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June 19, 2026

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Comments on the Draft Supplemental Environmental Impact Statement (DSEIS) for the Key Mill Tailings Storage Facility - Filtered Tailings Stack Height Raise

Dear Sarah,

I am writing to address your request for comments on the Draft Supplemental Environmental Impact Statement (DSEIS) for the Key Mill Tailings Storage Facility - Filtered Tailings Stack Height Raise (WSDE, 2026).

I will first review my qualifications for providing these comments.

I have 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. I have 31 years of experience teaching hydrology and geophysics, including teaching as a Fulbright Professor in Ecuador and Nepal, and have over 70 peer-reviewed publications in these areas. Since 2018 I have 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. I have evaluated proposed and existing tailings storage facilities in North America, South America, Europe, Africa, Asia and Oceania, and have 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, the Minnesota Senate Environment, Climate and Legacy Committee, and the Nevada Assembly Natural Resources Committee. I am the former Chair of the Body of Knowledge Subcommittee of the U.S. Society on Dams, one of the authors of Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022), and the author of Filtered Tailings in Indonesia: The Catastrophic Failure of a Disruptive Technology (Emerman, 2026).

Each of my comments is stated in bold italics followed by more detailed explanations.

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1) ***The filtered tailings storage facility would be constructed on top of an existing tailings storage facility that was constructed using methods that were regarded as unsafe even three decades prior to the time of construction.***

The filtered tailings storage facility would be constructed on top of an existing tailings storage facility that was constructed using the upstream method (see Figs. 1a-b, 2) with the excessively steep slope of 1V:2H (1 meter vertical for two meters horizontal) (see Fig. 3). The upstream construction method was known to be unsafe even three decades prior to the use of the method at the Key Mill Tailings Storage Facility. The construction of outer embankments with such excessively steep slopes was known to be unsafe at the time of construction of these embankments at the Key Mill Tailings Storage Facility.

According to the DSEIS, "In 2001, the Key Mill's Dam Construction Permit was modified to provide additional capacity at the TSF by increasing the height of the earthen dam embankment to a total height of 3,257 feet amsl. This allowed for an amended storage capacity of approximately 8.5 MT of conventional tailings. Phase IV of the TSF was an upstream raise …In 2008, the Key Mill's Dam Construction Permit was modified again to allow for an additional height increase of the embankment. The increase in dam height from 3,257 to 3,285 feet amsl allowed for an amended storage capacity of about 12.2 MT of conventional tailings. Phase V was also an upstream raise" (WSDE, 2026, pdf p. 18).

I am reviewing the meaning and the known danger of the upstream construction method in some detail here, since this background is entirely missing in the DSEIS. Following the review of the upstream construction method, I will also review industry standards and regulations for embankment slopes, since this background is equally entirely missing in the DSEIS.

Each of the three common methods of building tailings dams (upstream, downstream and centerline) begins with a starter dike, which is constructed from natural soil, rockfill, mine waste rock or the tailings from an earlier episode of ore processing (see Figs. 4a). If the starter dike is never raised, then the tailings dam is called a single-stage dam. In the upstream construction method, successive dikes are built in the upstream direction as the level of stored tailings increases. It is most common to build successive dikes from waste rock or the coarser fraction of tailings (typically with appropriate compaction). The advantage of the method is its low cost since very little material is required for the construction of the dam (see Fig. 4a). The downstream construction method is the most expensive since it requires the most construction material (compare Figs. 4a and 4b). In this method, successive dikes are constructed in the downstream direction as the level of stored tailings increases. The centerline construction method is a balance between the advantages and disadvantages of the downstream and upstream construction methods (compare Figs. 4a-c). In this method, successive dikes are constructed by

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placing construction material on the beach and on the slope downstream of the previous dike. The center lines of the raises coincide as the dam is built upwards (see Fig. 4c).

It will not be surprising that the less expensive construction methods are also more vulnerable to failure. Tailings dams constructed using the upstream method are especially vulnerable to failure by either seismic liquefaction or static liquefaction because the dam is built on top of the uncompacted tailings (see Fig. 4a). Thus, even if the dam temporarily maintains its structural integrity while the underlying tailings liquefy, the dam could fail by either falling into or sliding over the liquefied tailings. Dams constructed using the centerline method retain some vulnerability to failure during liquefaction because there are still some uncompacted tailings underneath the dikes (see Fig. 4c). On the other hand, a tailings dam constructed using the downstream method could survive the complete liquefaction of the tailings stored behind the dam (see Fig. 4b). Of course, proper design and construction are still needed to prevent liquefaction of the dam itself even when the downstream method is used.

