release of contaminated water had reportedly occurred in 2018 (Desinformémonos, 2024). The third failure occurred on December 7, 2024, when a filtered tailings stack collapsed at the Turmalina gold mine again in Brazil, resulting in burial of part of the mining infrastructure, including the emergency escape exit, and the evacuation of 134 community members (Petley, 2024; see Fig. 17).

Figure 14. A 48-meter-high filtered tailings stack collapsed at the Pau Branco iron-ore mine in Brazil on January 8, 2022. Although filtered tailings are regarded as the Best Available Technology at the present time (Independent Expert Engineering Investigation and Review Panel, 2015; Morrill et al., 2022), the use of filtered tailings technology is not a license to ignore every other aspect of safety. Photo from Angelo (2022).

Figure 15a. Based on the highway width of 27 meters, the slump at the filtered tailings storage facility at the Pau Branco mine in Brazil on January 8, 2022 (see Fig. 14), extended for 104 meters past Highway BR-40. Highway width was measured from Google Earth image from June 29, 2022 (see Fig. 15b). Still image at 0:38 of drone video (Observatório da Mineração [Mining Observatory], 2022).

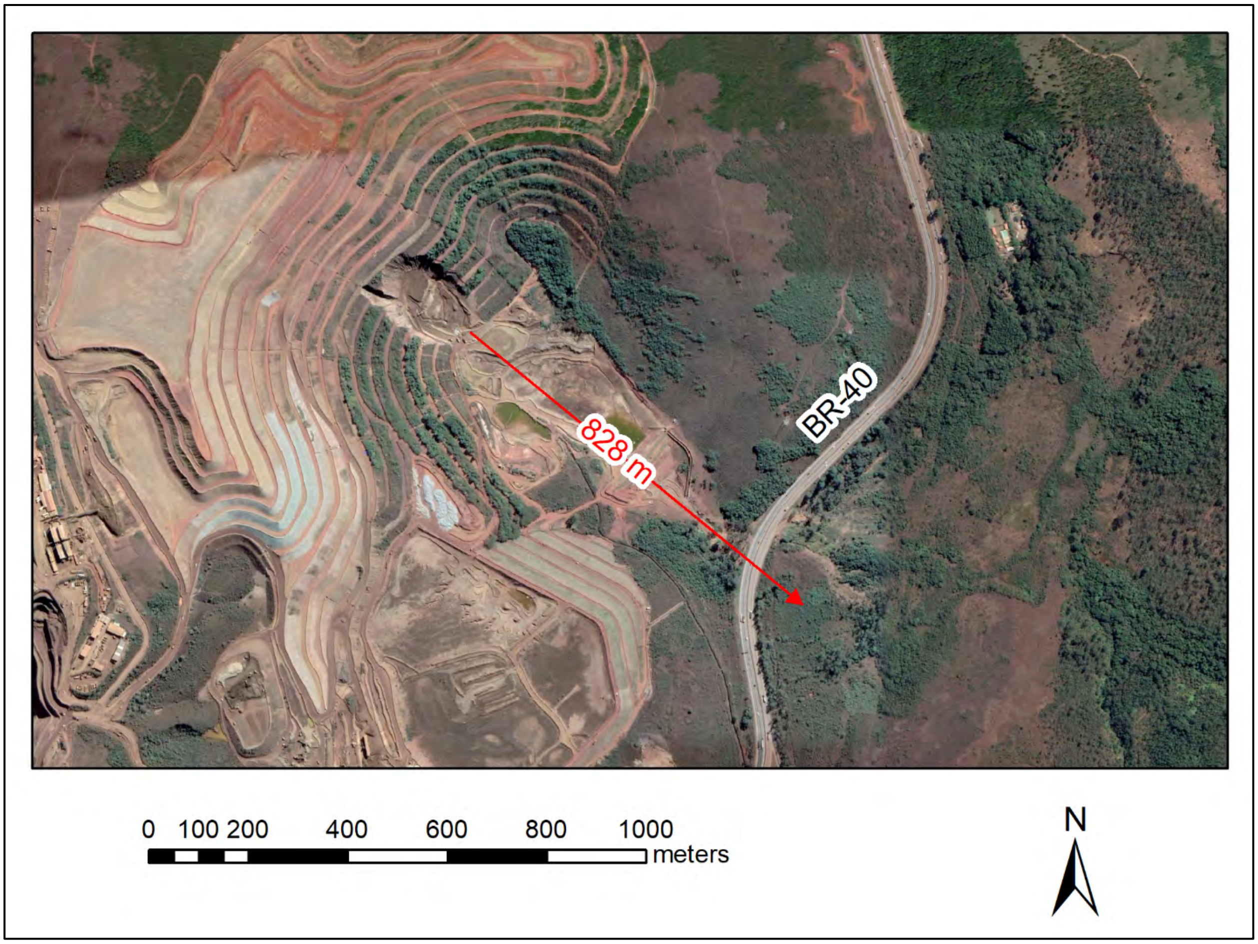

Figure 15b. The slump of the filtered tailings storage facility at the Pau Branco mine in Brazil on January 8, 2022 (see Fig. 14), extended for 828 meters past the toe of the facility or 17.25 times the height of the filtered tailings storage facility of 48 meters (Agência Nacional de Mineração [National Mining Agency], 2025). Background is Google Earth image from June 29, 2022.

A key issue is that, although filtered tailings may be unsaturated when deposited in the tailings storage facility, it is still necessary to prevent resaturation of the tailings in order to prevent future liquefaction. The problem is particularly acute since the target geotechnical water content for maximum compaction is typically only a few percentage points less than the saturated geotechnical water content. The pore spaces between the tailing particles can become resaturated simply by consolidation under the weight of additional overlying tailings, which reduces the volume of pores so that they become filled with water (Klohn Crippen Berger, 2017). In fact, it is not unusual for the lower one-third to one-half of a filtered tailings stack to be saturated. Water can also enter the filtered tailings storage facility through surface runoff, upward groundwater seepage, and direct precipitation onto the tailings. The above water sources require diversion canals that isolate the tailings storage facility from the rest of the watershed and appropriate drainage infrastructure for conveying any excess water out of the tailings.

Figure 16. On September 24, 2024, a failure of the filtered tailings storage facility of the mining company Cuzcatlán SA de CV, a subsidiary of the Canadian company Fortuna Mining, in Oaxaca, Mexico, released contaminated water into the El Coyote river. The contamination extended to the drinking water well that supplies the communities of Magdalena Ocotlán and San Matías Chilazoa. A previous failure with release of contaminated water had occurred in 2018. Photo from Desinformémonos (2024).

The aftermath of the 7 December 2024 Turmalina Mine landslide in Brazil. Image posted to LinkedIn by Walinton Sousa.

Figure 17. A filtered tailings stack collapsed at the Turmalina gold mine in Brazil on December 7, 2024, resulting in burial of part of the mining infrastructure, including the emergency escape exit, and the evacuation of 134 community members. Although filtered tailings are regarded as the Best Available Technology at the present time (Independent Expert Engineering Investigation and Review Panel, 2015; Morrill et al., 2022), the use of filtered tailings technology is not a license to ignore every other aspect of safety. Based on a height of 19 meters (Agência Nacional de Mineração, 2025) and runout of 400 meters, the tailings slump extended for 21 times the height, which is similar to the height-runout relation for the collapse at the Pau Branco mine (see Figs. 15a-b). Photo from Petley (2024).

It is important to point out that filtered tailings storage facilities have other possible failure mechanisms besides liquefaction. For example, surface runoff flowing over the structural zone could erode it away, thus exposing the uncompacted tailings that were behind the structural zone (see Fig. 13). Uneven settlement or failure of the foundation beneath the filtered tailings storage facility could cause failure of the entire structure. Finally, the structural zone (dam) could fail simply by sliding with no liquefaction or other flow behavior. According to Klohn Crippen Berger (2017), due to the typical low water content of filtered tailings, “Failure, if it occurs, would likely be local slumping and consequences would be restricted to the local area (or the distance equivalent to roughly 10 times the height [of the tailings dam]) … ” On the other hand, flow behavior of the tailings could develop if the tailings mixed with sufficient water after dam failure. The above quote continues, “ … unless the material slumps into a water body … When large water ponds are located downstream of high-density thickened/paste facilities, cascading failures are possible and should be accounted for when developing the risk profile of tailings failure management” (Klohn Crippen Berger, 2017). On the above basis, drainage and runoff collection ponds should be located sufficiently far downstream from the tailings storage facility and excessive accumulation of water in these ponds should be avoided (Klohn Crippen Berger, 2017; see Fig. 13).

The estimate of a runout distance for slumping of filtered tailings by Klohn Crippen Berger (2017) was not based on any specified dataset and it preceded the failures of filtered tailings storage facilities in Brazil (Pau Branco mine in 2022 and Turmalina mine in 2024) for which the runout distances could be measured. In fact, the failures of filtered tailings storage facilities in Brazil in 2022 and 2024 make it possible to estimate the slumping distance of a filtered tailings stack based on empirical data. Based on a width of Highway BR-40 of 27 meters (measured from Google Earth imagery from June 29, 2022), drone imagery obtained after the failure of the filtered tailings storage facility at the Pau Branco mine (Observatório da Mineração [Mining Observatory], 2022) shows that the slump extended 104 meters past the highway (see Fig. 15a). Thus, the slump extended for 828 meters past the toe of the filtered tailings storage facility (see Fig. 15c), or 17.25 times the stack height of 48 meters (Agência Nacional de Mineração [National Mining Agency], 2025). For the failure of the filtered tailings storage facility at the Turmalina mine, Petley (2024) used drone imagery to show that the slump extended for 400 meters past the toe of the facility (see Fig. 17). Thus, based on a stack height of 19 meters (Agência Nacional de Mineração, 2025), the slump extended for 21 times the stack height. In summary, the expected distance of solid slumping from a filtered tailings storage facility, without liquefaction of the tailings, is about 20 times the height. An important point is that, if solid slumping carries the released tailings into a body of water, the mixture of tailings and water could then develop into a fully liquefied mass, even if no initial liquefaction accompanied the solid slumping.

Limit Equilibrium Method and Factor of Safety

The limit equilibrium method evaluates the stability of a mass of rock or soil by assessing the tendency of a slope or structure to fail by one rigid block sliding over another (see Fig. 18). The output of the limit equilibrium method is the factor of safety, which is the ratio of the resistance to the load, or the ratio of the shear strength to the shear stress. Thus, a factor of safety equal to 1.0 indicates a slope on the cusp of failure, while higher factors of safety indicate slopes with increasing stability. The limitation of the limit equilibrium method is that not all failures involve the sliding of one rigid block over another. For example, the limit equilibrium method does not assess the tendency of a slope to fail by slow creep that could accelerate into more rapid motion, by rockfall, or by structurally-controlled failures along pre-existing joints or faults. In summary, the limit equilibrium method is a useful starting point, but should not be the totality of a slope stability analysis.

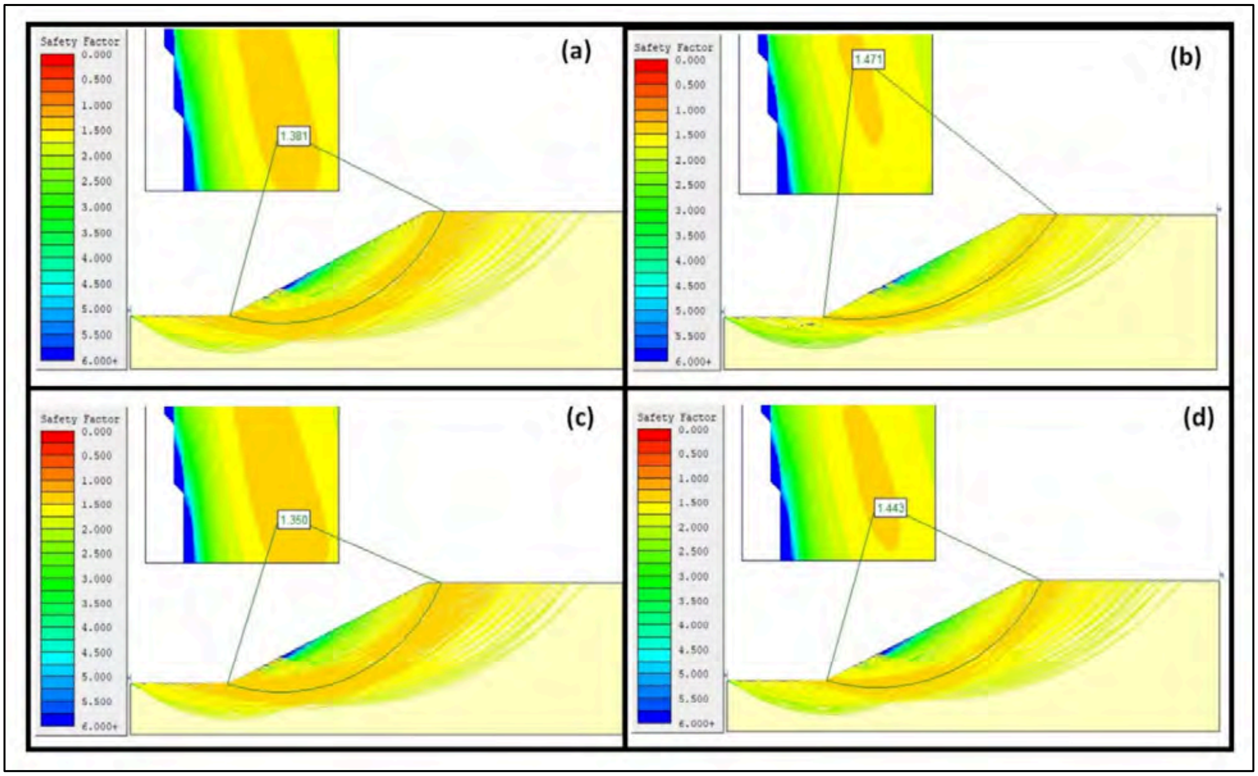

Figure 18. The factor of safety is the ratio of the shear strength to the shear stress (ratio of the resistance to the load) at some point within a slope, embankment or other type of earthen structure. The limit equilibrium method uses the unit weight, the shear strength parameters (cohesion and friction angle), pore water pressure, and position of the water table to calculate the factor of safety as averaged along every possible failure surface. The failure surface with the minimum factor of safety is called the critical failure surface. The factor of safety of the critical failure surface is regarded as the factor of safety of the structure. A factor of safety equal to 1.0 indicates that a structure is on the cusp of failure or, more precisely, that the probability of failure is 50%. Figure from Sengani and Allopi (2022).

The input data for the limit equilibrium method are the topography (geometry), the unit weights (densities), shear stress parameters (cohesion and friction angle), and pore water pressures throughout the slope or structure and its foundation, as well as the position of the water table. The precise meanings of cohesion and friction angle are not necessary for this report, except that higher cohesion and higher friction angle correspond to greater shear strength. Materials that are saturated (below the water table) have lower shear strength and materials that are over-pressurized with water have even lower shear strengths. The limit equilibrium method considers all possible failure surfaces and calculates the factor of safety at each point along a possible failure surface (see Fig. 18). The factor of safety of a failure surface is the average of the factors of safety along every point of a surface. The failure surface with the lowest factor of safety is called the critical failure surface and the factor of safety of the critical failure surface is regarded as the factor of safety of the slope or structure (see Fig. 18). Factors of safety can be calculated both for static loading (resulting in a static factor of safety) and loading in response to an earthquake (resulting in a pseudostatic factor of safety). The response of a structure to an earthquake is simulated by a pseudostatic analysis in which the earthquake is simulated by a horizontal force equal to the design seismic acceleration times the mass of the structure times a seismic coefficient (which accounts for the reduction in acceleration that occurs when seismic waves interact with materials softer than bedrock).

It cannot be overemphasized that a factor of safety is not a measurement that is made, but the outcome of a model that depends upon a wide range of measurements, estimates and assumptions. There can be considerable uncertainty in the factor of safety as a result of uncertainty in the measurements of the input data and the incomplete sampling of structures for which the geotechnical parameters can have considerable spatial variability. There are also multiple computational methods for carrying out the limit equilibrium method for a given set of input data, each with its advantages and disadvantages, so that there is uncertainty as to whether the correct computational method has been used (Fell et al., 2015). As a consequence of the uncertainty in the data and the computational method, the calculated factor of safety cannot be assumed to be the same as the true factor of safety.

A slope should be stable as long as the true factor of safety is greater than 1.0, although it should be kept in mind that the limit equilibrium method and its resulting factor of safety are evaluating only a narrow class of types of slope failures. However, because of the uncertainty in the calculated factor of safety, the engineering practice is to require a calculated factor of safety significantly greater than 1.0 in order to ensure that the true factor of safety (which could be less than the calculated factor of safety) is actually greater than 1.0. There are numerous publications, industry guidance documents, and regulations regarding the appropriate minimum factor of safety. These minimum factors of safety depend upon the application and the context, but a minimum factor of safety of 1.5 is common for many geotechnical applications (ANCOLD, 2012, 2019; Fell et al., 2015).

Deterministic vs. Statistical Models for Tailings Facility Failure Analysis

The use of deterministic models for tailings storage facility failure analysis using software such as HEC-RAS or FLO-2D is now well-established in the mining industry (Canadian Dam Association, 2021; Clohan and Kidner, 2022). These deterministic models can produce very detailed predictions, such as flow depths, flow velocities, and the arrival times of the tailings flood. The disadvantage of these deterministic methods is that they require a very large number of input parameters, including detailed topography, the details of the facility breach (such as the dimensions and rate of growth of the breach), the roughness of the stream bed, and the rheology (flow behavior) of the tailings. Many of these parameters are poorly known, especially the rheology, so that they could be subject to manipulation, which could be intentional or unintentional.

The standard method in engineering for building confidence in models that are based on a very large number of parameters, some of which are poorly known, is to validate and then calibrate the model. Model validation refers to the comparison of model predictions with observations. For example, a city might have a model for its stormwater management system. The model should make predictions regarding, for example, the flow velocities or flow depths in some stormwater channel, during a particular precipitation event that can also be observed. If the predictions are completely different from what is observed during that particular precipitation event, then the model needs to be completely re-considered. However, most typically, the predictions are somewhat close to, but not exactly the same, as the observations. In that case, the model is calibrated, meaning that the most poorly-known parameters are adjusted until the predictions match the observations. In the ideal circumstances, these types of deterministic models are continually updated through calibration as more observations become available that can be compared with predictions.

The problem with deterministic models for tailings storage facility failure analyses is that the models are apparently never calibrated. Such models could be calibrated only if a minor failure had already occurred for a particular tailings storage facility and the observations from that minor failure were being used to calibrate a model for a future major failure. The author is not aware of any deterministic model that has ever been calibrated under the preceding circumstances. Thus, in all cases, deterministic models for tailings storage facility failures are uncalibrated because there are no observations (no flow depths, flow velocities or tailings flood arrival times) to compare with predictions. In other words, deterministic tailings storage facility failure analyses should have a low level of confidence almost by definition.

An alternative to the reliance on deterministic models with their intensive input parameters is the use of statistical models (also called empirical models) developed from past tailings storage facility failures. A disadvantage of the statistical or empirical method is that it typically provides only the spill volume and the runout distance, in place of the two-dimensional detail of flow depths, flow velocities, and arrival times of the tailings flood that is provided by a deterministic model. Another disadvantage is that the statistical method takes into account only the tailings facility height and storage volume and no other characteristics of the tailings storage facility, the tailings, or the downstream topography (although those characteristics can be poorly known). The best approach is usually a comparison of the results of a statistical model and a deterministic model. If a deterministic model makes predictions that are very different from a statistical model, the deterministic model should be viewed with great suspicion. If a deterministic model makes predictions that are roughly consistent with past tailings storage facility failures, then it is appropriate to use the deterministic model to make predictions that are more detailed than can be obtained from statistical models.

The most recent and comprehensive statistical model for tailings storage facility failure analysis was developed by Larrauri and Lall (2018). The statistical model predicts release volume and the initial runout of tailings following facility 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 storage facility. 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, it can be difficult to separate the initial runout from the subsequent normal fluvial processes. For example, the failure of the tailings storage facility 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).

Although there are numerous examples of tailings storage facility failures, with 368 documented failures in the database in Center for Science in Public Participation (2024), Larrauri and Lall (2018) located only 28 with sufficient information for the development of a statistical model (see Table 3). (The numbering system in Table 3 follows 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

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

where H is the height of the facility (meters), V_T is the total volume of confined tailings and water (millions of cubic meters), and V_F is the volume of the spill (millions of cubic meters). Based on the 28 examples, the most-likely predictions for the volume of the spill and the initial runout D_{max} (kilometers) are (see Figs. 19a-b)

$$V_F = 0.332 \times V_T^{0.96} \quad (2)$$

$$D_{max} = 3.01 \times H_f^{0.551} \quad (3)$$

Table 3. Empirical measurements of past tailings storage facility failures: Release volume and runout

No.	Mine	Year	Dam Height (m)	Storage Volume (Mm^3)	Release Volume (Mm^3)	Runout (km)
	Dataset of Larrauri and Lall (2018)					
1	(unidentified), Southwestern USA	1973	43	0.5	0.17	25
2	Aitik mine, Sweden (Boliden Ltd.)	2000	15	15	1.8	5.2
4	Bafokeng, South Africa	1974	20	13	3	45
5	Balka Chuficheva, Russia	1981	25	27	3.5	1.3
6	Bellavista, Chile	1965	20	0.45	0.07	0.8
7	Bonsal, North Carolina, USA	1985	6	0.038	0.011	0.8
8	Cerro Negro No. (3 of 5)	1965	20	0.5	0.085	5
9	Cerro Negro No. (4 of 5)	1985	40	2	0.5	8
10	Churchrock, New Mexico, United Nuclear	1979	11	0.37	0.37	110
11	Cities Service, Fort Meade, Florida	1971	15	12.34	9	120
12	Deneen Mica Yancey County, North Carolina, USA	1974	18	0.3	0.038	0.03
13	El Cobre New Dam	1965	19	0.35	0.35	12
14	El Cobre Old Dam	1965	35	4.25	1.9	12
15	Fundão-Santarem, Minas Gerais, Brazil (Samarco)	2015	90	55	32	637
18	Hokkaido, Japan	1968	12	0.3	0.09	0.15
19	Imperial Metals, Mount Polley, British Columbia, Canada	2014	40	74	23.6	7
22	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	27	15	6.8	41
23	Los Maquis No. 3	1965	15	0.043	0.021	5
24	Merriespruit, South Africa (Harmony)-No. 4A Tailings Complex	1994	31	7.04	0.6	4
25	Mochikoshi No. 1, Japan (1 of 2)	1978	28	0.48	0.08	8
27	Olinghouse, Nevada, USA	1985	5	0.12	0.025	1.5

28	Omai Mine, No. 1, 2, Guyana (Cambior)	1995	44	5.25	4.2	80
29	Prestavel Mine-Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	29.5	0.3	0.2	8
30	Sgurigrad, Bulgaria	1996	45	1.52	0.22	6
31	Stancil, Maryland, USA	1989	9	0.074	0.038	0.1
32	Taoshi, Linfen City, Shanxi province, China (Tahsan Mining Co.)	2008	50.7	0.29	0.19	2.5
34	Tyrone, New Mexico (Phelps Dodge)	1980	66	2.5	2	8
35	Veta de Agua (Chile)	1985	24	0.7	0.28	5
	Additional Data Points[1]					
	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	87	12	9.57	600
	Hector Mine Pit Pond, Minnesota, USA	2018	17	0.185	0.123	
	Dahegou Village, Luoyang, Henan Province, China (Luoyang Xiangjiang Wanji Aluminium Co., Ltd.)	2016	45	2	2	2

[1]Center for Science in Public Participation (2024)

The most recent tailings storage facility failure in the database used by Larrauri and Lall (2018) was the failure at the Samarco mine in November 2015 (see Table 3). The database in Center for Science in Public Participation (2024) lists three later tailings storage facility failures for which the facility height, storage volume, and release volume are known, including two for which the runout is also known (see Table 3). The additional data points adjust Eqs. (2)-(3) to yield (see Figs. 19a-b)

$$V_F = 0.361 \times V_T^{0.97} \tag{4}$$

$$D_{max} = 2.89 \times H_f^{0.551} \tag{5}$$

Thus, the addition of new data slightly increases the expected release volume for a given storage volume (see Fig. 19a) and slightly decreases the expected runout for a given dam factor (see Fig. 19b).

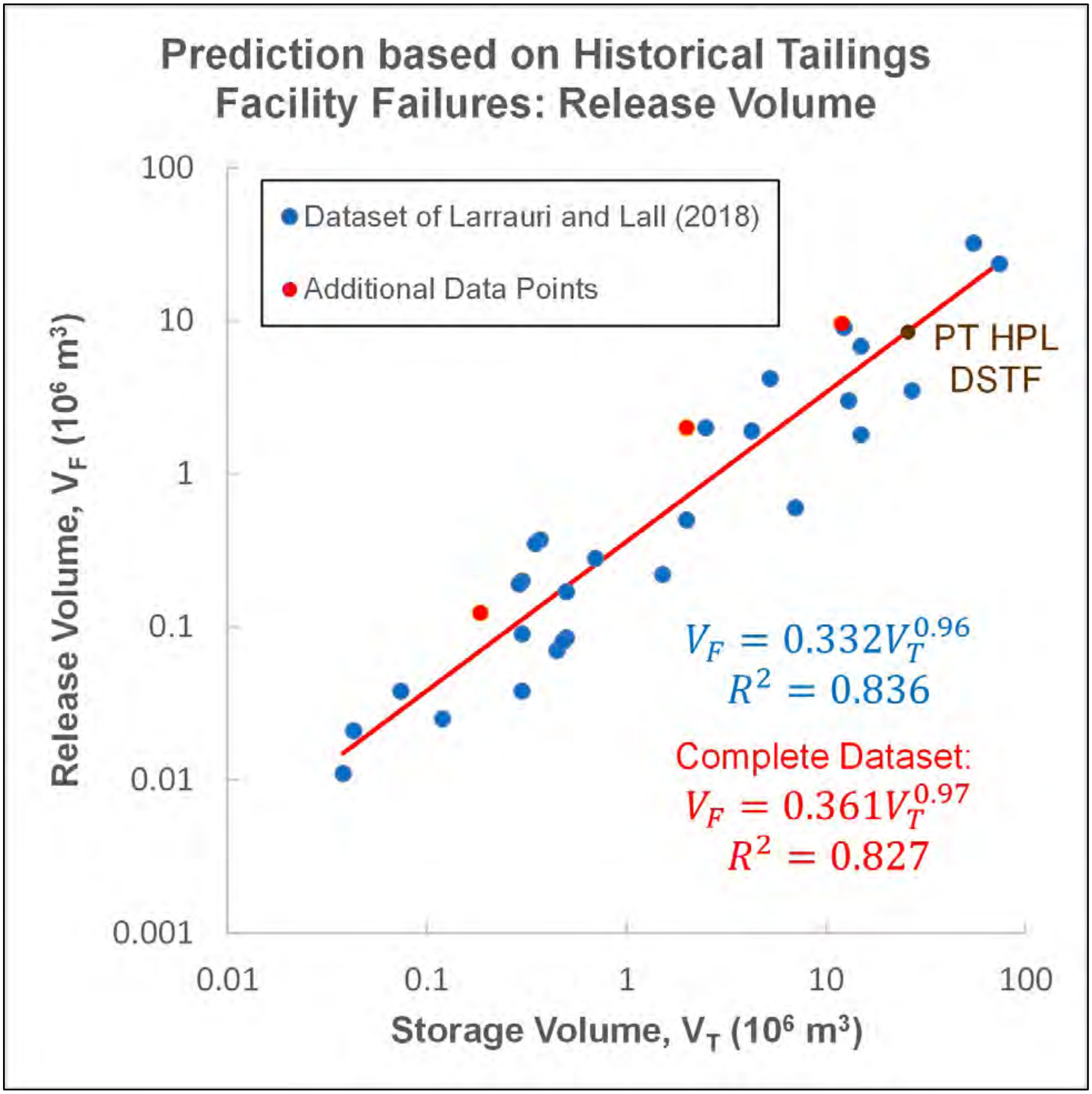

Figure 19a. Larrauri and Lall (2018) found a strong relationship between the storage volume and release volume for past tailings facility failures. The addition of three new data points (see Table 3) slightly increases the expected release volume for a given storage volume. The power-law relation stated in the figure represents the most-likely scenario for tailings facility failure. The worst-case scenario will be the release of 100% of the stored tailings, for which there are at least four documented examples. Based on the historical record and a storage volume of 25.8 million cubic meters, a failure of the Dry Stack Tailings Facility (DSTF) operated by PT HPL (Halmahera Persada Lygend) on Obi Island (see Figs. 3, 20, and 34 and Table 1a) will release 8.4 million cubic meters of tailings (33% of the storage volume). The statistical model should be regarded as highly reliable in the case of the PT HPL DSTF because the storage volume of 25.8 million cubic meters places the tailings facility well within the dataset that was used to develop the statistical model. Data from Larrauri and Lall (2018) and Center for Science in Public Participation (2024) (see Table 3).

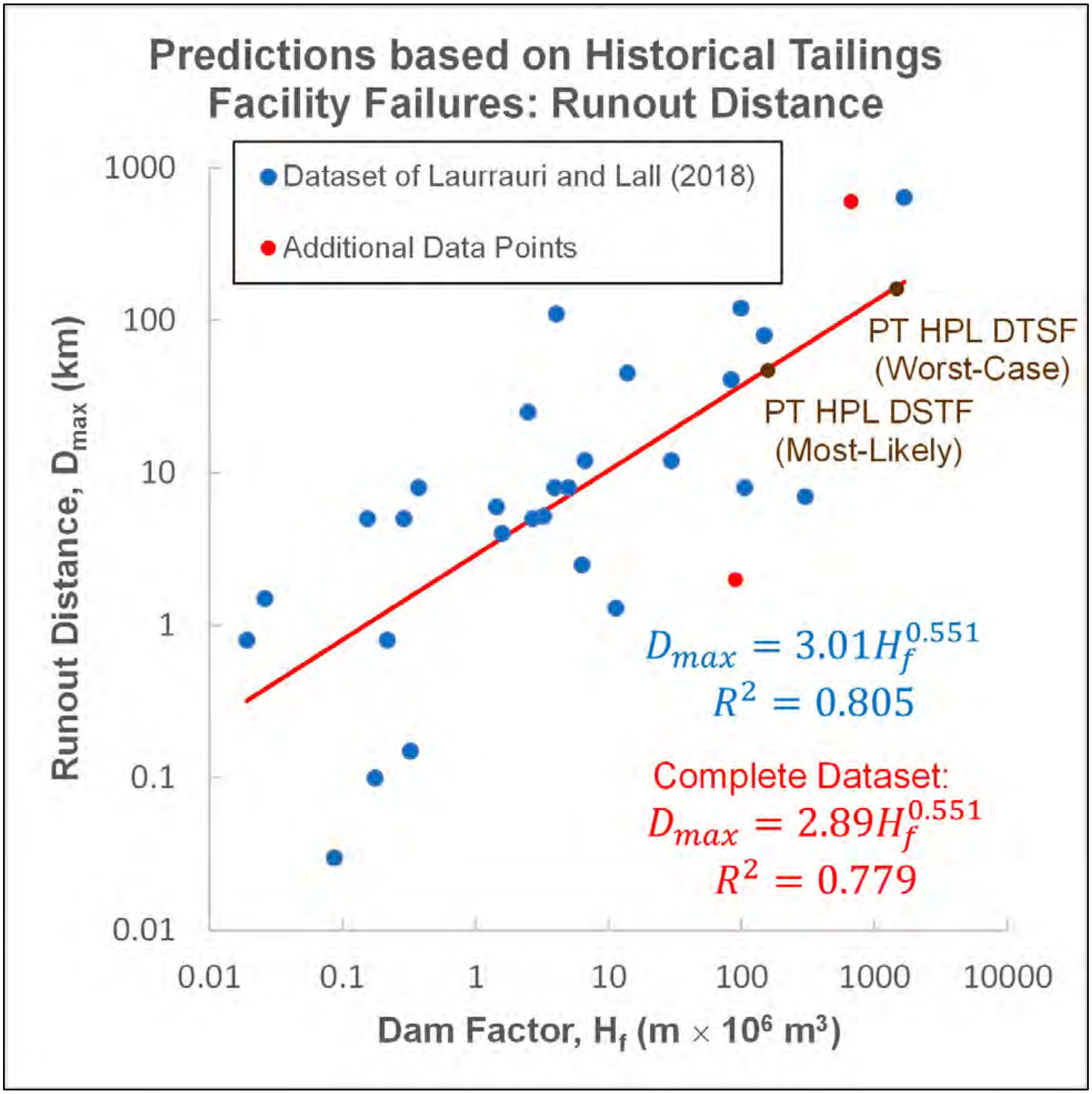

Figure 19b. Larrauri and Lall (2018) found a strong relationship between the dam factor (a function of the dam height, storage volume, and release volume; see Eq. 3) and the runout distance for past tailings facility failures. The addition of two new data points (see Table 3) slightly decreases the expected runout for a given dam factor. Based on the historical record and a storage volume of 25.8 million cubic meters and height of 57 meters, a failure of the Dry Stack Tailings Facility (DSTF) operated by PT HPL (Halmahera Persada Lygend) on Obi Island (see Figs. 3, 20, and 34 and Table 1a) will result in a run-out distance of 47 kilometers under the most-likely scenario (release of 33% of the storage volume) and 161 kilometers under the worst-case scenario (release of 100% of the storage volume). Thus, the runout distance of only 2200 meters that was predicted by PT Lapi ITB (2020) (see Fig. 34) even after liquefaction of the tailings is unrealistic and inconsistent with the historical record. The statistical model should be regarded as highly reliable in the case of the PT HPL DSTF because the storage volume of 25.8 million cubic meters and height of 57 meters places the tailings facility well within the dataset that was used to develop the statistical model. Data from Larrauri and Lall (2018) and Center for Science in Public Participation (2024) (see Table 3).

It should be noted that Eqs. (4)-(5) express the most-likely consequences of tailings storage facility failure. In particular, the most-likely consequence is that tailings storage facility failure will result in the release of about 35% of the stored tailings (see Eq. (4)). However, the worst-case scenario is that tailings storage facility failure will result in the release of 100% of the stored tailings. Therefore, the worst-case runout ($V_F = V_T$) should be calculated using Eq. (5) with

$$H_f = HV_T \quad (6)$$

There are at least four documented examples of total losses of tailings, including the failure of the El Cobre New Dam in Chile in March 1965 (350,000 cubic meters), and the failures at the Pittston Coal mine in Buffalo Creek, West Virginia (USA) in February 1972 (500,000 cubic meters), the United Nuclear uranium mine in Churchrock, New Mexico in July 1979 (370,000 cubic meters), and the Louyang Xiangjiang Wanji aluminum mine in China in August 2016 (2 million cubic meters) (see Table 3; Center for Science in Public Participation, 2024). According to Safety First: Guidelines for Responsible Mine Tailings Management, "Worst-case tailings failure scenarios must consider the loss of all tailings at full tailings facility buildout" (Morrill et al., 2022).

Acid Mine Drainage and Metal Leaching

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

The general acid-generating reaction can be written as a balanced chemical reaction as

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

or in words as

$$\text{pyrite + oxygen + water} \rightarrow \text{dissolved iron + sulfuric acid} \quad (7b)$$

Pyrite (iron sulfide) is the most common sulfide mineral, but many other metallic elements form sulfides, such as arsenopyrite (arsenic-iron sulfide or $AsFeS$), chalcopyrite (copper-iron sulfide or $CuFeS_2$), bornite (copper-iron sulfide or Cu_5FeS_4), galena (lead sulfide or PbS), and sphalerite (zinc sulfide or ZnS). Based on the above reaction, a by-product of acid generation is the mobilization of heavy metals into the dissolved form. The oxidation of pyrite results in the mobilization of dissolved iron. However, most sulfide minerals include a variety of other heavy metals that can substitute for the primary metal (such as substitutes for iron in the mineral pyrite), so that the oxidation of pyrite can result in the mobilization of a wide range of other heavy metals.

Acid mine drainage (AMD) results when the dissolved metals and sulfuric acid are introduced into surface water or groundwater, which can have detrimental impacts on public water supply and aquatic life. Acid mine drainage in streams is typically characterized by strong colors in the range of red, brown and yellow, which result from the oxidation of dissolved metals to form very fine-grained particles of metal oxides or metal oxyhydroxides that are transported with the streamflow. Under some circumstances, metal leaching (introduction of dissolved metals from mining by-products into surface water or groundwater) from sulfide minerals can also occur in the absence of acidity or even under alkaline conditions. Thus, streams affected by neutral (non-acidic) metal leaching can have the same colors as those affected by acid mine drainage. Of course, the determination of acid mine drainage requires that visual observations of color be supported by measurements of acidity and heavy metal concentrations. The literature on acid mine drainage and its impacts on human health and the environment is vast and good starting points are Maest et al. (2005) and the Global Acid Rock Drainage Guide (INAP, 2014).

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

Tests for predicting the acid mine drainage and metal leaching that could result from a particular body of exposed mine waste fall into the general categories of static tests, short-term leach tests, and kinetic (long-term) tests. Static tests are used to screen for potential contaminants and to categorize mine waste as either potentially acid-generating (PAG) or non-acid-generating (NAG). Static tests do not take into account the reaction rates (either oxidation or neutralization) or the availability of minerals for chemical reactions. An assessment of the elemental composition of mine waste is a common static test for the possibility of metal leaching in terms of screening for any potential contaminants that are unusually abundant. A common static test for acid mine drainage is acid-base accounting, in which the sulfide (or sulfur) content of mine waste leads to the acidity potential (AP). In the same way, the carbonate content or the content that will react with acid leads to the neutralization potential (NP). Both AP and NP are expressed in units such as kilograms of calcium carbonate ($CaCO_3$) equivalent per metric ton of mine waste. The net neutralization potential (NNP) is calculated as NP – AP, while the neutralization potential ratio (NPR) is the ratio NP/AP. There are no fixed thresholds for NNP or NPR for separation of PAG and NAG materials. Recommended thresholds for PAG materials range from NPR < 1 to NPR < 4 (Maest et al., 2005). By comparison with kinetic data on depletion rates of neutralizing minerals, Scharer et al. (2000) concluded that heterogeneous waste rock piles with NPR as high as 5.0 may still generate acid mine drainage in the long term. According to USEPA (1994), "If the difference between NP and AP is negative then the potential exists for the waste to form acid. If it is positive then there may be lower risk. Prediction of the acid potential when the NNP is between -20 and 20 [kg $CaCO_3$ per metric ton] is more difficult." Other static tests that are often used in conjunction with acid-base accounting are the pyritic sulfur content and the pH of mine waste after oxidation (called NAG pH). Common thresholds for assessing mine waste as PAG are pyritic sulfur content greater than 0.3% by weight and NAG pH less than 4.5 (INAP, 2014).

A wide range of tools have been developed for the mitigation of acid mine drainage and metal leaching from mining that involves the excavation of sulfide minerals. For example, soil or clay covers on tailings storage facilities can minimize the contact of tailings with oxygen and rainfall, while stormwater diversion channels around the facilities can minimize the contact with surface water. Crushed limestone can be mixed with mine waste to neutralize any acidity that is generated. Impermeable liners can be placed beneath tailings storage facilities to prevent seepage into groundwater. Wells can be placed around tailings storage facilities for the capture and treatment of any acid mine drainage that escapes into groundwater. Water from tailings storage facilities can be treated for removal of acidity and dissolved metals prior to release into surface water. In fact, most of the above tools should be used at any mine site that carries out excavation of sulfide minerals and there should be no reliance on a single tool, such as a liner. Despite the available tools, it is important to note that there are no examples of mines that have exploited sulfide ore deposits without acid mine drainage or other forms of contamination of groundwater or surface water (Emerman, 2023a).

Indonesian Tailings Regulations

Indonesia has no single document that contains all of the regulations regarding mine tailings. The regulations can be found in two documents both called Tentang Bendungan [Regarding Dams] (Government of the Republic of Indonesia, 2010a; Ministry of Public Works and People's Housing (Republic of Indonesia), 2015) and a third document entitled Tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup [Regarding Protection and Management of the Environment] (Government of the Republic of Indonesia, 2021). The tailings regulations include very few actual standards and largely consist of the procedures for obtaining permits. Of particular relevance to this report is that Indonesia lacks standards for all of the following:

1) prioritization of safety over all other considerations
2) minimum separation between tailings storage facilities and downstream mining infrastructure
3) minimum separation between tailings storage facilities and downstream communities
4) minimum separation between tailings storage facilities and downstream sources of public water supply
5) flood or precipitation design criteria depending upon consequences of failure or other factors
6) filtering or dewatering of tailings
7) minimum factors of safety

8) requirements for safe closure of tailings storage facilities
9) transparency or disclosure of relevant documents to local or environmental organizations or to local governments

An additional issue is that there seem to be discrepancies between the interpretation of the regulations and the literal text of the regulations, both on the part of the government and non-governmental organizations. One of these discrepancies relates to the lack of flood or precipitation design criteria at the literal level

The Indonesian dam regulations are very clear that the regulations apply both to water-retention dams and tailings dams. Article 1 defines a dam as "*bangunan yang berupa urukan tanah, urukan batu, beton, dan/atau pasangan batu yang dibangun selain untuk menahan dan menampung air, dapat pula dibangun untuk menahan dan menampung limbah tambang (tailing), atau menampung lumpur sehingga terbentuk waduk*" [a structure in the form of an embankment, rockfill, concrete, and/or stone masonry that is constructed not only to hold and store water, but also to hold and store mine waste (tailings) or collect sludge to form a reservoir] (Government of the Republic of Indonesia, 2010a). Article 5 then confirms that "*Pembangunan bendungan untuk penampungan limbah tambang (tailing) dan penampungan lumpur mengikuti ketentuan dalam peraturan pemerintah ini*" [The construction of dams for mine waste (tailings) and sludge storage follows the provisions in this government regulation] (Government of the Republic of Indonesia, 2010a). For both water-retention and tailings dams, the Indonesian regulations confirm the need for a dam failure consequence analysis as an essential component of the emergency action plan. Article 52 of *Tentang Bendungan* [Regarding Dams] (Government of the Republic of Indonesia, 2010a) states, "*Rencana tindak darurat ... harus dilengkapi dengan analisis keruntuhan bendungan* … The emergency action plan …must be accompanied by an analysis of the dam collapse].

A source of confusion in the Indonesian regulations is that there appears to be a strong dam safety standard for the design flood that has been adopted in practice, but which has not yet been codified into regulations. According to a 2015 publication by employees of the Dam Safety Unit of the Indonesian Ministry of Public Works and People's Housing, "So in this paper, it will going to explain the dam safety in Indonesia based on Water Law No. 11 of 1974 and Ministerial Regulation Number 72/PRT/1997 about Dam Safety … Nowadays dam safety concept in Indonesia was adopted by dam safety concept from Swiss Dam … The dam, including dam body, appurtenance structure, reservoir and foundation, should be safe for: - All possible loading, include earthquake and flood. Consequently, the design must be based on the largest possible events at the site when it comes to the natural hazards of flood and earthquake" (Mayangsari and Adji, 2015). In other words, based upon the preceding quote, all dams in Indonesia, with no exception for tailings dams, should be designed to withstand the Probable Maximum Flood (PMF) and the Maximum Credible Earthquake (MCE).

The requirement for design of all dams to withstand the PMF and MCE, regardless of the consequences of dam failure, would give Indonesia the strongest dam safety standards in the world. Switzerland is generally regarded as having the strongest dam safety standards in the world. Although Mayangsari and Adji (2015) refer to Swiss regulations, no explicit connection is made between any particular Swiss and Indonesian dam safety regulations. Mayangsari and Adji (2015) do not clarify how or whether the requirement to design all dams to withstand the PMF is connected with the regulations they mentioned, which were Water Law No. 11 of 1974 and Ministerial Regulation Number 72/PRT/1997. In fact, the requirement of a particular flood return period for dam design is not mentioned in any of the Indonesian regulations that might be relevant (Government of the Republic of Indonesia, 2007, 2009, 2010a-b, 2021; Ministry of Public Works and People's Housing, 2015; Ministry of Environment and Forestry, 2020). The most likely regulations in which a required flood return period would be mentioned, if it existed, would be the two versions of Tentang Bendungan [Regarding Dams] (Government of the Republic of Indonesia, 2010a; Ministry of Public Works and People's Housing, 2015).

Article 1 of the regulation Tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup [Regarding Protection and Management of the Environment] defines "*Bahan Berbahaya dan Beracun*" [Hazardous and Toxic Materials] (abbreviated as B3) as "*zat, energi, dan/atau komponen lain yang karena sifat, konsentrasi, dan/atau jumlahnya, baik secara langsung maupun tidak langsung, dapat mencemarkan dan/atau merusak Lingkungan Hidup, dan/atau membahayakan Lingkungan Hidup, kesehatan. serta kelangsungan hidup manusia dan makhluk hidup lain*" [substances, energy, and/or other components which due to their nature, concentration, and/or quantity, either directly or indirectly, can pollute and/or damage the Environment, and/or endanger the Environment, health, and survival of humans and other living creatures] (Government of the Republic of Indonesia, 2021). Article 1 continues, "*Limbah Bahan Berbahaya dan Beracun yang selanjutnya disebut Limbah B3 adalah sisa suatu usaha dan/atau kegiatan yang mengandung B3*" [Hazardous and Toxic Waste, hereinafter referred to as B3 Waste, is the residue of a business and/or activity that contains B3] (Government of the Republic of Indonesia, 2021).

It is sometimes stated that all tailings are automatically classified as B3 Waste, regardless of any measurements on the toxicity of the tailings. For example, according to Yayasan Tanah Merdeka (YTM) (2025a-b), "*Peraturan pemerintah (PP) Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup mengelompokkan tailing sebagai Bahan Beracun dan Berbahaya (B3) Spesifik Khusus dengan kategori bahaya 2 (dua) yang dianggap memiliki toksisitas kronis dan berjangka panjang terkait dampak terhadap manusia dan lingkungan hidup. Oleh karena itu, tailing harus diolah sebagai limbah B3*" [Government Regulation (PP) Number 22 of 2021 concerning the Implementation of Environmental Protection and Management classifies tailings as Specific Toxic and Hazardous Materials (B3) with hazard category 2 (two) which are considered to have chronic and long-term toxicity related to impacts on humans and the environment. Therefore, tailings must be processed as B3 waste]. However, the information that all tailings are automatically classified as B3 Waste cannot be found in the literal text of the stated document (Government of the Republic of Indonesia, 2021).

At the same time, in various places, Government of the Republic of Indonesia (2021) does imply that all tailings are B3 Waste. For example, Article 400 states, "*Setelah Persetujuan Teknis untuk kegiatan Dumping (Pembuangan) Limbah B3 terbit, pemegang Persetujuan Teknis wajib ... melakukan netralisasi atau penurunan kadar racun untuk Dumping (Pembuangan) Limbah B3 berupa tailing*" [After the Technical Approval for B3 Waste Dumping (Disposal) activities is issued, the holder of the Technical Approval is obliged to ... neutralize or reduce the toxicity levels for B3 Waste Dumping (Disposal) in the form of tailings]. The preceding article allows the possibility that tailings that had been approved for dumping might be inherently non-toxic (so that the tailings would not be B3 Waste) and might not require any reduction in the toxicity level. However, it is not clear as to whether the regulations are meant to be read in such a literal way. In any event, the Indonesian regulations clearly do not specify any quantitative degree of neutralization or reduction of toxicity, which is consistent with the general lack of quantitative standards in the Indonesian tailings regulations.

The Indonesian regulations do not prohibit the deep sea disposal of tailings or other forms of mine waste. Article 392 states, "*Limbah B3 yang dapat dilakukan Dumping (Pembuangan) Limbah B3 ke media Lingkungan Hidup berupa laut ...*

a. *tailing dari kegiatan pengolahan hasil pertambangan;*
b. *serbuk bor dari hasil pemboran Usaha dan/atau Kegiatan eksplorasi dan/atau eksploitasi di laut menggunakan lumpur bor berbahan dasar sintetis (synthetic-based mud); dan*
c. *serbuk bor dan lumpur bor dari hasil pemboran Usaha dan/atau Kegiatan eksplorasi dan/atau eksploitasi di laut menggunakan lumpur bor berbahan dasar air (water-based mud)"*

[B3 waste that can be dumped (disposal) into the Environmental media in the form of the sea ...

a. tailings from mining processing activities;
b. drill cuttings from drilling results of exploration and/or exploitation businesses and/or activities at sea using synthetic-based mud; and
c. drill cuttings and drill mud from drilling results of exploration and/or exploitation businesses and/or activities at sea using water-based mud]

(Government of the Republic of Indonesia, 2021).

Deep sea disposal of tailings should not be carried out in sensitive areas. Moreover, it is preferred to carry out deep sea disposal of tailings in areas that have a permanent thermocline, a surficial layer of warm water that would suppress upwelling. Article 395 of Government of the Republic of Indonesia, 2021) states, "*Lokasi tempat dilakukan Dumping (Pembuangan) Limbah B3 sebagaimana ... harus memenuhi persyaratan yang meliputi:*

a. *terletak di dasar laut pada laut yang memiliki lapisan termoklin permanen; dan*
b. *tidak berada di lokasi tertentu atau di daerah sensitif sesuai dengan ketentuan peraturan perundang-undangan"*

[The location where B3 Waste Dumping is carried out as ... must meet the requirements which include:

a. located on the seabed in the sea which has a permanent thermocline layer; and
b. not located in a specific location or in a sensitive area in accordance with the provisions of laws and regulations].

However, deep sea disposal of tailings can still be carried out in areas where there is no permanent thermocline as long as certain other requirements are met. Article 395 continues, "*Dalam hal tidak terdapat laut yang memiliki lapisan termoklin permanen ... lokasi tempat dilakukan Dumping (Pembuangan) Limbah B3 berupa tailing dari kegiatan pengolahan hasil pertambangan harus memenuhi persyaratan lokasi yang meliputi:*

a. *terletak di dasar laut dengan kedalaman lebih dari atau sama dengan 100 m (seratus meter);*
b. *secara topografi dan batimetri menunjukkan adanya ngarai dan/atau saluran di dasar laut yang mengarahkan tailing ke kedalaman lebih dari atau sama dengan 200 m (dua ratus meter); dan*
c. *tidak ada fenomena up-welling"*

[In the absence of a sea that has a permanent thermocline layer ... the location where the dumping of B3 Waste in the form of tailings from mining processing activities is carried out must meet the location requirements which include:

a. location on the seabed with a depth of more than or equal to 100 m (one hundred meters);
b. topographically and bathymetrically showing the presence of canyons and/or channels on the seabed that direct the tailings to a depth of more than or equal to 200 m (two hundred meters); and
c. no upwelling phenomenon].

The Indonesian tailings regulations do not prohibit the disposal of tailings into rivers or other inland water bodies. However, the only mine in Indonesia with a permit to discharge tailings into a river is the Grasberg copper-gold mine in West Papua, which is currently owned and operated by PT Freeport Indonesia, a joint venture of the American company Freeport-McMoRan (48.8%) and the Indonesian state-owned company PT Indonesia Asahan Aluminum, (51.2%). There are no operating Indonesian mines that discharge tailings into lakes, wetlands, or other water bodies, although the practice is not specifically prohibited. It has already been mentioned that in 2021 the government of Indonesia announced that no new permits will be issued for deep sea tailings disposal (Nangoy and Ungku, 2021), even though the practice is not prohibited in regulations.

Safety First: Guidelines for Responsible Mine Tailings Management

The revision of the guidance document Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022) was released in May 2022, with the first version released two years earlier. The revision was endorsed by 164 non-governmental organizations, Tribal governments, labor unions, and political parties. Safety First contains 17 guidelines for the safe design, construction, operation, and closure of tailings storage facilities. At the present time, Safety First represents the highest standard in tailings safety, but even strict adherence to the guidelines of Safety First is not a guarantee of safety. According to Safety First, “There may be circumstances under which a tailings facility can meet all the guidelines in this document but must not be built or allowed to continue in operation … This document recognizes that the safest tailings facility is the one that is never built” (Morrill et al., 2022).

A document that is often compared with Safety First is the Global Industry Standard on Tailings Management (GISTM), which was jointly authored by the International Council on Mining and Metals (ICMM), the United Nations Environment Programme (UNEP), and Principles for Responsible Investment (PRI), and released in August 2020 (ICMM-UNEP-PRI, 2020). The chief difference between Safety First and the GISTM is that Safety First has stricter standards. Moreover, in many ways, the GISTM is lacking in standards and focuses on procedures, somewhat in common with the Indonesian tailings regulations. The goal of Safety First was to maximize the protection of people and the environment, while the GISTM tried to strike an unstated balance between the maintenance of corporate profits and the protection of people and the environment. 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” (ICMM-UNEP-PRI, 2020). Although the Preamble of the GISTM is very similar to the theme of Safety First, the goal stated in the Preamble was not rigorously pursued throughout the rest of the document. Two members of the expert panel that wrote the draft of the GISTM have recounted the ways in which the mining industry dominated the process of writing the GISTM with the exclusion of representatives of Indigenous peoples, labor unions, and mining-affected communities (Hopkins and Kemp, 2021). In terms of standards that emphasize protection of people and the environment, the recent guidance document Tailings Dam Safety Best Practices (FEMA, 2025) is generally intermediate between the GISTM and Safety First.

The remainder of this subsection reviews the guidelines of Safety First that are most relevant to the HPAL projects discussed in this report, which are the eight standards that were listed as missing in the Indonesian tailings regulations in the previous subsection. Guideline #1 is "Make safety the guiding principle in design, construction, operation, and closure" (Morrill et al., 2022). Safety First explains, "Given the hazardous nature of mine tailings, the fundamental goal of tailings management must be to 'ensure that public safety, environmental safety, and economic safety are the determinative factors in governing what tailings disposal system will be implemented' [University of Victoria Environmental Law Centre, 2019]" (Morrill et al., 2022). Somewhat in contrast to the Preamble of the GISTM, Safety First continues, "It is important to recognize that mining is a fundamentally destructive industry, meaning that a goal of zero harm to the environment is impossible to achieve. Nevertheless, operating companies must do all that they can to minimize environmental harm everywhere. In particular, they must limit any environmental harm that inevitably occurs to within the mine site" (Morrill et al., 2022). Guideline #2 is "Consent of affected communities" (Morrill et al., 2022). Although consent is certainly a critical issue, the issue of consent for the filtered tailings storage facilities in Indonesia is beyond the scope of this report.

Guideline #3 addresses the issue of minimum separation between a tailings storage facility and downstream mining infrastructure, communities, and bodies of water. Guideline #3 states "Ban new tailings facilities where inhabited areas are in the path of a tailings dam failure" (Morrill et al., 2022). Safety First explains, "The most effective way to minimize risk to people is to prevent the construction of new tailings facilities where there is a population living or working in close proximity, downstream, or down gradient from the facility. Operating companies must not build infrastructure in which workers are likely to be present—offices, cafeterias, warehouses—in the zone of influence. The zone of influence is the 'area that would be significantly affected in case of a [tailings facility] failure and should be categorized as a risk zone' [University of Victoria Environmental Law Centre, 2019]" (Morrill et al., 2022).

Safety First specifies that the minimum separation between a tailings facility depends upon the time required to evacuate the community. According to Safety First, "Therefore, the minimum distance between communities and new dams must be defined on a case-by-case basis. This distance must be calculated based on the time it would take to evacuate the entire community with the support of a rescue team and the time it would take for a tailings flood to reach the community, with a safety buffer built into the calculation. The time it takes for a tailings flood to reach a community must be calculated based on a dam break study conducted for the specific tailings disposal facility" (Morrill et al., 2022). Finally, Safety First specifies a separation between a tailings facility and downstream water bodies, but not in a quantitative way. According to Safety First, "Tailings facilities must not be constructed in a location where a failure would materially impact public water supplies or critical habitats, or near protected ecological resources. Additionally, tailings must never be deposited in bodies of water, such as rivers, streams, oceans, etc." (Morrill et al., 2022).

Guideline #5 addresses the flood and seismic design criteria for tailings storage facilities. Guideline #5 states, "Any potential loss of life is an extreme event and design must respond accordingly" (Morrill et al., 2022). Safety First explains, "If an operating company, regulatory agency, or independent third-party identifies any potential loss of life as a result of a tailings dam failure, the dam must be designed to withstand the Probable Maximum Flood (PMF), which is the largest flood that is theoretically possible at a given location, and the Maximum Credible Earthquake (MCE), which is the largest earthquake that is theoretically possible at a given location. Where the failure of a tailings dam would have no potential for the loss of human life, the facility must be designed to withstand a 10,000-year flood and a 10,000-year earthquake" (Morrill et al., 2022).

Guideline #6 states, "Mandate the use of Best Available Technology for tailings, in particular filtered tailings" (Morrill et al., 2022). Thus, Safety First regards the use of filtered tailing technology not only as a best practice, but as mandatory. According to Safety First, "Best available technology and practices in tailings management will continue to change, but tailings BAT [Best Available Technology] was specified by the Mount Polley Independent Expert Engineering Investigation and Review Panel (the 'Mount Polley Report') in the following way: 'The goal of BAT 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. 2. Promote unsaturated conditions in the tailings with drainage provisions. 3. Achieve dilatant conditions throughout the tailings deposit by compaction' [Independent Expert Engineering Investigation and Review Panel (2015)]" (Morrill et al., 2022).

Safety First emphasizes that best practices do not eliminate all risks. In particular, best practices must still be carried out correctly. According to Safety First, "Nevertheless, filtered tailings do not eliminate all risks … While filtered tailings are considered Best Available Technology, filtered tailings can still fail and their use is not an excuse to ignore other aspects of tailings safety … The design of filtered tailings facilities must include an effective drainage system, as well as the water management infrastructure for preventing the rewetting of the tailings by precipitation or surface runoff. If there are existing tailings facilities that use drainage ponds, they must be located a safe distance from the tailings facilities to prevent the failure of one structure from impacting the stability of the other structure" (Morrill et al., 2022).

Guideline #7 states, "Implement rigorous controls for safety" (Morrill et al., 2022). Among other requirements within the guideline, Safety First mandates a minimum static factor of safety of 1.5, which is consistent with the vast majority of international regulations and guidance documents (ANCOLD, 2012, 2019; Canadian Dam Association, 2013, 2019; Fell et al., 2015; Government Gazette—Republic of South Africa, 2025; Schnaid et al., 2020; ICOLD, 2022; Ministry of Energy, Mines and Low Carbon Innovation (British Columbia), 2024; FEMA, 2025). According to Safety First, "As a guidance for safe operation and closure, a conservative Factors of Safety (FoS), meaning the FoS that is the most protective of people, property and the environment, must be established and enforced for all tailings dams. When calculating FoS, single input values must be avoided and a range of values, methods, and/or models must be applied to assess the various possible FoS values (static and pseudo-static). For operation and closure of a tailings dam, a static FoS of 1.5 (in non-earthquake conditions), and pseudo-static FoS of 1.1 (in response to the design earthquake, which establishes that even during the strongest seismic acceleration theoretically possible, the dam will still have 10% more shear resistance than is necessary to avoid failure), is presently viewed as conservative" (Morrill et al., 2022).

Guideline #11 is entitled "Towards safer closure with no credible failure modes" (Morrill et al., 2022). Safety First emphasizes that the closure plan must be an essential component of the design and the permitting process. According to Safety First, "It is imperative that the reclamation and closure of tailings facilities be a factor in their initial design and siting" (Morrill et al., 2022). Safety First defines safe closure in the following way: "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" (Morrill et al., 2022). The concept of credible failure modes will be discussed further in the subsection "Lack of Closure Plan" in the section "Obi Island: Imminent Catastrophic Failure."

The concept of the need for perpetual care requires careful consideration and must be a part of the permitting process. Safety First continues, "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 or MCE 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" (Morrill et al., 2022).

Finally, Guideline #15 states that "Information regarding mine safety must be made publicly available" (Morrill et al., 2022). Safety First elaborates, "Operating companies must make all information relevant to the safety and stability of tailings facilities publicly available, including the name, exact location, ownership, date of initial operation, footprint, and height. Information related to tailings disposal facilities must be made publicly available during the design stage and must be updated on a regular basis over the life of the mine. Operating companies must immediately publicly disclose the date, location, amount of tailings released, and impacts on surrounding areas following any tailings failure" (Morrill et al., 2022). Safety First continues by listing a wide range of documents that must be provided to the public and all stakeholders. According to Safety First, "This information must be made available by operating companies and regulators at no charge, as soon as possible, in one or more languages as necessary, in an accessible format, and in plain language whenever possible to afford adequate access for all interested stakeholders" (Morrill et al., 2022).

SUMMARY OF FILTERED TAILINGS STORAGE FACILITIES IN INDONESIA

The only filtered tailings storage facility in Indonesia for which detailed knowledge is available is the "Dry Stack Tailings Facility" (DSTF) that currently receives all tailings produced by the PT Halmahera Persada Lygend (HPL) HPAL project on Obi Island (see Fig. 3 and Table 4). As mentioned earlier, the tailings are not literally dry and expressions such as "dry tailings" or "dry stack" are used in this report only to refer to formal names of facilities or to quote from other documents. In fact, the target geotechnical water content of the tailings is 35% (SRK Consulting, 2022a; see Table 4). According to Lu (2023), filtered tailings at the facilities for the Indonesia Morowali Industrial Park (IMIP) on Sulawesi Island (see Fig. 3) also have target geotechnical water contents of 35%. Souisa (2023) has started a target geotechnical water content of 31% for the filtered tailings storage facility for PT Huayue Nickel Cobalt (HYNC), which is within IMIP. Target geotechnical water contents for filtered tailings at PT Huafei Nickel Cobalt (HFNC) within the Weda Bay Industrial Park on Halmahera Island (see Fig. 3) have been reported as 31% (Huayou Cobalt, 2023) and 30% (Zhejiang Huayou Cobalt, 2024; see Table 4).

Table 4. Filtered tailings storage facilities in Indonesia[1]

Name	Footprint (hectares)	Maximum Capacity (metric tons)	Maximum Capacity (cubic meters)	Annual Throughput (metric tons)	Target Water Content (%)
Operating					
PT Halmahera Persada Lygend (HPL)[2]	195[3] 94.9[4]	57,200,000[3] 33,200,000[4]	25,800,000[3]	7,496,050[5]	35[4]
Indonesia Morowali Industrial Park[6]	600[7]	—	—	—	35[8]
PT Huayue Nickel Cobalt (HYNC)[2,9,10,11]	—	—	—	9,300,000[12]	31[10]
PT Qing Mei Bang (QMB) New Energy Materials[2,9]	—	—	—	6,600,000[13]	—
PT Huafei Nickel Cobalt (HFNC)[2,14,15,16]	—	66,000,000[17]	—	17,900,000[18]	31[14] 30[15]
PT Nusa Halmahera Minerals (NHM) Gosowong Gold Mine[19,20]	—	—	—	800,000[21]	—
Permitted and/or under Construction					
PT Excelsior Nickel Cobalt (ENC)[22,23]	—	—	—	9,600,000[24]	—
Sorowako/PT Huali Nickel Indonesia (HNI)[22,25]	—	—	—	8,600,000[26]	—
Pomalaa/PT Kolaka Nickel Indonesia (KNI)[22,25]	—	—	—	17,900,000[27]	—
Paused or Cancelled					
Sonic Bay[26,29]	—	—	67,000,000[30]	10,350,000[29] 8,000,000[31]	—

[1]According to Hidayat et al. (2024) and Heyokha Brothers (2024), all HPAL projects in Indonesia use or will use filtered tailings technology. This table includes only HPAL projects for which there is explicit mention of the use of filtered tailings technology. All filtered tailings storage facilities in the table are HPAL projects, unless otherwise indicated.
[2]See Table 1a.
[3]PT Halmahera Persada Lygend (2024)
[4]SRK Consulting (2022a)
[5]Annual throughput for 2023 (PT Halmahera Persada Lygend, 2024). Annual throughputs were 4,605,300 metric tons in 2022 and 1,595,180 metric tons in 2021 (PT Halmahera Persada Lygend, 2024). PT Halmahera Persada Lygend, 2024) also states both that 5.7 million metric tons of tailings and 28,399,985 metric tons of tailings were stored as of December 2023, which are contradictory and which contradict the information in the table.

[6]There are multiple filtered tailings storage facilities for the HPAL projects in the Indonesia Morowali Industrial Park (Fisher and Grossl, 2023; Lee, 2023). Note that PT Huayue Nickel Cobalt and PT Qing Mei Bang (QMB) New Energy Materials are both located within the Morowali Industrial Park (see Table 1a).
[7]The footprint refers to the sum of the footprints of all filtered tailings storage facilities within the Indonesia Morowali Industrial Park (Lee, 2023).
[8]Lu (2023)
[9]Fisher and Grossl (2023)
[10]Souisa (2023)
[11]PT Huayue Nickel Cobalt (2021)
[12]Estimated by multiplying the annual capacity of 70,000 metric tons Ni and Co (IMIP, 2025a; see Table 1a) by a tailings to metal ratio of 133 (justified in text).
[13]Estimated by multiplying the annual capacity of 50,000 metric tons Ni and Co (IMIP, 2025b; see Table 1a) by a tailings to metal ratio of 133 (justified in text).
[14]Huayou Cobalt (2023)
[15]Zhejiang Huayou Cobalt (2024)
[16]International Mining (2022)
[17]Mecater Ingénierie (2023a)
[18]Estimated by multiplying the annual capacity of 120,000 metric tons Ni and 15,000 metric tons Co (Nangoy, 2023; see Table 1a) by a tailings to metal ratio of 133 (justified in text).
[19]The PT Nusa Halmahera Minerals (NHM) Gosowong Gold Mine is not an HPAL project.
[20]Tampi (2024)
[21]NHM Gosowong Gold Mine (2025)
[22]See Table 1b.
[23]Nickel Industries (2025)
[24]Estimated by multiplying the annual capacity of 72,000 metric tons Ni (Nickel Industries, 2025; see Table 3b) by a tailings to metal ratio of 133 (justified in text).
[25]Silva (2023)
[26]Estimated by multiplying the annual capacity of 60,000 metric tons Ni and 5000 metric tons Co (Nickel Industries, 2025; see Table 1b) by a tailings to metal ratio of 133 (justified in text).
[27]Estimated by multiplying the annual capacity of 120,000 metric tons Ni and 15,000 metric tons Co (Vale, 2025; see Table 1b) by a tailings to metal ratio of 133 (justified in text).
[28]See Table 1d.
[29]Saputra et al. (2023)
[30]Mecater Ingénierie (2023b)
[31]Estimated by multiplying the annual capacity of 60,000 metric tons Ni (IndoPremier, 2024; see Table 1d) by a tailings to metal ratio of 133 (justified in text).

Nothing is yet definitively known about the filtered tailings storage facility for PT Obi Nickel Cobalt (ONC), which is also on Obi Island (see Fig. 3). PT HPL and PT ONC have overlapping ownership, since PT HPL is owned by PT Trimegah Bangun Persada (45.1%) and Ningbo Lygend Mining (54.9%), while PT ONC is owned by PT Trimegah Bangun Persada (10%), Ningbo Lygend Mining (60%), and Harita Group (30%) (see Table 1a). The Harita Group is, in turn, the majority owner (86.48%) of PT Trimegah Bangun Persada through its subsidiary PT Harita Jayaraya (TBP and Harita Nickel, 2025). There is considerable potential for further tailings storage facilities on Obi Island. As of August 2023, the island had already been divided among 21 mining concessions, covering 470.5322 square kilometers, including 15 mining concessions for nickel and nickel-derived products, covering 311.7758 square kilometers (see Table 5 and Fig. 20). Thus, as of August 2023, 18.5% of the surface area of Obi Island had been assigned to mining concessions.

Table 5. Mining concessions on Obi Island[1]

No.[2]	Company	Commodity	Status	Area (ha)
1	PT Gane Permai Sentosa	Nickel and derived products	Production	1276.99
2	PT Trimegah Bangun Persada	Nickel	Production	4247
3	PT Rimba Kurnia Alam	Nickel	Production	1800
4	PT Wanatiara Persada	Nickel	Production	1725.54
5	PT Mineral Perkasa Sentosa	Gabbro	Exploration	58.64
6	PT Obi Putra Mandiri	Nickel and derived products	Production	4058
7	PT Jikodolong Megah Pertiwi	Nickel and derived products	Production	884.84
8	PT Halim Pratama	Nickel	Production	1317
9	PT Mulia Putra Sejahtera	Nickel	Production	2967.75
10	PT Intim Mining Sentosa	Nickel	Production	1935
11	PT Anugrah Bukit Besar	Nickel	Production	853.6
12	PT Aneka Tambang Resources Indonesia	Nickel	Production	607.88
13	PT Obi Anugerah Mineral	Nickel	Production	1775.4
14	PT Obi Mayor Nusantara	Industrial limestone	Exploration	3153
15	PT Budhi Java Mineral	Limestone	Production	4711
16	PT Cita Karya Sejahtera	Limestone	Exploration	1146
17	PT Gamping Adika Sejahtera	Industrial limestone	Reserve	2517
18	PT Bela Sarana Permai	Heavy mineral sands and derived products	Production	4290
19	PT Intim Mining Sentosa	Nickel and derived products	Production	3185
20	PT Serongga Sumber Lestari	Nickel and derived products	Production	2229.58
21	PT Gane Tambang Sentosa	Nickel	Production	2314

[1]Data from MOMI (2023) accessed on August 15, 2023
[2]Concessions numbered by author (see Fig. 20).

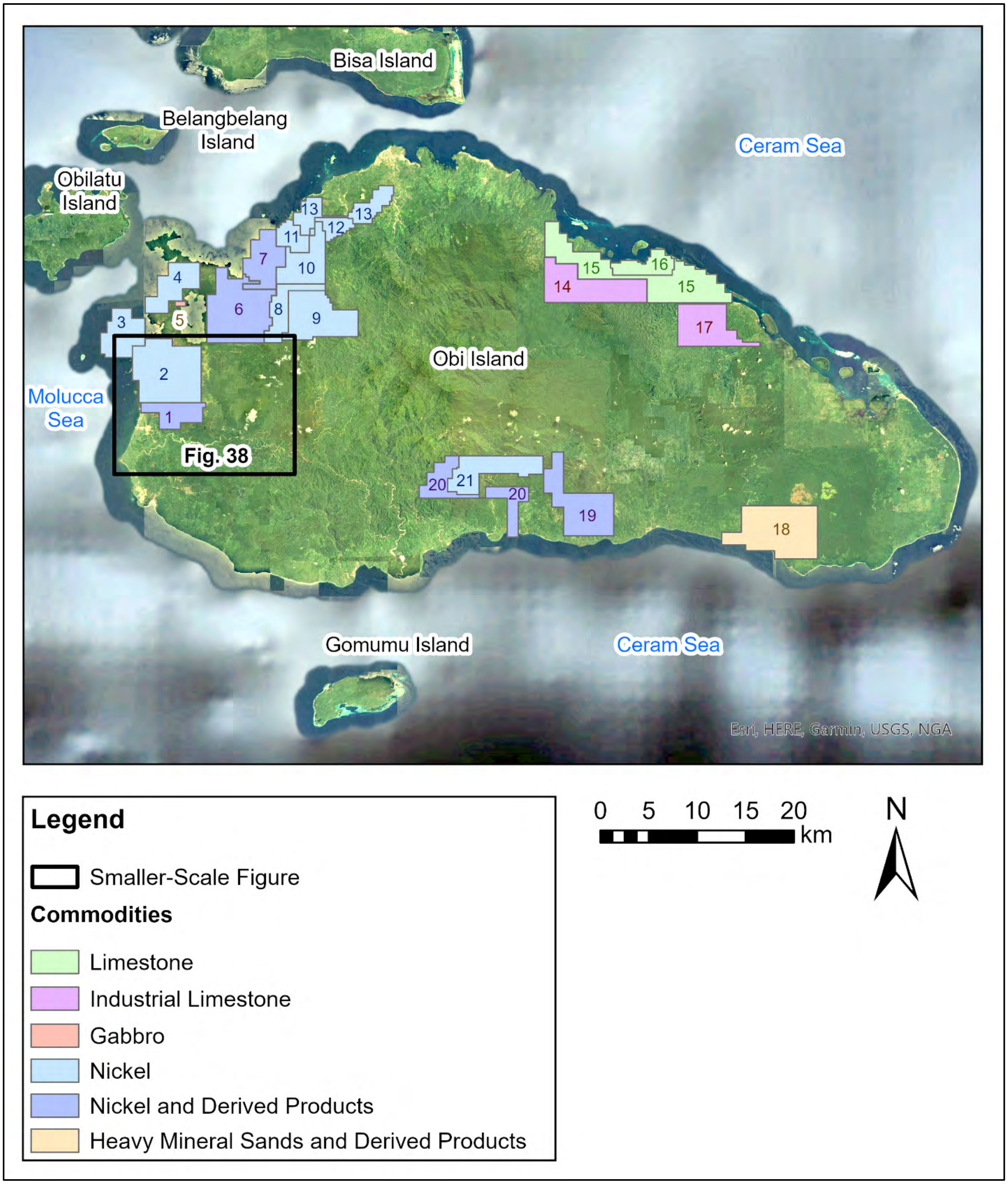

Figure 20. As of August 15, 2023, there were 21 mining concessions on Obi Island, covering 470.5322 square kilometers, including 15 mining concessions for nickel and nickel-derived products, covering 311.7758 square kilometers (see Table 5). Numbering is by the author. Data from MOMI (2023).

At the end of its useful life, the DSTF for PT HPL will have a height of 57 meters, footprint of 195 hectares, and maximum capacity of 57.2 million metric tons or 25.8 million cubic meters of tailings (PT Halmahera Persada Lygend (2024); see Table 4). Thus, the target dry density (density of solid particles, not including water) is 2.22 metric tons per cubic meter, which is within the mining industry range of 1.9 to 2.6 metric tons per cubic meter with 2.0 metric tons per cubic meter as a typical dry density (Cacciuttolo Vargas and Pérez Campomanes, 2022). The DSTF at the PT HPL mine is being constructed in three stages, starting with P-23, then moving to P-09, and concluding with P-08 (see Fig. 21). The construction includes both temporary and permanent rockfill buttresses, which consist of coarse fragments of ultramafic rocks with a minor amount of soil, all of which is obtained from the mine site (PT Lapi ITB, 2022; see Fig. 22). The tailings are being stacked far higher than the tops of the rockfill buttresses (see Fig. 22). Thus, the rockfill buttresses do not actually serve the function of dams, since if the tailings liquefied, they could easily flow over the tops of the buttresses (see Fig. 22). The actual density and corresponding maximum capacity by mass will be discussed in the section "Obi Island: Imminent Catastrophic Failure," along with a possible reason for the short heights of the buttresses.

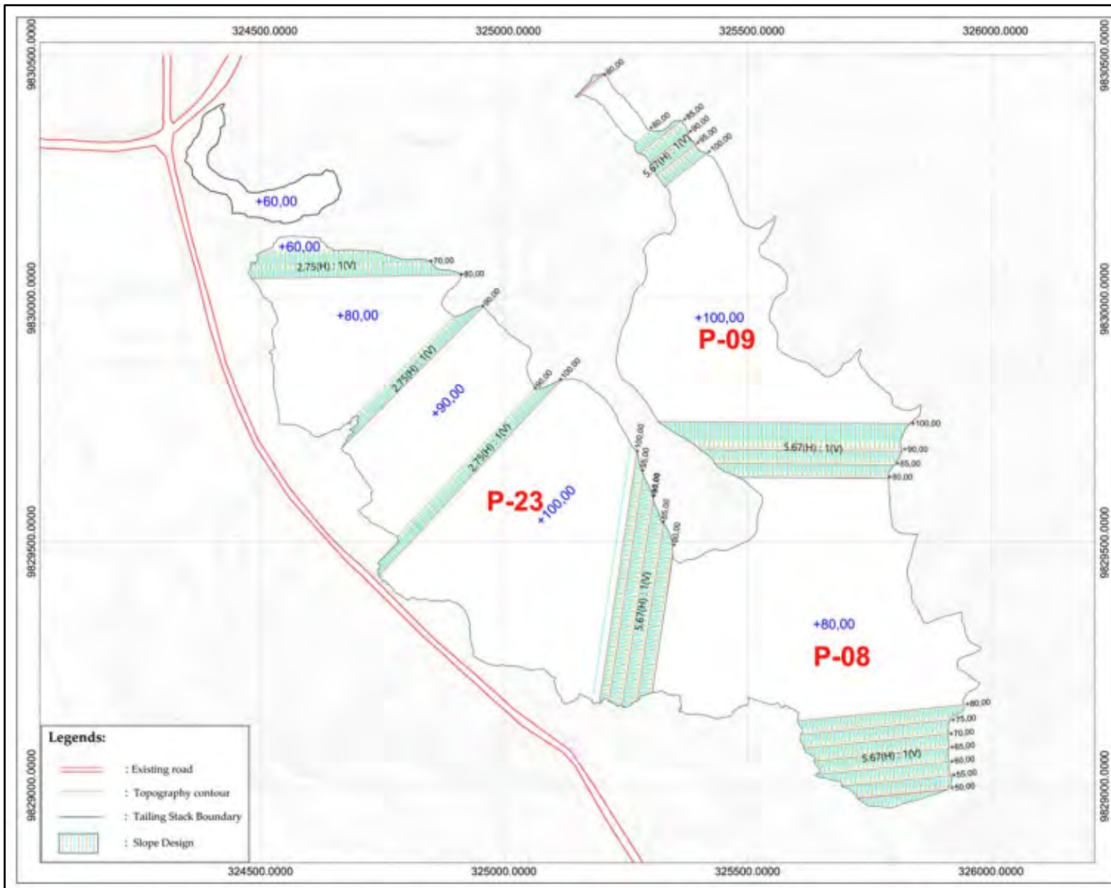

Figure I-3 General layout of dry backing stack plan (dry stack design)

Figure 21. The Dry Stack Tailings Facility (DSTF) at the PT HPL mine is being constructed in three stages, starting with P-23, then moving to P-09, and concluding with P-08. The rockfill buttresses are indicated by green stripes. See longitudinal sections of the three stages in Fig. 22. Figure from PT Lapi ITB (2022).

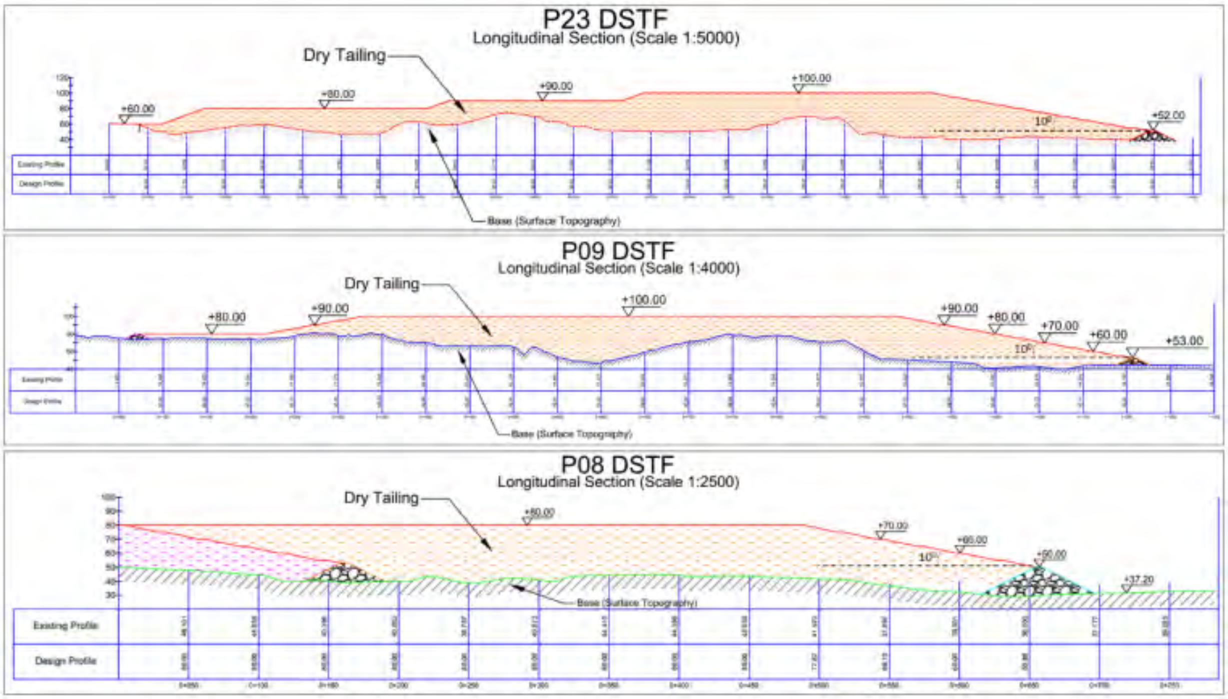

Figure I-4 Typical cross section of dry stack tailings of each area

Figure 22. The Dry Stack Tailings Facility (DSTF) at the PT HPL mine is being constructed in three stages, starting with P-23, then moving to P-09, and concluding with P-08. The maximum height will be 57 meters (see Table 1a). The tailings are being stacked far higher than the tops of the rockfill buttresses. Thus, the rockfill buttresses do not actually serve the function of dams. If the tailings liquefied, they could easily flow over the tops of the buttresses. See map views of the three stages in Fig. 21. Figure from PT Lapi ITB (2022).

According to PT Trimegah Bangun Persada (2023a), annual productions of tailings at PT HPL were 7,496,050 metric tons in 2023, 4,605,300 metric tons in 2022, and 1,595,180 metric tons in 2021. Since the PT HPL project was functioning at its nameplate capacity in 2023 (PT Halmahera Persada Lygend, 2023a), it could be assumed that the annual rate of tailings production in 2023 will continue into the future, so that the design capacity of the DSTF (57.2 million metric tons) will be reached before the end of 2029. PT Halmahera Persada Lygend (2023a) stated the nameplate capacity as 50,000 metric tons of nickel and 6500 metric tons of cobalt, so that the ratio of tailings to metal is 133, which is somewhat greater than the ratio of 100 that was assumed by Sangadji and Ginting (2023) and Sangadji (2024) or the ratio of 125 that was assumed by Fisher and Grossl (2023). In the absence of any other comparisons of tailings and metal productions for particular HPAL projects in Indonesia, a tailings-to-metal ratio of 133 will be assumed in this report.

The ratio of tailings to metal can be used to estimate the production rates of tailings by HPAL projects in Indonesia. The annual capacity for the seven existing HPAL projects is 405,000 metric tons of nickel and 26,500 metric tons of cobalt (see Table 1a). The 14 HPAL projects that are permitted and/or are under construction, including the eight new projects in the Indonesia Morowali Industrial Park, would have a combined annual capacity of 850,900 metric tons of nickel and 38,800 metric tons of cobalt (see Table 1b). Although, as already mentioned, the distinction between permitted and proposed projects is not always clear, the additional 12 HPAL projects in the proposal stage, including three more on Obi Island, would have a combined annual capacity of 745,900 metric tons of nickel (see Table 1c). Thus, the annual capacity of all operating and permitted projects would be 1,255,900 metric tons of nickel and 65,300 metric tons of cobalt, while the annual capacity of all operating, permitted, and proposed projects would be 2,001,800 metric tons of nickel and 65,300 metric tons of cobalt. The two HPAL projects in the Weda Bay Industrial Park that have been paused or cancelled would have had a combined annual capacity of 183,000 metric tons of nickel and 15,000 metric tons of cobalt. In summary, based on the ratio of HPAL tailings to metal of 133, the annual production rates of HPAL tailings by all operating projects, all operating plus permitted projects, and all operating plus permitted plus proposed projects would be 57 million metric tons per year, 176 million metric tons per year, and 275 million metric tons per year, respectively.

There are multiple filtered tailings storage facilities for the HPAL projects in the Indonesia Morowali Industrial Park with a total footprint of 600 hectares (Fisher and Grossl, 2023; Lee, 2023; see Table 4). According to mineworkers, filtered tailings storage facilities belonging to PT Huayue Nickel Cobalt (HYNC) and PT Qing Mei Bang (QMB) New Energy Materials are located at a site called KM8 or IMIP8 about 7.5 kilometers west of the Indonesia Morowali Industrial Park, at which the PT QMB tailings facility is northwest of the highway and the PT HYNC tailings facility is southeast of the highway (see Figs. 23-24). The combined footprint of the PT HYNC and PT QMB tailings facilities is less than 20 hectares, so a considerable footprint of tailings storage facilities must exist elsewhere on Sulawesi Island. Mineworkers have identified another location about two kilometers northwest of the PT HYNC/PT QMB tailings facilities as the site of a filtered tailings storage facility of an unknown company, which could be either PT HYNC or PT QMB, or potentially either PT ESG New Energy Material or PT Meiming New Energy Material, which began production in 2025 (see Table 1a). According to Fisher and Grossl (2023), "The tailings [for PT HYNC] are sent to a dry stack site – which is 7.5 kilometres away [apparently referring to the site KM8] … Dry stack tailings site [for PT QMB] is even further than for PT Huayue, at around 10 to 15 kilometres from the HPAL operation." It should be noted that even the location for the HPAL plant for PT Meiming New Energy Material within the Indonesia Morowali Industrial Park is unknown (see Fig. 23). The question as to whether PT QMB and PT HYNC have separate tailings facilities at the site KM8 or IMIP8 or whether they are the same facility, as well as company recognition that KM8 is the site of a tailings storage facility, will be discussed further in the section "Sulawesi Island: Ongoing Catastrophic Failure."

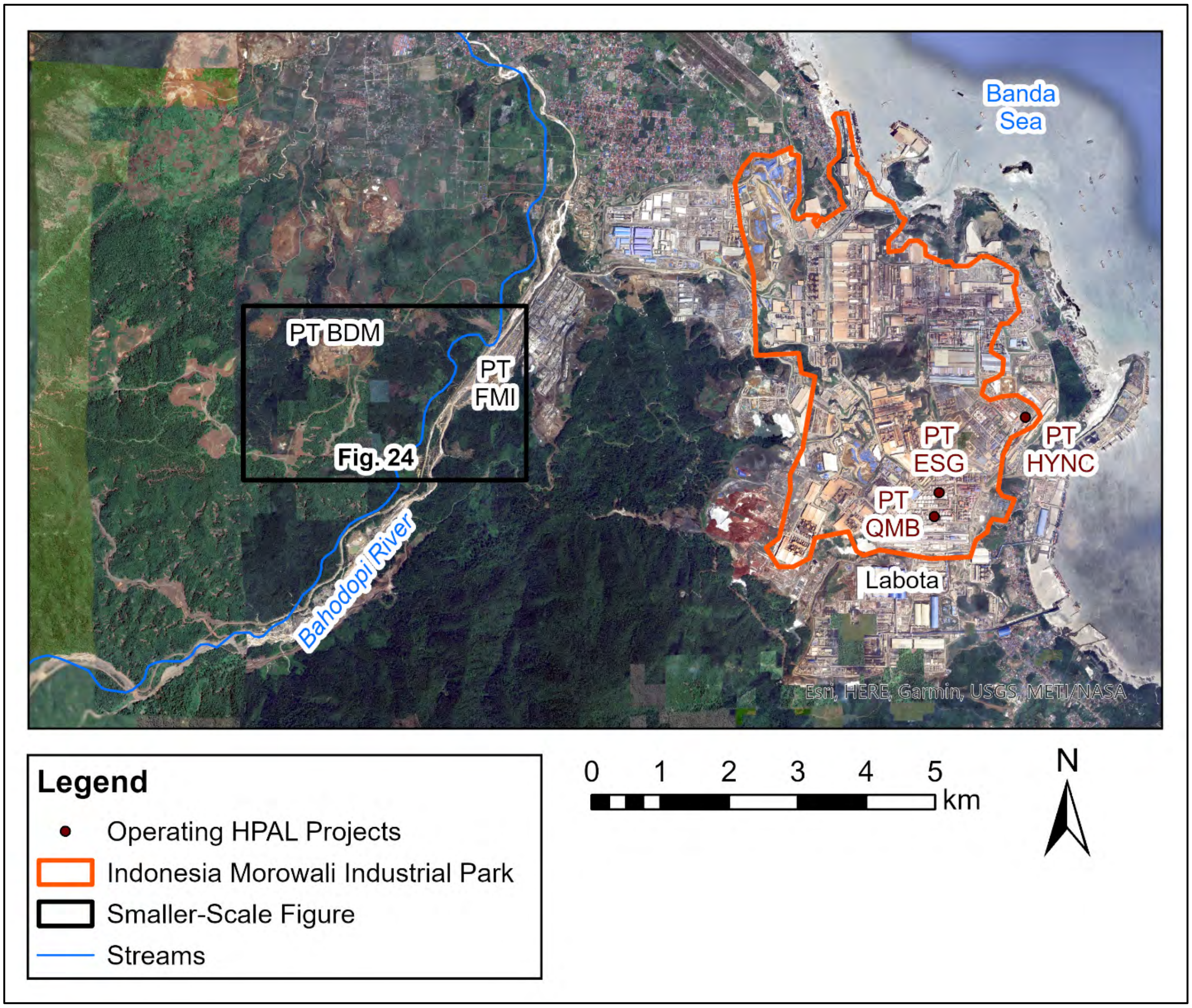

Figure 23. The only operating HPAL projects in the Indonesia Morowali Industrial Park IIMIP) are PT Huayue Nickel Cobalt (HYNC), PT Qing Mei Bang (QMB) New Energy Materials, PT ESG New Energy Material, and PT Meiming New Energy Material (see Table 1a). However, an additional eight HPAL projects have been permitted or are in the construction phase within the IMIP (see Table 1b). The exact location of PT Meiming New Energy Material is unknown. Outline of Indonesia Morowali Industrial Park from AidData (2025) and streams from EnergyData.info (2020).

Based upon an annual capacity of 70,000 metric tons of nickel and cobalt (IMIP, 2025a) and a tailings to metal ratio of 133, PT HYNC is currently generating 9.3 million metric tons of tailings per year (see Table 4). Based upon an annual capacity of 50,000 metric tons of nickel and cobalt (IMPI, 2025b) and the same ratio of tailings to metal, PT QMB is currently generating 6.6 million metric tons of tailings per year. The nameplate capacities of PT ESG New Energy Material and PT Meiming New Energy Material are 30,000 metric tons of nickel (IndoPremier, 2024) and 25,000 metric tons of nickel (Merdeka Battery Materials, 2025), respectively (see Table 1a). Thus, when the four HPAL projects in the Indonesia Morowali Industrial Park are all operating at nameplate capacity, potentially by mid-2026, the combined annual output will be

175,000 metric tons of nickel and cobalt, corresponding to annual production of 23.275 million metric tons of tailings.

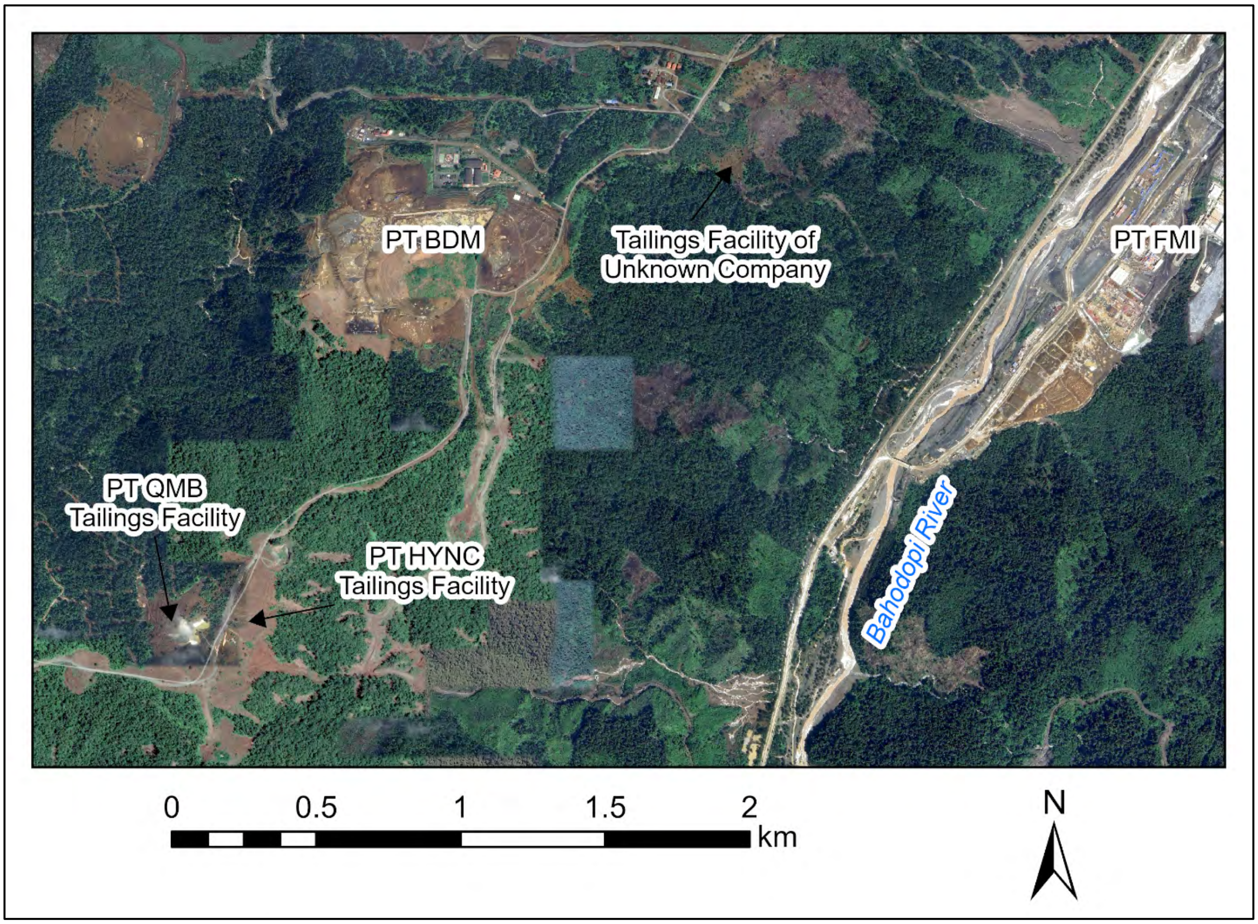

Figure 24. Within the Indonesia Morowali Industrial Park (IMIP), only three filtered tailings storage facilities have been located, which are the tailings facilities for PT Qing Mei Bang (QMB) New Energy Materials, PT Huayue Nickel Cobalt (HYNC), and an unknown company. The three facilities occupy an area far less than the total footprint of 600 hectares (6 square kilometers) for all filtered tailings storage facilities in IMIP (see Table 4). A collapse of any one of the three facilities could potentially transport tailings to the Bahodopi River (see smaller-scale view with tailings pathway in Figs. 41a-b). The location of the filtered tailings storage facilities for PT HYNC and PT QMB is known locally as KM8 or IMIP8. It is not entirely clear as to whether the filtered tailings storage facilities for PT HYNC and PT QMB are actually separate facilities (see Figs.40a and 42a). PT BDM (Bintang Delapan Mineral) and PT FMI (Fajar Metal Industry) are not HPAL projects. PT BDM is a nickel-ore mine, while PT FMI produces nickel sulfide for electric batteries. Background is Google Earth imagery from January 7, 2020, and January 3, 2025. Indonesian version of map available in Yayasan Tanah Merdeka (YTM) (2025b).

The least information is available regarding the filtered tailings storage facilities for the Weda Bay Industrial Park on Halmahera Island, for which even the locations of the tailings facilities is not known. Mecater Ingénierie (2023a) reported a contract to design a filtered tailings storage facility with a tailings capacity of 66 million metric tons (see Table 4) for PT Huafei Nickel Cobalt (HFNC), the only operating HPAL project in the Weda Bay Industrial Park. Based upon an annual capacity of 120,000 metric tons of nickel and 15,000 metric tons of cobalt for PT

HFNC (Nangoy, 2023; see Table 1a), and a tailings to metal ratio of 133, PT HFNC generates 17.9 million metric tons of tailings per year (see Table 4), so that the filtered tailings storage facility would completely fill in less than four years. Thus, just as with the Indonesia Morowali Industrial Park, there must be an intention to construct multiple filtered tailings storage facilities for the Weda Bay Industrial Park, especially considering that the HPAL project of PT Blue Sparkling Energy (BSE) should begin production in 2026 with nameplate capacity of 67,000 metric tons of nickel and 7500 metric tons of cobalt per year (Argus, 2024; IndoPremier, 2024; see Table 1b). Mecater Ingénierie (2023b) also reported a contract to design a filtered tailings storage facility with a tailings capacity of 67 million cubic meters for the Sonic Bay HPAL project in the Weda Bay Industrial Park, although the Sonic Bay project has since been paused or cancelled (see Table 4). Assuming a compacted tailings dry density of 2.0 metric tons per cubic meter (Cacciuttolo Vargas and Pérez Campomanes, 2022) and an anticipated annual tailings production rate of 10.35 million metric tons (Saputra et al., 2023), the proposed tailings facility would have filled in slightly over three years. The proposed nameplate capacity of 60,000 metric tons of nickel per year (IndoPremier, 2024; see Table 1d) and tailings to metal ratio of 133 would correspond to the generation of 8.0 million metric tons of tailings per year, which would have filled the tailings facility in slightly more than four years.

The only filtered tailings storage facility in Indonesia that does not store tailings from an HPAL project is the facility for the PT Nusa Halmahera Minerals (NHM) Gosowong gold mine (Tampi, 2024), for which the location is not known. According to Tampi (2024), "*Selain reklamasi dan rehabilitasi, pihak PT NHM juga memperkuat pengelolaan limbah dan Bahan Berbahaya Beracun (B3) sebagai upaya penambangan hijau. Bahkan, pada Februari 2023, NHM telah meresmikan pabrik Dry Stack Tailing (DST) yang merupakan fasilitas pengolahan limbah yang ramah lingkungan pertama di Indonesia tanpa merkuri*" [In addition to reclamation and rehabilitation, PT NHM also strengthens the management of waste and Hazardous and Toxic Materials (B3) as an effort for green mining. In fact, in February 2023, NHM inaugurated the Dry Stack Tailing (DST) plant, which is the first environmentally friendly waste processing facility in Indonesia without mercury]. Thus, as with the tailings from HPAL projects, filtered tailings storage facilities are viewed as an essential component of "*penambangan hijau*" [green mining]. The reference to "*tanpa merkuri"* [without mercury] in Tampi (2024) is unclear. Moreover, when the filtered tailings storage facility at the PT NHM Gosowong gold mine was opened in 2023, filtered tailings storage facilities already existed for the PT HPL, PT HYNC, and PT QMB projects (see Table 1a), so that the reference to the "*fasilitas pengolahan limbah yang ramah lingkungan pertama di Indonesia*" [first environmentally friendly waste processing facility in Indonesia] is also unclear. According to NHM Gosowong Gold Mine (2025), the ore processing plant has an annual capacity of 800,000 dry metric tons. Therefore, the annual production rate of gold tailings is limited by and probably close to 800,000 metric tons, which is far less than the filtered tailings storage facilities for HPAL projects (see Table 4).

An understanding of filtered tailings technology in Indonesia is hampered by the large amount of contradictory information among company documents and media articles. The tables of HPAL projects listing only the name, location, ownership, annual capacity, and operational year (see Tables 1a-d) rely upon the survey by IndoPremier (2024) as the default, but also state alternative information from other sources. The greatest discrepancies were among annual cobalt capacities, with many sources stating only annual nickel capacities, so that it was not clear as to whether the source intended to state that there was or would be zero cobalt production.

Unfortunately, contradictory information was found even with single company documents, especially for the filtered tailings storage facility of PT Halmahera Persada Lygend (HPL) on Obi Island, which is the only tailings facility in Indonesia for which detailed information is available. For example, PT Halmahera Persada Lygend (2024) states that 7,496,050 metric tons of tailings were generated by PT HPL in 2023 (in exact agreement with PT Trimegah Bangun Persada (2023a)) and also that "as of December 2023, 5.7 million tons of tailings were stored at the DSTF [Dry Stack Tailings Facility]. The total tailings production for 2023 is in exact agreement with the value stated by PT Trimegah Bangun Persada (2023a), who also state that "since start of PT HPL operations … 100% of tailings sent to dry stack tailing facilities (DSTF)." As a second example, PT Halmahera Persada Lygend (2024) states a maximum storage capacity of 57.2 million metric tons for the DSTF, but also that 28,399,985 and 28,862,204 metric tons of tailings are currently stored, in section P23 and section P89 (presumably meaning sections P-08 and P-09 combined), respectively (see Fig. 21). No attempt was made in this report to document all contradictory information. In all cases, the most accurate values were determined to be the ones that were most frequently stated and most consistent with values in the same source and other sources (see Table 4). The possibility that the Dry Stack Tailings Facility (DSTF) is not the only filtered tailings storage facility for PT HPL is further discussed in the section "Obi Island: Imminent Catastrophic Failure."

CURRENT TECHNOLOGICAL LIMITS FOR FILTERED TAILINGS

The purpose of this section is to locate filtered tailings storage facilities in Indonesia within the global context of filtered tailings storage facilities, especially in terms of current technological limits on filtered tailings. Because of the tendency for high precipitation to re-saturate filtered tailings, the precipitation rate is the primary constraint on the height, storage volume, and throughput (tailings production rate) of filtered tailings storage facilities. The current technological limit for filtered tailings storage facilities was determined by collecting data on 84 filtered tailings facilities with known heights and storage volumes, as well as 23 facilities with known throughputs (Klohn Crippen Berger, 2017; Franks et al., 2021; Cacciuttolo Vargas and Pérez Campomanes, 2022; UNEP et al., 2025; see Table 6a-b). For all tailings facility sites, the mean annual precipitation was determined from the climate model developed by (Fick and Hijmans, 2017) with a spatial resolution of one kilometer (see Tables 6a-b). Further information about the significance of the current technological limit can be found in Russell et al. (2024) and Emerman (2024).

The current technological limit on storage volume was constrained by a line connecting the filtered tailings storage facility at the La Coipa mine in Chile with tailings storage of 71 million cubic meters and mean annual precipitation of 43 mm and the filtered tailings storage facility at the COMILOG mine in Gabon with tailings storage of 8.6 million cubic meters and mean annual precipitation of 1779 mm (see Fig. 25a). It can easily be seen that filtered tailings storage facilities with large storage volumes are found exclusively at mines in arid or semi-arid climates, such as the Orapa and Jwaneng mines in Botswana, with mean annual precipitations of 307 and 357 mm, respectively (see Table 6a and Fig. 25a). In fact, the greatest tailings storage volumes in even moderately wet climates are found at the Khwezela mine in South Africa with a storage volume of 13.1 million cubic meters and mean annual precipitation of 685 mm, and the Alamo Dorado mine in Mexico with storage volume of 11.5 million cubic meters and mean annual precipitation of 711 mm (see Table 6a and Fig. 25a). The failures of the filtered tailings storage facilities at the Pau Branco and Turmalina mines in Brazil have already been discussed (see Figs. 14, 15a-b, and 17). The filtered tailings storage facility at the Pinos Altos mine in Mexico has also been reported as unstable with no further information (Franks et al., 2021; UNEP et al., 2025). Assigning mean annual precipitations of 1597, 1360, and 1046 mm (Fick and Hijmans, 2017), and tailings storage volumes of 2.85, 0.71, and 5.152 million cubic meters (Agência Nacional de Mineração, 2025; UNEP et al., 2025) for the filtered tailings storage facilities at the Pau Branco, Turmalina, and Pinos Altos mines, respectively, shows that construction even well within the current technological limit is no guarantee of success (see Fig. 25a).

Table 6a. Filtered tailings storage facilities outside of Indonesia with known heights and storage volumes[1]

Country	Mine	Filtered Tailings Storage Facility	Height (m)	Storage Volume (Mm^3)	Annual Precipitation (mm)[2]
Australia	Gove[3]	Pond 3	29	9.6	1313
Australia	Gove[3]	Pond 4	42	10.33	1313
Botswana	Damtshaa	Damtshaa CRD	56	12	311
Botswana	Jwaneng	Jwaneng JMP CRD	17	0.3	358
Botswana	Jwaneng	Jwaneng RP CRD	35	37.5	357
Botswana	Letlhakane	Letlhakane -LTP CRD	22	5	324
Botswana	Orapa	Orapa Plant 1 CRD	73	52.4	307
Botswana	Orapa	Orapa Plant 2 CRD	68	11.9	306
Brazil	Barro Alto	Slag Pile No. 1	80	7.4	1465
Brazil	Codemin	Codemin: Slag Pile No. 1	45	3.5	1517
Brazil	Codemin	Codemin: Slag Pile No. 2	60	3.8	1517
Brazil	Serra Azul	Serra Azul Dry Stack	64	3.08	1571
Canada	Caribou	TSF 2 Anaconda	11	0.165	1136
Canada	CEZinc Processing Plant	Ferrite (West)	3	3	989
Canada	Gahcho Kue	Gahcho Kue Course PKC Pile	20	2.9	297
Canada	Meliadine[3]	Meliadine TSF	5	0.089	306
Canada	Raglan Mine	Raglan (Tailings Dry Stack)	35	11	447
Canada	Sorel-Tracy	P84	33	3.28533	990
Canada	Victor	Victor Coarse PK & Lo rade Ore Stockpile	12	5.94	615

Canada	Victor	Victor Coarse PK & overburden Stockpile	14	5.4	612
Chile	Chagres	Chagres Slag Heap	25	0.861435	311
Chile	El Indio	Dry Stack TSFs 1,2 and 3	215	2.8	152
Chile	La Coipa	La Coipa	200	71	43
France	Montgrand	Montgrand 0128	15	0.65	589
Gabon	COMILOG	COMILOG CIM	30	8.6	1779
Guatemala	Escobal	Escobal	42	1.5	1543
Kyrgyzstan	Bozymchak	Bozymchak	35	2	527
Mexico	Alamo Dorado	Alamo Dorado	60	11.5	711
Mexico	Pinos Altos[3]	Pinos Altos TMF	105	5.152	1047
Mexico	San Jose Mine	Cuzcatlan Dry Stack	22.5	1.157847	680
Namibia	Orange River	Auchas CRD	64	5.2	51
Namibia	Orange River	Daberas DTP CRD	68	11.2	37
Namibia	Orange River	Daberas OTP CRD	57	8.8	39
Namibia	Orange River	Sendelingsdrif CRD - TD1	55	0.3	33
Namibia	Southern Coastal	1 Plant CRD	46	3.3	48
Namibia	Southern Coastal	2 Plant CRD	65	10.9	43
Namibia	Southern Coastal	3 Plant CRD	59	3.6	52
Namibia	Southern Coastal	4 Plant CRD	72	10.1	49
Namibia	Southern Coastal	Elizabeth Bay CRD	66	6.5	17
Namibia	Southern Coastal	PTF CRD	49	6	53
Peru	Tombomayo[3]	Relavera 1	20	0.8	570
Russia	Amursk	Amursk DSF	—	1.7454	583
Russia	Kupol Gold Mine	Kupol Dry Stack TSF	23	2.2	315
Russia	Voro	Voro DSF	—	—	495
Saudi Arabia	Jabal Sayid	Dry Stack TSF	28	2.4	100
South Africa	Goedehoop	Klein Shaft	14	0.5	696
South Africa	Goedehoop	Old Springbok No.1	39	2.5	686
South Africa	Goedehoop	Old Springbok No.2	13	1.25	674
South Africa	Goedehoop	Schoonie Dump	31	0.7	690
South Africa	Greenside	Clydesdale Dump	10	0.1	695
South Africa	Ingagane	Ingagane No. 1	18	0.51	788
South Africa	Ingagane	Ingagane No. 2	8	0.1	788
South Africa	Khwezela	Anglo French	22	0.18	696
South Africa	Khwezela	Kleinkopje Dump/Roof Coal Dump combined	46	13.1	685
South Africa	Khwezela	Klipfontein Dump	45	10	697
South Africa	Khwezela	Landau 1 Dump	2	0.2	700
South Africa	Khwezela	Landau 2 Dump	24	2	701

South Africa	Khwezela	Old Navigation Dump	36	5.7	700
South Africa	Mafube	Mafube De-watered Fines Dump	25	4.5	709
South Africa	Mafube	Mafube Discards Dump	30	3.84	709
South Africa	Middelburg Steam & Station Colliery	No. 2 Dump	20	0.4	704
South Africa	Middelburg Steam & Station Colliery	Presentation Dump	10	0.2	701
South Africa	Mortimer	Mortimer Slag Stockpile	28	1.6	613
South Africa	Namaqualand	Namaqualand AK3 CRD	51	11.1	96
South Africa	Namaqualand	Namaqualand Bulk Sample CRD	34	2.6	83
South Africa	Namaqualand	Namaqualand Tweepad CRD	66	16	77
South Africa	Natal Anthracite Colliery	Boschhoek	42	0.7	864
South Africa	Polokwane	Polokwane Slag Stockpile	38	3.3	703
South Africa	Venetia	Venetia CRD	42	16.4	359
South Africa	Voorspoed	Voorspoed CRD	40	9	615
South Africa	Vryheid Coronation Colliery	No. 1 Dump	20	1.25	860
South Africa	Vryheid Coronation Colliery	No. 2 Dump	40	1.25	861
South Africa	Vryheid Coronation Colliery	No. 3 Dump	36	1.7	864
South Africa	Vryheid Coronation Colliery	No. 4 Dump	20	3.75	866
Spain	N/A	Cobre Las Cruces TSF	35	7.076	522
USA	Greens Creek	Greens Creek	109	3.89	1760
USA	Idarado	Red Mountain #1	15	0.04	806
USA	Idarado	Red Mountain #2	20	0.1	806
USA	Idarado	Red Mountain #3	15	0.1	806
USA	Idarado	Red Mountain #4	15	1.5	806

USA	Idarado	Red Mountain Buried Tailings	30		806
USA	Idarado	Telluride Tailings Pile 1-4	13	0.22	806
USA	Idarado	Telluride Tailings Pile 5-6	30	9.5	806
Zimbabwe	Unki	Unki Slag Stockpile	—	0.01	695

[1]All data from UNEP et al. (2025) except where otherwise indicated.
[2]Annual precipitation estimated by comparing latitude and longitude in UNEP et al. (2025) with Fick and Hijmans (2017).
[3]Data from Franks et al. (2021)

Table 6b. Filtered tailings storage facilities outside of Indonesia with known tailings production rates

Mine	Country	Tailings Production Rate (metric tons per day)		Mean Annual Precipitation[1] (mm)
		2017[2]	2022[3]	
Alamo Dorado	Mexico	4000	3500	800
Bellekeno	Canada	188	—	280
Catalina Huanca	Peru	2000	1850	854
Cerro Lindo	Peru	6480	5000	200
Efemçukuru	Turkey	700	1500	740
El Indio	Chile		3000	12
El Peñon	Chile	4200	3500	50
El Sauzal	Mexico	5770	5300	800
El Toqui	Chile	1725	—	1480
Éléonore	Canada	4000	—	720
Escobal	Guatemala	1528	—	1689
Gold Road	USA	500	—	261
Greens Creek	USA	750	1500	1450
Karara	Australia	35000	50000	310
La Coipa	Chile	18000	20000	9
Mantos Blancos	Chile	12000	12000	50
Marlin	Guatemala	6000	—	1136
Meliadine	Canada	5000	—	412
Minto	Canada	3800	—	250
Pogo	USA	1360	2500	356
Raglan	Canada	3520	—	520
San Dimas	Mexico	2500	—	87
Skorpion Zinc	Namibia	5040	—	20

[1]Data from Klohn Crippen Berger (2017), Fick and Hijmans (2017), and Cacciuttolo Vargas and Pérez Campomanes (2022)
[2]Data from Klohn Crippen Berger (2017)
[3]Data from Cacciuttolo Vargas and Pérez Campomanes (2022)

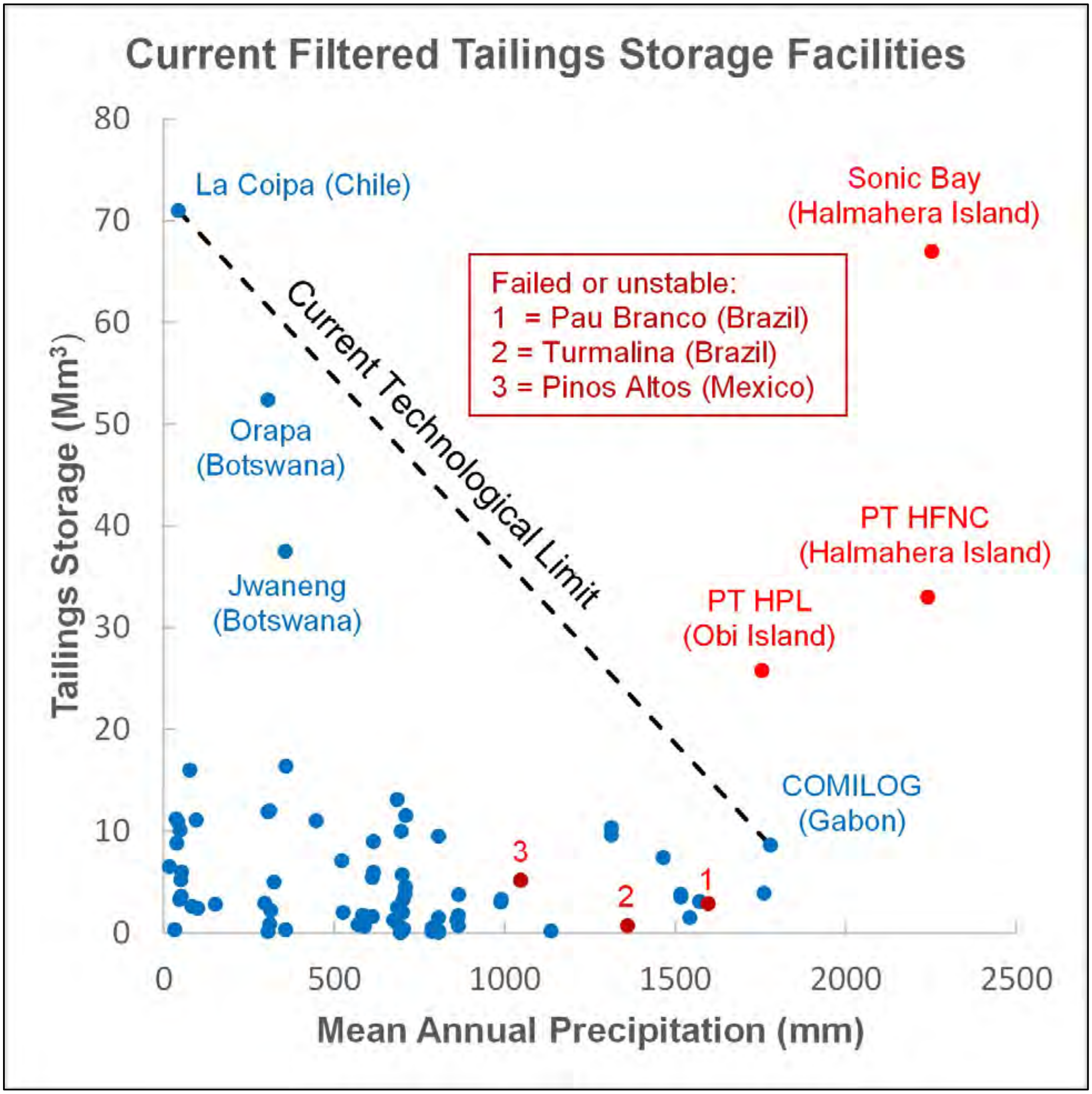

Figure 25a. The chief limitation on the size of filtered tailings storage facilities is the impact of precipitation. The current technological limit is constrained by a line connecting the filtered tailings storage facility at the La Coipa mine in Chile with tailings storage of 71 million cubic meters and mean annual precipitation of 43 mm and the filtered tailings storage facility at the COMILOG mine in Gabon with tailings storage of 8.6 million cubic meters and mean annual precipitation of 1779 mm. The mean annual precipitations of 2252, 2241, and 1754 mm, and tailings storage volumes of 67, 33, and 25.8 million cubic meters for the filtered tailings storage facilities at the Sonic Bay, PT HFNC, and PT HPL projects, respectively (see Table 4), place all three facilities well outside of the current technological limit. The mean annual precipitations of 1597, 1360, and 1046 mm, and tailings storage volumes of 2.85, 0.71, and 5.152 million cubic meters for the filtered tailings storage facilities at the Pau Branco, Turmalina, and Pinos Altos mines, respectively, show that construction within the current technological limit is not a guarantee of success. Data on existing filtered tailings storage facilities from Franks et al. (2021), UNEP et al. (2025) and Agência Nacional de Mineração (2025), and mean annual precipitation from Fick and Hijmans (2017).

The model of Fick and Hijmans (2017) was also used to assign mean annual precipitations of 2252, 2241, and 1754 mm to the sites of the filtered tailings storage facilities at the Sonic Bay, PT HFNC, and PT HPL projects, respectively. The exact locations for the sites of the filtered tailings storage facilities on Halmahera Island (PT HFNC and Sonic Bay) are not actually known, but the mean annual precipitations are based upon the best estimates by staff at Survival International. Combining the mean annual precipitations with tailings storage volumes of 67, 33, and 25.8 million cubic meters for the filtered tailings storage facilities at the Sonic Bay, PT HFNC, and PT HPL projects, respectively (see Table 4), places all three facilities well outside of the current technological limit (see Fig. 25a). The assignment of a storage volume of 33 million cubic meters for the tailings facility at the PT HFNC project was based on the assumption of a compacted tailings dry density of 2.0 metric tons per cubic meter (see Table 4). It is especially noteworthy that the sites for the two projects on Halmahera Island have mean annual precipitations that far exceed the rainfall for any existing filtered tailings storage facility, the wettest site being the COMILOG mine in Gabon with a mean annual precipitation of 1779 mm (see Fig. 25a).

In a similar way, the current technological limit on height was constrained by a line connecting the La Coipa filtered tailings storage facility with a height of 200 meters and mean annual precipitation of 43 mm and the COMILOG filtered tailings storage facility with a height of 30 meters and mean annual precipitation of 1779 mm (see Fig. 25b). Although the filtered tailings storage facility at the Greens Creek mine in Alaska has a height of 109 meters at a mean annual precipitation of 1760 mm (see Table 6a), the throughput (tailings production rate) is only 1500 metric tons per day (see Table 6b). Therefore, the success of the Greens Creek facility is probably not relevant to the success of the Sonic Bay, PT HFNC, and PT HPL projects, which have throughputs of 28,356, 49,041, and 20,537 metric tons per day, respectively (see Table 4). It is curious that, with mean annual precipitations of 1597, 1360, and 1046 mm (Fick and Hijmans, 2017), and heights of 48, 19, and 105 meters for the filtered tailings storage facilities at the Pau Branco, Turmalina, and Pinos Altos mines, respectively (Agência Nacional de Mineração, 2025; UNEP et al., 2025), the heights of the Pau Branco and Pinos Altos facilities roughly met the current technological limit, although the height of the Turmalina facility was well below the limit. In any event, the mean annual precipitations of 1754 mm and height of 57 meters for the filtered tailings storage facility at the PT HPL mine (see Table 4) places the height of the facility 25 meters above the current technological limit (see Fig. 25b). Unfortunately, the Dry Stack Tailings Facility (DSTF) at the PT HPL project is the only filtered tailings storage facility in Indonesia with a known maximum height.

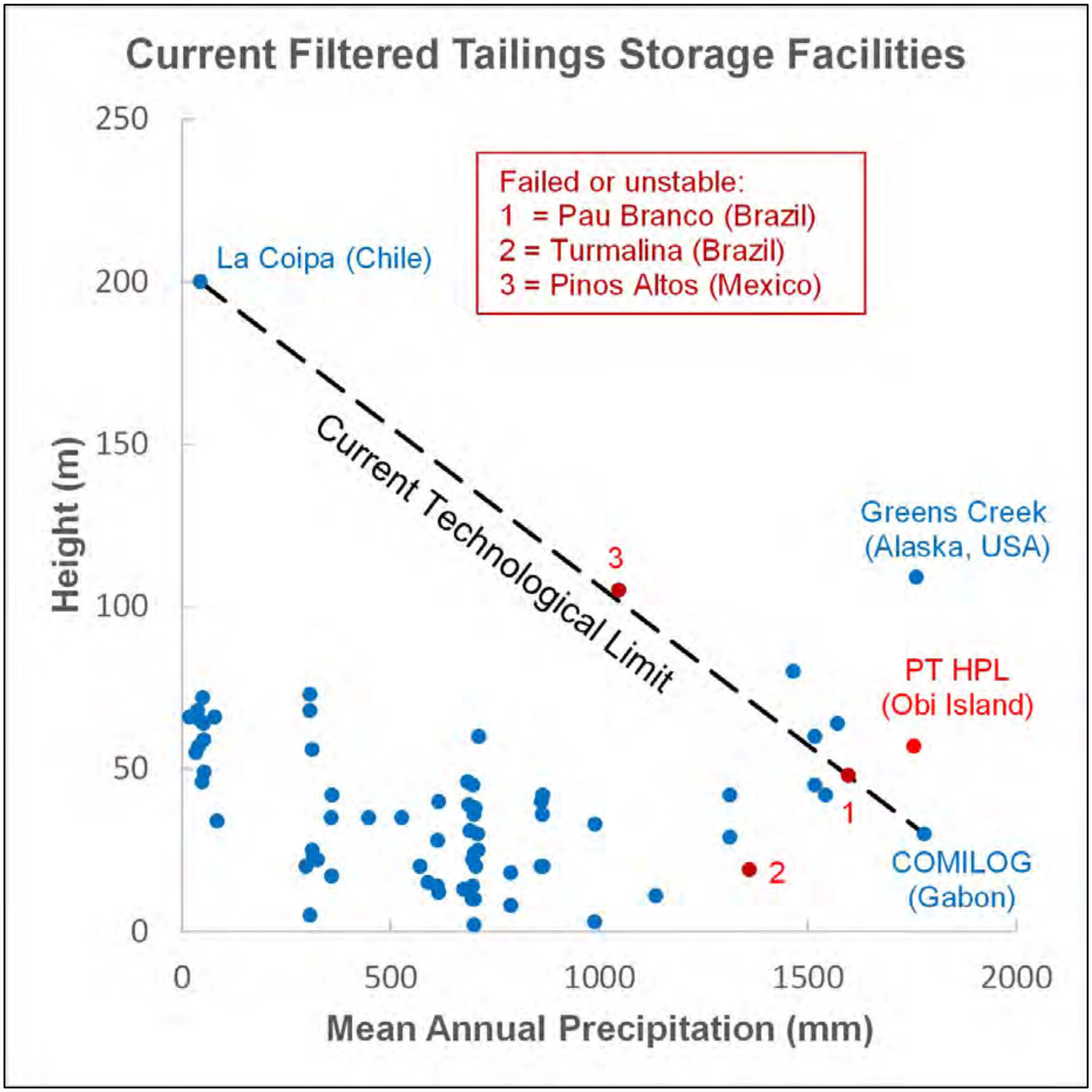

Figure 25b. At the present time, the chief limitation on the size of filtered tailings storage facilities is the impact of precipitation. Thus, the current technological limit is roughly constrained by a line connecting the La Coipa filtered tailings storage facility in Chile with a height of 200 meters and mean annual precipitation of 43 mm and the COMILOG filtered tailings storage facility in Gabon with a height of 30 meters and mean annual precipitation of 1779 mm. The height of the filtered tailings storage facility at the Greens Creek mine is not relevant since its tailings production rate had been only 750 metric tons per day, which increased to 1500 metric tons per day by 2022 (see Table 6b), as opposed to the planned tailings production rate of 20,537 metric tons per day at the PT HPL mine (see Table 4). The mean annual precipitations of 1754 mm and height of 57 meters for the filtered tailings storage facility at the PT HPL mine (see Table 1a) places the height of the facility 25 meters above the current technological limit. The mean annual precipitations of 1597, 1360, and 1046 mm, and heights of 48, 19, and 105 meters for the filtered tailings storage facilities at the Pau Branco, Turmalina, and Pinos Altos mines, respectively, show that the heights of the Pau Branco and Pinos Altos facilities roughly met the current technological limit, while the height of the Turmalina facility was well below the limit. Data on existing filtered tailings storage facilities from Franks et al. (2021), UNEP et al. (2025) and Agência Nacional de Mineração (2025), and mean annual precipitation from Fick and Hijmans (2017).

Finally, the current technological limit on throughput was constrained by a line connecting the Karara filtered tailings stack in Australia with a tailings production rate of 50,000 metric tons per day and mean annual precipitation of 310 mm and the Escobal filtered tailings stack in Guatemala with a tailings production rate of 1528 metric tons per day and mean annual precipitation of 1689 mm (see Fig. 25c). Thus far, the greatest known tailings throughput in a wet climate has been carried out at the Marlin mine in Guatemala with a throughput of 6000 metric tons per day at a mean annual precipitation of 1136 mm (see Table 6b). Using the mean annual precipitations of 2252, 2241, and 1754 mm, and tailings production rates of 28,356, 49,041, and 20,537 metric tons per day for the filtered tailings storage facilities at the Sonic Bay, PT HFNC, and PT HPL projects, respectively (see Table 4), as stated above, then places all three facilities far outside of the current technological limit (see Fig. 25c). In summary, the Sonic Bay, PT HFNC, and PT HPL projects are all clearly beyond current technological limits for storage volume, height, and throughput for a given precipitation rate.

It could reasonably be argued that the assessment of the current technological limits for storage volume, height and throughput (see Figs. 25a-c) are not based upon the most recent data. Although most of the data on storage volume and height come from the database maintained by UNEP et al. (2025), some of the entries have not been updated since 2020, and the database does not clarify when an entry was last updated. In addition, there has been no compilation of filtered tailings production rates since the review by Cacciuttolo Vargas and Pérez Campomanes (2022). Thus, it is possible that some large filtered tailings storage facilities may have appeared in wet climates over the last several years and have gone unnoticed by the author. However, the mere appearance of a large filtered tailings storage facility in a wet climate does not guarantee the success of such an endeavor because the community of tailings specialists needs time to learn from the successes and failures of these large facilities in wet climates. Even so, it could be questioned as to how much knowledge is actually exchanged among tailings specialists, due to the scarcity of publicly available information about filtered tailings storage facilities. In particular, there have been no publicly available analyses of the causes of and lessons to be learned from the recent failures of the filtered tailings storage facilities at the Pau Branco or Turmalina mines in Brazil, nor of the failures and reported instabilities of the filtered tailings storage facilities at the Cuzcatlán and Pinos Altos mines in Mexico. On the subject of failure to learn, this report now turns to the imminent catastrophic failure of the filtered tailings storage facility of the PT Halmahera Persada Lygend (HPL) project on Obi Island.

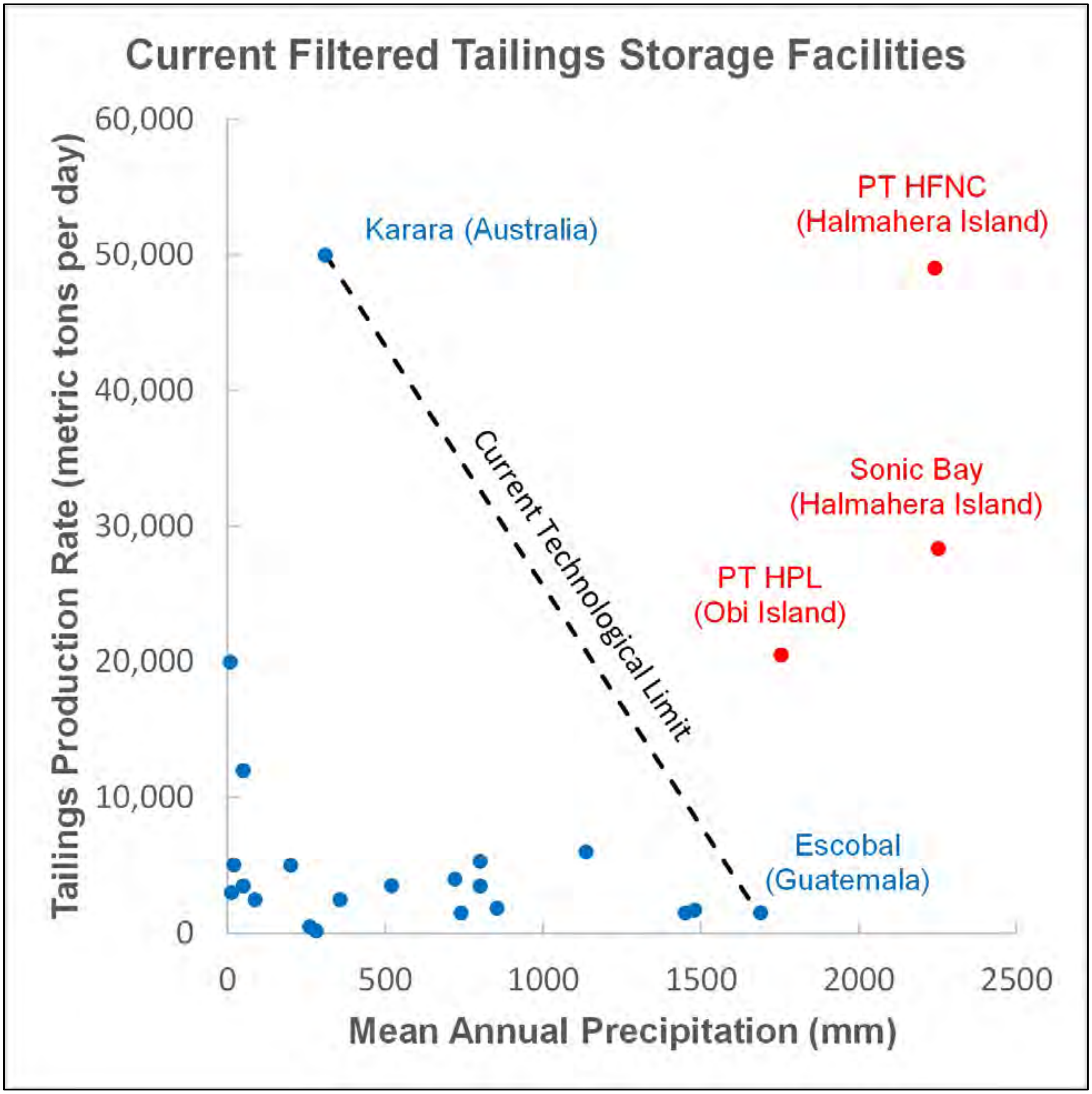

Figure 25c. At the present time, the chief limitation on the size of filtered tailings stacks is the impact of precipitation. Thus, the current technological limit is constrained by a line connecting the Karara filtered tailings stack in Australia with a tailings production rate of 50,000 metric tons per day and mean annual precipitation of 310 mm and the Escobal filtered tailings stack in Guatemala with a tailings production rate of 1528 metric tons per day and mean annual precipitation of 1689 mm. The mean annual precipitations of 2252, 2241, and 1754 mm, and tailings production rates of 28,356, 49,041, and 20,537 metric tons per day for the filtered tailings storage facilities at the Sonic Bay, PT HFNC, and PT HPL projects, respectively (see Table 4), place all three facilities far outside of the current technological limit. Data on existing filtered tailings stacks from Klohn Crippen Berger (2017) and Cacciuttolo Vargas and Pérez Campomanes (2022). Mean annual precipitation from Klohn Crippen Berger (2017), Fick and Hijmans (2017), and Cacciuttolo Vargas and Pérez Campomanes (2022).

Groundwater Contamination

In December 2022 SRK Consulting submitted a consulting report on the PT HPL project on Obi Island entitled “Final—Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Project Green ITAR, Obi Island, Sulawesi, Indonesia” (SRK Consulting, 2022a). The report had gone through nine major revisions with numerous minor revisions, such as Revisions 7A, 7B, 7C, 7D, and 7E. According to SRK Consulting (2022a), “SRK was advised that moisture content of the dry stack tailings facility, the groundwater quality and the leachate quality monitoring is undertaken monthly and reported every 3 months … Several markers of groundwater quality exceeded the standards (B, Ni, Cr6+).” SRK Consulting (2022a) pointed to deficiencies in both design and construction, but did not directly connect the deficiencies with groundwater contamination. According to SRK Consulting (2022a), “Figure 7-10 (Lapi ITB, 2022) [see Fig. 26 in this report] shows the drainage plan, but [how] the discharge of P 23-SE and P09-SW drains away from the dry stack tailings facility is unclear. It was also noted that part of the drainage infrastructure was still under construction …Water treatment ponds in poor condition and some areas are still under construction.”

In a table with the heading “Risk analysis for HPAL dry stack tailings facility,” SRK Consulting (2022a) identified “Assessment of the potential of metals to resolubilise and leach into the natural ground” as a “Gap/Risk” with the “Possible Impact” being “Possible contamination of natural ground.” The only “Mitigation” that was recommended by SRK Consulting (2022a) was “Investigate potential leachability of metals into natural ground.” A study of the metal leaching potential of the HPAL tailings would certainly not count as a means of preventing (mitigating) groundwater contamination, nor as a means of remediating groundwater contamination that had already been known to occur. In a sense, the recommendation simply accepts that groundwater contamination will occur if the tailings have the potential to leach metals.

In a similar way, Revision 1 identified “Assessment of geochemistry of the waste, and the potential of Acid Forming (PAF) and acid drainage is required” in the category of “Gap/Risk” with the “Possible Impact” of “Potential acid drainage into water bodies. The impact will vary depending on the material geochemistry but carries the risk of environmental contamination and fines” and the recommendation of “Investigate geochemistry and potential acidification of both slag and dry-stack storage facilities” (SRK Consulting, 2022b). The recommendation to investigate the potential for acid mine drainage remained in the next minor update (SRK Consulting, 2022c), but had disappeared by Revision 2 (SRK Consulting, 2022d). However, whether the tailings were potentially acid generating had still not been resolved by the time of submission of the final Revision 9, since Revision 9 states “The material has not been classified according to the potential to generate acid drainage” (SRK Consulting, 2022a).

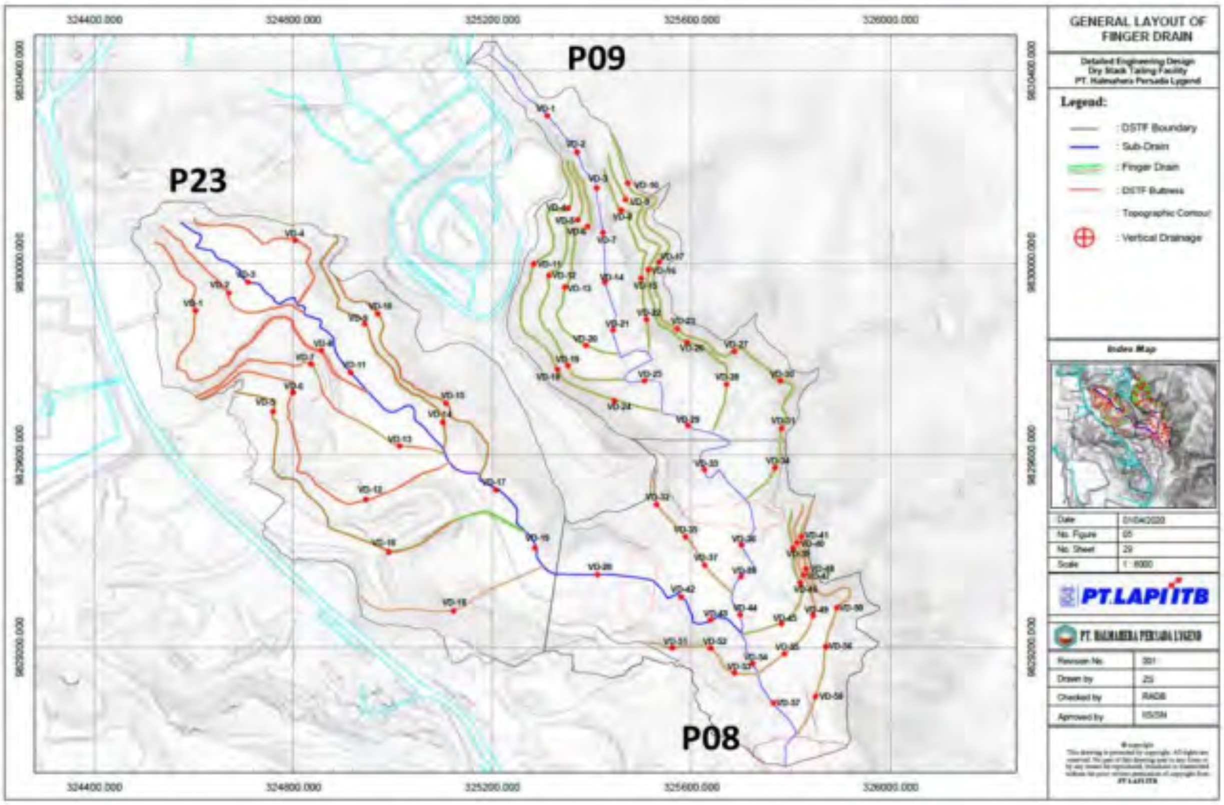

Figure I-20 Location of vertical drain placement

Figure 26. Although the Dry Stack Tailings Facility (DSTF) at the PT HPL mine had been operating for 1.5 years out of an anticipated lifetime of six years, SRK Consulting (2022a) noted that the drainage infrastructure had still not been completed. Moreover, SRK Consulting (2022a) could not understand how the drainage system was supposed to function. According to SRK Consulting (2022a), " [How] the discharge of P 23-SE and P09-SW drains away from the dry stack tailings facility is unclear. It was also noted that part of the drainage infrastructure was still under construction." Figure from PT Lapi ITB (2022).

In a sense, groundwater contamination was built into the design of the Dry Stack Tailings Facility (DSTF). None of the available documents on the DSTF (Hatch, 2020; PT Lapi ITB, 2020, 2022; SRK Consulting, 2022a) mention the existence of a liner system, which would be the standard means of preventing groundwater contamination, together with appropriate drainage infrastructure both above and below the liner system. In fact, PT Lapi ITB (2020) predicted mean annual leakage to the underlying aquifer of 29,326 cubic meters per year with a daily peak of 82.86 cubic meters per day (see Figs. 27a-b). According to PT Lapi ITB (2020), "The generation of leachate is caused principally by water percolating through tailing deposited. Once in contact with tailings, the percolating water becomes contaminated, and if it then flows out of the tailing deposit it is termed leachate." PT Lapi ITB (2020) further predicted rises in the water table within the DSTF of 31 meters due to the inability of the leachate from the DSTF to flow away fast enough into the underlying aquifer (see Fig. 28). Finally, PT Lapi ITB (2020) produced a series of maps predicting the "Spread of Contaminants" 10 years, 50 years, and 100 years after the opening of the DSTF (see Figs. 29a-c). The implication of the predicted high water table for the physical stability and liquefaction potential of the DSTF is further discussed in the following subsection.

Table III-10 Estimated Annual Average and Daily Peaks Leachate Quantity

DSTF	Parameters	Annual Average		Peaks Daily	
		mm/year	m^3/year	mm/day	m^3/day
P23	Precipitation	3,024.06	1,463,341.60	861.1	416,686.28
	Estimation Drainage collected	562.34	272,117.34	4.28	2071.60
	Estimation Leakege to Aquifer	30.94	14,974.89	0.08	42.27
P09	Precipitation	3,024.06	793,210.00	861.1	225,866.51

Figure 27a. A consulting report by PT Lapi ITB predicted that 14,975 cubic meters of potentially contaminated water would leak each year from section P23 (see Fig. 21) of the Dry Stack Tailings Facility (DSTF) at the PT HPL mine into the underlying aquifer. Thus, the potential contamination of groundwater seems to have been implicit in the design of the facility. See continuation of table in Fig. 27b. Table from PT Lapi ITB (2020).

DSTF	Parameters	Annual Average		Peaks Daily	
		mm/year	m^3/year	mm/day	m^3/day
	Estimation Drainage collected	652.08	147,434.81	4.16	1092.62
	Estimation Leakege to Aquifer	30.96	8120.99	0.08	22.92
P08	Precipitation	3,024.06	612,069.30	861.1	174,286.64
	Estimation Drainage collected	565.08	114,373.24	6.43	1302.64
	Estimation Leakege to Aquifer	30.78	6,230.60	0.08	17.67
Total Estimation Drainage collected		533,925 m^3/year		4466.86 m^3/day	
Total Estimation Leakege to Aquifer		29,326 m^3/ year		82.86 m^3/day	

Figure 27b. A consulting report by PT Lapi ITB predicted that 8121 and 6231 cubic meters of potentially contaminated water would leak each year from sections P09 and P08, respectively (see Fig. 21), of the Dry Stack Tailings Facility (DSTF) at the PT HPL mine into the underlying aquifer. The total leakage from all sections was predicted to be 29,326 cubic meters of potentially contaminated water per year. Thus, the potential contamination of groundwater seems to have been implicit in the design of the facility. See beginning of table in Fig. 27a. Table from PT Lapi ITB (2020).

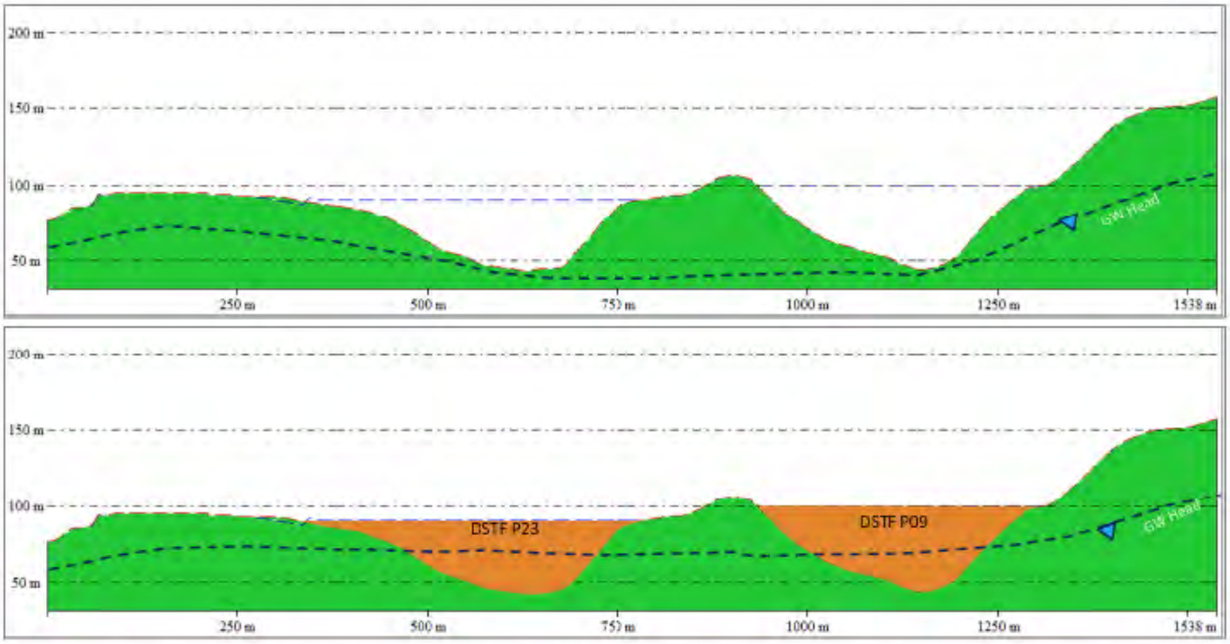

Figure III-11 Changes in Groundwater Contour Results of Numerical Simulation Due to DSTF Placement

Figure 28. A consulting report by PT Lapi ITB predicted the rise in the water table within the Dry Stack Tailings Facility (DSTF) at the PT HPL mine due to the inability of leakage from the facility to flow away fast enough into the underlying aquifer (see Figs. 27a-b). Another consulting report by Hatch (2020) expressed concern that the rise in the water table could lead to instability and liquefaction of the filtered tailings stack. According to Hatch (2020), "In their hydrogeological modelling [by PT Lapi] it was shown that the groundwater table will rise locally in the tailings stack sites to approximately 30 m to 80 masl … This indicates that a system of internal drainage within the tailings stack will also be required in order to lower the groundwater table and reduce the risk of slope instability and liquefaction of the tailings … The conclusion of this stability analysis is that the phreatic surface or water level within the tailings stack should be kept below the 30 m depth mark from the final stack elevation to satisfy the pseudostatic [seismic] stability condition." Figure from PT Lapi ITB (2020).

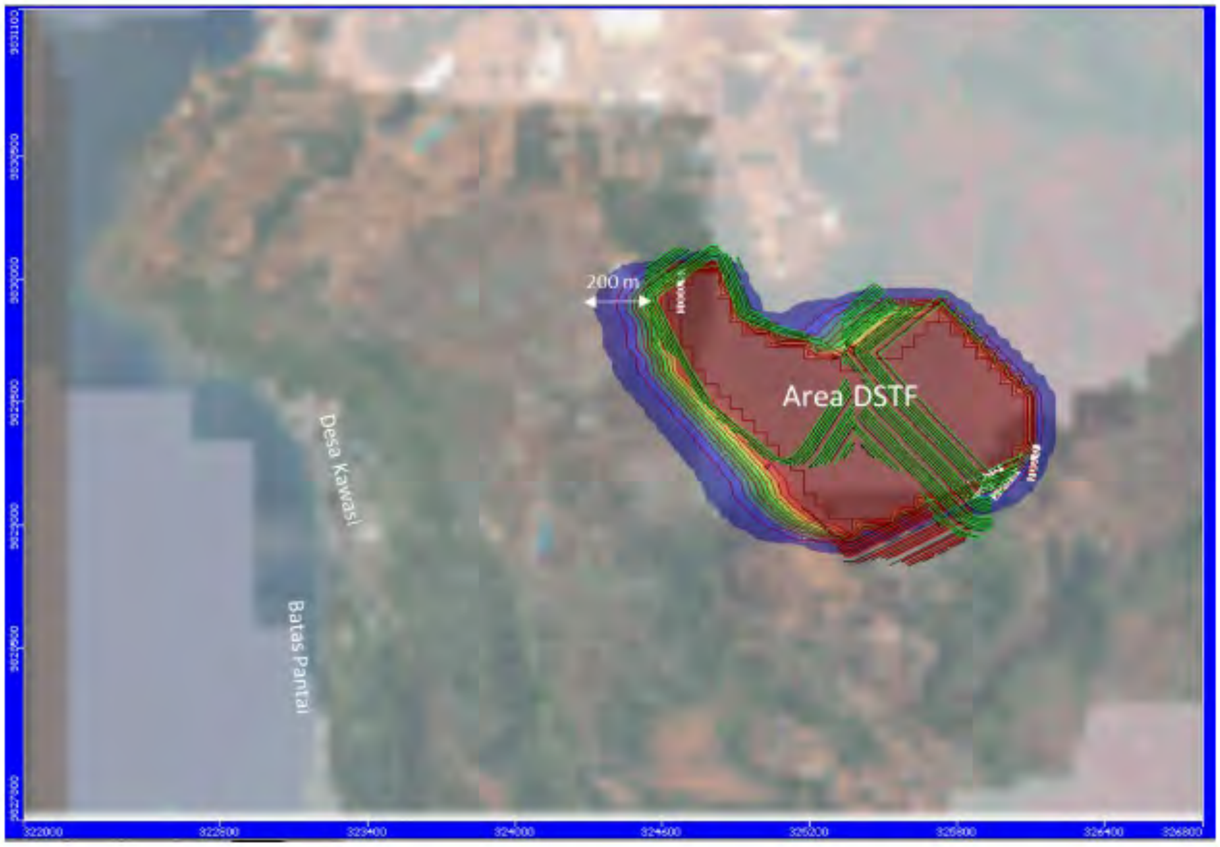

Figure III-12 Spread of Contaminants In 10th Year

Figure 29a. A consulting report by PT Lapi ITB predicted the spread of potentially contaminated water that would leak from the Dry Stack Tailings Facility (DSTF) at the PT HPL mine into the underlying aquifer. Thus, the potential contamination of groundwater seems to have been implicit in the design of the facility. See spread after 50 years and 100 years, respectively, in Figs. 29b and 29c. Figure from PT Lapi ITB (2020).

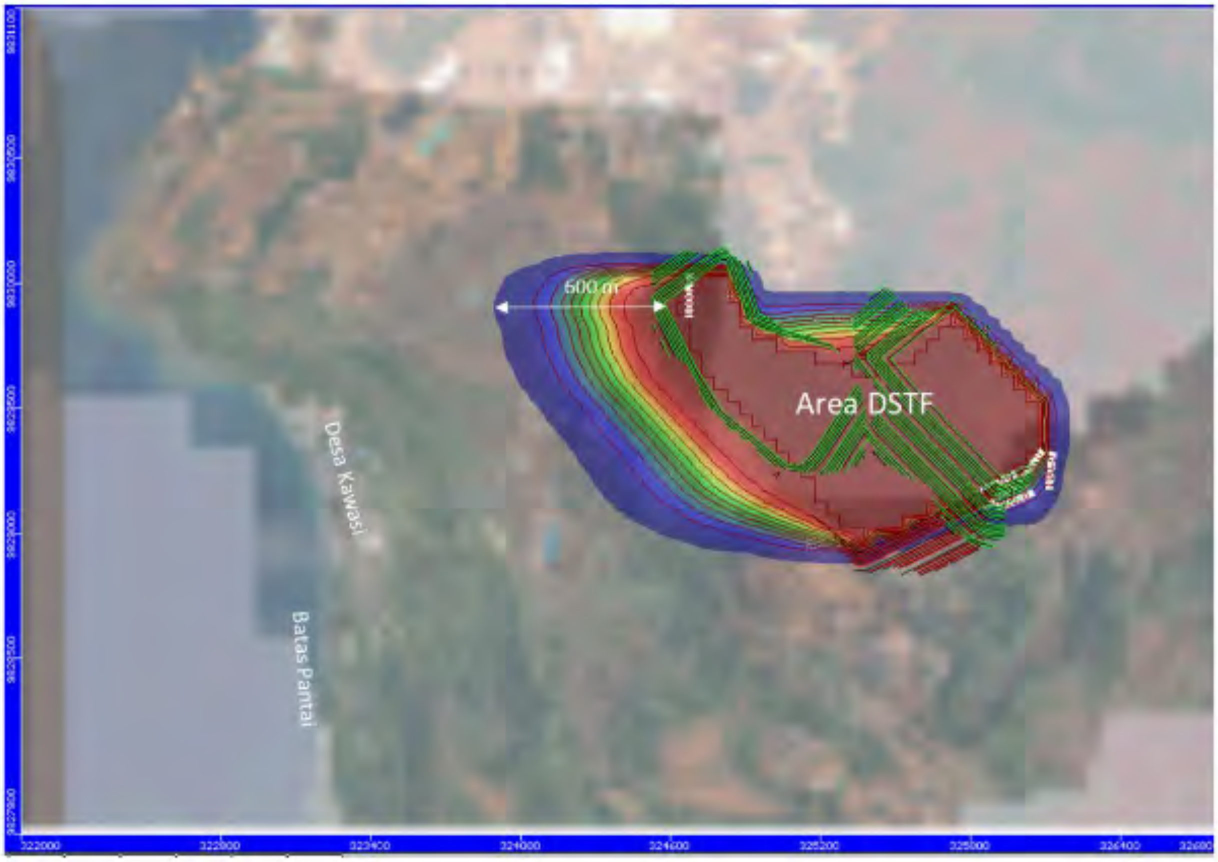

Figure III-13 Spread of Contaminants 50th Year

Figure 29b. A consulting report by PT Lapi ITB predicted the spread of potentially contaminated water that would leak from the Dry Stack Tailings Facility (DSTF) at the PT HPL mine into the underlying aquifer. Thus, the potential contamination of groundwater seems to have been implicit in the design of the facility. See spread after 10 years and 100 years, respectively, in Figs. 29a and 29c. Figure from PT Lapi ITB (2020).

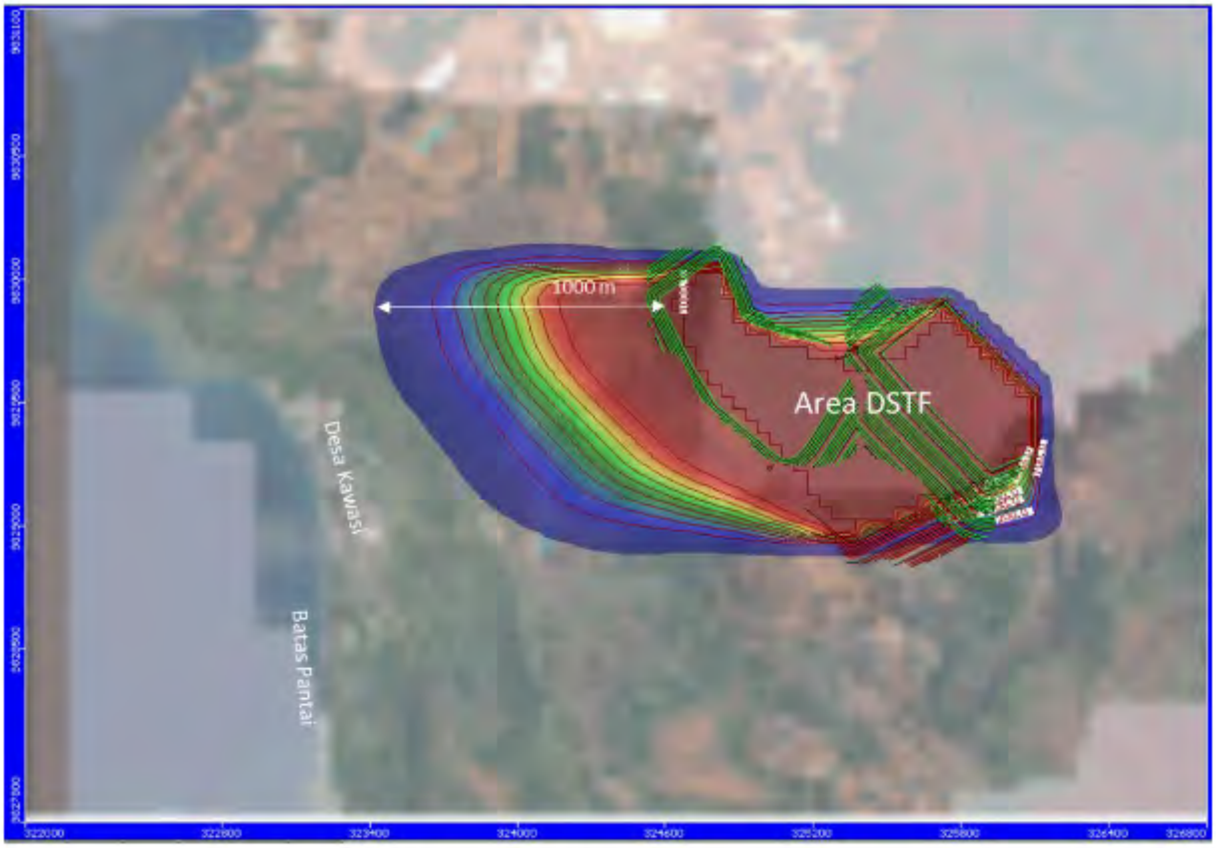

Figure III-14 Spread of Contaminants 100th Year

Figure 29c. A consulting report by PT Lapi ITB predicted the spread of potentially contaminated water that would leak from the Dry Stack Tailings Facility (DSTF) at the PT HPL mine into the underlying aquifer. Thus, the potential contamination of groundwater seems to have been implicit in the design of the facility. See spread after 10 years and 50 years, respectively, in Figs. 29a and 29b. Figure from PT Lapi ITB (2020).

The summary of groundwater contamination from the DSTF by SRK Consulting (2022a) seems remarkably mild and non-quantitative in comparison with the large amount of data on groundwater contamination that was in the possession of Harita Nickel, the operating company for PT HPL, at the time of final submission of the consulting report. Moskowitz et al. (2025) and Leavitt (2025) documented that Harita Nickel had been aware of groundwater contamination with Cr^{+6} since at least 2012. Moreover, there had even been media reports of groundwater contamination by the PT HPL project in February 2022 (Firdaus, 2022), well prior to finalization of the report by SRK Consulting (2022a) in December 2022. Further media reporting of groundwater contamination by the PT HPL project took place the subsequent year (Tan et al., 2023), followed by a denial by PT Trimegah Bangun Persada (2023b), for which the Harita Group is the majority owner (86.48%) (TBP and Harita Nickel, 2025).

Moskowitz et al. (2025) summarized the history of groundwater contamination, largely in terms of the impacts on a spring that supplies drinking water to the village of Kawasi, which is only 200 meters from the HPAL processing plant. According to Moskowitz et al. (2025), "In February 2022, the Guardian reported that Kawasi's drinking water contained high levels of hexavalent chromium, a toxic chemical also known as chromium-6 … For a decade, Harita Group's own internal monitoring repeatedly found chromium-6 contaminating the waters around Kawasi, hundreds of leaked company emails, testing records, and other documents show. Data collected just two days before the Guardian story was published showed that chromium-6 levels were well above the legal limit at that time … Internal reporting performed in the first four days of the month [February 2022] showed chromium-6 levels in Kawasi's spring breaching Indonesia's legal limit on six out of eight readings. Another reading, taken just two days before the Guardian report went live, showed chromium-6 levels at 128 parts per billion in Kawasi's spring—more than double the limit." Moskowitz et al. (2025) continued, "In August 2022, Harita launched an internal investigation into how much chromium-6 was being released by its Obi operation. The probe found that chromium-6 levels at Kawasi Spring had breached Indonesia's limit of 50 parts per billion on all 30 days that month that testing was conducted … But an internal Harita report, circulated just days later, on September 5 [2022], said Kawasi's spring 'exhibited persistently high Cr6+ levels.' It cited wastewater from its facilities as the source of contamination in the local river. Contaminated groundwater was identified as the source of pollution in the spring … That same month, in February 2023, Harita recorded a chromium-6 reading of 173 parts per billion in Kawasi's spring, more than three times the legal threshold for drinking water."

Based on the available information, it does not appear as though SRK Consulting requested the relevant documents from the mining company or asked the most obvious questions. Since SRK Consulting was commenting on groundwater contamination in the context of evaluating the DSTF, it would have been relevant to ask whether the reported groundwater contamination was originating from the DSTF or from some other infrastructure of the PT HPL project, such as the HPAL processing plant, and to include that information in its report. The question was especially relevant, since another consulting report (PT Lapi ITB, 2020) had already made quantitative predictions of the groundwater contamination that would occur from the DSTF. A first attempt at answering the question would have been to request the quantitative data on both groundwater and surface water contamination with the sampling locations in order to assess whether the spatial pattern was consistent with the DSTF as the source of contamination. The apparent failure on the part of SRK Consulting to ask key questions and gather relevant data will be further discussed throughout this section.

Susceptibility to Liquefaction

The consulting report by PT Lapi ITB (2020) further evaluated the susceptibility of the tailings to liquefaction based on an empirical relationship among the plasticity index (PI), the liquid limit (LL), and the geotechnical water content (w_C) of the tailings that was developed by Seed et al. (2003) (see Fig. 30a). According to PT Lapi ITB (2020), "Soils with $12 < PI \leq 20$, $37 < LL \leq 47$ and $w_C/LL > 0.85$ fall into zone B, are classified to be moderately susceptible to liquefaction and need further testing … Based on this methodology, the dry tailing fall into zone B [and are] categorized as susceptible to liquefaction if the water content $> 35.45\%$." According to SRK Consulting (2022a), the target geotechnical water content was 35%, so that susceptibility to liquefaction should be the normal condition. A consulting report by Hatch (2020) later in the same year assessed the liquefaction potential of the tailings based on a different empirical relationship between the plasticity index (PI) and the ratio of the geotechnical water content (w_C) to the liquid limit (LL) that was developed by Bray et al. (2004) (see Fig. 30b). According to

Hatch (2020), “It is observed that PT HPL’s Obi Project filtered tailings possess a moderate susceptibility to liquefaction and further testing was recommended.”

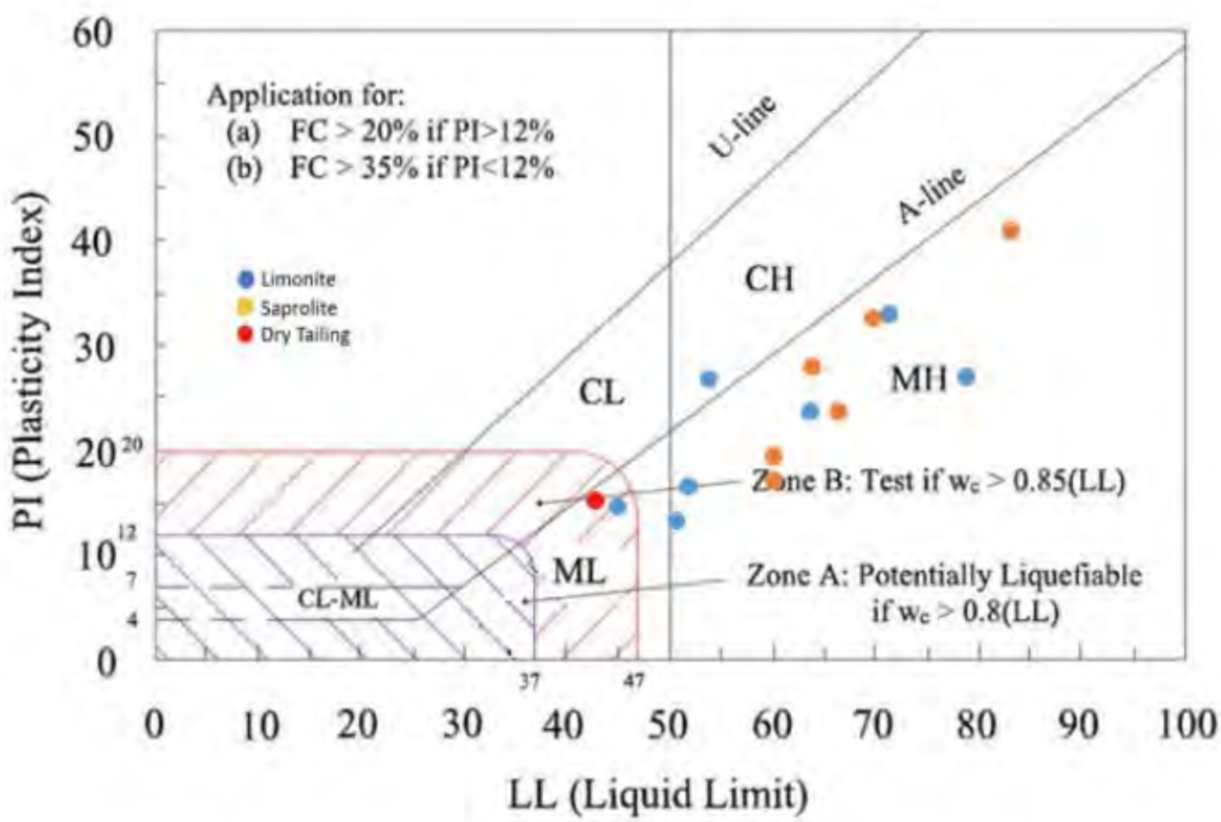

Figure II-5 Early Assessment of Liquefaction Susceptibility (Seed et al. (2003))

Figure 30a. According to a consulting report by PT Lapi ITB (2020), based on criteria determined by Seed et al. (2003), “Soils with 12 <PI ≤20, 37 < LL ≤ 47 and w_C/LL > 0.85 fall into zone B, are classified to be moderately susceptible to liquefaction and need further testing … Based on this methodology, the dry tailing fall into zone B [and are] categorized as susceptible to liquefaction if the water content > 35.45%.” The geotechnical water content (w_C) is the ratio of the mass of water to the mass of solid particles. The liquid limit (LL) is the geotechnical water content above which the mixture of water and solid particles behaves like a liquid, while the plastic limit (PL) is the geotechnical water content above which the mixture of water and solid particles behaves like a plastic. The plasticity index (PI) is the difference between the liquid limit and plastic limit, in which the limits are expressed as percentages. CL = Clay with low plasticity, ML = Silt with low plasticity, CH = clay with high plasticity, MH = silt with high plasticity. Figure from PT Lapi ITB (2020).

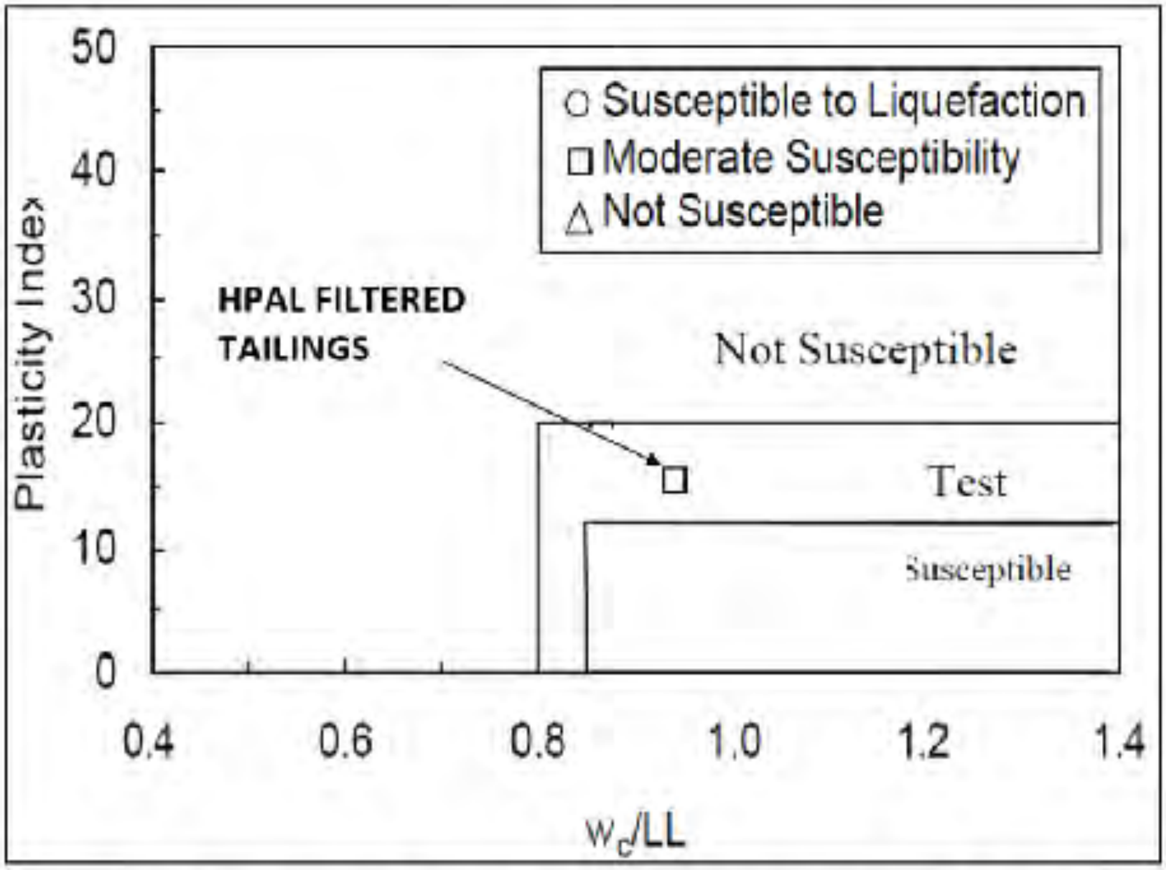

Figure 7-4: Liquefaction Potential of Fine-Grained Soils (Bray 2004)

Figure 30b. According to a consulting report by Hatch (2020), based on criteria determined by Bray et al. (2004), "It is observed that PT HPL's Obi Project filtered tailings possess a moderate susceptibility to liquefaction and further testing was recommended." The criteria developed by Bray et al. (2004) depend upon an empirical relationship between the plasticity index and the ratio of the geotechnical water content (w_C) to the liquid limit (LL). The geotechnical water content is the ratio of the mass of water to the mass of solid particles. The liquid limit is the geotechnical water content above which the mixture of water and solid particles behaves like a liquid, while the plastic limit is the geotechnical water content above which the mixture of water and solid particles behaves like a plastic. The plasticity index is the difference between the liquid limit and plastic limit, in which the limits are expressed as percentages. Figure from Hatch (2020).

The report by Hatch (2020) expressed concern that the rise in the water table within the DSTF that was predicted by PT Lapi ITB (2020) (see Fig. 28) could lead to instability and liquefaction of the filtered tailings stack. According to Hatch (2020), "In their hydrogeological modelling [by PT Lapi ITB] it was shown that the groundwater table will rise locally in the tailings stack sites to approximately 30 m to 80 masl … This indicates that a system of internal drainage within the tailings stack will also be required in order to lower the groundwater table and reduce the risk of slope instability and liquefaction of the tailings … The conclusion of this stability analysis is that the phreatic surface or water level within the tailings stack should be kept below the 30 m depth mark from the final stack elevation to satisfy the pseudostatic [seismic] stability condition." Hatch (2020) emphasized that the excess water within the filtered tailings stack would arise not only from precipitation and surface runoff, but from the release of water as the filtered tailings consolidated with time and due to the weight of overlying tailings. In this respect, the unusually high geotechnical water content of the tailings was a critical factor. According to Hatch (2020), "The filtered tailings as designed has [have] 30 % in place moisture content. Upon consolidation of the tailings with time, this will generate substantial quantity of water … The consultant should select the best location of each drains [drain] and size the drains based on anticipated quantities of water to be collected. This water is mostly the water from the consolidation of the filtered tailings as well as rise in the water table with [within] the tailings stack." It should be noted that Hatch (2020) was assuming a lower target geotechnical water content (30%) than the 35% stated by SRK Consulting (2022a), while PT Lapi ITB (2020) stated the target geotechnical water content as "around 30%-35%." A later report by PT Lapi ITB (2022) did not state a target geotechnical water content, but emphasized that the tailings water contents should not deviate from the target by more than 2.5%.

According to Hatch (2020), the DSTF was designed to have a minimum static factor of safety of 1.5 (see Fig. 31), which is consistent with the vast majority of international regulations and guidance documents (ANCOLD, 2012, 2019; Canadian Dam Association, 2013, 2019; Fell et al., 2015; Government Gazette—Republic of South Africa, 2015; Schnaid et al., 2020; ICOLD, 2022; Ministry of Energy, Mines and Low Carbon Innovation (British Columbia), 2024; FEMA, 2025). The loading condition "End of Construction," for which a minimum static factor of safety of 1.3 would be acceptable (see Fig. 31), refers to the time before placement of any tailings or water. For example, according to FEMA (2025), "End of construction conditions are conventionally applied to water dams to recognize that construction-induced pore pressures frequently develop in foundations and/or embankments prior to placing the dam into service. The minimum factor of safety has typically been set to 1.3 because this is a temporary condition with no storage and the consequence of failure would be low. For tailings dams, this could apply to the construction of the starter dam or the raised section before solids and water are stored considering excess pore pressures. However, when a sustained or longterm undrained shearing risk exists, factors of safety developed for short-term loading conditions do not apply." Thus, in the case of the DSTF, the "End of Construction" would refer to the time when a rockfill buttress has been constructed, but no tailings or water have yet been placed behind the buttress (see Figs. 21-22).

Although Hatch (2020) referred to ANCOLD (Australian National Committee on Large Dams) in setting a minimum factor of safety of 1.1 for the pseudostatic (seismic) loading condition (see Fig. 31), the pseudostatic factor of safety is actually not found in ANCOLD (2012, 2019). In fact, according to ANCOLD (2012, 2019), "Of particular note, pseudo-static analysis as a screening tool for earthquake stability is now not recommended." In their review of the DSTF, SRK Consulting (2022a) confirmed, "It must be noted that according to the latest update of the guidelines the pseudo-static value should be removed, and a post-seismic analysis undertaken. This will also require additional work to amend." However, the minimum factor of safety of 1.1 for the pseudostatic loading condition can be found in many other guidance documents, including internal mining company standards (Barrick Gold, 2012; ABNT, 2017; Morrill et al., 2022), and is a useful starting point. It should be further noted that the concept of a lower factor of safety for "End of Construction" is also not found in ANCOLD (2012, 2019).

LAPIITB confirms that the Slope Stability Acceptance Criteria as recommended has been applied in the final design.

Table 9-2: Slope Stability Acceptance Criteria

Loading Conditions	Required Factor of Safety
End of Construction (short-term)	1.3
Static Long-term	1.5
Pseudostatic	1.1 (ANCOLD)

Figure 31. According to Hatch (2020), the Dry Stack Tailings Facility (DSTF) at the PT HPL mine was designed to have a minimum static factor of safety of 1.5, which is consistent with the vast majority of international regulations and guidance documents. The loading condition "End of Construction" refers to the time before placement of any tailings or water. Thus, in the case of the DSTF, the "End of Construction" would refer to the time when a rockfill buttress has been constructed, but no tailings or water have yet been placed behind the buttress (see Figs. 21-22). The minimum factor of safety of 1.1 for the pseudostatic (seismic) loading condition is actually not found in ANCOLD (2012, 2019), although it can be found in other international regulations and guidance documents. Figure from Hatch (2020).

Based on the selected minimum factors of safety (see Fig. 31), PT Lapi ITB (2020) showed that the DSTF will be unstable under a wide variety of circumstances, mostly in response to seismic loading. For example, if the design earthquake occurred while the water table within the DSTF reached 90% of the height of the stack, pseudostatic factors of safety could be as low as 0.93, depending upon the stack height and the embankment slope, while pseudostatic factors of safety could be as low as 1.05 if the water table reached 80% of the stack height (see Fig. 32a). According to SRK Consulting (2022a), the embankment slope of the DSTF is 10°, so that seismic instability could occur at any stack height greater than 30 meters if the water table reached 90% of the stack height (see Fig. 32a). PT Lapi ITB (2020) further showed that, if the foundation of the DSTF is limonite, the foundation will be marginally stable (factor of safety = 1.1) in response to seismic loading at stack heights of 14 meters (end of Phase 1) and 60 meters (end of Phase 3), and will be unstable (factor of safety = 1.05) at a stack height of 80 meters (end of Phase 4) (see Fig. 32b). No available document indicates whether the foundation of the DSTF is limonite or saprolite (see Fig. 32b).

Table II-19 Results of Slope Design Simulation

Height	Angel	Static	Dynamic (k=0.3)	
		Fos (Water table 90%)	FoS (Water table 90%)	FoS (Water table 80%)
20	5	5.73	1.24	1.31
	10	3.35	1.16	1.25
	15	2.51	1.09	1.19
	20	2.06	1.03	1.13
30	5	5.49	1.20	1.27
	10	3.10	1.09	1.19
	15	2.30	1.00	1.12
	20	1.89	0.93	1.05
40	5	5.36	1.17	1.25
	10	3.03	1.04	1.15
	15	2.21	0.96	1.08
50	5	5.28	1.15	1.24
	10	2.97	1.03	1.14
60	5	5.22	1.14	1.23
	10	2.92	1.01	1.13

Figure 32a. A consulting report by PT Lapi ITB (2020) found that, under seismic (dynamic) loading, the Dry Stack Tailings Facility (DSTF) at the PT HPL mine would be unstable, corresponding to a factor of safety (FoS) less than 1.1, as indicated in red (compare with Fig. 31), if the water table were too high within the DSTF. The units of height should be meters, while the misspelling "Angel" refers to the slope of the outer embankment. According to SRK Consulting (2022a), the maximum height is 57 meters, while the slope is 10°. Table from PT Lapi ITB (2020).

In terms of the design of the DSTF (see Figs. 21-22), the stability of the rockfill buttresses is most significant. PT Lapi ITB (2020) showed that the buttresses will be highly unstable (factor of safety = 0.948) in response to seismic loading at a buttress height of 20 meters (see Fig. 32c). According to PT Lapi ITB (2020), "From the simulation results, it can be seen with the buttress height of 20 meters, the FoS in the dynamic conditions [does] not meet the design acceptance criteria … It is recommended that the maximum rise of the buttress during the construction stage is 15 meters." The above finding could be the reason why the heights of the buttresses are restricted to 15 meters, despite the fact that the tailings are stacked far taller than the buttresses, so that the tailings could easily flow over the tops of the buttresses after liquefaction (see Fig. 22). It should be noted that the cross-section in PT Lapi ITB (2022) shows a rockfill buttress with a height of 18 meters at the downstream end of section P-08 of the DSTF (see Figs. 21-22).

Table II-21 Consolidation of Base Soil Foundation and Stability Analysis Results

Fondation Material	Construction Phase	Height (m)	Consolidation at 15 days		Final Consolidation		
			Max. Displacement (m)	FoS	Max. Displacement (m)	FoS	
						Static	Dynamic
Limonite	Phase 1	14	0.2648	1.859	0.3197	3.47	1.10
	Phase 2	30	0.7574	2.565	1.295	2.60	1.19
	Phase 3	60	1.494	1.944	2.978	2.61	1.10
	Phase 4	80	2.544	1.396	4.314	3.61	1.05
Saprolite	Phase 1	14	0.206	2.609	0.2041	2.60	1.46
	Phase 2	30	0.808	2.556	0.8515	2.60	1.36
	Phase 3	60	1.596	2.009	1.971	2.58	1.13
	Phase 4	80	2.451	1.412	3.023	3.29	1.11

Figure 32b. A consulting report by PT Lapi ITB (2020) found that, under seismic (dynamic) loading, the foundation beneath the Dry Stack Tailings Facility (DSTF) at the PT HPL mine would be unstable, corresponding to a factor of safety (FoS) less than 1.1, as indicated in red (compare with Fig. 31), if the height of the stack were increased to 80 meters (Phase 4). However, the report also indicated that the foundation would be at the upper limit of stability (FoS = 1.1) if the stack were either 14 meters high or 60 meters high. No available document indicates whether the foundation beneath the DSTF is limonite or saprolite. Table from PT Lapi ITB (2020).

Table II-23 Results of Buttress Consolidation and Stability Analysis

Fondation Material	Construction Phase	Height (m)	Consolidation at 6 days		Final Consolidation		
			Max. Displacement (m)	FoS	Max. Displacement (m)	FoS	
						Static	Dynamic
Stage 1	Phase 1	5	0.0911	2.606	0.1193	2.618	1.334
	Phase 2	10	0.1817	1.945	0.2501	1.989	1.304
	Phase 3	15	0.2411	1.593	0.3839	1.756	1.276
	Phase 4	20	0.4057	1.394	0.5234	1.622	0.948
Stage 2	Phase 1	5	0.4309	1.741	0.5162	1.753	1.285

Figure 32c. A consulting report by PT Lapi ITB (2020) found that, under seismic (dynamic) loading, the rockfill buttresses (see Figs. 21-22) of the Dry Stack Tailings Facility (DSTF) at the PT HPL mine would be unstable, corresponding to a factor of safety (FoS) less than 1.1, as indicated in red (compare with Fig. 31), if the height were of the buttress were increased to 20 meters. According to PT Lapi ITB (20200, "From the simulation results, it can be seen with the buttress height of 20 meters, the FoS in the dynamic conditions [does] not meet the design acceptance criteria … It is recommended that the maximum rise of the buttress during the construction stage is 15 meters." However, note that buttresses that are much lower than the stacked tailings would allow liquefied tailings to flow over the tops of the buttresses (see Fig. 22). Table from PT Lapi ITB (2020).

Finally, PT Lapi ITB (2020) showed that the DSTF would be unstable in response to seismic loading if the tailings were deposited too rapidly (see Fig. 32d). PT Lapi ITB (2020) indicated only that the factor of safety would be less than 1.0, but not the calculated value. PT Lapi ITB (2020) did not state the expected loading rate (see Fig. 32d). However, since the facility has an expected lifetime of six years (SRK Consulting, 2022a) and is being constructed in three sections, with three or four phases (height increases of about 15 meters per phase), then the expected loading rate is 183-243 days per phase. Thus, for the expected loading rates, the pseudostatic factor of safety for section P-09 (1.105) would only slightly exceed the minimum factor of safety at the maximum height (55.72 meters) (see Fig. 32d). Although this discussion has focused on seismic instability, it should be noted the PT Lapi ITB (2020) showed adequate static factors of safety (see Figs. 32a-d). The actual static factors of safety will be reconsidered in the following subsection "Lack of Quality Control, Monitoring, and Adherence to Design."

Table II-25 Results of Stability Analysis with Loading Rate 90 days/phase and 240 days/phase

Location	Construction Phase	Height (m)	Loading rate 90 days/phase			Loading rate 240 days/phase		
			Consolidation (m)	FoS		Consolidation (m)	FoS	
				Static	Dynamic		Static	Dynamic
P23	Phase 1	15	0.1444	1.918	1.647	0.1708	2.6	1.817
	Phase 2	30	0.2039	2.611	1.13	0.2513	2.594	1.398
	Phase 3	45	0.2287	2.793	<1	0.3038	3.621	1.243
	Phase 4	61.85	0.3064	2.577	<1	0.3964	3.53	1.168
P09	Phase 1	15	0.2603	5.535	1.62	0.2797	5.537	1.687
	Phase 2	30	0.2384	3.861	1.162	0.2595	3.889	1.161
	Phase 3	45	0.2901	3.352	<1	0.3221	3.381	1.128
	Phase 4	55.72	0.1923	2.868	<1	0.1911	2.933	1.105
P08	Phase 1	15	0.3641	4.308	2.065	0.4126	4.83	2.294
	Phase 2	30	0.2266	4.02	1.084	0.2267	4.019	1.693
	Phase 3	43	0.2673	3.194	<1	0.273	3.995	1.286

Figure 32d. A consulting report by PT Lapi ITB (2020) found that, under seismic (dynamic) loading, the Dry Stack Tailings Facility (DSTF) at the PT HPL mine would be unstable, corresponding to a factor of safety (FoS) less than 1.1, as indicated in red (compare with Fig. 31), if the tailings were deposited too rapidly. PT Lapi ITB (2020) indicated only that the factor of safety would be less than 1.0, but not the calculated value. PT Lapi ITB (2020) did not state the expected loading rate. However, since the facility has an expected lifetime of six years and is being constructed in three sections, with three or four phases (height increases of about 15 meters per phase), then the expected loading rate is 183-243 days per phase. Thus, for the expected loading rates, the dynamic factor of safety for section P09 (1.105) would only slightly exceed the minimum factor of safety at the maximum height (55.72 meters). Table from PT Lapi ITB (2020).

As a final point, the consulting report by Hatch (2020) showed, as expected, a strong dependence of the density of the compacted tailings on the geotechnical water content, with the maximum density achieved at an optimum water content of 35.6% (see Fig. 33), although Hatch (2020) also stated "The filtered tailings as designed has [have] 30 % in place moisture content." The surprising observation was that the graph shows a maximum density of 1.566 metric tons per cubic meter at the optimum water content (see Fig. 33), which was stated as ~1.6 metric tons per cubic meter by Hatch (2020). By contrast, the design compacted density is 2.22 metric tons per cubic meter, based on the maximum capacity of DSTF of 57.2 million metric tons or 25.8 million cubic meters of tailings (PT Halmahera Persada Lygend (2024); see Table 4). PT Lapi ITB

(2020) critiqued the maximum density determined by Hatch (2020) and suggested that a maximum density of 1.76 metric tons per cubic meter was more accurate. According to PT Lapi ITB (2020), “Resume of the laboratories result [laboratory results] and liquefaction potential assessment based on the CSL [Critical State Line] approach which [were] develops [developed] by Hatch, are: … As an indication via phase relationships and based on particle size distribution (PSD), a theoretical dry density (ρd) of 1.76 t/m3 should be expected for a saturated soil that would yield a void ratio (e) of 1.22 considering a Gs of 3.9. Both SP [Standard Proctor] tests resulted in an maximum dry density (MDD) of 1.6 t/m3, which is not credible given that the result of the normally consolidated line (without any compaction) shows a void ratio of about 1.42 and a ρd of 1.61 t/m3 between the 50 and 400 kPa range. The compacted value and the normally consolidated values cannot be that similar for the same sample of soil.” The report by Hatch (2020) was submitted on September 18, 2020, while the report by PT Lapi ITB (2020) was submitted in August 2020, so that, apparently, PT Lapi ITB (2020) was responding to an earlier version of Hatch (2020).

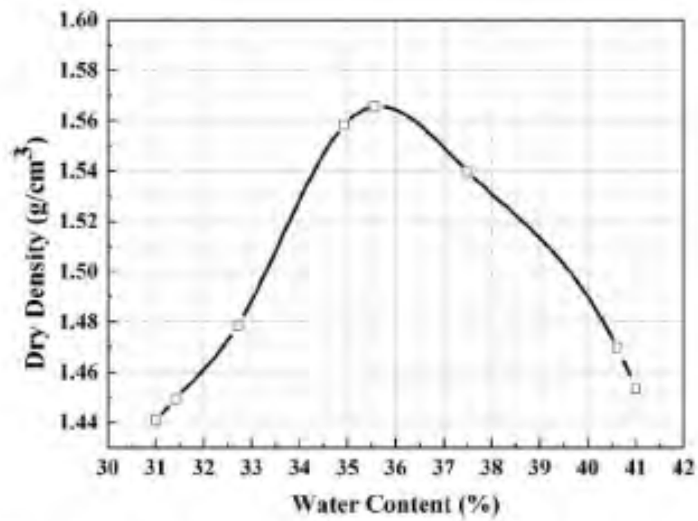

Figure 7-2: Results of Compaction Tests showing Dry Density and Water Content Relationship

Figure 33. A consulting report by Hatch (2020) showed a strong dependence of the dry density of the compacted tailings on the geotechnical water content with a maximum dry density of 1.566 metric tons per cubic meter (stated as ~1.6 metric tons per cubic meter by Hatch (2020)) achieved at an optimum water content of 35.6%. PT Lapi ITB (2020) stated that the maximum dry density measured by Hatch (2020) was “not credible,” and proposed an alternative value of 1.76 metric tons per cubic meter. SRK Consulting (2020a) and PT Halmahera Persada Lygend (2024) both assumed the much higher maximum densities of 2.20 and 2.22 metric tons per cubic meter, respectively, which are more typical for filtered tailings, but which suggests some confusion as to the correct way to measure density. Figure from Hatch (2020).

In their study of experiments on HPAL tailings in New Caledonia, Bodley and Vaguener (2022) reported similar confusion as to the correct method to measure the dry density of compacted tailings, as well as discrepancies between laboratory and field measurements. According to Bodley and Vaguener (2022), “The average in-situ dry density was 1.62 t/m3 . This value is higher than the conservative estimate of 1.29 t/m3 used during the study phases. The dry density of 1.29 t/m3 was defined by numerous standard proctor compaction tests performed on samples generated during pilot testing. The results show deficiencies and limitation in accurate determination of the residue dry density. The difference in density is a function of material variability and highlights the value of the larger scale field trial in the determination of this critical design parameter." For comparison, the typical dry density for all types of filtered tailings is 2.0 metric tons per cubic meter, with a range of 1.9 to 2.6 metric tons per cubic meter (Cacciuttolo Vargas and Pérez Campomanes, 2022), which is close to the value of 2.22 metric tons per cubic meter that was assumed by PT Halmahera Persada Lygend (2024) (see Table 4). The correct value of the target compacted tailings density, as well as the reliability of the stability analyses, will be discussed further in the next subsection.

Lack of Quality Control, Monitoring, and Adherence to Design

The report by SRK Consulting (2022a) emphasized repeatedly the complete lack of quality control in the construction of the Dry Stack Tailings Facility (DSTF) as of December 2022, especially in terms of failure to achieve the target water contents or compacted dry densities. According to SRK Consulting (2022a), "SRK was advised that moisture content of the dry stack tailings facility, the groundwater quality and the leachate quality monitoring is undertaken monthly and reported every 3 months. SRK has reviewed the monitoring reports for Q2, Q3 and Q4 of 2021, which show that the moisture reported was consistently around 30% lower than the target of 35%." It is not clear whether the preceding means that the typical geotechnical water content was 5% or 24.5%, although either option would be far less than the target water content of 35%. SRK Consulting (2022a) continued, "Density testing results provided for May to October 2022 show dry density achieved was between 1.66 and 2.20 t/m^3, with moisture contents of 8%-36% … In addition, summary tables with laboratory and field moisture and density test results were provided, which show a range of dry densities ranging from 0.93 to 2.20." SRK Consulting (2022a) also reported a dry tailings density of 1.287-1.355 t/m^3 with the note "Range of values noted was provided by TBP" [PT Trimegah Bangun Persada]. SRK Consulting (2022a) summarized, "The consequences of low levels of quality control carries the risk that the dry stack tailings facility could be built to a lower standard than design."

The following observations can be made regarding the lack of quality control of water content or compacted tailings density:

1) The maximum compacted dry density is probably 2.20 metric tons per cubic meter or slightly higher, which is close to the value of 2.22 metric tons per cubic meter assumed by PT Halmahera Persada Lygend (2024); see Table 4) and much higher than the value of 1.6 metric tons per cubic meter measured by Hatch (2020) (see Fig. 33) or the value of 1.76 metric tons per cubic meter proposed by PT Lapi ITB (2020).
2) The lowest measured dry density of 0.93 metric tons per cubic meter is even less dense than water (1.00 metric tons per cubic meter) and implies an extreme lack of compaction.
3) The data provided by the mining company seem to arrive in a wide variety of forms, from quarterly monitoring reports, summary tables, and e-mails.
4) In the experience of the author, such an extreme lack of quality control is unprecedented in the mining industry.

SRK Consulting (2022a) acknowledged that stability analyses had shown adequate factors of safety for static loading (see Figs. 32a-d), but pointed out that all of those analyses had assumed adequate compaction of the filtered tailings. Based on the complete lack of quality control in the density of the tailings, static stability could no longer be assumed. According to SRK Consulting (2022a), “Slope stability design results show that the dry stack tailings facility has a robust design, with an FoS above 2.5 (which is above the FoS value of 1.5 usually required) … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK’s opinion that given the height of the facility (57 m) and the lack of quality control in the placement of tailings, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing.” The preceding sentence is critical and will be further considered in the subsection “Surface Ponding and Willful Blindness.”

SRK Consulting (2022a) did not comment on the wide range of circumstances under which the DSTF would be unstable in response to seismic loading (see Figs. 32a-d). However, SRK Consulting (2022a) implicitly noted the lack of any analysis of the post-liquefaction stability of the DSTF. With regard to the measured geotechnical parameters of the tailings, SRK Consulting (2022a) wrote, “The parameters seem to have reasonable values; however, a key gap is that the residual strength of the tailings is not considered.” The residual strength (also called the liquefied strength or the post-liquefaction strength) is the shear strength of the tailings after liquefaction (see Fig. 11). The contemporary practice is that tailings storage facilities should be designed so that they will not undergo catastrophic failure even after liquefaction. Thus, a minimum post-liquefaction factor of safety of 1.1 is a common standard (Barrick Gold, 2012; ICOLD, 2022; FEMA, 2025), which is calculated by assigning the residual strength to the potentially liquefiable tailings. Although it is not possible to calculate the post-liquefaction factor of safety of the DSTF, it is difficult to imagine how the DSTF could survive liquefaction, since the liquefied tailings could slide over the tops of the rockfill buttresses (see Fig. 22).

SRK Consulting (2022a) further emphasized the essential lack of any monitoring instrumentation or inspection program for the DSTF, contrary to the design of the DSTF. According to SRK Consulting (2022a), “The design specifies a number of monitoring regimes required for operation of the facility, such as groundwater monitoring via vibrating wire piezometers (VWPs) and standpipes, toe seepage measurement with v-notch weirs, regular surveys and installation of inclinometers, provision for cone penetration test (CPT) investigations once the dry stack tailings facility reaches certain heights, water quality and meteorological monitoring.” SRK Consulting (2022a) added “regular inspections” to the above list and noted that “no data regarding the above were available.” SRK Consulting (2022a) described “Monitoring via piezometers and inclinometers, routine inspections, v-notch weir installation and monitoring, water quality monitoring and maintenance” as “Controls” against “Uncontrolled risks” and stated, “It is noted that no evidence has been provided as to whether any of the controls have been implemented.” SRK Consulting (2022a) concluded, “In line with international standards, SRK recommends a thorough monitoring system to be established.” Some aspects of the lack of adherence to the design were already noted in the subsection “Groundwater Contamination” in this report. SRK Consulting (2022a) further noted, “Perimeter/toe drains issues identified and some areas are still under construction … Water treatment ponds in poor condition and some areas are still under construction.”

Based on the lower bound on the range of compacted densities that were provided to SRK Consulting by e-mail (1.287 metric tons per cubic meter), SRK Consulting (2022a) calculated that the maximum capacity of the DSTF was actually 33.2 million metric tons, not 57.2 million metric tons, as was stated by PT Halmahera Persada Lygend (2024) (see Table 4). According to SRK Consulting (2022a), “At the current production rate, this is equivalent to approximately 4.5 years of operation.” In other words, SRK Consulting (2022a) predicted that the DSTF would reach full capacity by mid-2027, rather than filling before the end of 2029, which would be consistent with the data provided by PT Halmahera Persada Lygend (2024) (see Table 4). The preceding conclusion by SRK Consulting (2022a) is quite disturbing, not only because of the rapidly approaching closure deadline, but because it assumed that tailings would continue to be stacked at 58% of the target compaction density, whereas the reasonable course of action should have been an immediate cessation to the placement of tailings on the DSTF.

Under the heading of “Risk assessment,” SRK Consulting (2022a) described “Dry stack tailings facility failure” as an “Uncontrolled risk.” In the opinion of the author, the catastrophic failure of the DSTF at the PT HPL project is imminent. It is important to note that the lack of adequate compaction of the lower levels of the DSTF is not a problem that can be fixed. The worst possible course of action would be to continue placing tailings on top of tailings that were not adequately compacted, which is apparently what has happened according to the mining company (PT Halmahera Persada Lygend, 2024). Even if perfect quality control were carried out after submission of the report by SRK Consulting (2022a) in December 2022, any increase in the weight on top of the improperly compacted tailings increases the likelihood that the underlying tailings could undergo a sudden consolidation that would lead to liquefaction (see Fig. 10) and the catastrophic failure of the DSTF. In this regard, it should be noted that some portions of the lower levels of the DSTF have densities as low as 0.93 metric tons per cubic meter (even less dense than water and 42% of the target compacted density), so that an extreme degree of sudden consolidation is possible. In the opinion of the author, the correct course of action, which should have been recommended by SRK Consulting, would have been to cease deposition of tailings on the DSTF, take immediate measures to protect the safety of mineworkers and community residents downstream from the DSTF, and then to develop a plan for safe closure of the DSTF. The lack of a closure plan is the subject of the following subsection. Following the subsection “Lack of Realism in the Dam Break Analysis,” the subsection “Surface Ponding and Willful Blindness” will provide further evidence for the imminent catastrophic failure of the DSTF.

Before proceeding to the following subsections, it is necessary to counter any argument that catastrophic failure of the DSTF cannot be imminent because catastrophic failure has not yet occurred as of June 2025. Within the literature on the safety of tailings storage facilities, the persistence of an emergency situation together with the lack of appropriate response to the emergency situation is known as the “normalization of deviance.” According to Vick (2017), “Vaughan (1996) introduced the term normalization of deviance in her groundbreaking analysis of the Space Shuttle Challenger disaster, the signature technological failure of its era. Within NASA, normalization of deviance was the repeated acceptance of risks from known failure modes until they became expected and routine. More generally, a potential failure initiator happens enough times without adverse effect until a false sense of security develops and a former anomaly becomes the new norm. Rather than being seen as moving closer to the edge, these serial anomalies are taken to validate the view that they are inconsequential. With this, the unexpected becomes the expected, which in turn becomes the accepted (Pinto 2014).”

In his review of the application of “normalization of deviance” to tailings storage facilities, Vick (2017) continued, “Normalization of deviance can be seen to contain the following elements: 1. Intended performance is established from design or operating criteria, field experience, or standard practices. 2. Repeated or sustained deviations from intended performance arise from anomalies, unexpected events, or adopted modifications. These deviations cause reduced performance and elevated risk. 3. Over time, reduced performance and increased risk become rationalized, expected, and accepted as normal, often despite warning signs or near-misses. 4. Reduced performance allows unrecognized events or conditions to trigger failure mode occurrence, making foreseeable failures unforeseen.”

Of particular relevance to the DSTF at the PT HPL project, Vick (2017) specifically applied the concept of “normalization of deviance” to the failure to address the persistent lack of study of the foundation of the tailings storage facility at the Mount Polley mine in British Columbia and the lack of adequate drainage for the tailings storage facility at the Samarco mine in Brazil, which led to the catastrophic failures of the facilities in August 2014 and November 2015, respectively (see Table 3). It should be noted that the lower levels of uncompacted or weakly compacted tailings constitute a foundation for the overlying tailings. Moreover, PT Lapi ITB (2020) identified circumstances under which the soil foundation beneath the DSTF would liquefy in response to seismic loading (see Fig. 32b) if the foundation were limonite. The author is not aware of any document that has studied the foundation of the DSTF, even in terms of whether the foundation is limonite or saprolite (see Fig. 32b).

With respect to the failure of the tailings storage facility at Mount Polley, Vick (2017) wrote, “The Mount Polley dam was raised repeatedly without confirming the intended absence of soft foundation clay … a Potential Failure Mode (PFM) assessment identified slope failure due to weak foundation materials as a failure mode, but the risk was dismissed as inconsequential … An undrained strength analysis (USA) for normally-consolidated GLU [Glacial Lacustrine Unit] showed that such materials, if present, would reduce FS to 1.1. Even so, such a marginal value was accepted despite the reduced standard of performance and elevated risk it embodied. Because by now, the absence of any softer GLU had become expected and normal—so much so that the Perimeter Embankment was raised during the next four stages without any deep borings within its footprint over its 2 km length. The elevated risk had become accepted and normal as well, allowing the oversteepened slope to become a permanent, not temporary, fixture.”

With respect to the failure of the tailings storage facility at Samarco, Vick (2017) wrote, “The Fundão dam continued to be raised despite increasing saturation never anticipated in the original concept for mitigating liquefaction risk … No sooner had the starter dam been placed into operation than internal erosion resulting from construction defects in the base drain produced damage so severe that the original concept could not be implemented. Instead, upstream raising would continue without the base drain, resulting in saturation that deviated from the original design premise. As raising progressed, increasing saturation of the sands, manifested by repeated breakout of seepage on the dam face, introduced the potential for sand liquefaction (Morgenstern, et al. 2016). But by then, saturation and the associated liquefaction risk had become an accepted, hence normal, aspect of dam operation, notwithstanding the adoption of FMEA [Failure Modes and Effects Analysis] on a continuing basis.”

Lack of Closure Plan

Despite the rapidly approaching deadline for closure of the DSTF (mid-2027), the report by SRK Consulting wrote that there was essentially still no plan for safe closure of the DSTF.

For clarification, according to Safety First: Guidelines for Responsible Mine Tailings Management, “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” (Morrill et al., 2022). According to the Global Industry Standard on Tailings Management (GISTM), “The term ‘credible failure mode’ is not associated with a probability of this event occurring” (ICMM-UNEP-PRI, 2020). Thus, Safety First defined a “credible failure mode” as “a physically possible sequence of events that could potentially end in tailings dam failure” (Morrill et al., 2022). The SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook further clarified, “While evaluating risks associated with PFMs [Potential Failure Modes], it is important to consider whether the failure modes are credible or plausible. Is the PFM conceivable or physically possible and is there a technical basis for its occurrence? A non-credible failure mode has a zero likelihood of occurrence” (Morrison and Byler, 2022). There are not many ways to eliminate all credible failure modes from an aboveground tailings storage facility, aside from the possibility of moving all of the tailings to an exhausted open pit or exhausted underground galleries. In particular, it is difficult to imagine how seismic failure of the DSTF could ever cease to be “physically possible.”

In Revision 1, SRK Consulting (2022b) stated that the “Closure plan and cost estimate” was “Not available” and noted that “It is currently a requirement by international standards and good industry practice to undertake closure and rehabilitation studies including cost estimates.” By the final version, SRK Consulting (2022a) still stated that the “Closure plan and cost estimate” was “Not available,” but added the note “The study presented is at concept level,” before repeating the above phrase regarding international standards and industry practice. Thus, it is not entirely clear as to the distinction between a non-existent closure plan and a closure plan “at concept level.” SRK Consulting (2022a) concluded, “Detailed closure and rehabilitation studies, including cost estimates, are recommended to be completed.”

An example of a relevant international standard is the Global Industry Standard on Tailings Management (GISTM), which repeatedly emphasizes that the plan for safe closure must be fully integrated into the initial design of a new tailings storage facility, and not something that is considered only at the time of closure. For example, Principle 5 requires mining companies to “Develop a robust design that integrates the knowledge base and minimises the risk of failure to people and the environment for all phases of the tailings facility lifecycle, including closure and post-closure” (ICMM-UNEP-PRI, 2020). Within Principle 5, Requirement 5.5 requires that companies “Develop a design for each stage of construction of the tailings facility, including but not limited to start-up, partial raises and interim configurations, final raise, and all closure stages” (ICMM-UNEP-PRI, 2020). Requirement 5.6 requires that companies “Design the closure phase in a manner that meets all the Requirements of the Standard with sufficient detail to demonstrate the feasibility of the closure scenario and to allow implementation of elements of the design during construction and operation as appropriate. The design should include progressive closure and reclamation during operations” (ICMM-UNEP-PRI, 2020). Company Members of ICMM have been obligated to fully comply with the GISTM by August 5, 2023 (ICMM, 2020, 2021). Although neither PT Halmahera Persada Lygend nor any of its parent companies are Company Members, it is noteworthy that Association Members of ICMM include the Australasian Institute of Mining and Metallurgy (AusIMM), the Cobalt Institute, the Japan Mining Association (JMAI), the Minerals Council of Australia (MCA), and the Nickel Institute.

Thus, the expectation for compliance with the GISTM is well-established in Australia, East Asia, and the nickel and cobalt mining industries.

Lack of Realism in the Dam Break Analysis

SRK Consulting (2022a) reprinted a map from PT Lapi ITB (2020) that showed the area that will be inundated with tailings following the catastrophic failure of the DSTF at the PT HPL project (see Fig. 34). PT Lapi ITB (2020) explained that the inundation area was developed using a deterministic model that assumed that the tailings had fully liquefied, but did not provide any of the other assumptions and input parameters behind the model. According to PT Lapi ITB (2020), “The assessment approach of DSTF risk failure is carried out through a DAM break analysis simulation. Even though the tailing material is a solid material and non-liquefaction material, the risk assessment is made very conservative by assumed [assuming] the tailings material is liquid. DAM break analysis is performed by numerical simulation based on predicted volume and flow, the model calculates the depth reached by the peak flow based on channel geometry, slope, and roughness coefficient.” The description of the tailings as “non-liquefaction material” is in contradiction to the extensive discussion of liquefaction potential and seismic instability that is available in the same document, as well as in Hatch (2020), and which has already been discussed in the subsection “Susceptibility to Liquefaction” (see Figs. 30a-b and 32a-d). PT Lapi ITB (2020) continued, “The result of [the] simulation show [shows] the maximum distance from the DSTF failure is around 2.2 Km to the downstream of [the] DSTF location.”

SRK Consulting (2022a) described the methodology for the dam break analysis as “Not stated,” but confirmed that “Tailings was [were] considered as liquid, which will generate greater affected mass than if it was [were] assessed as a solids [solid] mass” and that the “maximum distance travelled” will be 2200 meters. SRK Consulting (2022a) further stated that “The Kawasi village [see Fig. 34] is not affected but some mining areas (Toba) are disrupted.” Finally, SRK Consulting (2022a) described both the “People at risk (PAR)” and the “Potential loss of life (PLL)” as “Not reported.” In fact, PT Lapi ITB (2020) did not discuss threats to people, including mineworkers, but only threats to infrastructure. According to PT Lapi ITB (2020), “The affected area is [does] not reach the community location (Kawasi Village), and there is [are] no important buildings and assets that is [are] included in the affected area.”

SRK Consulting showed a remarkable lack of due diligence in accepting the inundation map by PT Lapi ITB (2020) (see Fig. 34) at face value. First, although PT Lapi ITB (2020) did not provide any of the input parameters, the residual strength of the liquefied tailings is a crucial parameter and SRK Consulting (2022a) had already noted that the residual strength had never been measured. Second, the runout distance of only 2200 meters is completely out of line with the history of catastrophic failures of tailings storage facilities (see Table 3 and Fig. 19b). Based on the statistical model for catastrophic failures of tailings storage facilities that was discussed in the “Tutorial” section and a storage volume of 25.8 million cubic meters, in the most-likely scenario, the collapse of the DSTF will release 8.4 million cubic meters of tailings (33% of the storage volume) (see Fig. 19a). The statistical model should be regarded as highly reliable in the case of the PT HPL DSTF because the storage volume of 25.8 million cubic meters places the tailings facility well within the dataset that was used to develop the statistical model (see Fig. 19a). The height of 57 meters then predicts a runout distance of 47 kilometers under the most-likely scenario (release of 33% of the storage volume) and 161 kilometers under the worst-case scenario (release of 100% of the storage volume) (see Fig. 19b). The statistical model should again be regarded as highly reliable because the storage volume of 25.8 million cubic meters and height of 57 meters places the tailings facility well within the dataset that was used to develop the statistical model for runout distance (see Fig. 19b). Thus, the conclusion that the released tailings will reach the Molucca Sea (see Fig. 34) is inescapable.

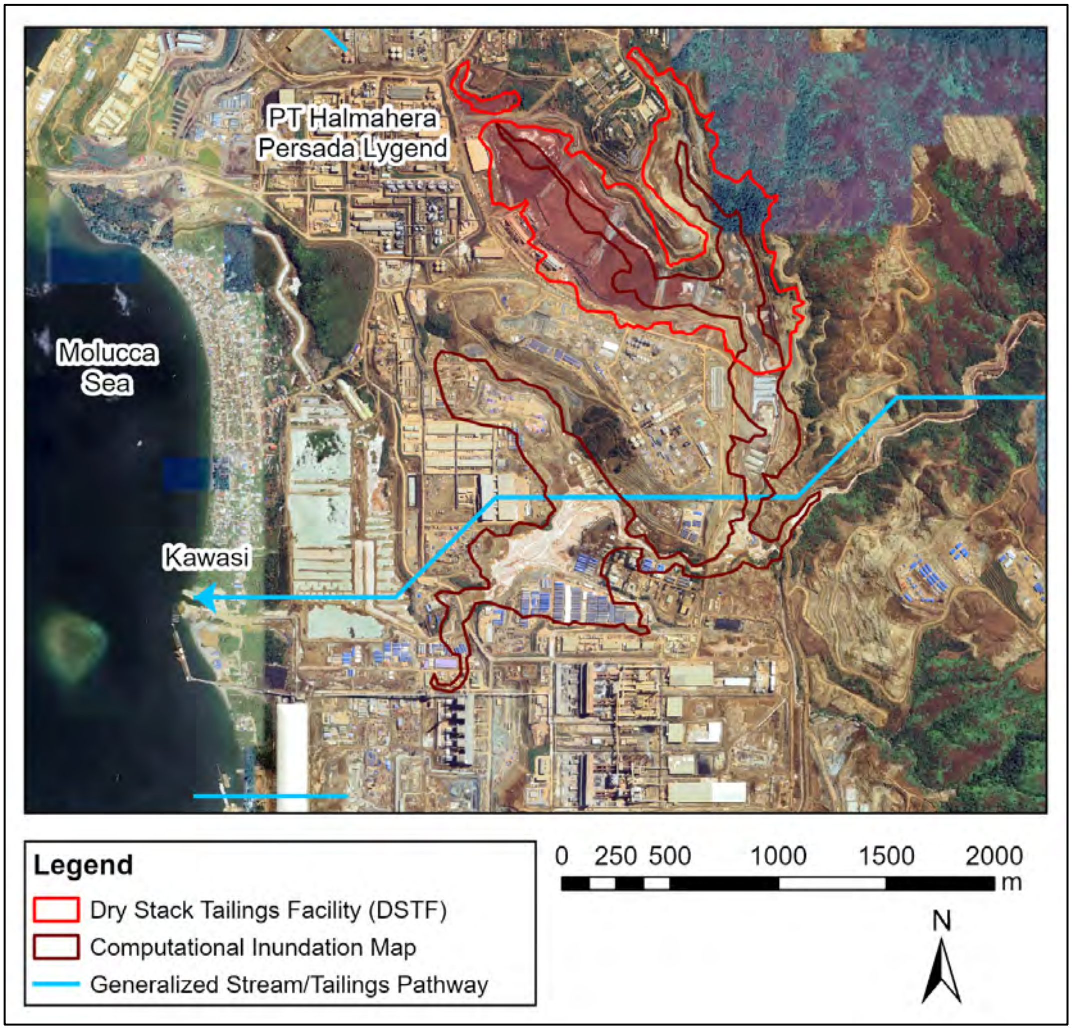

Figure 34. A computational model by consultants for Harita Nickel shows a runout distance of 2200 meters after collapse of the Dry Stack Tailings Facility (DSTF) assuming liquefaction of the tailings. By contrast, based on a statistical model of past tailings facility failures, the height (57 meters) and storage volume (25.8 million cubic meters) of the facility predict a runout distance of 47 kilometers (see Fig. 19b), which would easily transport the tailings to the ocean. The limited distance and irregular ponding predicted by the computational model probably results from an incorrect topographic model that creates fictitious barriers to flow. The most-likely scenario is that the tailings will enter an unnamed stream less than 600 meters downslope from the DSTF and then flow westward to the Molucca Sea with crossing of considerable mining infrastructure and overtopping of the stream channel onto the village of Kawasi. Note the small offset between the generalized stream from HydroSheds (2025) and the Google Earth imagery from August 6 and November 20, 2023. Even without initial liquefaction, a slump of the DSTF will carry the tailings to the unnamed stream, at which point the tailings will become a fully fluidized mass. Outline of Dry Stack Tailings Facility from PT Lapi ITB (2022) and outline of computational inundation map from PT Lapi ITB (2020).

The third consideration is that the inundation area intersects a westward-flowing river about 570 meters from the toe of the filtered tailings storage facility along the tailings flow path. (see Fig. 34). Thus, the most likely prediction is that the tailings will reach the river and then flow westward 1600 meters to the Molucca Sea just south of the village of Kawasi with considerable crossings of mining infrastructure (see Fig. 34). Thus, potential impacts on mineworkers of the PT HPL project and other mines need to be taken into consideration, as well as the potential for overtopping of the stream channel onto the village of Kawasi. The likely source of error in the deterministic model can be surmised from the irregular ponding that can be seen in the predicted inundation area (see Fig. 34). Such irregular ponding usually results from an incorrect topographic model that creates fictitious barriers to flow. For example, the topographic model might include the elevation of a bridge as the natural topography, which would block the flow of a river from the standpoint of the computational model.

Although the dam break analysis assumed full liquefaction of the tailings, it is likely that the tailings will flow to the Molucca Sea even without initial liquefaction. It was shown in the "Tutorial" section that, based on failures of filtered tailings storage facilities in Brazil in January 2022 and December 2024, a solid slump of filtered tailings without liquefaction will transport the tailings a distance equal to about 20 times the height of the filtered tailings stack. In the case of the DSTF at the PT HPL project, the stack height of 57 meters implies that the released tailings will travel about 1140 meters even without liquefaction. Since the closest river is only 570 meters from the toe of the DSTF (see Fig. 34), the released tailings will become a fully liquified mass as soon as they mix with the river water, after which the liquefied tailings will flow to the Molucca Sea (see Fig. 34).

Surface Ponding and Willful Blindness

The purpose of this subsection is to provide further evidence for the imminent catastrophic failure of the DSTF, as well as examples of the actions that SRK Consulting took to dramatically minimize the evidence of serious problems with the DSTF. Revision 1 of the 2022 report by SRK Consulting (2022b) included a large (half-page) photo with the heading "View of DSTF area with significant water ponding" (see Fig. 35a). SRK Consulting (2022b) interpreted the surface ponding as a significant risk for liquefaction. According to SRK Consulting (2022b),"**During the site visit, some issues with water ponding and poor drainage appeared to be present (Figure 9-11)** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing" (emphasis added). The above photo was gradually reduced in size, while the heading and interpretation were completely eliminated through the sequence of revisions (see Figs. 35b-e). Before reviewing the edits made to a series of report drafts that minimize the issues with the DSTF, it is important to discuss why surface ponding matters.

Figure 9-11: View of DSTF area with significant water ponding

Source: SRK site visit

Figure 35a. The first revision of the 2022 report by SRK Consulting (2022b) included a large photo with the heading “View of DSTF area with significant water ponding.” Surface ponding is a very serious problem for a filtered tailings storage facility because the ponded water can lead to erosion and washouts (gully formation) of the filtered tailings stack and because the ponded areas are not trafficable. Moreover, ponding raises the possibility that the entire stack might be saturated and liquefiable, while the surface water would promote flow behavior if a collapse did occur. According to SRK Consulting (2022b),“**During the site visit, some issues with water ponding and poor drainage appeared to be present (Figure 9-11)** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing” (emphasis added). A simple way to assess whether the entire stack might be saturated would be to inquire as to the persistence of surface ponding after the cessation of rainfall. SRK Consulting did not include information on the persistence of water ponding in their 2022 report. Photo from SRK Consulting (2022b). Photo from SRK Consulting (2022b).

Figure 8-6: DSFT operation

Source: SRK site visit

Note: A: filter presses, B: Conveyor belt with filtered material, C: View of conveyors and earthmoving plant and D: View of DSTF area with water ponding issue

Figure 35b. The large photo with the heading "View of DSTF area with significant water ponding" in the first revision of the 2022 report by SRK Consulting (2022b) was made much smaller in a follow-up to the first revision (SRK Consulting, 2022c) and the caption was changed to "View of DSTF area with water ponding issues." Otherwise, the photo is identical. The follow-up to the first revision still states, "**During the site visit, some issues with water ponding and poor drainage appeared to be present** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction, however it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, a further study is required to assess the risk for the tailings to have contractive behaviour during undrained shearing" (emphasis added). The above photo, caption, and quote in SRK Consulting (2022c) are unchanged through Revision 8 (SRK Consulting, 2022e), except that "DSTF" was changed to "dry stack tailings facility" in the photo caption and "poor drainage" was changed to "drainage" in the quote. Photo from SRK Consulting (2022c).

Figure 7-6: Dry stack tailings facility operation

Source: SRK site visit

Note: A: filter presses, B: Conveyor belt with filtered material, C: View of conveyors and earthmoving plant and D: View of dry stack tailings facility area

Figure 35c. In Revision 8A, the photo caption of the previous revisions that stated, “View of DSTF area with water ponding issues” or “View of dry stack tailings facility area with water ponding issues” (see Fig. 35b) was changed to “View of dry stack tailings facility area” with no change in the photo. In the quote from Revision 8 that stated, “**During the site visit, some issues with water ponding and drainage appeared to be present** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction, however it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, a further study is required to assess the risk for the tailings to have contractive behaviour during undrained shearing” (emphasis added) (SRK Consulting, 2022e), the sentence “During the site visit, some issues with water ponding and drainage appeared to be present” was removed, as well as the phrase “and the observed surface water issues,” which actually left the last sentence grammatically incorrect. The photo, caption, and quote were unchanged through the final revision (SRK Consulting, 2022a), except that the quote was fixed to be grammatically correct: “The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m) and the lack of quality control in the placement of tailings, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing.” Photo from SRK Consulting (2022f).

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Figure 7-6: **Dry stack tailings facility operation**

Source: SRK site visit

Note: A: filter presses, B: Conveyor belt with filtered material, C: View of conveyors and earthmoving plant and D: View of dry stack tailings facility area.

Deleted: with water ponding issue

Figure 35d. The Track Changes version that compares Revision 8A with Revision 8 clarifies the changes that were made. First, the phrase “with water ponding issue” was removed from the photo caption. See additional change in Fig. 35e. Photo with changes from SRK Consulting (2022g).

2022) shows the drainage plan, but the discharge of P23-SE and P09-SW drains away from the dry stack tailings facility is unclear. It was also noted that part of the drainage infrastructure was still under construction.

Deleted: During the site visit, some issues with water ponding and drainage appeared to be present (Figure 7-8).

Slope stability design results show that the dry stack tailings facility has a robust design, with an FoS above 2.5 (which is above the FoS value of 1.5 usually required). The geotechnical parameters appear within reasonable values based on SRK's experience. The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing.

Deleted: and the observed surface water issues,

Figure 35e. The Track Changes version that compares Revision 8A with Revision 8 clarifies the changes that were made. Namely, the sentence “During the site visit, some issues with water ponding and drainage appeared to be present (Figure 7-8)” and the phrase “and the observed surface water issues” were removed See additional change to photo caption in Fig. 35d. Text with changes from SRK Consulting (2022g).

Surface ponding is a very serious problem for a filtered tailings storage facility because the ponded water can lead to erosion and washouts (gully formation) of the filtered tailings stack. In this respect, after “Dry stack tailings failure,” SRK Consulting (2022a) listed “Erosion of dry stack tailings facility” and “Contact water spilled” as the second and third of the “Uncontrolled risks.” The areas with ponded water could not be compacted because the areas would not be trafficable. Even if heavy equipment could be driven over the ponded areas, the tailings below the surface ponds would be saturated with water, so that they could not be properly compacted. Attempts to compact saturated materials or materials that are significantly wetter than the optimum water content for maximum compaction can lead to materials with very little shear strength (Holtz et al, 2011), which would lead to reduced stability. Thus, the newly deposited tailings could not be adequately compacted even if surface water could be moved from one part of the filtered tailings stack to another in order to allow for the passage of heavy equipment. Moreover, saturated tailings can potentially liquefy, especially if they were never properly compacted. Finally, if a collapse of the filtered tailings stack did occur, the presence of free water would promote flow behavior of the released tailings.

Overall, surface ponding indicates improper construction of the filtered tailings stack. Surface ponding could result from improper filtering of the tailings (so that water contents are too high) or from stacking of the tailings during high rainfall (which could result from a lack of space for temporary storage of tailings during periods of high rainfall). Surface ponding could also result from insufficient sloping of the surfaces to promote runoff. According to the filtered tailings manual by the BHP Rio Tinto Tailings Management Consortium (2024), "Positive surface grading is critical to avoid surface water ponding on the surface of the filtered tailings stack which can lead to increased seepage, stability impacts through rising phreatic levels or difficulties in equipment trafficability." Finally, surface ponding could be a result of insufficient drainage infrastructure within the filtered tailings stack. In this respect, the numerous observations by SRK Consulting (2022a) that the parts of the drainage infrastructure had still not been constructed should be taken into consideration, as well as their assertion that parts of the drainage design did not even make sense (see Fig. 26).

The most serious problem of all is that the observation of surface ponding raises the possibility that the entire filtered tailings stack might be saturated from top to bottom. According to PT Lapi ITB (2020), the DSTF should be placed into Emergency Levels 1, 2, and 3, if the water table rose to 25%, 50%, or 80% of the stack height, respectively (see Fig. 36). Emergency Level 1 corresponds to "Conditions that do not require an emergency response but require prompt investigation and resolution" (PT Lapi ITB, 2020). Emergency Level 2 corresponds to "Potential for emergencies if conditions are sustainable or allowed to develop; need a response plan" (PT Lapi ITB, 2020). Emergency Level 3 corresponds to "Immediate or actual failure that requires partial or complete evacuation, emergency communication and response measures" (PT Lapi ITB, 2020). Thus, simply the observation of surface ponding raises the possibility that the DSTF might require an emergency response that might include the need for evacuation of the downstream area.

The height of the water table within the DSTF could have been determined using the piezometers (instruments that measure water table height and pore pressures) on the DSTF, except that SRK Consulting (2022b) also pointed out that there were no piezometers or any other type of monitoring instrumentation. However, inquiry into the persistence of surface ponding after the cessation of rainfall is another simple way to begin to determine the scope of the issue. The persistence of surface ponding for hours or days after the cessation of rainfall would have been a very dangerous sign because it could have suggested that the filtered tailings stack was completely saturated and was not draining at all. SRK Consulting (2022a) does not answer the question of the persistence of water ponding after rainfall in their report.

Table VII-6 Threshold Value from Monitoring Instrument

Monitoring instrument	Threshold value	Emergency level
Piezometer	25% drystack height	1
	50% drystack height	2
	80% drystack height	3
Channel (Weir)	50% weir height	1
	75% weir height	2
	100% weir height	3
Point Survey (RTK)	0.2 mm/hr	1
	1 mm/hr	2
	1.5 mm/hr	3

Figure 36. According to a consulting report by PT Lapi ITB (2020), the Dry Stack Tailings Facility (DSTF) should be placed into Emergency Levels 1, 2, and 3, if the water table rose to 25%, 50%, or 80% of the stack height, respectively. Emergency Level 1 corresponds to "Conditions that do not require an emergency response but require prompt investigation and resolution." Emergency Level 2 corresponds to "Potential for emergencies if conditions are sustainable or allowed to develop; need a response plan." Emergency Level 3 corresponds to "Immediate or actual failure that requires partial or complete evacuation, emergency communication and response measures." Thus, surface ponding (see Figs. 35a-d) raises the possibility that the entire stack might be saturated, which would place the tailings facility into the highest Emergency Level 3. Table from PT Lapi ITB (2020).

Given the available information, it does not appear that SRK Consulting determined the cause or causes of the surface ponding. SRK Consulting did observe the significant ponding and poor drainage issues, but successive drafts of their report removed key language, minimizing the risks these issues pose to the DSTF. In the follow-up to Revision 1 (called Rev1_Draft) (SRK Consulting, 2022c), the large photo of surface ponding in Revision 1 (see Fig. 35a) was reduced to a one-quarter of its previous size (see Fig. 35b). The heading "View of DSTF area with significant water ponding" (SRK Consulting, 2022b; see Fig. 35a) was softened to the caption "View of DSTF area with water ponding issues" (SRK Consulting, 2022c; see Fig. 35b). Otherwise, the photo is identical between the two versions (compare Figs. 35a-b). The follow-up to Revision 1 still states, "**During the site visit, some issues with water ponding and poor drainage appeared to be present** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction, however it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, a further study is required to assess the risk for the tailings to have contractive behaviour during undrained shearing" (emphasis added) (SRK Consulting, 2022c). The above photo, caption, and quote in SRK Consulting (2022c) were unchanged through Revision 8 (SRK Consulting, 2022e), except that "DSTF" was changed to "dry stack tailings facility" in the photo caption and "poor drainage" was softened to "drainage" in the quote.

The significant change occurred in the transition from Revision 8 (SRK Consulting, 2022e) to Revision 8A (SRK Consulting, 2022f). In Revision 8A, the photo caption of the previous revisions that had stated "View of DSTF area with water ponding issues" (SRK Consulting, 2022c; see Fig. 35b) or "View of dry stack tailings facility area with water ponding issues" (SRK Consulting, 2022e) was changed to "View of dry stack tailings facility area" (SRK Consulting, 2022e; see Fig. 35c) with no change in the photo. Thus, the observation of surface ponding was eliminated entirely. In the quote from Revision 8 that stated, "**During the site visit, some issues with water ponding and drainage appeared to be present** … The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction, however it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, **and the observed surface water issues**, a further study is required to assess the risk for the tailings to have contractive behaviour during undrained shearing" (emphasis added) (SRK Consulting, 2022e), the sentence "During the site visit, some issues with water ponding and drainage appeared to be present" was removed, as well as the phrase "and the observed surface water issues," which actually left the last sentence grammatically incorrect. Thus, all mention of the observation of surface ponding, as well the significance of surface ponding, was removed from Revision 8A (SRK Consulting, 2022e). The full quote in Revision 8A states, "The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however it is SRK's opinion that given the height of the facility (57 m), the lack of quality control in the placement of tailings, a further study is required to assess the risk for the tailings to have contractive behaviour during undrained shearing" (SRK Consulting, 2022e). Figs. 35d-e shows the Track Changes version of Revision 8A (SRK Consulting, 2022g) that clarifies the critical deletions that were made in the transition from Revision 8 to Revision 8A.

The only change that was made to the quote in the final Revision 9 was that the sentence was fixed to be grammatically correct. Thus, Revision 9 states, "The design considered that the compaction imposed on the tailings would be sufficient to prevent liquefaction; however, it is SRK's opinion that given the height of the facility (57 m) and the lack of quality control in the placement of tailings, further study is required to assess the risk for the tailings to exhibit contractive behaviour during undrained shearing." In summary, by the end of the sequence of revisions, there is no mention of surface ponding and no discussion of the significance of surface ponding. Only the photo remains with one-quarter of its size in Revision 1 (compare Fig. 35a with Figs. 35b-c). At this point, only the most extremely attentive reader would be aware of the surface ponding, unless the reader had access to the previous versions of the report.

Compliance with Indonesian Regulations

The conclusion by SRK Consulting (2022a) was that "Both facilities [the RKEF processing plant and the HPAL processing plant] appear to be in general compliance with local regulations by the Indonesian government." SRK Consulting (2022a) did not make any reference to Indonesian regulations, nor carry out any comparison with Indonesian regulations. SRK Consulting (2022a) also did not clarify how "general" compliance might be different from "complete" compliance. The statement of compliance is probably correct, but the lack of standards in the Indonesian regulations, as was discussed in the "Tutorial" section, should be borne in mind. In fact, the only standards related to land disposal of tailings state the need for an analysis of the consequences of dam failure. This analysis was carried out for the DSTF, although with a lack of realism (see Fig. 34). SRK Consulting (2022a) did draw attention to the lack of compliance with international standards and recommended that PT HPL "Undertake further work to prove compliance with GISTM [Global Industry Standard on Tailings Management] / ANCOLD [Australian National Committee on Large Dams] … [which] should include a consequence category type risk assessment, stability analyses and surface water management."

Unstable Tailings Dumps

An Indonesian-language internal memo from Harita Nickel and PT TBP (2023) dated January 31, 2023, contains the surprising information that, in addition to the Dry Stack Tailings Facility (DSTF), there are at least four other filtered tailings storage facilities associated with the PT HPL project (see Figs. 37-38). There is no mention of these additional filtered tailings storage facilities in any of the official documents related to the PT HPL project, such as the ESG or sustainability reports (PT Halmahera Persada Lygend, 2022, 2023, 2024; PT Trimegah Bangun Persada, 2023a). The four additional facilities are northwest of the DSTF and northwest of most of the infrastructure of the PT HPL project (see Figs. 37-38). Each of the four filtered tailings storage facilities is described as a "Disposal Tailing Dam" within the text of the memo and as a "WD Tailings Dump" on a map within the memo (Harita Nickel and PT TBP, 2023). The expression "Tailings Disposal Dam" would be a more grammatically correct English version. The significance of "WD" is not clear, although it might stand for "Waste Disposal." Each of the four tailings facilities is also referred to as "Dry Stack Tailing" (Harita Nickel and PT TBP, 2023), which clarifies that they are filtered tailings storage facilities.

The four additional filtered tailings storage facilities were designed according to much weaker safety standards than the DSTF. According to Harita Nickel and PT TBP (2023), "*Faktor Keamanan (FK) Minimum : FK Statis ≥ 1,3 dan FK Dinamis ≥ 1,05"* [Minimum Factor of Safety (FS): Static FS ≥ 1.3 and Dynamic FS ≥ 1.05]. By contrast, the DSTF was designed for a minimum static factor of safety of 1.5 and minimum pseudostatic (seismic or dynamic) factor of safety of 1.1, which is consistent with the vast majority of international guidance documents and regulations (see Fig. 31). The reference for the lower safety standards is the internal company document HNG-TBP-EBI-39-021-SOP Pengelolaan Geoteknik [Geotechnical Management], which is not available to the author. The lower minimum static factor of safety might possibly reflect the tailings regulations in the People's Republic of China that require a minimum static factor of safety of 1.30 for a Class III tailings storage facility, which is a facility with a height in the range 60 to 100 meters or storage volume in the range 10-100 million cubic meters (National Standards of the People's Republic of China, 2020). The Chinese regulations require minimum static factors of safety as low as 1.25 for smaller tailings storage facilities. (English translations of Chinese tailings regulations are available as appendices to Emerman (2023b)). The author is not aware of any regulations or guidance documents that specify a minimum pseudostatic factor of safety of 1.05.

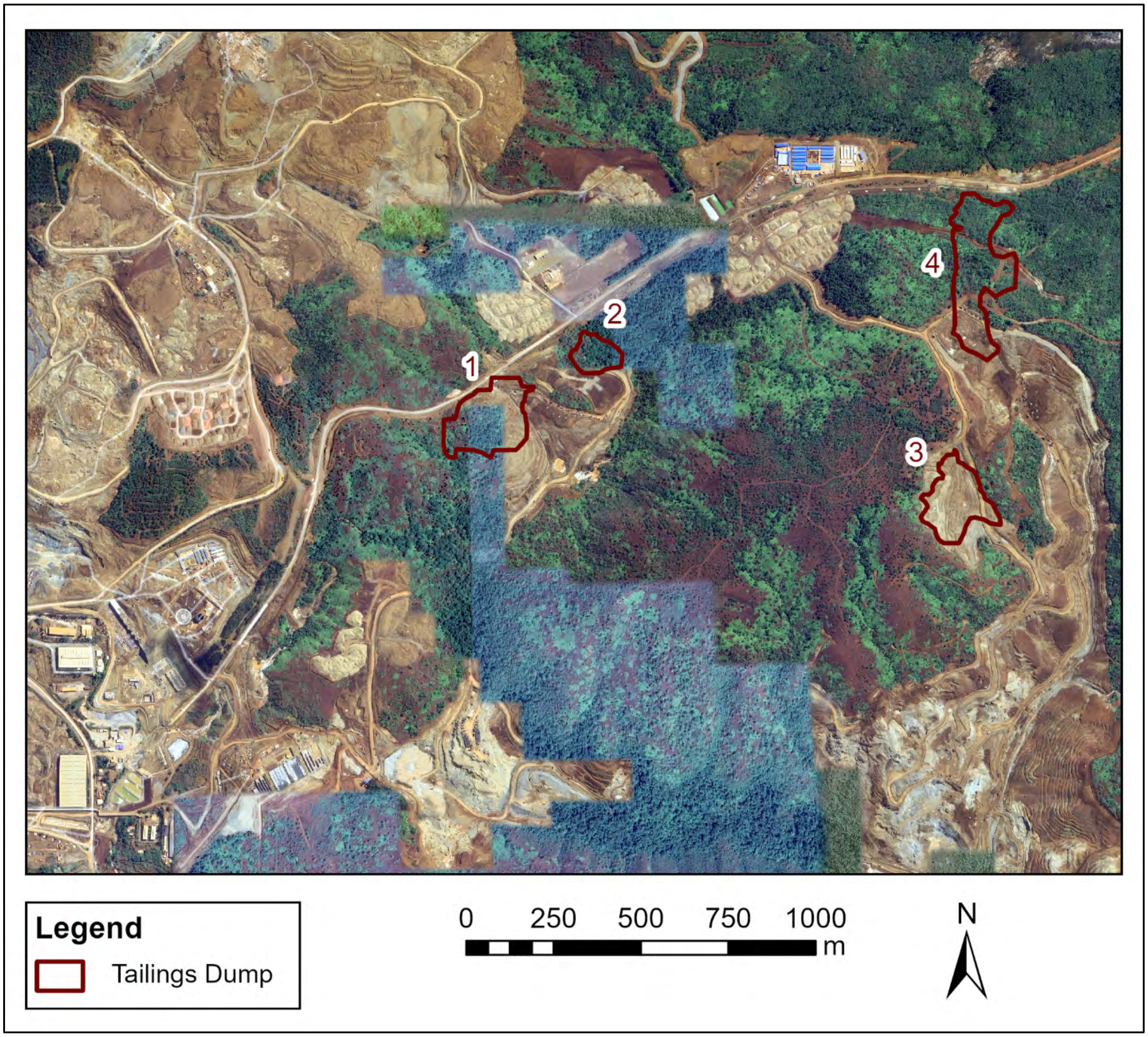

Figure 37. Harita Nickel and PT TBP (2023) discussed four filtered tailings storage facilities that were distinct from the PT HPL Dry Stack Tailings Facility (DSTF). Numbering of filtered tailings storage facilities is by the author. A map in Harita Nickel and PT TBP (2023) labels each of the facilities as "WD Tailings Dump" and also labels Tailings Dump #1 as "Karo Disposal Tailings Dump." According to Harita Nickel and PT TBP (2023), the factor safety of Tailings Dump #1 was 1.045, so that the facility was on the cusp of catastrophic failure. Harita Nickel and PT TBP (2023) recommended that no additional tailings be placed in Tailings Dump #1, but made no recommendations regarding the safety of mineworkers, even though Tailings Dump #1 is only several hundred meters upslope from considerable mining infrastructure. Tailings dumps traced from map in Harita Nickel and PT TBP (2023). Background is Google Earth imagery from August 6, 2023.

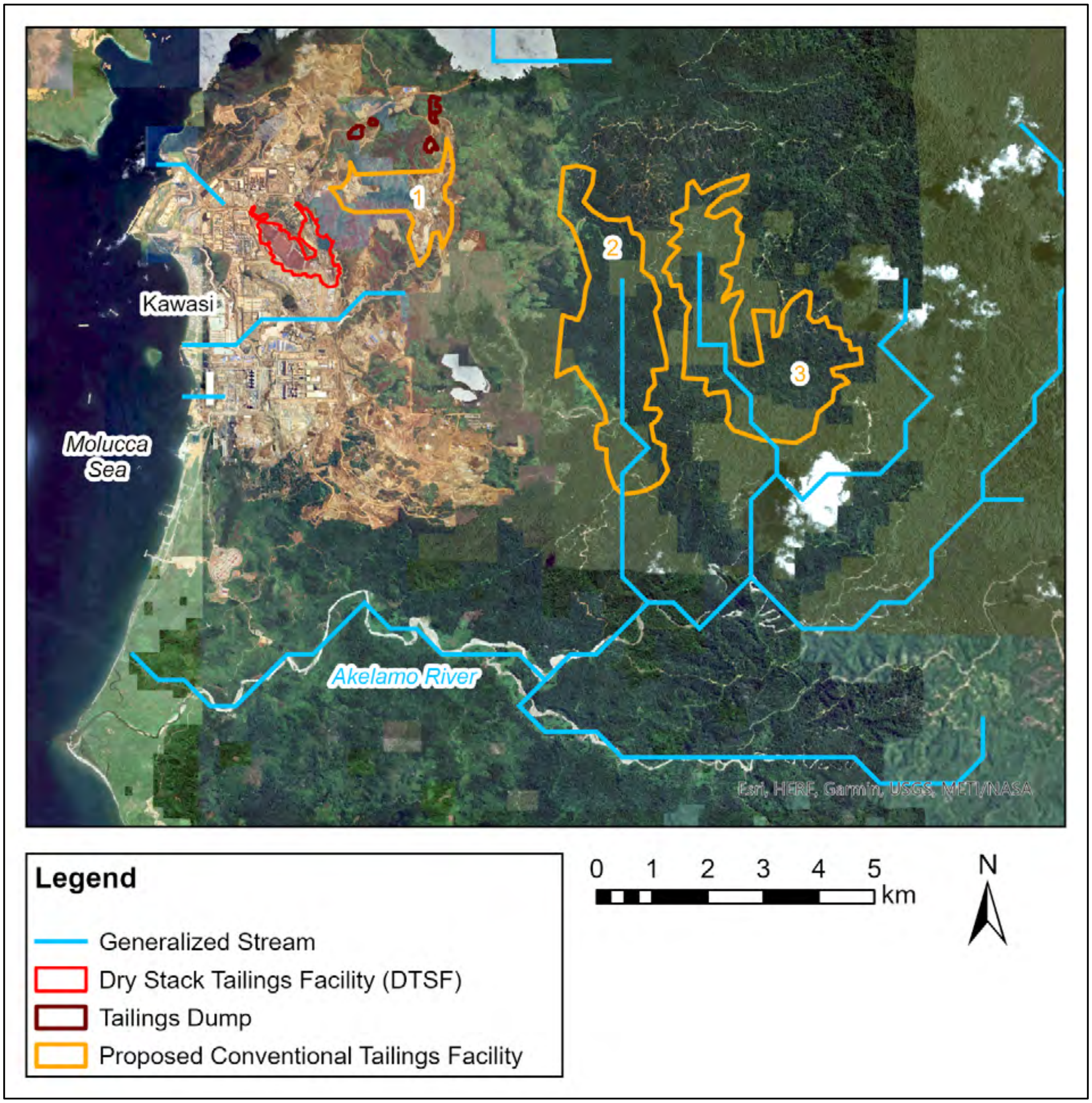

Figure 38. PT Halmahera Persada Lygend (HPL) is considering the construction of three conventional tailings facilities to store additional tailings after the Dry Stack Tailings Facility (DSTF) reaches full capacity in mid-2027. With a combined footprint of 1556 hectares, the conventional tailings storage facilities would cover eight times the area of the existing DSTF. SRK Consulting (2022a) refers to the conventional tailings storage facilities as Residue Storage Facilities (RSF) and denotes the proposed facilities as RSF 1, RSF 2, and RSF 3. As of December 2022, the conventional tailings storage facilities were already in the permitting phase. The presence of RSF 2 and RSF 3 at the headwaters of the Akelamo River indicates that a tailings dam failure could contaminate the entire Akelamo River Basin. See Figs. 34 and 37 for smaller-scale views of the DSTF and the tailings dumps, respectively. Generalized streams from HydroSHEDS (2025) with name of river from Yasya et al. (2024). DSTF, tailings dumps, and proposed conventional tailings facilities traced from maps in PT Lapi ITB (2022), Harita Nickel and PT TBP (2023), and SRK Consulting (2022a), respectively. The outlines of the proposed conventional tailings facilities are approximate since the outlines are obscured by numerous labels in the map in SRK Consulting (2022a) (see Fig. 47). Background is Google Earth imagery from December 31, 2020, and August 6, 2023.

Many of the same problems that were described by SRK Consulting (2022a) for the DSTF in terms of lack of monitoring and lack of adherence to design are also present in the four additional filtered tailings storage facilities. According to Harita Nickel and TBP (2023), "*Dalam melakukan kajian kestabilan lereng aktual Disposal Tailing Dam, masih terdapat kemungkinan kegagalan geoteknik (kelongsoran) yang disebabkan oleh:*

a. Keterbatasan parameter sifat fisik dan mekanik material; timbunan (Overburden), & Tanah dasar (Limonite, Saprolite, dan Bedrock).
b. Keterbatasan informasi kondisi air tanah.
c. Praktek kerja yang tidak aman serta tidak mengikuti standar/kajian geoteknik yang berlaku (Faktor Operasional)"

[In conducting a study of the actual slope stability of the Tailings Disposal Dam, there is still the possibility of geotechnical failure (slides) caused by:

a. Limitations of physical and mechanical properties of materials; Overburden, & Base soil (Limonite, Saprolite, and Bedrock).
b. Limited information on groundwater conditions.
c. Unsafe work practices and failure to comply with applicable geotechnical standards/studies (Operational Factors)].

Harita Nickel and PT TBP (2023) further emphasized the need to adhere to both designs and internal company standards. According to Harita Nickel and PT TBP (2023), "*Geometri lereng disposal yang tidak sesuai dengan geometri lereng timbunan rekomendasi perlu dibentuk bench/jenjang*" [The geometry of the disposal slope that does not match the geometry of the recommended embankment slope requires the formation of a bench/level]. Moreover, Harita Nickel and PT TBP underscored the need to construct proper drainage infrastructure to prevent surface ponding, which is the recommendation that should have been present in the review by SRK Consulting (2022a) (compare with Figs. 35a-e). According to Harita Nickel and PT TBP (2023), "*Drainase yang baik diperlukan untuk mencegah arah aliran air menggenang pada badan disposal*" [Good drainage is needed to prevent water flow from pooling in the disposal body].

Harita Nickel and PT TBP (2023) drew particular attention to one filtered tailings storage facility, referred to as the "Disposal Tailing Dam Karo" (Tailings Dump #1 in Fig. 37). According to Harita Nickel and PT TBP (2023), the filtered tailings storage facility was on the cusp of catastrophic failure with a static factor of safety of only 1.045 (see Fig. 39). The recommendation of Harita Nickel and PT TBP (2023) was that "*Kegiatan dumping di area disposal ini tidak direkomendasikan untuk dilanjutkan kembali*" [Dumping activities in this disposal area are not recommended to be continued]. The memo continued with recommendations regarding the repair of the filtered tailings storage facility, but it is disappointing that there were no recommendations regarding measures to be taken to protect mineworkers, despite the fact that Tailings Dump #1 is only several hundred meters upslope from considerable mining infrastructure (see Fig. 37).

Tabel 3. Nilai FK Lereng pada setiap sayatan

Desain	Sayatan	FK Statis (FK min. ≥ 1.3)	Keterangan
Disposal Tailing Dam (Karo)	A-A'	3.203	Stabil
	B-B'	2.184	Stabil
	C-C'	1.045	Kritis
	D-D'	1.856	Stabil

Figure 39. According to Harita Nickel and PT TBP (2023), the filtered tailings storage facility called "Disposal Tailing Dam (Karo)" (see Tailings Dump #1 in Fig. 37) had a static factor of safety of 1.045, so that the facility was on the cusp of catastrophic failure ("kritis" in Indonesian corresponds to "critical" in English). Harita Nickel and PT TBP (2023) recommended that no additional tailings be placed in Tailings Dump #1, but made no recommendations regarding the safety of mineworkers, even though Tailings Dump #1 is only several hundred meters upslope from considerable mining infrastructure (see Fig. 37). Table from Harita Nickel and PT TBP (2023).

SULAWESI ISLAND: ONGOING CATASTROPHIC FAILURE

Liquefaction and Release of Tailings on March 16, 2025

The purpose of this section is to recount the ongoing catastrophic failure of filtered tailings storage facilities connected with the Indonesia Morowali Industrial Park on Sulawesi Island (see Figs. 3, 23, and 24). The catastrophic failure has been ongoing since at least September 2023 and intensified in both severity and frequency in March and April of 2025. The previous section on the imminent catastrophic failure on Obi Island relied largely on consulting reports, as well as internal and public documents of mining companies. By contrast, in the absence of such information, this section relies primarily on media reports and on information, photos, and videos provided by mineworkers whose names cannot be revealed.

On March 16, 2025, the filtered tailings storage facility of PT Huayue Nickel Cobalt (HYNC) failed by liquefaction (see Fig. 40a), which was the first documented case of liquefaction of a filtered tailings stack. According to Asnawi (2025), "*Morowali yang memiliki curah hujan tinggi menjadikan dried tailing berubah menjadi lumpur dan membelah dinding tanggul*" [Morowali, which has high rainfall, causes dried tailings to turn into mud and split the embankment walls]. From the PT HYNC tailings facility, the released tailings flowed approximately two kilometers eastward to reach the Bahodopi River, from where the tailings flowed northwestward toward the Banda Sea with overflow onto the site of PT Fajar Metal Industry (FMI) (see Figs. 24, 40b-c, and 41a) (Bhawano, 2025; Business & Human Rights Resource Centre, 2025a; Da Costa, 2025; Kabar Sulteng, 2025b; Media Alkhairaat, 2025a-b; Moore, 2025; Morrill, 2025; TribunPalun.com, 2025; Yayasan Tanah Merderka (YTM), 2025a). According to TribunPalun.com (2025), "*Persitiwa banjir tersebut diduga berhubungan dengan jebolnya tanggung di area Fasilitas Penyimpanan Tailing PT Huayue Nickel Cobalt*" [The flood incident is thought to be related to the collapse of the embankment in the PT Huayue Nickel Cobalt Tailings Storage Facility area]. Google Earth imagery from January 3, 2025, shows a clearly-defined landslide from the filtered tailings storage facility operated by PT HYNC with clearly-defined channels for tailings to travel to the Bahodopi River (see Figs. 41a-b) (Media

Alkhairaat, 2025a; Yayasan Tanah Merdeka (YTM), 2025b). Thus, it appears that at least one collapse of the PT HYNC tailings facility occurred even before the collapse on March 16, 2025.

Figure 40a. Liquefied tailings flow through a breach of the filtered tailings storage facility of PT Huayue Nickel Cobalt (HYNC) in the Indonesia Morowali Industrial Park (see Figs. 3, 24, and 41a-b) on March 16, 2025. Still image at 0:00 of 9-second video by mineworker at PT HYNC. Photo also available in Business & Human Rights Resource Centre (2025a) and Moore (2025).

Figure 40b. Tailings released by a collapse on March 16, 2025, of the filtered tailings storage facility of PT Huayue Nickel Cobalt (HYNC) in the Indonesia Morowali Industrial Park (see Figs. 3, 23, 24, and 41a-b) flow down the Bahodopi River. Photo by mineworker at PT HYNC and available in Business & Human Rights Resource Centre (2025a) and Moore (2025). Similar photos are available in Bhawano (2025), Pristiandaru (2025), Teraskabar.id (2025), and Wikaksono (2025).

Figure 40c. Liquefied tailings from the failure of the filtered tailings storage facility of PT HYNC plus flood water from the Bahodopi River (see Figs. 40a-b) overflow onto the site of PT Fajar Metal Industry (FMI) on March 16, 2025 (see Figs. 23-24). Still image at 0:03 of 10-second video by mineworker.

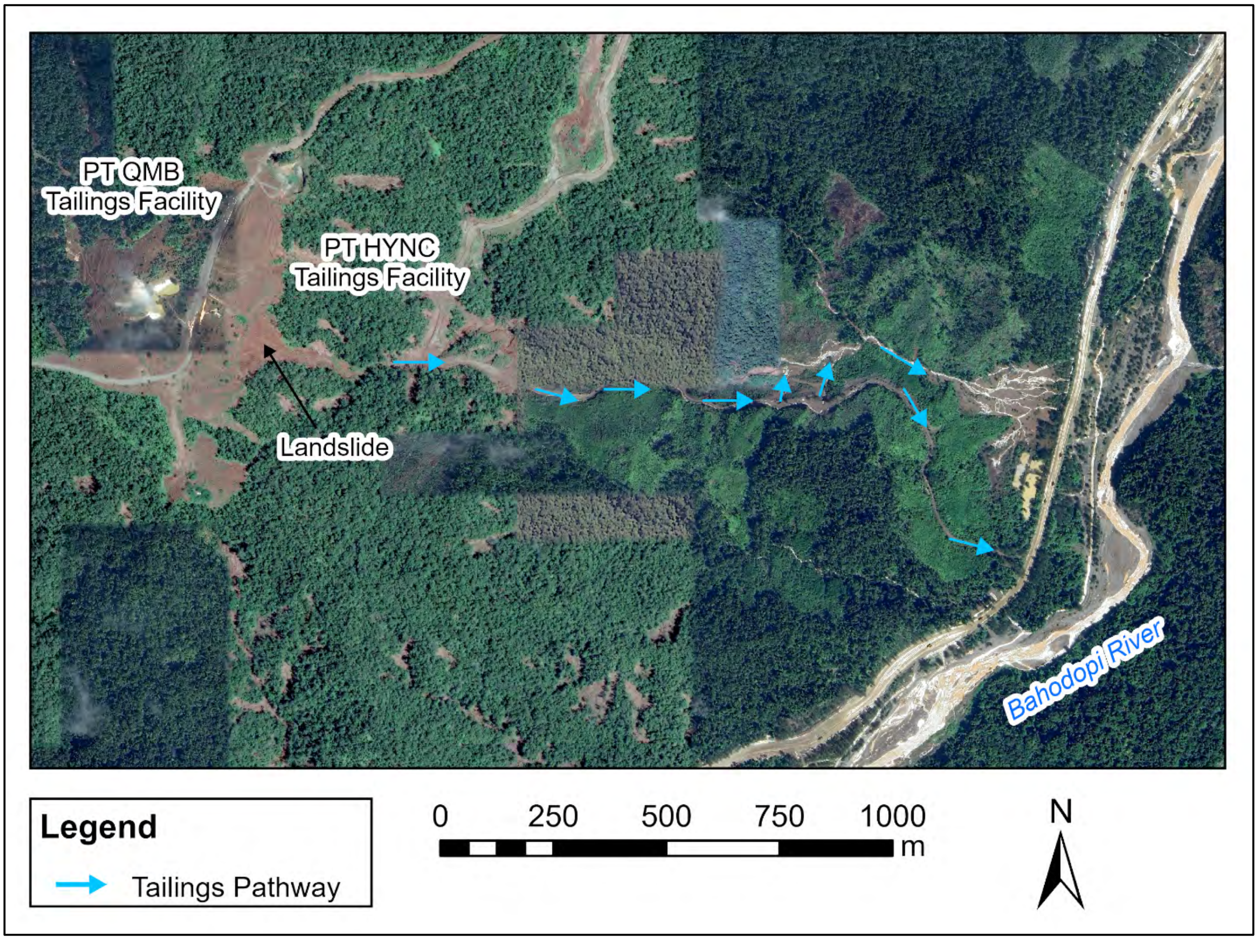

Figure 41a. Google Earth imagery from January 3, 2025, shows a clearly-defined landslide from the filtered tailings storage facility operated by PT Huayue Nickel Cobalt (HYNC) with clearly-defined channels for tailings to travel to the Bahodopi River (see smaller-scale view in Fig. 41b). Thus, it appears that at least one collapse of the PT HYNC tailings facility occurred even before the collapse on March 16, 2025 (see Fig. 40a-c). It is not entirely clear as to whether the filtered tailings storage facilities for PT HYNC and PT QMB are actually separate facilities (see Figs. 40a and 42a). The darker Google Earth imagery is from January 7, 2020. Indonesian versions of the above map are available in Bhawano (2025) and Yayasan Tanah Merdeka (YTM) (2025b).

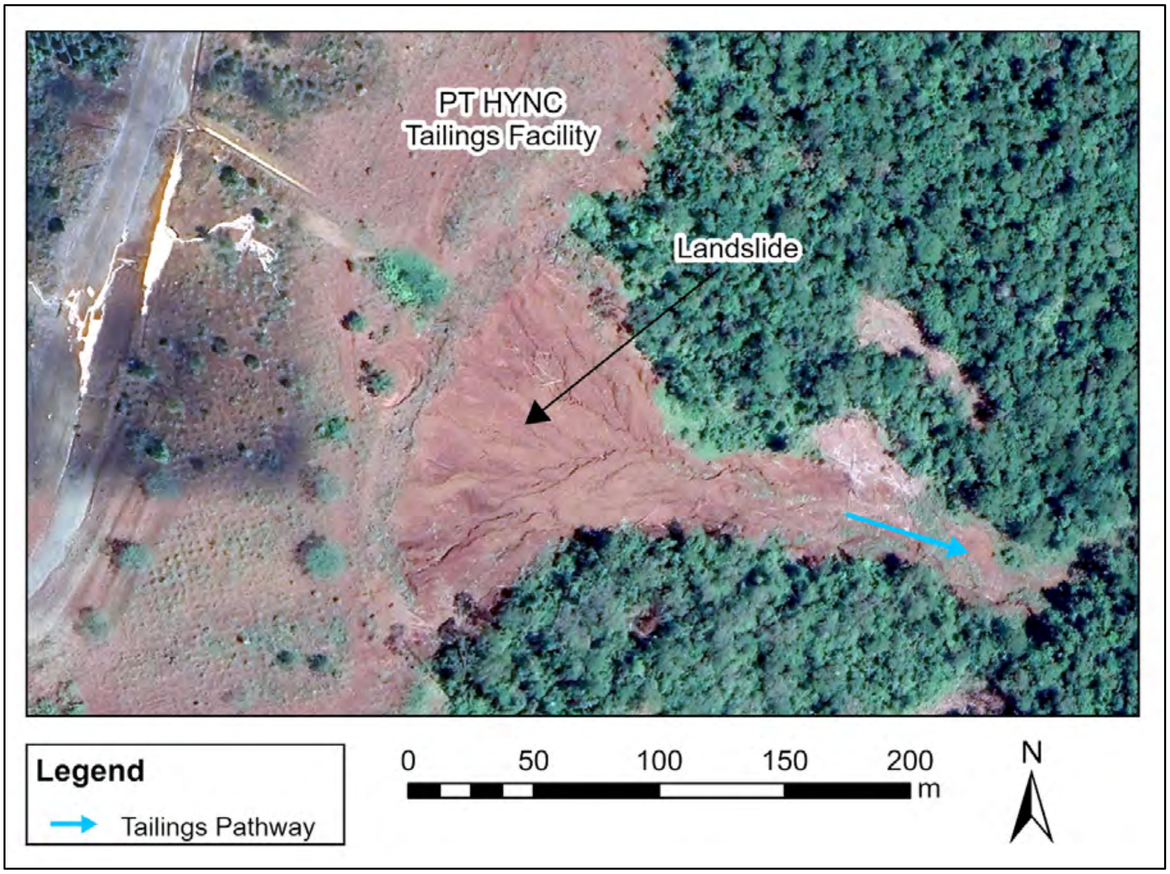

Figure 41b. Google Earth imagery from January 3, 2025, shows a clearly-defined landslide from the filtered tailings storage facility operated by PT Huayue Nickel Cobalt (HYNC) (see larger-scale view with continuation of tailings pathway in Fig. 41a). Thus, it appears that at least one collapse of the PT HYNC tailings facility occurred even before the collapse on March 16, 2025 (see Figs. 40a-c). Map also available in Business & Human Rights Resource Centre (2025a) and Moore (2025).

The location of the PT HYNC tailings facility is known as IMIP8 or KM8 (see Figs. 24 and 41a) with the PT HYNC facility on the southeastern side of the highway and the tailings facility for PT Qing Mei Bang (QMB) New Energy Materials on the northwestern side of the highway. Based on a comparison of photos and satellite imagery, Petley (2025a) has proposed that the landslide event actually occurred about 4 kilometers southeast of the Bahodopi River, at a site where there is actually no tailings storage facility. However, the site of IMIP8 as the site of the failure has been confirmed by both mineworkers and PT IMIP (the company that manages the Indonesia Morowali Industrial Park). According to CNN Indonesia (2025), *"'Benar. Banjir ini terjadi di kawasan IMIP khususnya di area IMIP 8,' kata Head of Media Relations Department PT IMIP, Dedy Kurniawan dalam keterangan tertulisnya, Rabu (19/3)"* ["That's right. This flood occurred in the IMIP area, especially in the IMIP 8 area," said Head of Media Relations Department PT IMIP, Dedy Kurniawan in a written statement, Wednesday (3/19)]. The location of the March 16 failure, as well as the March 21 failure, will be further considered in the following subsection.

Recent media reports have emphasized the ongoing threat to the Bahodopi River, especially in light of what appears to be a history of landslides from the PT HYNC tailings facility (see Figs. 41a-b). According to Bhawano (2025), "*Banjir dan longsor yang melanda kawasan PT Indonesia Morowali Industrial Park (IMIP) pada Maret 2025 lalu menunjukkan rentannya pencemaran limbah tailing. Analisis Yayasan Tanam Merdeka menyebutkan sebanyak 11,5 juta ton limbah tailing di kawasan PT IMIP mengancam Sungai Bahodopi*" [Floods and landslides that hit the PT Indonesia Morowali Industrial Park (IMIP) area in March 2025 showed the vulnerability of tailings waste pollution. Analysis by the Tanam Merdeka Foundation stated that as much as 11.5 million tons of tailings waste in the PT IMIP area threatens the Bahodopi River]. The figure of 11.5 million metric tons of tailings apparently arises from the assumption that the annual tailings production in the Indonesia Morowali Industrial Park is 11.5 million metric tons. According to Da Costa (2025), "Currently, IMIP generates 11.5 million tons of tailings each year." According to Yayasan Tanah Merdeka (YTM) (2025b), "*Saat ini, setiap tahun total tailing yang dihasilkan PT Huayue Nickel Cobalt dan PT QMB New Energy Materials mencapai 11,5 juta ton*" [Currently, the total tailings produced by PT Huayue Nickel Cobalt and PT QMB New Energy Materials each year reaches 11.5 million tons].

Since PT HYNC and PT QMB began operation in 2021 and 2022, respectively (see Table 1a), the annual tailings production is not necessarily the same as the quantity of tailings that could potentially flow into the Bahodopi River. In any event, the best estimate of this report is that annual tailings production rates of PT HYNC and PT QMB would be 9.3 million metric tons and 6.6 million metric tons, respectively (see Table 4). It is likely that both PT HYNC and PT QMB are currently operating at nameplate capacity since PT HYNC had reached nameplate capacity by July 2023 (Fisher and Grossl, 2023) and, as stated earlier, the attainment of nameplate capacity in 12-18 months seems to have become the standard practice for HPAL projects in Indonesia. Thus, the current tailings production rates from PT HYNC and PT QMB is more likely to be 15.9 million metric tons per year, so that it is possible that a complete collapse of the PT HYNC and PT QMB tailings facilities could lead to the release of far more than 11.5 million metric tons of tailings into the Bahodopi River, especially since both HPAL projects have probably been operating at nameplate capacity for two years. The great unknown in the calculation is the fraction of tailings that have been stored at IMIP8, as opposed to some other sites that have not yet been identified.

Tailings Landslide and Worker Fatalities on March 21, 2025

Tragedy struck only five days later, on March 21, 2025, when a landslide at the PT QMB tailings facility buried four mineworkers (see Figs. 42a-b). Some reports have stated the date as March 22 with the clarification that the landslide occurred shortly after midnight local time. One worker was excavated alive, while two bodies were recovered. The last body was never located, so that the official death toll stood at three. All four workers were employees of PT Morowali Investasi Konstruksi Indonesia (MIKI), which is a contractor of PT QMB. The catastrophic failure of the PT QMB tailings facility was widely reported in the Indonesian, Chinese, and English-language media (Asnawi, 2025; Bhawano, 2025; Business & Human Rights Resource Centre, 2025a; Da Costa, 2025; Hamdam, 2025; Harian Sulteng, 2025; Jakarta Post, 2025; Kabar Sulteng, 2025a-b; Man in Indonesia, 2025; Media Alkhairaat, 2025a; Moore, 2025; Morrill, 2025; Prihatini and Jatmiko, 2025; TribunPalun.com, 2025; Yayasan Tanah Merdeka (YTM), 2025a-b).

Figure 42a. The collapse of the filtered tailings storage facility of PT Qing Mei Bang (QMB) New Energy Materials in the Indonesia Morowali Industrial Park (see Figs. 3, 23, 24, and 41a) on March 21, 2025, resulted in the burial of four workers with three fatalities and one survivor. The four workers were employees of PT Morowali Investasi Konstruksi Indonesia (MIKI), which is a contractor of PT QMB New Energy Materials. Because of the similarity with Fig. 40a, it is not clear as to whether the filtered tailings storage facilities of PT HYNC and PT QMB are actually separate facilities. Still image at 0:12 from video shared by mineworker.

Figure 42b. On March 22, 2025, excavators search for four buried workers from the collapse on the previous day of the filtered tailings storage facility of PT Qing Mei Bang (QMB) New Energy Materials in the Indonesia Morowali Industrial Park (see Figs. 3, 23, 24, and 41a). The four workers were employees of PT Morowali Investasi Konstruksi Indonesia (MIKI), which is a contractor of PT QMB New Energy Materials. Photo from 曼谈印尼 [Man in Indonesia] (2025).

Photos published in local media of the use of excavators to locate the four buried workers on March 22 show a pond, even though no pond is visible in satellite imagery of the PT HYNC/PT QMB filtered tailings storage facility (see Figs. 24 and 41a). According to mineworkers, a pond had been infilled to construct the filtered tailings storage facility. As the excavators dug below the water table, the pond re-formed at its previous location. One of the dead mineworkers was found at the bottom of the pond. Construction on an infilled pond is a questionable practice because it could result in a high water table within the filtered tailings storage facility. For example, according to the SME Tailings Management Handbook, "Do not site [filtered tailings storage facilities] where 'blinding off' groundwater discharge areas" (Davies et al., 2022). Thus, the filtered tailings storage facility apparently collapsed at its weakest spot where the water table was highest.

The site of the collapse of the PT QMB tailings facility looks very similar to the site of the breach of the PT HYNC tailings facility (compare Fig. 40a with Fig. 42a), which raises the question as to whether these are actually separate tailings storage facilities. On the other hand, both PT HYNC and PT IMIP stated that the failure on March 16 and the landslide on March 21 occurred at different sites, with PT HYNC emphatically declaring that their tailings facility is distinct from the PT QMB tailings facility. According to a statement from, Zhejiang Huayou Cobalt, the majority owner of PT HYNC, "It has been verified that the tailings incident that occurred within IMIP on March 21, 2025, was not associated with the Huayue project, but another HPAL company operating in the industrial park. The Huayue tailings storage facility is independently managed and operates separately from other entities" (Business & Human Rights Resource Centre, 2025b). According to Prihatini and Jatmiko (2025), "*Dihubungi secara terpisah, Head of Media Relations Department PT IMIP, Dedy Kurniawan, membantah bahwa longsor terjadi akibat amblesnya tanggul penyimpanan tailing. 'Itu keliru, longsor terjadi bukan karena jebol kolam limbah. Seminggu sebelum longsor memang sempat terjadi banjir, namun lokasinya berbeda dengan lokasi longsor ini,' jelas Dedy*" [Contacted separately, Head of Media Relations Department of PT IMIP, Dedy Kurniawan, denied that the landslide occurred due to the collapse of the tailing storage embankment. 'That is wrong, the landslide did not occur because of a burst waste pond. A week before the landslide, there was indeed a flood, but the location was different from the location of this landslide,' explained Dedy].

Based on a comparison of media photos and satellite imagery, Petley (2025b) concluded that the March 16 failure and the March 21 landslide occurred at the same site, not at IMIP8, but a site 4 kilometers southeast of the Bahodopi River that is not a tailings storage facility. On the contrary, the information from mineworkers has been that the March 16 failure occurred at the PT HYNC tailings facility, and the March 21 landslide occurred at the PT QMB facility, with both tailings facilities being at IMIP8, although on opposite sides of the highway (see Figs. 24 and 41a). According to Kabar Sulteng (2025b), "*Yayasan Tanah Merdeka (YTM) mengungkapkan bahwa longsor terjadi di area fasilitas penyimpanan tailing (Tailings Storage Facility/TSF) di kilometer 8 PT IMIP, Kabupaten Morowali*" [Yayasan Tanah Merdeka (YTM) revealed that the landslide occurred in the tailings storage facility (TSF) area at kilometer 8 of PT IMIP, Morowali Regency]. According to Yayasan Tanah Merdeka (YTM) (2025a), "*Berdasarkan hasil pengumpulan informasi hingga saat ini, Yayasan Tanah Merdeka menganggap bahwa kecelakaan kerja terjadi di area Fasilitas Penyimpanan Tailing PT QMB New Energy Materials di kilometer 8*" [Based on the results of information collection to date, the Yayasan Tanah

Merdeka considers that the work accident occurred in the PT QMB New Energy Materials Tailings Storage Facility area at kilometer 8].

Collapse of Ore Stockpile on March 27, 2025

On March 27, 2025, an ore stockpile collapsed at the PT Qing Mei Bang (QMB) New Energy Materials project, resulting in the burial of heavy equipment, but no fatalities (Business & Human Rights Resource Centre, 2025a; Moore, 2025; Petley, 2025b; see Fig. 43). The incident has not been reported in the Indonesian media and is known only through photos and videos by mineworkers (Destination954; 2025; Pakiding, 2025a-b). The location of the PT QMB ore stockpile is not known. Although an ore stockpile is not a tailings storage facility, the repeated collapses of mine material draw serious questions regarding the quality of geotechnical engineering at the Indonesia Morowali Industrial Park.

Figure 43. On March 27, 2025, an ore stockpile collapsed at the PT Qing Mei Bang (QMB) New Energy Materials project in the Indonesia Morowali Industrial Park (see Figs. 3 and 23), resulting in the burial of heavy equipment. The location of the ore stockpile is not known. Still image at 0:13 from video shared by mineworker.

Tailings Landslide on April 30, 2025 and Earlier Tailings Landslides

The most recent landslide at the PT QMB tailings facility occurred on April 30, 2025 (see Fig. 44). The landslide is known only from photos and videos distributed by mineworkers and has not been reported by any media. An earlier video posted by a mineworker shows a bulldozer being completely engulfed by a landslide at an unidentified filtered tailings storage facility in September 2023 (Petley, 2025b; see Fig. 45). It has already been mentioned that satellite imagery shows at least one major landslide from the PT HYNC tailings facility prior to January 3, 2025 (see Figs. 41a-b).

The mineworkers union has stated that landslides have occurred frequently within the Indonesia Morowali Industrial Park, but they have not been documented, even when fatalities have occurred. According to Kabar Sulteng (2025a), "*Serikat Buruh Industri Pertambangan dan Energi (SBIPE) menyebut kecelakaan kerja sudah berulang kali terjadi di kompleks PT IMIP. 'Kasus kecelakaan kerja ini terus berulang. Tidak hanya di lokasi yang saat ini terjadi longsor, tetapi di semua bagian pekerjaan di PT IMIP,' kata Ketua SBIPE IMIP Morowali, Henry saat dihubungi, Minggu (23/03/2025).' Henry mengatakan, pihaknya masih terus menghimpun data di lapangan terkait jumlah korban jiwa akibat longsor*" [The Mining and Energy Industry Workers Union (SBIPE) said that work accidents have occurred repeatedly in the PT IMIP complex. "These work accident cases continue to recur. Not only at the location where the landslide is currently occurring, but in all parts of the work at PT IMIP," said the Head of SBIPE IMIP Morowali, Henry when contacted, Sunday (03/23/2025). Henry said that his party was still collecting data in the field regarding the number of fatalities due to landslides]. It is not clear as to whether the recurring landslides have taken place at tailings storage facilities or other mining infrastructure, such as ore stockpiles.

Figure 44. On April 30, 2025, a landslide occurred at the filtered tailings storage facility of PT Qing Mei Bang (QMB) New Energy Materials project in the Indonesia Morowali Industrial Park (see Figs. 3, 23, and 24), Still image at 0:12 of 30-second video by mineworker.

Figure 45. A bulldozer was engulfed by a landslide at a filtered tailings storage facility of the Indonesia Morowali Industrial Park (see Figs. 3 and 23) in September 2023. Still image at 0:03 from Kuli Tambang Random [Random Mineworker] (2023).

Government and Company Responses to Catastrophic Failures

To date, there has been no response on the part of the Indonesian government to the catastrophic failures of filtered tailings storage facilities in the Indonesia Morowali Industrial Park. Quite the contrary, on May 4, 2025, PT IMIP, PT HYNC, and PT QMB all received environmental awards from the Ministry of Forestry of the Republic of Indonesia called the Proper Blue Award (Media Alkhairaat, 2025b). According to Media Alkhairaat (2025b), "*Di akun official Instagram IMIP mereka mengakui penghargaan tersebut sebagai prestasi perusahaan baik dalam pengelolaan lingkungan hidup [Governance Sustainability Company]*" [On the official Instagram account of IMIP, they acknowledged the award as the company's achievement in environmental management [Governance Sustainability Company]]. The organization Yayasan Tanah Merdeka expressed predictable outrage at the award. According to Media Alkhairaat

(2025b), "*Direktur Eskeutif Yayasan Tanah Merdeka Richard F Labiro, mengatakan, proper biru KLHK kepada PT IMIP bertentangan dengan fakta sebenarnya. 'Bagi kami, penghargaan Proper itu telah membutakan mata publik atas serangkaian pelanggaran lingkungan hakiki PT IMIP …,' kata Richard … Lebih lanjut kata Richard, Maret 2025, dua bencana terjadi. Pada 16 Maret, banjir dan longsor menimpa Desa Labota dan kawasan PT IMIP, berdampak pada 341 KK (1.092 jiwa). Pada 22 Maret, longsor di fasilitas tailing PT QMB menewaskan tiga pekerja*" [The Executive Director of Yayasan Tanah Merdeka, Richard F Labiro, said that the KLHK's Proper Blue to PT IMIP contradicts the actual facts. "For us, the Proper award has blinded the public to a series of fundamental environmental violations by PT IMIP …," said Richard … Richard further said that in March 2025, two disasters occurred. On March 16, floods and landslides hit Labota Village and the PT IMIP area, affecting 341 families (1,092 people). On March 22, a landslide at the PT QMB tailings facility killed three workers].

The first response by PT IMIP, the company that manages the Indonesia Morowali Industrial Park, was to say that nothing was wrong. According to Reuters (2025), "Operations are normal at Indonesia's largest nickel processing complex, the Morowali industrial park on the eastern island of Sulawesi, despite floods this week, a company spokesperson said on Wednesday [March 19, 2025] … Dedy Kurniawan, a spokesperson of the company that runs the park, said four hours of heavy rain on Monday flooded an area of the park where new plants are being built. 'The floods did not halt plants' operations,' he said, adding that construction work on the new plants had also returned to normal." The preceding response was provided after the event of March 16, in which the PT HYNC tailings facility liquefied with contamination of the Bahodopi River (see Figs. 40a-c), but before the event of March 21, in which three mineworkers perished after a landslide at the PT QMB tailings facility (see Figs. 42a-c). No response to the March 16 event was ever provided by PT HYNC or their parent companies.

The second response by PT IMIP was to blame the deaths of three mineworkers on rainfall. According to Da Costa (2025), "Dedy Kurniawan, spokesperson for PT IMIP, denied that accusation that the March 22 landslide was caused by a failed tailings dam. 'The landslide that occurred on March 22 at around midnight was the result of intense rainfall for over four consecutive hours in the southern part of the IMIP area. In the days leading up to the incident, Bahodopi District and the IMIP complex experienced heavy rainfall almost daily. It is incorrect and misleading to link the landslide to a dam failure …" According to Hamdam (2025), *"'Intensitas hujan yang cukup tinggi menyebabkan longsor di dalam kawasan PT IMIP,' ujar Head of Media Relations Department PT IMIP Dedy Kurniawan dalam keterangannya, Sabtu (22/3/2025)"* ["The fairly high intensity of rain caused landslides in the PT IMIP area," said Head of Media Relations Department PT IMIP Dedy Kurniawan in his statement, Saturday (3/22/2025)]. Similar responses from PT IMIP also appeared in the Chinese-language press (Man in Indonesia, 2025).

The response by PT IMIP to the March 21 accident can be summarized as follows:

1) The landslide at the PT QMB tailings facility that resulted in the deaths of three mineworkers did not constitute a "dam failure."
2) The landslide was caused by heavy rainfall.

The first part of the response is quite confusing. It is entirely unclear as to why PT IMIP does not regard the landslide as a failure of the tailings storage facility. It is possible that PT IMIP is implying that the landslide was not a failure because no tailings or water were released from the site of the filtered tailings storage facility, but that was not explicitly stated by PT IMIP.

Moreover, it does not seem to be actually known as to whether any tailings were released from the facility site into the environment as a result from the March 21 event. In any event, as was stated in the "Overview" section, it should go without saying that any incident at a tailings storage facility that results in at least one fatality should be regarded as a "catastrophic failure," regardless of the quantity of water or tailings that were or were not released.

The second part of the response is simply false. Heavy rainfall can be the cause of a landslide from a naturally-occurring landform, but cannot be the cause of failure of a tailings storage facility. Heavy rainfall would not be considered as the root cause or the proximal cause or as any other cause within the chain of causes. In Indonesia, heavy rainfall is just a fact of life. Tailings storage facilities in Indonesia are supposed to be designed to withstand heavy rainfall. Thus, the cause is some variation on improper design, improper construction, or improper operation, and not heavy rainfall at all.

The response to the March 21 event by PT QMB continued the theme of heavy rainfall with the added provision that the rainfall was such an extreme event that it was "beyond human control." According to the response by PT QMB, "At 00:10 a.m. on 22 March 2025 (Central Indonesia Time), continuous heavy rainfall triggered flash floods and a landslide, resulting in three nickel mine workers employed by contractor PT Morowali Investasi Konstruksi Indonesia (MIKI) being buried under debris. This was an extraordinary natural disaster, classified as a once-in-50-years rainfall event, where the resulting floods and landslides were beyond human control" (Business & Human Rights Resource Centre, 2025c).

In the first place, it is not all clear as to how the PT QMB management even knows the magnitude of a precipitation event with a return period of 50 years (corresponding to an annual exceedance probability of 2%). There are 11 long-term weather stations on Sulawesi Island, with the closest to the PT HYNC/PT QMB filtered tailings storage facility at the Indonesia Morowali Industrial Park being Kendari Wolter Mong at a distance of 143 kilometers (see Table 7 and Fig. 46). Typically, the estimation of the magnitudes of extreme precipitation events would require on-site precipitation data for at least 30 years. In the second place, in the context of a tailings storage facility, a 50-year precipitation event is not all extreme or "extraordinary." The design for only a 50-year precipitation event is literally the criterion for the design of storm drains for a shopping mall parking lot (Nathanson, 2007), that is, the design criterion for an engineered system with very low consequences for failure.

Table 7. Long-term weather stations on Sulawesi Island with distance to PT HYNC/PT QMB filtered tailings storage facility[1]

	Latitude (°N)	Longitude (°E)	Distance (km)	Start Date (mm/dd/yr)	Coverage (%)
Bau Bau Beto Ambiri	-5.467	122.617	296	5/20/1980	67
Bubung	-1.030	122.770	215	9/19/1978	78
Hasanuddin	-5.062	119.554	373	4/1/1958	72
Jalaluddin	0.637	122.850	395	3/1/1959	76
Kasiguncu	-1.417	120.658	224	8/26/1978	53
Kendari Wolter Mong	-4.100	122.433	143	3/20/1959	44
Masamba Andi Jemma	-2.550	120.367	194	5/6/1989	87
Menado Sam Ratulan	1.533	124.917	580	11/1/1961	80
Mutiara	-0.919	119.910	323	12/1/1959	68

Toli Toli Lalos	1.017	120.800	453	5/10/1982	69
Ujang Pandang Paotere	-5.067	119.550	373	10/23/1986	73

[1]Data from NOAA (2025)

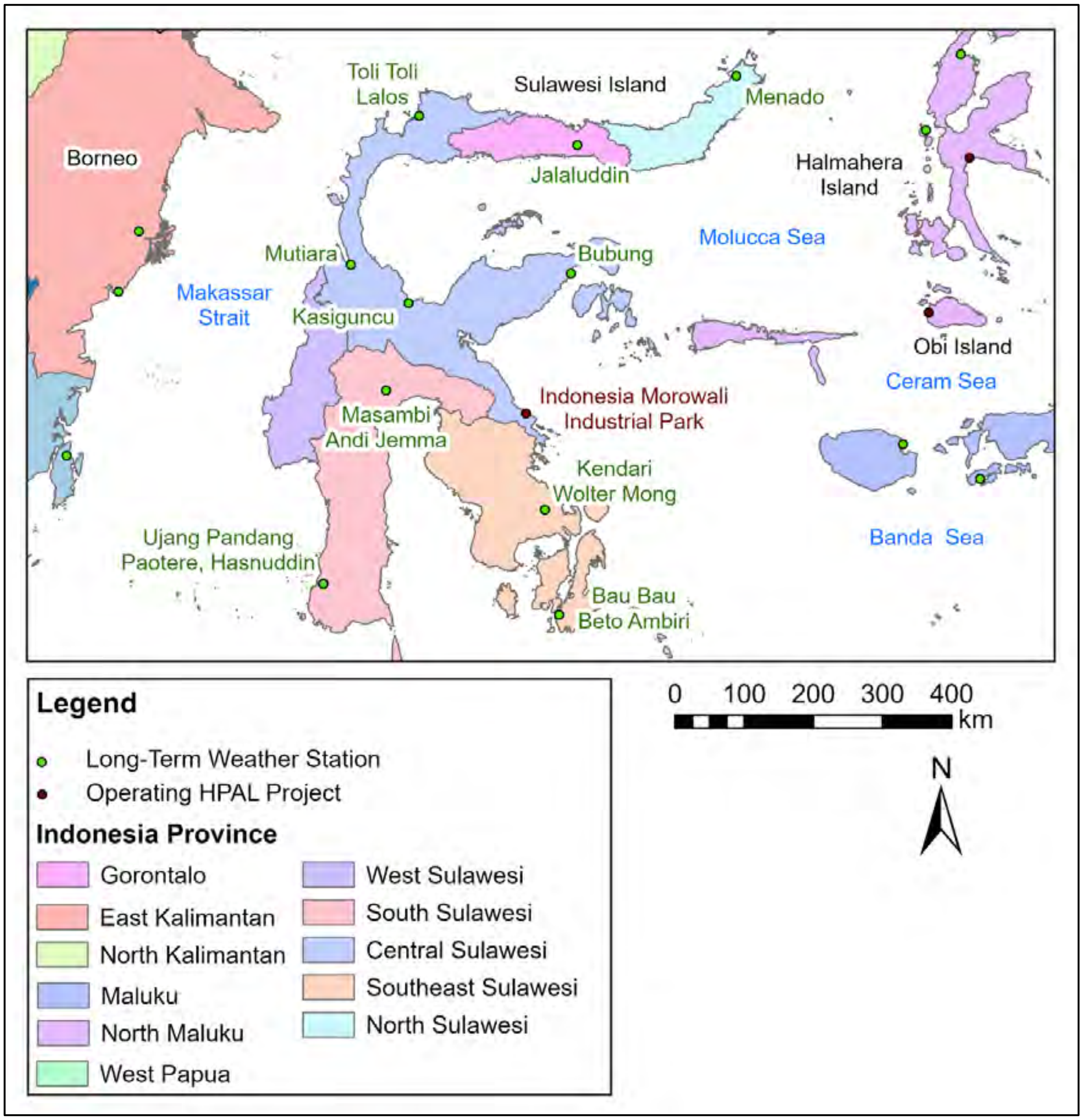

Figure 46. There are 11 long-term weather stations on Sulawesi Island, with the closest to the PT HYNC/PT QMB filtered tailings storage facility at the Indonesia Morowali Industrial Park (see Figs. 23-24) being Kendari Wolter Mong at a distance of 143 kilometers (see Table 7). Although PT QMB blames the landslide on March 21, 2025, that resulted in three fatalities (see Figs. 42a-c) on a precipitation event that was "beyond human control," the magnitude of the 50-year event at the site of the fatal accident must be very poorly known. Long-term weather stations from NOAA (2025).

The Global Industry Standard on Tailings Management (GISTM) has a five-way system of consequence classification (Low, Significant, High, Very High, Extreme) with each classification corresponding to an appropriate design precipitation event. The consequence classifications High, Very High, and Extreme involve potential loss of life of 1-10 persons, 10-100 persons, and more than 100 persons, respectively (ICMM-UNEP-PRI, 2020). The corresponding precipitation design criteria are return periods of 2475 years, 5000 years, and 10,000 years for High, Very High, and Extreme consequence classifications, respectively. Regardless of the consequences of failure during operation, all tailings storage facilities must be designed to withstand a precipitation event with a return period of 10,000 years after closure (ICMM-UNEP-PRI, 2020). At a minimum, the PT QMB tailings facility has High consequences of failure, since a failure has already resulted in the deaths of three mineworkers. Therefore, at a minimum, according to the GISTM, the PT QMB tailings facility should have been designed to withstand a 2475-year precipitation event. Although neither PT QMB nor any of its parent companies are Company Members of ICMM, the wide acceptance of the GISTM in Australia, East Asia, and the nickel and cobalt mining industries has already been mentioned.

The guidance document Safety First: Guidelines for Responsible Mine Tailings Management does not count the number of lost lives in setting the design criteria and states that "Any potential loss of life is an extreme event and design must respond accordingly" (Morrill et al., 2022). According to Safety First, "If an operating company, regulatory agency, or independent third-party identifies any potential loss of life as a result of a tailings dam failure, the dam must be designed to withstand the Probable Maximum Flood (PMF), which is the largest flood that is theoretically possible at a given location …" (Morrill et al., 2022). It is worth noting that, according to the U.S. Army Corps of Engineers, "the PMF does not incorporate a specific exceedance probability, but is generally thought to be well beyond the 10,000 year recurrence interval" (USACE-HEC, 2003). The (U.S.) FEMA Tailings Dam Safety Best Practices are in agreement with the stricter safety standards of Safety First. According to FEMA (2025), High consequences corresponds to potential loss of life "greater than zero." For tailings storage facilities with High failure consequences, FEMA (2025) requires design for either the precipitation event with a return period of 10,000 years or the PMF. In summary, the inability of the PT QMB tailings facility to survive a 50-year event is far out of line with any international standards, which would require design to withstand the 2475-year event at an absolute minimum and design to withstand the Probable Maximum Flood (PMF) or the 10,000-year event in compliance with the stricter international standards.

THE DANGEROUS PATHWAYS AHEAD

If business as usual were continued, there would continue to be more filtered tailings storage facilities with an ever-increasing frequency and severity of catastrophic failures. There are three alternative pathways to business as usual, each of which is more dangerous than the one before. The first alternative, which was already in progress as of December 2022, is the abandonment of filtered tailings technology with the replacement of future filtered tailings storage facilities by conventional tailings dams. With regard to the PT HPL project on Obi Island, SRK Consulting (2022a) wrote, "Once the dry stack tailings facility capacity is reached, it is proposed that future tailings will be managed by deposition of the slurry into a series of three residue storage facility (RSF) dams, which have a combined storage of 410 Mm3 and are projected to provide storage for another 28 years." That capacity would be reached by mid-2027 according to SRK Consulting (2022a) or before the end of 2029 according to the mining company (PT Halmahera Persada Lygend, 2024). In fact, the mining company had already applied for the permits for the conventional tailings dams. According to SRK Consulting (2022a), "It is SRK's opinion that this design [for conventional tailings dams] remains at a concept level stage … It is noted that the design plans were submitted for approval to the Indonesian government and are currently under review." It is unclear as to how plans that were at only a conceptual stage could be submitted for governmental approval and also unclear as to whether governmental approval at this stage would constitute final permits for tailings dam construction.

According to SRK Consulting (2022a), RSF #1, RSF #2, and RSF #3 will be operated during Years 1-4, 5-17, and 18-28, respectively. The tailings storage volumes of RSF #1, RSF #2, and RSF #3 will be 58.5, 196, and 157 million cubic meters, respectively, for a total of 411.5 million cubic meters (slightly greater than stated in the quote above). The tailings dam heights of RSF #1, RSF #2, and RSF #3 will be 106 meters, 75 meters, and 66 meters, respectively. The perimeters of the conventional tailings facilities as shown in SRK Consulting (2022a) are somewhat obscured because of the placement of labels (see Fig. 47). Fig. 38 in this report shows a best attempt at tracing the perimeters to show the locations with respect to other mining infrastructure and the river system on Obi Island. Measurements on Fig. 38 yield a combined footprint for the three conventional tailings facilities of 1556 hectares, which is eight times the maximum footprint of the Dry Stack Tailings Facility (DSTF) of the PT HPL project (195 hectares). Thus, the anticipated conventional tailings dams will destroy far more forest than was removed to construct the DSTF. The presence of RSF #2 and RSF #3 at the headwaters of the Akelamo River also raise the possibility that a tailings dam failure could contaminate the entire Akelamo River Basin (see Fig. 38).

The reasons as to why filtered tailings storage facilities are superior to conventional tailings dams have already been discussed in the "Overview" and "Tutorial" sections and do not need to be repeated here. In addition, the history of conventional tailings dams in Indonesia has not been entirely positive, especially with regard to closure. In their survey of tailings dams in Asia, Baker et al. (2025) were able to identify sixty mines in Indonesia with at least one tailings dam. Baker et al. (2025) identified another 155 mines for which information was available regarding the disposal or storage of mine tailings. According to Baker et al. (2025), "However, there is a history of poor compliance with these post mining obligations (Narendra et al 2021). More than 60% of companies holding a mining concession license (known as an Izin Usaha Pertambangan (IUP)) in 2018 had not lodged the required reclamation or post mining guarantee funds. Despite being a legal requirement of a mining license, non-compliance generally has little adverse impact on mining companies (Sinaga et al 2020). A report by the NGO, Bersihkan Indonesia (2020), included an evaluation of corruption vulnerability within post-mining guarantee fund policies. It had 4 major conclusions:

- Licensing mechanisms do not audit reclamation and post mining guarantee fund deposit compliance.
- Reclamation and post mining obligations are not considered by mining companies to be an integral part of business operations.
- The scope of reclamation activities provides opportunities to evade responsibility for rectifying the environment to its original condition.
- The guarantee fund is set up in a way that does not provide environmental protection."

Figure 7-4: Dry stack tailings facility and conventional RSF locations

Source: ENFI (undated)

Notes: Image taken from the conventional TSF design report. The blue shaded area is the approximate location and size of the dry stack tailings facility.

Figure 47. PT Halmahera Persada Lygend (HPL) is considering the construction of three conventional tailings facilities to store additional tailings after the Dry Stack Tailings Facility (DSTF) reaches full capacity in mid-2027. With a combined footprint of 1556 hectares, the conventional tailings storage facilities would cover eight times the area of the existing DSTF. SRK Consulting (2022a) refers to the conventional tailings storage facilities as Residue Storage Facilities (RSF) and denotes the proposed facilities as #1 RSF, #2 RSF, and #3 RSF. As of December 2022, the conventional tailings storage facilities were already in the permitting phase. See Fig. 38 for the outlines of the conventional tailings storage facilities traced onto satellite imagery that also shows the DSTF and four tailings dumps. The outlines of the proposed conventional tailings facilities in Fig. 38 are approximate since the outlines are obscured by numerous labels in the map provided by SRK Consulting (2022a).

The second and more dangerous alternative is that filtered tailings storage facilities will continue to be built, their collapse will be regarded as inevitable, and the tailings facilities will be constructed in a pre-collapsed state. According to mineworkers at PT Obi Nickel Cobalt (ONC) on Obi Island, the plan for the management of 132 million metric tons of HPAL tailings is to filter the tailings and then permanently store the tailings on 2344 hectares. Based on a nameplate capacity of 65,000 metric tons of nickel per year (see Table 1a) and a tailings to metal ratio of 133, the planned filtered tailings storage facility will contain the tailings production from 15 years of mining and HPAL processing. The surprising aspect of the plan is the footprint of the tailings facility in comparison with the 195-hectare footprint of the DSTF for PT Halmahera Persada Lygend (HPL). By analogy with the height of 57 meters and storage capacity of 57.2 million metric tons for the PT HPL project, the height of the PT ONC tailings facility will be slightly less than 11 meters. The actual height will depend upon whether there is a pre-existing mining pit or valley into which the tailings can be placed, which helped to minimize the height of the DSTF (see Fig. 22). For example, if the PT ONC tailings facility were modeled as a rectangular prism on a flat surface with a typical compacted tailings density of 2.0 metric tons per cubic meter (Cacciuttolo Vargas and Pérez Campomanes, 2022), the height of the tailings facility would be only 2.8 meters. Thus, the collapse of the filtered tailings storage facility will be avoided by constructing a facility very low to the ground. In other words, the future collapse will be avoided by constructing the tailings facility in a pre-collapsed state. While there is an apparent logic to the plan, it involves the maximum destruction of forest for a given quantity of tailings and cannot be a sustainable solution.

The third and most dangerous alternative of all is that the government of Indonesia and the mining companies will reach a consensus that filtered tailings are not a feasible technology given the high precipitation and high seismicity of Indonesia. The consensus could even extend to the decision that the aboveground storage of tailings is not feasible in Indonesia. The logic would then be that there is no alternative to the deep sea disposal of tailings. It has already been discussed that the deep sea disposal of tailings had always been the intention at the PT HPL project on Obi Island. To repeat, just one year before the opening of PT HPL project in 2021, managerial employees of PT HPL wrote in a peer-reviewed publication, "Tailings application for Halmahera tropical region is less suitable. Halmahera tropical region, particularly at Obi island, is an earthquake active area with 3,000 mm/year rainfall, and ±7,000 people living in the village downstream. Due to this condition, the cost of construction and water control will be very high and is not feasible for the project economically. The main composition residue will be pumped to DSTP [Deep Sea Tailings Disposal] " (Gultom and Sianipar, 2020). The publication even described the plan for deep sea tailings disposal. According to Gultom and Sianipar (2020), "DSTP with 15km onshore and 0.7 km offshore pipelines in 40" diameter from refinery plant to the sea canyon at the depth of > 200 m below sea level. Tailings will flow from pipeline outfall to 1000-2000 m deep of the seabed below sea water level." The following section will be devoted to the discussion of a potentially safe and workable alternative followed by specific recommendations to the Indonesian government.

THE ALTERNATIVE PATHWAY AHEAD

Based on everything that has been written in this report, it is certainly tempting to come to the conclusion that filtered tailings technology simply does not work in Indonesia. At the same time, it is also difficult to escape the conclusion that no one has yet tried very hard to make the technology work. The later conclusion is based on the evaluation of the HPAL projects of PT Halmahera Persada Lygend (HPL) on Obi Island and PT Huayue Nickel Cobalt (HYNC) and PT Qing Mei Bang (QMB) New Energy Materials on Sulawesi Island. There is very little information available regarding the design, construction and operation of the filtered tailings storage facilities managed by PT Obi Nickel Cobalt (ONC) on Obi Island or PT Huafei Nickel Cobalt (HFNC) on Halmahera Island. However, it is difficult to be optimistic about the little-known filtered tailings storage facilities since PT HYNC and PT ONC have overlapping ownership and PT HYNC and PT HFNC both have the Chinese company Zhejiang Huayou Cobalt as the majority owner (see Table 1a).

In brief, the practices that have been carried out at the PT HPL project would scarcely be suitable to make the simplest technologies work under the most hospitable circumstances. These practices include the virtual lack of any quality control, the virtual lack of any monitoring instrumentation, and the lack of adherence to design. To the preceding list must be added the failure on the part of senior management to disclose groundwater contamination to the public and impacted residents, the decision on the part of consultants to minimize and edit away key information related to surface ponding, and the failure to include answers to obvious and relevant questions. The opinion of the author is that the safest pathway forward is not to give up on filtered tailings technology, but to continue with filtered tailings technology with the intention of doing it right. This report concludes with 11 specific recommendations for the Indonesian government.

RECOMMENDATIONS

This report makes the following specific recommendations to the Indonesian government to be carried out in the following order:

1) Immediate measures must be taken to protect the safety of mineworkers and community residents downstream from the Dry Stack Tailings Facility (DSTF) of the PT HPL project on Obi Island.
2) Deposition of tailings must cease at all filtered tailings storage facilities in Indonesia.
3) There must be a moratorium on permits for new filtered tailings storage facilities in Indonesia.
4) Existing permits for filtered tailings storage facilities that have not yet been constructed must be revoked.
5) Safety audits must be carried out on all filtered tailings storage facilities in Indonesia by independent consulting companies to be chosen by the Indonesian government, but paid by the owners of the filtered tailings storage facilities.
6) Indonesia must develop a manual for the safe construction of filtered tailings storage facilities in the Indonesian context. Useful starting points are the manual developed by the BHP Rio Tinto Tailings Management Consortium (2024) for the mining industry, the manual developed by AECOM (2023) for the Office of the Public Prosecutor in Minas Gerais (Brazil), and the relevant sections of the FEMA ((U.S.) Federal Emergency Management Agency), 2025) Tailings Dam Best Safety Practices. Particular attention should be paid to past shortcomings in the construction of filtered tailings storage facilities in Indonesia, such as the need for monitoring, the need for a closure plan prior

to permitting, and the need for quality control in tailings geotechnical water contents and compacted densities.

7) Existing filtered tailings storage facilities that receive satisfactory safety audits may be re-opened with a commitment to follow the requirements of the Indonesian filtered tailings manual.
8) Filtered tailings storage facilities that were previously permitted may be constructed with a commitment to follow the requirements of the Indonesian filtered tailings manual.
9) Permits may be issued for new filtered tailings storage facilities with a commitment to follow the requirements of the Indonesian filtered tailings manual.
10) Indonesia must pass legislation prohibiting deep sea tailings disposal.
11) Indonesia must fully adopt the guidance document Safety First: Guidelines for Responsible Mine Tailings Management.

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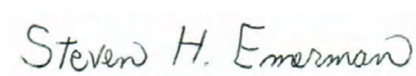
Dr. Steven H. Emerman has a B.S. in Mathematics from The Ohio State University, M.A. in Geophysics from Princeton University, and Ph.D. in Geophysics from Cornell University. Dr. Emerman has 31 years of experience teaching hydrology and geophysics, including teaching as a Fulbright Professor in Ecuador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



REFERENCES

ABNT (Associação Brasileira de Normas Técnicas [Brazilian Association for Technical Standards]), 2017. Mineração – e laboração e apresentação de projeto de barragens para disposição de rejeitos, contenção de sedimentos e reservação de água – Requisitos [Mining – Preparation and presentation of design of tailings, sediments and/or water dams – Requirements]: Norma Brasileira ABNT NBR 13.028, 3rd ed., 22 p.

AECOM, 2023. Report 01 – Technical and Socio-environmental Report – Guidelines for Tailing Piles and Tailing & Overburden Piles: Report prepared for the Public Prosecutor's Office of Minas Gerais – MPMG, Report 60695029 – ACM-DM-ZZ-RP-PM-0001-2022, June 26, 2023, 150 p.

Agência Nacional de Mineração [National Mining Agency], 2025. SIGBM (Sistema Integrado de Gestão de Barragens de Mineração [Integrated Management System for Mining Dams]). Available online at: https://www.gov.br/anm/pt-br/assuntos/acesso-a-sistemas/sistema-integrado-de-gestao-de-barragens-de-mineracao-sigbm-versao-minerador

AidData, 2025. Project ID: 66200—CDB provides $384 million loan for Phase 1 of Sulawesi Mining Power Station Project in Morowali Industrial Park (Linked to Project ID#61986, #66207, #66216, #69488, #85817): A Research Lab at William & Mary. Available online at: https://china.aiddata.org/projects/66200/

ANCOLD (Australian National Committee on Large Dams), 2012. Guidelines on tailings dams—Planning, design, construction, operation and closure, 84 p. Available online at: https://www.resolutionmineeis.us/sites/default/files/references/ancold-2012.pdf

ANCOLD (Australian National Committee on Large Dams), 2019. Guidelines on tailings dams—Planning, design, construction, operation and closure—Addendum—July 2019, 11 p. Available online at: https://www.ancold.org.au/wp-content/uploads/2019/07/Tailings-Guideline-Addendum-July-2019.pdf

Angelo, M., 2022. Exclusivo: Estrutura da Vallourec que cedeu em MG teve reunião extraordinária, licenciamento expresso e alertas de ambientalistas em sua ampliação [Exclusive: Vallourec structure that failed in MG had an extraordinary meeting, fast-track licensing and warnings from environmentalists regarding its expansion]: Observatório da Mineração, January 10, 2022. Available online at: https://observatoriodamineracao.com.br/exclusivo-estrutura-da-vallourec-que-cedeu-em-mg-teve-reuniao-extraordinaria-licenciamento-expresso-e-alertas-de-ambientalistas-em-sua-ampliacao/

Argus, 2023. Huayou, Vale commit to Indonesian Huali MHP project: August 28, 2023. Available online at: https://www.argusmedia.com/ja/news-and-insights/latest-market-news/2483610-huayou-vale-commit-to-indonesian-huali-mhp-project

Argus, 2024. Indonesian coal firm Harum buys nickel processing stake: April 3, 2024. Available online at: https://www.argusmedia.com/en/news-and-insights/latest-market-news/2554287-indonesian-coal-firm-harum-buys-nickel-processing-stake

Asian Metal, 2022. Hanrui Cobalt to build 60,000-metal-ton nickel high-pressure leaching project in Indonesia Huabao Industrial Park: September 22, 2022. Available online at: https://www.asianmetal.com/news/1856491/Hanrui-Cobalt-to-build-60,000-metal-ton-nickel-high-pressure-leaching-project-in-Indonesia-Huabao-Industrial-Park

Asnawi, A., 2025. Riset ungkap ribuan orang tewas tertimbun limbah tambang [Research reveals thousands died buried in mining waste]: Mongabay, April 13, 2025. Available online at: https://www.mongabay.co.id/2025/04/13/riset-ungkap-ribuan-orang-tewas-tertimbun-limbah-tambang/

Baker, E., K. Thygesen, and B. Haworth, 2025. Mining and mine tailings in Asia—Moving towards adoption of the Global Industry Standard on Tailings Management: GRID-Arendal, 68 p. Available online at: https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/1923/original/AsianTailings_2025.pdf?1747223114

Barrick Gold, 2012. Tailings Management Standard, Revision 2: Document Reference—BCG-MI-ST-01, Original Issue Date—August 9, 2012, Effective Date—March 7, 2022, 45 p. Available online at: https://s25.q4cdn.com/322814910/files/doc_downloads/gov_docs/policies/Tailings_Management_Standard.pdf

Bersihkan Indonesia, 2020. Untouchable; the vulnerability of reclamation and post-mining guarantees to corruption, 20 p. Available online at: https://auriga.or.id/resources/reports/64/untouchable-the-vulnerability-of-reclamation-and-post-mining-guarantees-to-corruption

Bhawano, A., 2025. 11,5 juta ton limbah tailing IMIP ancam Sungai Bahodopi [11.5 million tons of IMIP tailings threaten Bahodopi River]: Betahita [The World], April 22, 2025. Available online at: https://betahita.id/news/detail/11026/11-5-juta-ton-limbah-tailing-imip-ancam-sungai-bahodopi.html?v=1745280966

BHP Rio Tinto Tailings Management Consortium, 2024. Filtered stacked tailings—A guide for study managers, 134 p.

Birol, O., 2023. Update on Meta Nikel Gördes Operation: Deputy General Manager, Meta Nikel Kobalt Madencilik A.Ş, ALTA 2023, May 1-5, 2023, Perth, Australia, PowerPoint presentation, 37 slides. Available online at: https://d3e2i5nuh73s15.cloudfront.net/wp-content/uploads/2023/05/ALTA-2023-NCC-3-Paper-Meta-Nikel.pdf

Bodley, A.J. and C. Vaguener, 2022. Learnings from dry stacking fine grained nickel residue in the tropics: Tailings and Mine Waste 2022, Denver, Colorado, November 2022, 9 p. Available online at:

https://www.researchgate.net/publication/366093867_Learnings_from_Dry_Stacking_Fine_Grained_Nickel_Residue_in_the_Tropics

Bray, J.D., R.B. Sancio, M.F. Riemer, M.F. and T. Durgunoglu, 2004. Liquefaction susceptibility of fine-grained soils: In Proceedings of the 11th International Conference on Soil Dynamics and Earthquake Engineering and 3rd International Conference on Earthquake Geotechnical Engineering, Berkeley, CA, January 7-9, 2004, pp. 655-662. Available online at: https://assets-global.website-files.com/63d0fcf37700711149421763/64a28b02a276228b93a24ce1_paperno45.pdf

Business & Human Rights Resource Centre, 2025a. Indonesia: Residents and workers' safety at risk from several dam failures in Indonesia Morowali Industrial Park where nickel is processed: March 28, 2025. Available online at: https://www.business-humanrights.org/en/latest-news/indonesia-tailings-storage-facility-failures-in-imip-causing-death-of-workers-ngo-says/

Business & Human Rights Resource Centre, 2025b. Zhejiang Huayou Cobalt's response to news coverage on river pollution reportedly caused by flooding of tailings facility in Indonesia: April 21, 2025. Available online at: https://www.business-humanrights.org/en/latest-news/zhejiang-huayou-cobalts-response-to-news-coverage-on-river-pollution-reportedly-caused-by-tailings-facility/

Business & Human Rights Resource Centre, 2025c. PT. QMB New Energy Material's response to flooding & landslide incident at tailing storage facility located in Indonesia: April 27, 2025. Available online at: https://www.business-humanrights.org/en/latest-news/pt-qmb-new-energy-materials-response-to-flooding-landslide-incident-at-tailing-storage-facility-located-in-indonesia/

Cacciuttolo Vargas, C. and G. Pérez Campomanes, 2022. Practical experience of filtered tailings technology in Chile and Peru—An environmentally friendly solution: Minerals, vol. 12, 64 p. Available online at: https://doi.org/10.3390/min12070889

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

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

Canadian Dam Association, 2021. Technical Bulletin—Tailings dam breach analysis, 68 p.

CBL (Contemporary Brunp Lygend), 2025. About CBL. Available online at: http://www.cbl.com.cn/en/Content/488847.html

Center for Science in Public Participation, 2024. Tailings Dam Failures 1915 - 2024 as of 22Apr24: Excel spreadsheet. Available online at: http://www.csp2.org/tsf-failures-from-1915

Ceria Nugraha Indotama, 2025. Nickel Cobalt Refining and Processing. Available online at: https://cerindocorp.com/business-nickel-cobalt

Clohan, D. and E. Kidner, 2022. Tailings breach studies and inundation mapping: In K.F. Morrison (Ed.), Tailings management handbook—A life-cycle approach (pp. 211-220), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.

CNN Indonesia, 2025. IMIP sudah pulihkan kawasan yang diterjang banjir bandang [IMIP has restored areas hit by flash floods]: March 19, 2025. Available online at: https://www.cnnindonesia.com/nasional/20250319073035-20-1210441/imip-sudah-pulihkan-kawasan-yang-diterjang-banjir-bandang

Crystal, C., C. Hore, and I. Ezama, 2018. Filter-pressed dry stacking—Design considerations based on practical experience: Tailings and Mine Waste 2018, 11 p. Available online at: https://dxi97tvbmhbca.cloudfront.net/upload/user/image/CCrystal-CHore-IEzama_FilterPressedDryStacking_20182019112819106686.pdf

Da Costa, G., 2025. Morowali under environmental threat from nickel industry tailings— Tanah Merdeka: Indonesia Business Post, April 11, 2025. Available online at : https://indonesiabusinesspost.com/4079/society-environment-and-culture/morowali-under-environmental-threat-from-nickel-industry-tailings-tanah-merdeka

Davies, M., K. Mayhew, and C. Anderson, 2022. Chapter 6—Dewatered tailings: In K.F. Morrison (Ed.), Tailings management handbook—A life-cycle approach (pp. 85-108), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.

Desinformémonos [Let’s Get Informed], 2024. Denuncian derrame de presa de jales secos de la Minera Cuzcatlán en el río Coyote [They denounce spill from the dry tailings dam of the Cuzcatlán Mining Company into the Coyote River]: October 1, 2024. Available online at: https://desinformemonos.org/denuncian-derrame-de-presa-de-jales-secos-de-la-minera-cuzcatlan-en-el-rio-coyote/

Destination954, 2025. TikTok video: March 27, 2025, 0:30. Available online at: https://www.tiktok.com/@destination954/video/7486618507413622034

DoITPoMS [Dissemination of IT for the Promotion of Materials Science], 2025. Liquefaction. Available online at: https://www.doitpoms.ac.uk/tlplib/granular_materials/liquefaction.php

Durrant, A., 2023. The rise and rise of Indonesian HPAL – but can it continue?: The Assay. Available online at: https://www.theassay.com/articles/analysis/the-rise-and-rise-of-indonesian-hpal-but-can-it-continue/

EDUCA—Servicios para una Educación Alternativa A.C (Asociación Civil) [Services for an Alternative Education A.C. (Civil Association)], 2024. Local authorities accuse—Federal Attorney for Environmental Protection has not acted on new mining contamination in Oaxaca: October 8, 2024. Available online at: https://www.educaoaxaca.org/local-authorities-accuse-federal-attorney-for-environmental-protection-has-not-acted-on-new-mining-contamination-in-oaxaca/

Emerman, S.H., 2021a. Evaluation of the tailings storage facility for the proposed Savannah Lithium Barroso mine, northern Portugal: Report prepared for Povo e Natureza do

Barroso, 43 p. Available online at: https://unece.org/sites/default/files/2021-10/frCommC186_15.10.2021_annex1.pdf

Emerman, S.H., 2021b. Testimony of Dr. Steven H. Emerman to the European Parliament Public Hearing on Environmental and Social Impacts of Mining in the EU, December 2, 2021. Available online at: https://www.europarl.europa.eu/cmsdata/243324/Hearing%2002.12.2021%20testimony%20Emerman.pdf

Emerman, S.H., 2022a. The myth of high environmental standards for mining in the European Union: EUropainfo—Das Magazin des EU-Umweltbüros [The Magazine of the EU Environment Office], vol. 3/22 (Bergbau und Rohstoffe—Der Mythos vom "Green Mining" [Mining and Resources—The Myth of "Green Mining"]), pp. 3-4. Available online at: https://www.eu-umweltbuero.at/assets/EU-Umweltbuero/Magazin-EUropainfo/EUropainfo-3-22.pdf

Emerman, S.H., 2022b. Prediction of seepage from the Clay Tailings Filter Stack (CTFS) at the Lithium Nevada Thacker Pass mine, northern Nevada: Report prepared for Great Basin Resource Watch, 76 p. Available online at: https://gbrw.org/wp-content/uploads/2022/06/Exhibit-4-Thacker_Pass_Report_Emerman_Revised2.pdf

Emerman, S.H., 2023a. The Minnesota Prove It First bill and the myth of sulfide ore mining without environmental contamination: Report prepared at the request of Friends of the Boundary Waters, 43 p. Available online at: https://www.friends-bwca.org/wp-content/uploads/Prove_It_First_Bill_Report_Emerman_Revised.pdf

Emerman, S.H., 2023b. Hydrologic aspects of the 2022 Addendum to the Environmental Impact Statement for the DPM lead-zinc mine, North Sumatra, Indonesia: Report prepared for Jaringan Advokasi Tambang, 84 p. Available online at: https://www.inclusivedevelopment.net/wp-content/uploads/2024/06/Expert-review-of-final-2022-DPM-EIA-Addendum_Dr-Steven-Emerman_May-2023.pdf

Emerman, S.H., 2024. Memo to C. Russell and S. Grieg (Survival International): August 21, 2024, 17 p.

EnergyData.info, 2020. Indonesia - Small Hydro GIS Database. Available online at: https://energydata.info/dataset/indonesia-small-hydro-gis-database

Espinosa-Gomez, R., S. Gomez-Hernandez, and P.D. Munro, 2018. Tailing filtration practices in Mexican gold and silver mines: 14th AusIMM Mill Operators' Conference 2018, Brisbane, Queensland, Australia, August 29-31, 2018, 8 p.

Fell, R., P. MacGregor, D. Stapledon, G. Bell, and M. Foster, 2015. Geotechnical engineering of dams, 2nd ed.: CRC Press, 1348 p.

FEMA (Federal Emergency Management Agency (U.S.)), 2004. Federal guidelines for dam safety: April 2004, 63 p. Available online at: https://www.fema.gov/sites/default/files/2020-08/fema_dam-safety_P-93.pdf

FEMA (Federal Emergency Management Agency (U.S.)), 2025. Tailings dam safety best practices: April 2025 Final Draft for Limited Release, 350 p.

Fick, S.E. and R.J. Hijmans, 2017. WorldClim 2—New 1km spatial resolution climate surfaces for global land areas: International Journal of Climatology, vol. 37, pp. 4302-4315. Available online at: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.5086

Firdaus, F., 2022. 'We are afraid'—Erin Brockovich pollutant linked to global electric car boom: The Guardian, February 19, 2022. Available online at: https://www.theguardian.com/global-development/2022/feb/19/we-are-afraid-erin-brockovich-pollutant-linked-to-global-electric-car-boom

Fisher, H. and b. Grossl, B. 2023. OPINION—Overcoming mining waste issues will be key to Indonesia's nickel ambitions: Benchmark Mineral Intelligence, July, 2023. Available online at: https://source.benchmarkminerals.com/article/opinion-overcoming-mining-waste-issues-will-be-key-to-indonesias-nickel-ambitions

Foss, M.M. and J. Koelsch, 2022. Need nickel? How electrifying transport and Chinese investment are playing out in the Indonesian archipelago: Center for Energy Studies, Baker Institute for Public Policy, Rice University, April 2022, 76 p. Available online at: https://www.bakerinstitute.org/sites/default/files/2022-04/import/research-paper-nickel-041122.pdf

Franks, D.M., M. Stringer, L.A. Torres-Cruz, E. Baker, R. Valenta, K. Thygesen, A. Matthews, J. Howchin and S. Barrie, 2021. Tailings facility disclosures reveal stability risks: Nature Scientific Reports, vol. 11, 7 p. Available online at: https://www.nature.com/articles/s41598-021-91384-z

Gagnon, A. and P. Lind, 2017. Evaluating the transition to filtered tailings at Cerro Negro: COM2017—The Conference of Metallurgists hosting World Gold Nickel Cobalt Proceedings, Canadian Institute of Mining, Metallurgy and Petroleum, 11 p.

GEM Co., 2024. The Third Quarterly Report of 2024, 19 p. Available online at: https://en.gem.com.cn/uploadfiles/2024/10/20241029220940795.pdf

GeotechniCAL, 2025. Stress in the ground. Available online at: http://environment.uwe.ac.uk/geocal/SoilMech/stresses/stresses.htm

Glencore, 2023. Sustainability Report 2023, 80 p. Available online at: https://www.glencore.com/.rest/api/v1/documents/static/be5b0554-2c1d-415d-8072-be6a30d91d79/GLEN-2023-Sustainability-Report.pdf

Government Gazette—Republic of South Africa, 2015. National Environmental Management: Waste Act, 2008 (Act No. 59 Of 2008)—Regulations regarding the planning and management of residue stockpiles and residue deposits from a prospecting, mining, exploration or production operation: Department of Environmental Affairs, No. R. 632, July 24, 2015, vol. 601, 20 p. Available online at: https://sawic.environment.gov.za/documents/4452.pdf

Government of the Republic of Indonesia, 2007. Tentang Penanggulangan Bencana [Regarding Disaster Management]: No. 24 of 2007, 50 p.

Government of the Republic of Indonesia, 2009. Tentang Perlindungan dan Pengelolaan Lingkungan Hidup [Regarding Environmental Protection and Management]: No. 32 of 2009, 110 p.

Government of the Republic of Indonesia, 2010a. Tentang Bendungan [Regarding Dams]: No. 37 of 2010, 105 p.

Government of the Republic of Indonesia, 2010b. Tentang Reklamasi dan Pascatambang [Regarding Reclamation and Post-Mining]: No. 78 of 2010, 29 p.

Government of the Republic of Indonesia, 2021. Tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup [Regarding Protection and Management of the Environment]: No. 22 of 2021, 483 p. Available online at: https://peraturan.bpk.go.id/Details/161852/pp-no-22-tahun-2021

Guberman, D., S. Schreiber, and A. Perry, 2024. Export restrictions on minerals and metals—Indonesia's export ban of nickel: Office of Industry and Competitiveness Analysis, Working Paper ICA-104, February 2024, 42 p. Available online at: https://www.usitc.gov/publications/332/working_papers/ermm_indonesia_export_ban_of_nickel.pdf

Gultom, T. and A. Sianipar, 2020. High-pressure acid leaching—A newly introduced technology in Indonesia: The 2019 International Conference on Mining and Environmental Technology, IOP Conference Series—Earth and Environmental Science, vol. 413, 6 p. Available online at: https://iopscience.iop.org/article/10.1088/1755-1315/413/1/012015/pdf?itid=lk_inline_enhanced-template

Hamdam, H., 2025. Longsor di Kawasan PT IMIP Morowali, 3 Pekerja hilang tertimbun [Landslide in PT IMIP Morowali Area, 3 workers missing buried]: Detiksulsel [South Sulawesi], March 22, 2025. Available online at: https://www.detik.com/sulsel/berita/d-7836548/longsor-di-kawasan-pt-imip-morowali-3-pekerja-hilang-tertimbun

Harian Sulteng [Central Sulawesi Daily], 2025. Yayasan Tanah Merdeka soroti bencana longsor di area penyimpanan limbah tailing PT IMIP [Tanah Merdeka Foundation highlights landslide disaster in PT IMIP tailings waste storage area]: March 23, 2025. Available online at: https://hariansulteng.com/yayasan-tanah-merdeka-soroti-bencana-longsor-di-area-penyimpanan-limbah-tailing-pt-imip/

Harita Nickel and PT TBP (Trimegah Bangun Persada), 2023. Kajian geoteknik lereng aktual disposal tailing dam Karo [Geotechnical study of current slope of Karo tailings disposal dam]: Memorandum from Business Improvement to Dedy Amrin (Environment and Business Improvement Manager) and Primus Priyanto (Head of Mining Engineering, PT TBP), January 31, 2023, 5 p.

Hatch, 2020. PT Halmahera Persada Lygend (HPAL) OBI Nickel Project—Technical Due Diligent Review Proposed Filtered Tailings Stack Disposal: Project Memo from R. Wong to T. Huang, H358687, September 18, 2020, 30 p.

Heyokha Brothers, 2024. The myths surrounding Indonesia's Nickel Revolution—Fact or fiction?: Emerging Trends Report—Q2 2024, 18 p. Available online at: https://heyokha-brothers.com/wp-content/uploads/2024/08/The%20myths%20of%20Indonesia's%20nickel%20fact%20or%20fiction.pdf?_t=1722506472

Hidayat, T., Z. Zulhan, M.Z. Mubarok, and E. Sanwani, 2024. Recent growth of nickel laterite processing in Indonesia: In Proceedings of Alta 2024 Nickel-Cobalt-Copper Sessions (pp. 1-18), May 27-31, Perth, Australia, 523 p. Available online at: https://d3e2i5nuh73s15.cloudfront.net/wp-content/uploads/2024/07/ALTA-2024-NCC-Paper-FINAL.pdf

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

Hopkins, A. and D. Kemp, 2021. Credibility crisis—Brumadinho and the politics of mining industry reform: Wolters Kluwer, 176 p.

Huayou Cobalt, 2023. 2023 Environmental, Social and Governance (ESG) Report, 66 p. Available online at: https://www.huayou.com/Public/Uploads/uploadfile2/files/20250326/HuayouCobalt2023Environmental,SocialandGovernanceReport.pdf

HydroSHEDS, 2025. Seamless hydrographic data for global and regional applications. Available online at: https://www.hydrosheds.org/

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

ICMM (International Council on Mining & Metals), 2021. Tailings management—Good practice guide: May 2021, 128 p. Available online at: https://www.icmm.com/en-gb/guidance/environmental-stewardship/tailings-management-good-practice

ICMM (International Council on Mining & Metals), 2025. Our Members. Available online at: https://www.icmm.com/en-gb/our-story/our-members

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

ICOLD (International Commission on Large Dams), 2022. Tailings dam safety: Bulletin 194, 192 p.

IMIP (Indonesia Morowali Industrial Park), 2025a. PT Huayue Nickel Cobalt. Available online at: https://imip.co.id/pt-huayue-nickel-cobalt/#

IMIP (Indonesia Morowali Industrial Park), 2025b. PT QMB New Energy Material. Available online at: https://imip.co.id/pt-qmb-new-energy-material/

IMIP (Indonesia Morowali Industrial Park), 2025c. PT Sulawesi Nickel Cobalt. Available online at: https://imip.co.id/pt-sulawesi-nickel-cobalt/

IMIP (Indonesia Morowali Industrial Park), 2025d. PT Green Eco Nickel. Available online at: https://imip.co.id/pt-green-eco-nickel/

IMIP (Indonesia Morowali Industrial Park), 2025e. PT Seawing New Energy. Available online at: https://imip.co.id/pt-seawing-new-energy/

IMIP (Indonesia Morowali Industrial Park), 2025f. PT Honch New Energy. Available online at: https://imip.co.id/pt-honch-new-energy/

IMIP (Indonesia Morowali Industrial Park), 2025g. PT Decho New Energy. Available online at: https://imip.co.id/pt-decho-new-energy/

IMIP (Indonesia Morowali Industrial Park), 2025h. PT Chengseng New Energy. Available online at: https://imip.co.id/pt-chengseng-new-energy/

IMIP (Indonesia Morowali Industrial Park), 2025i. PT ESG New Energy Material. Available online at: https://imip.co.id/pt-esg-new-energy-material/

IMIP (Indonesia Morowali Industrial Park), 2025j. PT Indonesia Qingmei Energy Materials. Available online at: https://imip.co.id/pt-indonesia-qingmei-energy-materials/

IMIP (Indonesia Morowali Industrial Park), 2025k. PT Meiming New Energy Materials. Available online at: https://imip.co.id/pt-meiming-new-energy-material/

INAP (International Network for Acid Prevention), 2014. Global acid rock drainage guide, 473 p. Available online at: https://www.inap.com.au/wp-content/uploads/Global-Acid-Rock-Drainage-Guide.pdf

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

IndoPremier, 2024. Metals—Sector Update—08 January 2024. Available online at: https://r.ipot.id/?g=r/s/3ci5o8

International Mining, 2022. Metso Outotec to provide PT Huafei Nickel Cobalt with Planet Positive Larox filters: March 28, 2022. Available online at: https://im-mining.com/2022/03/28/metso-outotec-to-provide-pt-huafei-nickel-cobalt-with-planet-positive-larox-filters/

Jakarta Post, 2025. One killed, two missing in latest work-related accident at IMIP: March 26, 2025. Available online at: https://www.thejakartapost.com/indonesia/2025/03/26/one-killed-two-missing-in-latest-work-related-accident-at-imip.html

Kabar Sulteng [Central Sulawesi News], 2025a. Longsor terjang kawasan PT IMIP, Serikat buruh sebut sudah berulang kali, Jumlah korban masih ditelusuri [Landslide hits PT IMIP area, Labor union says it has happened repeatedly, Number of victims still being investigated]: March 23, 2025. Available online at: https://www.kabarsulteng.id/2025/03/23/longsor-terjang-kawasan-pt-imip-serikat-buruh-sebut-sudah-berulang-kali-jumlah-korban-masih-ditelusuri/

Kabar Sulteng [Central Sulawesi News], 2025b. 3 pekerja tertimbun longsor di kawasan PT IMIP, YTM desak evaluasi Menyeluruh [3 workers buried in landslide in PT IMIP area, YTM urges comprehensive evaluation]: March 24, 2025. Available online at: https://www.kabarsulteng.id/2025/03/24/3-pekerja-tertimbun-longsor-di-kawasan-pt-imip-ytm-desak-evaluasi-menyeluruh/

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

Kuli Tambang Random [Random Miner], 2023. TikTok video: September 14, 2023, 0:15. Available online at: https://www.tiktok.com/@izxxxl999/video/7278915538158423302

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

Leavitt, T., 2025. Company supplying critical EV metal 'did not disclose' Erin Brockovich pollutant in drinking water: The Guardian, April 30, 2025. Available online at: https://www.theguardian.com/global-development/2025/apr/30/environment-water-pollution-green-transition-indonesia-harita-nickel-metal-mining-electric-vehicles-erin-brockovich-chromium-cr6

Lee, A., 2023. Indonesia nickel heartland wants to be greener link in EV chain: Bloomberg News, July 24, 2023. Available online at: https://www.mining.com/web/indonesia-nickel-heartland-wants-to-be-greener-link-in-ev-chain/

Lu, L., 2023. The success of Indonesian nickel and what's next?: The Assay, November 6, 2023. Available online at: https://www.theassay.com/articles/in-discussion/the-success-of-indonesian-nickel-and-whats-next/

Maest, A.S., J.R. Kuipers, C.L. Travers, and D.A. Atkins, 2005. Predicting water quality at hardrock mines—Methods and models, uncertainties, and state-of-the-art: Buka Environmental and Kuipers & Associates, Report prepared at the request of Earthworks, 90 p. Available online at: https://earthworks.org/cms/assets/uploads/archive/files/publications/PredictionsReportFinal.pdf

Man in Indonesia [曼谈印尼], 2025. 印尼苏拉威西莫罗瓦利山体滑坡 1 死 2 失踪, IMIP 称是暴雨所致,自由土地基金会关注尾矿废料储存问题 [1 dead and 2 missing in landslide in Morowali, Sulawesi, Indonesia. IMIP said it was caused by heavy rain. Free Land Foundation is concerned about the storage of tailings waste]: March 26, 2025. Available online at: https://mp.weixin.qq.com/s/mfcQN0jOtF5W-SLaVfw9Jw

Mayangsari, A. and T.B. Adji, 2015. Implementation of dam safety in Indonesia: Hydropower ’15, Stavanger, Norway, 15-16 June 2015, 8 p

MECATER Ingénierie, 2023a. LinkedIn post: Available online at: https://www.linkedin.com/posts/mecater-ing%C3%A9nierie_mecater-has-been-awarded-a-contract-by-pt-activity-7008419733259608064-YQPi

MECATER Ingénierie, 2023b. LinkedIn post: Available online at: https://www.linkedin.com/posts/mecatering%C3%A9nierie_mecater-has-been-awarded-a-contract-by-eramet-activity6988479881240014848-Vc34/

Media Alkhairaat, 2025a. Yayasan Tanah Merdeka—Morowali terancam limbah tailing industri nikel [Free Land Foundation—Morowali threatened by nickel industry tailings waste]: April 9, 2025. Available online at: https://media.alkhairaat.id/yayasan-tanah-merdeka-morowali-terancam-limbah-tailing-industri-nikel/

Media Alkhairaat, 2025b. Penghargaan Proper biru IMIP dikecam aktivis [IMIP Blue Proper Award criticized by activists]: May 4, 2025. Available online at: https://media.alkhairaat.id/penghargaan-proper-biru-imip-dikecam-aktivis/

Merdeka Battery Materials, 2024. Merdeka Battery Materials—Investor Presentation—August 2024: PowerPoint presentation, 24 slides. Available online at: https://assets.merdekabattery.com/dist/documents/MBM%20Investor%20Presentation%20(August%202024).pdf

Merdeka Battery Materials, 2025. HPAL. Available online at: https://merdekabattery.com/en/business/hpal

Merdeka Copper Gold, 2024. Merdeka Copper Gold—Investor Presentation—June 2024: 33 slides. Available online at: https://merdekacoppergold.com/wp-content/uploads/2024/06/MDKA-Investor-Presentation-June-2024.pdf

Mining,com, 2022. Goro nickel mine faces increased regulation after tailings leak: November 30, 2022. Available online at: https://www.mining.com/web/goro-nickel-mine-faces-increased-regulation-after-tailings-leak/

Ministry of Energy, Mines and Low Carbon Innovation (British Columbia), 2024. Code Guidance—Health, Safety and Reclamation Code for Mines in British Columbia—Part 10 – Tailings Storage Facilities (TSF) and Dams: June 2024, 122 p. Available online at: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/documents/health-and-safety/code-

review/bc_code_guidance_doc_part_10_tsfs_and_dams_guidance_document_june2024_final_v2.pdf
Ministry of Environment and Forestry (Republic of Indonesia), 2020. Tentang Pemanfaatan Limbah Bahan Berbahaya dan Beracun [Regarding the Utilization of Hazardous and Toxic Waste]: No. P.18/MENLHK/SETJEN/KUM.1/8/2020, 41 p.
Ministry of Public Works and People's Housing (Republic of Indonesia), 2015. Tentang Bendungan [Regarding Dams]: No. 27/PRT/M/2015, 70 p
Minnesota Department of Natural Resources, 2021. March 12, 2021 TMM [Twin Metals Minnesota] responses to DNR-RGU [Department of Natural Resources-Responsible Governmental Unit] comments, 172 p. Available online at: https://files.dnr.state.mn.us/input/environmentalreview/twinmetals/pd/tmm-responses-to-dnr-rgu-comments-march-2021.pdf
MOMI (Minerba One Map Indonesia), 2023. IUP (Izin Usaha Pertambangan [Mining License]) 2023: Shapefiles accessed on August 15, 2023 at: https://momi.minerba.esdm.go.id/gisportal/home/webmap/viewer.html?useExisting=1 (no longer available)
Montesori, J., 2025. Buruh berduka! Kecelakaan kerja di fasilitas penyimpanan limbah PT IMIP Morowali, satu pekerja ditemukan tewas, dua masih dicari [Workers mourn! Work accident at PT IMIP Morowali waste storage facility, one worker found dead, two still wanted]: IndoTren.com, March 24, 2025. Available online at: https://www.indotren.com/nasional/32214826950/buruh-berduka-kecelakaan-kerja-di-fasilitas-penyimpanan-limbah-pt-imip-morowali-satu-pekerja-ditemukan-tewas-dua-masih-dicari
Moore, E., 2025. Multiple dams fail at Indonesian nickel-mining facilities: Earthworks Blog, March 28, 2025. Available online at: https://earthworks.org/blog/multiple-dams-fail-at-indonesian-nickel-mining-facilities/
Moreno, J.J., S. Kendall, and A. Ortiz, 2018. Dewatering options for management of fine gold tailings in Western Australian goldfields: In Jewell, R.J. and A.B. Fourie (eds.), Paste 2018—Proceedings of the 21st International Seminar on Paste and Thickened Tailings, Australian Centre for Geomechanics, Perth, Australia, pp. 413-424. Available online at: https://papers.acg.uwa.edu.au/p/1805_34_Moreno/
Morrill, J., 2022. The unfolding disaster in Brazil—A warning of what's to come: Earthworks Blog, January 25, 2022. Available online at: https://earthworks.org/blog/the-unfolding-disaster-in-brazil-a-warning-of-whats-to-come/
Morrill, J., 2025. A string of tailings dam failures shows the urgency of putting safety first: Earthworks Blog, March 31, 2025. Available online at: https://earthworks.org/blog/a-string-of-tailings-dam-failures-shows-the-urgency-of-putting-safety-first/
Morrill, J., D. Chambers, S. Emerman, R. Harkinson, J. Kneen. U. Lapointe, A. Maest, B. Milanez, P. Personius, P. Sampat, and R. Turgeon, 2022. Safety first—Guidelines for

responsible mine tailings management: Earthworks, MiningWatch Canada, and London Mining Network: Version 2.0, May 2022, 55 p. Available online at: https://earthworks.org/wp-content/uploads/2022/05/Safety-First-Safe-Tailings-Management-V2.0-final.pdf

Morrison, K.F. and B. Byler, 2022. Chapter 38—Risk assessment and risk management: In K.F. Morrison (Ed.), Tailings management handbook—A life-cycle approach (pp. 749-780), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.

Moskowitz, E., A. Aviram, S. Vardar, and K. Dörrer, 2025. Major nickel supplier Harita knew about water contamination at Indonesian operation for a decade: OCCRP (Organized Crime and Corruption Reporting Project), April 30, 2025. Available online at: https://www.occrp.org/en/investigation/major-nickel-supplier-harita-knew-about-water-contamination-at-indonesian-operation-for-a-decade

MRDC, 2025. Ramu Nickel Cobalt Project. Available online at: https://site.mrdc.com.pg/?page_id=3704

Nangoy, F., 2023. Huayou Cobalt to add at least 500,000 T of nickel capacity in Indonesia: Reuters, May 31, 2023. Available online at: https://www.reuters.com/article/business/huayou-cobalt-to-add-at-least-500000-t-of-nickel-capacity-in-indonesia-idUSL1N37S0RJ/

Nangoy, F. and F. Ungku, 2021. Exclusive—Facing green pressure, Indonesia halts deep-sea mining disposal: Reuters, February 5, 2021. Available online at: https://www.reuters.com/article/world/exclusivefacing-green-pressure-indonesia-halts-deep-sea-mining-disposal-idUSKBN2A50VG/

Nangoy, F. and M. Nguyen, 2024. Indonesian nickel firm in talks with Glencore ahead of 2025 listing: Reuters, June 12, 2024. Available online at: https://www.mining.com/web/indonesia-nickel-firm-ceria-nugraha-in-talks-with-glencore-ahead-of-2025-listing/

Nassar, N.T., G.W. Lederer, J.L. Brainard, A.J. Padilla, and J.D. Lessard, 2022a. Rock-to-metal ratio—A foundational metric for understanding mine wastes: Environmental Science & Technology, vol. 56, pp. 6710-6721. Available online at: https://pubs.acs.org/doi/epdf/10.1021/acs.est.1c07875

Nassar, N.T., G.W. Lederer, J.L. Brainard, A.J. Padilla, and J.D. Lessard, 2022b. Supporting information for Rock-to-metal ratio—A foundational metric for understanding mine wastes: Environmental Science & Technology, vol. 56, pp. 6710-6721. Available online at: https://pubs.acs.org/doi/epdf/10.1021/acs.est.1c07875 v

Narendra, B.H., C.A. Siregar, M. Turjaman, A. Hidayat, H.H. Rachmat, B. Mulyanto, R. Maharani, Y. Rayadin, R. Prayudyaningsih, T.W. Yuwati, R. Prematuri, and A. Susilowati, 2021. Managing and reforesting degraded post-mining landscape in Indonesia—A Review: Land, vol. 10, 29 p. Available online at: https://www.mdpi.com/2073-445X/10/6/658

Nathanson, J.A., 2007. Basic environmental technology—Water supply, waste management, and pollution control, 5th ed.: Pearson College Division, 534 p.

National Standards of the People's Republic of China, 2020. 尾矿库安全规程 [Safety regulations for tailings ponds]: GB 39496-2020, Published October 11, 2020, Implementation on September 1, 2021, 30 p. Available online at: https://www.chinamine-safety.gov.cn/zfxxgk/fdzdgknr/zcfg/hybz_01/fmks/202012/P020201223407382392566.pdf

Nickel Industries, 2025. Operations—Nickel Operations in Indonesia. Available online at: https://nickelindustries.com/operations/?show=rkef-operations

NHM Gosowong Gold Mine, 2025. Underground Mining. Available online at: https://www.nhm.co.id/en/mining-operation/underground-mining/

NOAA (U.S.) National Oceanic and Atmospheric Administration), 2025. Climate Data Online: National Centers for Environmental Information. Available online at: https://www.ncei.noaa.gov/cdo-web/datasets

Oboni, F. and C. Oboni, 2020. Tailings dam management for the twenty-first century—What mining companies need to know and do to thrive in our complex world: Springer Nature Switzerland, 278 p.

Observatório da Mineração [Mining Observatory], 2022. Exclusivo—Imagens aéreas do deslizamento na Mina Pau Branco da Vallourec em MG [Exclusive—Aerial images of the landslide in the Pau Branco mine of Vallourec in MG]. Available online at: https://www.youtube.com/watch?v=BT6FqaT18vo

Pakiding, R., 2025a. TikTok video: March 27, 2025, 0:48. Available online at: https://www.tiktok.com/@eunike.sendi.ramp/video/7486506647532178693

Pakiding, R., 2025b. TikTok video: March 27, 2025, 0:46. Available online at: https://www.tiktok.com/@eunike.sendi.ramp/video/7486371626158787895

Petley, D., 2022. Pau Branco—Another significant mining-related landslide in Brazil: The Landslide Blog, American Geophysical Union, January 11, 2022. Available online at: *https://blogs.agu.org/landslideblog/2022/01/11/pau-branco-1/*

Petley, D., 2024. The 7 December 2024 mine waste landslide at Turmalina Mine in Brazil: The Landslide Blog, American Geophysical Union, December 16, 2024. Available online at: https://eos.org/thelandslideblog/turmalina-mine-1

Petley, D., 2025a. A fatal tailings landslide at Fatufia in Sulawesi in Indonesia—On Saturday, a tailings landslide occurred in Indonesia, killing three excavator operators: The Landslide Blog, American Geophysical Union, March 24, 2025. Available online at: https://eos.org/thelandslideblog/fatufia-1

Petley, D., 2025b. Continued uncertainty, but very real concerns, about mining related landslides in Morowali, Indonesia: The Landslide Blog, American Geophysical Union, March 28, 2025. Available online at: https://eos.org/thelandslideblog/marowali-1

Pinto, J., 2014. Project management, governance, and the normalization of deviance: International Journal of Project Management, vol. 32, pp. 376-387.

Prihatini, Z. and B.P. Jatmiko, 2025. Tiga pekerja tertimbun longsor di kawasan IMIP, dua di antaranya tewas [Three workers buried in landslide in IMIP area, two of them die]: Kompas.com, April 10, 2025. Available online at: https://lestari.kompas.com/read/2025/04/10/150257786/tiga-pekerja-tertimbun-longsor-di-kawasan-imip-dua-di-antaranya-tewas

Pristiandaru, D.L., 2025. Morowali jadi langganan Banjir, Walhi serukan moratorium tambang nikel [Morowali becomes a flood-prone area, Walhi calls for nickel mining moratorium]: Kompas.com—Jernih Melihat Dunia [Compass.com—Seeing the World Clearly], March 18, 2025. Available online at: https://lestari.kompas.com/read/2025/03/18/070000186/morowali-jadi-langganan-banjir-walhi-serukan-moratorium-tambang-nikel#google_vignette

PT Halmahera Persada Lygend, 2022. Dari Obi untuk Indonesia [From Obi for Indonesia]: Environmental, Social, & Governance Report—2021, 144 p. Available online at: https://hpalnickel.com/keberlanjutan/keberlanjutan#navgreen-selector

PT Halmahera Persada Lygend, 2023. 2022 Sustainability Update Report: October 13, 2023, 31 p. Available online at: https://hpalnickel.com/keberlanjutan/keberlanjutan#navgreen-selector

PT Halmahera Persada Lygend, 2024. 2023 Sustainability Update Report: November 29, 2024, 84 p. Available online at: https://hpalnickel.com/keberlanjutan/keberlanjutan#navgreen-selector

PT Huayue Nickel Cobalt, 2021. 2021 Environmental, Social and Governance (ESG) Report, 29 p. Available online at: https://www.huayou.com/Public/Uploads/uploadfile2/files/20230824/PTHuayueNickelCobalt2021Environment,SocialandGovernanceESGReport.pdf

PT Lapi ITB, 2020. Final Report—Engineering Design—Dry Stack Tailing Facility—PT Halmahera Persada Lygend—Halmahera Selatan, Maluku Utara, Indonesia: Report prepared for PT Halmahera Persada Lygend, August 2020, 155 p.

PT Lapi ITB, 2022. Final Report—Engineering Design—Dry Stack Tailing Facility—PT Halmahera Persada Lygend—South Halmahera, North Maluku, Indonesia: Report prepared for PT Halmahera Persada Lygend, November 2022, 46 p.

PT Obi Nickel Cobalt, 2025. ONC. Available online at: https://obinickelcobalt.com/id

PT Trimegah Bangun Persada, 2023a. Sustainability Report 2023—Laporan Keberlanjuta 2023, 270 p. Available online at: https://tbpnickel.com/sustainability/sustainability-report

PT Trimegah Bangun Persada, 2023b. Response to Washington Post Article: October 6, 2023. Available online at: https://tbpnickel.com/investor-relations/disclosure-information/article/response-to-washington-post-article

Reemeyer, H.C.L., 2022. Chapter 3—Mineral and tailings processing: In K.F. Morrison (Ed.), Tailings management handbook—A life-cycle approach (pp. 21-39), Society for Mining, Metallurgy and Exploration, Englewood, Colorado, 1004 p.

Reuters, 2025. Indonesia's largest nickel processor of Morowali unscathed by floods: March 18, 2025. Available online at: https://www.reuters.com/world/asia-pacific/indonesias-largest-nickel-processor-morowali-unscathed-by-floods-2025-03-19/

Ribero, H., J. Holman, and L. Tang, 2021. Rising EV-grade nickel demand fuels interest in risky HPAL process: S&P Global, March 3, 2021. Available online at: https://www.spglobal.com/commodity-insights/en/news-research/blog/metals/030321-nickel-hpal-technology-ev-batteries-emissions-environment-mining

Rio Tinto, 2020. Group procedure – D5 – Management of tailings and water storage facilities v1.2: HSEC-C-14, Approved November 2020, Effective January 1, 2021, Auditable July 1, 2021, 32 p. Available online at: https://www.riotinto.com/-/media/Content/Documents/Sustainability/Corporate-policies/RT-Management-tailings-water-storage-procedure.pdf?rev=de446fc5d65742b4bf6d597a2eb30ae1

Riskope, 2022. Recent Failure at Pau Branco Mine, MG, Brazil. Accessed on August 19, 2022 at: https://www.riskope.com/2022/01/13/recent-failure-at-pau-branco-mine-mg-brazil/ (no longer available)

Robertson, P.K., L. de Melo, D.J. Williams, and G.W. Wilson, 2019. Report of the expert panel on the technical causes of the failure of Feijão Dam I—December 12, 2019: Report prepared for Vale S.A., 81 p. Available online at: https://bdrb1investigationstacc.z15.web.core.windows.net/assets/Feijao-Dam-I-Expert-Panel-Report-ENG.pdf

Russell, C., S. Grieg, and C. Pearce, 2024. Driven to the edge—How the demand for electric cars is destroying uncontacted Indigenous people's lives and lands in Indonesia: Survival International, November 2024, 46 p. Available online at: https://assets.survivalinternational.org/documents/2684/original-3c8dda9a3227299a6d33458706fe76e6.pdf

Sanderson, H., 2022. Nickel drama highlights Tsingshan's role in energy transition: Dialogue Earth, May 13, 2022. Available online at: https://dialogue.earth/en/business/nickel-drama-highlights-tsingshans-role-in-energy-transition/

Sangadji, A., 2024. HPAL—A new challenge for the environment in Indonesia—A focus on nickel as a raw material of electric vehicle batteries: The Action for Ecology and People Emancipation (AEER), 70 p. Available online at: https://www.aeer.or.id/en/hpal-a-new-challenge-for-the-environment-in-indonesia/

Sangadji, A., M.F. Ngoyo, and P. Ginting, 2019. Road to ruin—Challenging the sustainability of nickel-based production for electric vehicle batteries: Rosa Luxemburg Stiftung, Dialogue Programme Climate Justice, 236 p. Available online at:

https://www.rai.it/dl/doc/2023/11/19/1700402970903_I%20rapporti%20su%20filiera%20del%20nichel%20indonesiana%20-%20Report.pdf

Sangadji, A. and P. Ginting, 2023. Multinational corporations and nickel downstreaming in Indonesia: M. Adzania (translator), Action for Ecology and People Emancipation (Perkumpulan Aksi Ekologi dan Emansipasi Rakyat - AEER), September 2023, 92 p. Available online at: https://www.aeer.or.id/wp-content/uploads/2023/10/Arianto_Sangadji_25_Juli_2023-Layouted.pdf

Saputra, A.R., C. Faliana, M.A. Durahman, and P. Ginting, 2023. Halmahera dilemma in the midst of nickel industry: Perkumpulan Aksi Ekologi dan Emansipasi Rakyat (AEER). July 2023, 120 p. Available online at: https://media.business-humanrights.org/media/documents/Halmahera-Dilemma-in-the-Midst-of-Nickel-Industry.pdf

Scharer, J.M., L. Bolduc, C.M. Pettit, and B.E. Halbert, 2000. Limitations of acid-base accounting for predicting acid rock drainage: In Proceedings from the Fifth International Conference on Acid Rock Drainage, ICARD 2000, Society for Mining, Metallurgy, and Exploration, pp. 591-601.

Schnaid, F., L.G.F.S. de Mello, and B. Dzialoszynski, 2020. Guidelines and recommendations on minimum factors of safety for slope stability of tailings dams: Soils and Rocks, vol. 43, pp. 369-395. Available online at: https://www.researchgate.net/publication/347741840_Guidelines_and_recommendations_on_minimum_factors_of_safety_for_slope_stability_of_tailings_dams

Seed, R.B., K,O. Cetin, R.E.S. Moss, A.M. Kammerer, J. Wu, J.M. Pestana, M.F. Riemer, R.B. Sancio, J.D. Bray, R.E. Kayen, and A, Faris, 2003. Recent advances in soil liquefaction engineering—A unified and consistent framework: Earthquake Engineering Research Center, Report No. EERC 2003-06, 72 p. Available online at: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1007&context=cenv_fac

Sengani, F. and D. Allopi, 2022. Accuracy of two-dimensional limit equilibrium methods in predicting stability of homogenous road-cut slopes: Sustainability, vol. 14, 26 p. Available online at: https://www.mdpi.com/2071-1050/14/7/3872

Senversa, 2020. Detailed Site Investigation—Former Bulong Mine Site, Bulong Road, Bulong, WA: Report prepared for Department of Mines, Industry Regulation and Safety, 100 Plain Street, East Perth, WA 6004—18 June 2020, 907 p. Available online at: https://www.wa.gov.au/system/files/2025-03/detailed-site-investigation.pdf

Sherritt International Corporation, 2025. 2024 Annual Report, 139 p. Available online at: https://s2.q4cdn.com/343762060/files/doc_financials/2024/ar/Sherritt-Intl_ANNUAL-REPORT-FINAL.pdf

Shibayama, K., T. Yokogawa, H. Sato, M. Enomoto, O. Nakai, T. Ito, F. Mizuno, and Y. Hattori, 2016. Taganito HPAL Plant Project: Minerals Engineering, vol. 88, pp. 61-65.

Silva, E., 2023. Indonesia's nickel processing boom raises questions over tailings disposal: S&P Global, April 17, 2023. Available online at: https://www.spglobal.com/market-intelligence/en/news-insights/articles/2023/4/indonesia-s-nickel-processing-boom-raises-questions-over-tailings-disposal-75180844

Sinaga, H.D.P., R.N. Pramugar, and A. Wirawan, 2020. Reconstruction of criminal provisions for non-tax state revenue—A case study in the mining sector in Indonesia: Ayer Journal, vol. 27, pp. 141-154.Available online at: https://www.researchgate.net/publication/344493591_Reconstruction_of_Criminal_Provisions_for_Non-Tax_State_Revenue_A_Case_Study_in_the_Mining_Sector_in_Indonesia

SMM, 2022. Huayou Cobalt plans to invest in the construction of Huashan Nickel-Cobalt through its wholly-owned subsidiary: June 21, 2022. Available online at: https://news.metal.com/newscontent/101867749/huayou-cobalt-plans-to-invest-in-the-construction-of-huashan-nickel-cobalt-through-its-wholly-owned-subsidiary

Souisa, H., 2023. 'What's the point of a boat if there are no fish?': ABC News, October 21, 2023. Available online at: https://www.abc.net.au/news/2023-10-22/indonesias-electric-vehicle-battery-nickel-rush/102862362

Spence, E., 2024. Indonesian coal miner Harum Energy buys stake in nickel plant: Bloomberg News, April 1, 2024. Available online at: https://www.mining.com/web/indonesian-coal-miner-harum-energy-buys-stake-in-nickel-plant/

Spiller, E. and R. Dunne, 2017. Reducing water usage in gold treatment—What is possible: COM2017—The Conference of Metallurgists hosting World Gold Nickel Cobalt Proceedings, Canadian Institute of Mining, Metallurgy and Petroleum, 10 p.

SRK Consulting, 2022a. Final—Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Project Green ITAR, Obi Island, Sulawesi, Indonesia—PT Trimegah Bangun Persada: Report prepared for PT Trimegah Bangun Persada, File saved as TBP001_Independent_Technical Assessment Report_Rev9.pdf, December 19, 2022, 214 p.

SRK Consulting, 2022b. Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Tailings—Draft: Report prepared for PT Trimegah Bangun Persada, File saved as TBP001_Independent Technical Assessment Report_DRAFT_Tailings_Infrastructure_Rev1.pdf, December 2022, 31 p.

SRK Consulting, 2022c. Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Tailings—Draft: Report prepared for PT Trimegah Bangun Persada, File saved as TBP001_Independent Technical Assessment Report_Rev1_Draft.pdf, December 2022, 24 p.

SRK Consulting, 2022d. Draft—Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Project Green ITAR, Obi Island, Sulawesi, Indonesia—PT Trimegah Bangun Persada: Report prepared for PT Trimegah

Bangun Persada, File saved as TBP001_Independent Technical Assessment Report_Rev2.pdf, December 16, 2022, 233 p.

SRK Consulting, 2022e. Draft—Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Project Green ITAR, Obi Island, Sulawesi, Indonesia—PT Trimegah Bangun Persada: Report prepared for PT Trimegah Bangun Persada, File saved as TBP001_Independent Technical Assessment Report_Rev8_clean.pdf, December 19, 2022, 214 p.

SRK Consulting, 2022f. Draft—Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Project Green ITAR, Obi Island, Sulawesi, Indonesia—PT Trimegah Bangun Persada: Report prepared for PT Trimegah Bangun Persada, File saved as TBP001_Independent Technical Assessment Report_Rev8A_clean.pdf, December 19, 2022, 214 p.

SRK Consulting, 2022g. Draft—Independent Technical Assessment Report on the Mineral Assets of PT Trimegah Bangun Persada, Indonesia—Project Green ITAR, Obi Island, Sulawesi, Indonesia—PT Trimegah Bangun Persada: Report prepared for PT Trimegah Bangun Persada, File saved as TBP001_Independent Technical Assessment Report_Rev8A_trackchanges.pdf, December 19, 2022, 214 p.

Tampi, A.A.N., 2024. From Dirt to Gold—Bagaimana green mining mentransformasi proses ekstraksi mineral [How green mining is transforming the mineral extraction process]: PEP BANDUNG Getme Majalah Geologi, Tambang, dan Metalurgi [Geology, Mining, and Metallurgy Magazine], vol. 3, pp. 88-93. Available online at: https://pepbandung.ac.id/uploads/PUBLIKASI/GETME_v2.pdf

Tan, R., D.M. Sijabat, and J. Irwandi, 2023. Clean cars, hidden toll—To meet EV demand, industry turns to technology long deemed hazardous—Indonesia is richly endowed with nickel, but refining this crucial mineral poses a daunting environmental challenge: Washington Post, May 10, 2023. Available online at: https://www.washingtonpost.com/world/interactive/2023/ev-nickel-refinery-dangers/

Taplin, J., 2017. Move fast and break things—How Facebook, Google, and Amazon cornered culture and undermined democracy: Little, Brown and Company, 320 p.

TBP (Trimegah Bangun Persada) and Harita Nickel, 2025. Shareholding Structure. Available online at: https://tbpnickel.com/about-us/shareholding-structure

Teraskabar.id—Bacaan Utama di Era Digital [News.id—Main Reading in the Digital Era, 2025. Warga Bahodopi langganan banjir, korban pertambangan nikel yang masif di Morowali [Bahodopi residents regularly suffer floods, victims of massive nickel mining in Morowali]: March 18, 2025. Available online at: https://teraskabar.id/warga-bahodopi-langganan-banjir-korban-pertambangan-nikel-yang-masif-di-morowali/

TribunPalun.com, 2025. Yayasan Tanah Merdeka desak pemerintah evaluasi izin penyimpanan tailing PT IMIP Morowali [Tanah Merdeka Foundation urges government to evaluate PT IMIP Morowali tailings storage permit]: March 24, 2025. Available online at:

https://palu.tribunnews.com/2025/03/24/yayasan-tanah-merdeka-desak-pemerintah-evaluasi-izin-fasilitas-penyimpanan-tailing-pt-imip?page=2

Twin Metals Minnesota, 2025. Dry Stack Tailings Storage. Available online at: https://www.twin-metals.com/learning-center/dry-stack-tailings-storage/

Ulrich, B.F. and J.G. Coffin, 2017. Characterization of unsaturated tailings & its effects on liquefaction: Tailings and Mine Waste 2017, 10 p. Available online at: http://knightpiesold.com/es/noticias/publicaciones/characterization-of-unsaturated-tailings-its-effects-on-liquefaction/

UNEP (United Nations Environment Program), The Church of England, GRID-Arendal, and Council on Ethics—Swedish National Pension Fund, 2025. Global Tailings Portal. Available online at: https://tailing.grida.no/

University of Victoria Environmental Law Centre, 2019. Waste Disposal & Management: BC Mining Law Reform, 12 p. Available online at: https://reformbcmining.ca/wp-content/uploads/2019/05/BCMLR-Waste-Disposal-and-Management.pdf

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

USGS (U.S. Geological Survey), 2025a. Nickel Statistics and Information. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/nickel-statistics-and-information

USGS (U.S. Geological Survey), 2025b. Cobalt Statistics and Information. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/cobalt-statistics-and-information

Vale, 2023. Shaping sustainability—Reach higher: Annual Report 2023, 432 p. Available online at: https://vale.com/documents/d/guest/pt-vale-laporan-tahunan-2023

Vale, 2025. IGP Pomalaa. Available online at: https://vale.com/fi/indonesia-growth-projects-pomalaa

Vardar, S. and K. Dörrer, 2025. The hidden cost of Indonesia's nickel boom: DW, April 30, 2025. Available online at: https://www.dw.com/en/leaked-documents-reveal-the-hidden-cost-of-indonesias-nickel-boom/a-72390311

Vaughan, D., 1996. The Challenger launch decision—Risky technology, culture, and deviance at NASA: University of Chicago Press, Chicago, 592 p.

Vick, S. G., 2017. Dam safety risk—From deviance to diligence: Geo-Risk 2017, pp. 19-30.

Wicaksono, R.A., 2025. Banjir berulang, tambang nikel di Morowali diminta dievaluasi [Recurring floods, nickel mine in Morowali asked to be evaluated]: Betahita [The World], March 19, 2025. Available online at: https://betahita.id/news/detail/10979/banjir-berulang-tambang-nikel-di-morowali-diminta-dievaluasi.html?v=1742342447

Woodward-Clyde, 1996. Cawse Nickel Project—Consultative Environmental Review: Report prepared for Centaur Mining and Exploration Limited, 147 p. Available online at:

https://www.epa.wa.gov.au/sites/default/files/PER_documentation/A1001_R0825_CER_0.pdf

World Construction Network, 2023. Anugrah Neo and Gotion to set up HPAL plant in Sulawesi: September 14, 2023. Available online at: https://www.worldconstructionnetwork.com/news/anugrah-neo-hpal-indonesia/?cf-view

World Gold Council, 2019. Responsible Gold Mining Principles: September 2019, 16 p. Available online at: https://www.gold.org/industry-standards/responsible-gold-mining

Yasya, H.R., M.S. Abfertiawan, T.H. Gultom, P. Gunardi and M. Syahroni, 2024. Water availability of Akelamo River, Obi Island, South Halmahera: The 7th Environmental Technology and Management Conference (ETMC 2023), 22 p. Available online at: https://www.e3s-conferences.org/articles/e3sconf/abs/2024/15/e3sconf_etmc2024_03015/e3sconf_etmc2024_03015.html

Yayasan Tanah Merdeka (YTM) [Free Land Foundation], 2025a. Tentang kecelakaan kerja di fasilitas penyimpanan limbah (tailing) di PT Indonesia Morowali Industrial Park [Regarding work accidents at the waste storage facility (tailing) at PT Indonesia Morowali Industrial Park]: Press Release, 3 p., March 23, 2025.

Yayasan Tanah Merdeka (YTM) [Free Land Foundation], 2025b. Morowali di bawah ancaman tailing industri nikel [Morowali under threat from nickel industry tailings]: Press Release, 7 p., April 8, 2025.

Zhejiang Huayou Cobalt, 2024. Letter from B. Lee (Head of ESG & Sustainability) to B. Adams (Climate Rights International), 7 p. Available online at: https://cri.org/wp-content/uploads/2024/01/The-response-of-Huayou-Cobalt.pdf