From another perspective, an upstream dam is constructed on top of an unknown foundation (see Fig. 4a; Fuller, 2019). An accurate knowledge of the foundation is an essential feature of dam safety since both tailings dams and water-retention dams have failed due to yielding or settling of the foundation. The geotechnical properties of the tailings underlying the dikes can be predicted, but they are not actually known until they can be measured after dikes have been constructed on top of them. In the same way, the future evolution of the tailings (for example, due to compaction by the overlying dikes or drying of the tailings) can be predicted, but is not actually known until the future has occurred. This feature of upstream dams sets them apart from any other type of dam in which the geotechnical properties of the foundation can and should be a known quantity before the dam is constructed.

The failure of the upstream tailings dam at the Córrego do Feijão mine near Brumadinho, Brazil, on January 25, 2019, which resulted in 272 deaths, including the deaths of 258 mineworkers (see Fig. 5; Robertson et al., 2019), was a watershed moment in the global awareness of the danger of the upstream construction method. However, in the five decades preceding the Brumadinho disaster, there were already numerous cautions and prohibitions regarding the use of the upstream method in guidance documents and regulations.

Based upon the engineering principles discussed above and the historical record at the time, the Environmental Protection Agency (EPA, 1994) concluded that “A tailings pond that is expected to receive high rates of water accumulation (due to climatic and topographic conditions) should be constructed using a method other than upstream construction … upstream construction is not appropriate in areas with a potential for high seismic activity.” The International Commission on Large Dams (ICOLD) and the United Nations Environment Programme (UNEP) came to the same conclusion in writing, “In general, dams built by the downstream or centreline method are

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much safer than those built by the upstream method, particularly when subject to earthquake shaking … Dams built by the upstream method are particularly susceptible to damage by earthquake shaking. There is a general suggestion that this method of construction should not be used in areas where there is risk of earthquake" (ICOLD and UNEP, 2001). The recommendation to UNEP in 2017 was to "adopt a presumption against the use of … upstream and cascading tailings dams unless justified by independent review" (Roche et al., 2017). Finally, the European Commission concurred in writing, "The main disadvantage of the upstream method is the risk of physical instability of the dam and its susceptibility to liquefaction … In general, downstream dams are much safer than those built using the upstream method, particularly when subject to seismic loads … [Upstream dams are] not applicable when the slightest risk of liquefaction has been identified after seismic evaluation … Upstream: this option has the highest risk associated to dam wall breaking" (Garbarino et al., 2018).

Even before the Brumadinho disaster, the upstream construction method for tailings dams was prohibited under all circumstances in Chile and Peru (Ministerio de Minería (Chile) [Ministry of Mining (Chile)], 2007; Sistema Nacional de Información Ambiental (Perú) [National System of Environmental Information (Peru)], 2014). The prohibition against upstream dams in Chile has been in place for over 55 years (since 1970) and was motivated by the major earthquake in 1965 that caused the failure of 17 tailings dams, 16 of which had been constructed using the upstream method (Villavicencio et al., 2013; Valenzuela, 2016). The same pattern was repeated in the major earthquake in 1997, in which four tailings dams failed, three of which had been constructed using the upstream method and one of which combined upstream and centerline raises. By contrast, Chile has 757 tailings dams, including 465 tailings dams for which the method of construction is known. Out of the dams with a known construction method, 213 (46%) were constructed using the upstream method, all of which are now closed (SNGM, 2020).

Again long before the Brumadinho disaster, the upstream construction method was thoroughly critiqued in the two available textbooks on tailings dams. The first textbook was Planning, Design, and Analysis of Tailings Dams (Vick, 1990), which was first published in 1983 and reprinted without revision in 1990. According to Vick (1990), "Use of the upstream raising method, however, is limited to very specific conditions and incorporates a number of inherent disadvantages. Factors that constrain the application of the upstream method include phreatic surface [water table] control, water storage capacity, and seismic liquefaction susceptibility. The location of the phreatic surface is a critical element in determining embankment stability. For upstream embankments constructed by tailings spigotting, there are few structural measures for control of the phreatic surface within the embankment … Many if not most failures of upstream embankments can be attributed to inadequate separation distance between the decant pond and the embankment crest … For this reason, upstream embankments are poorly suited to conditions where water accumulation is anticipated due to flooding, long-term accumulation of seasonal runoff, or high rates of mill water accumulation. In general, upstream embankments cannot be

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used for water retention … The susceptibility of upstream embankments to liquefaction under severe seismic ground motion is well documented (Dobry and Alvarez, 1967). The low relative density and generally high saturation within the tailings deposit can result in liquefaction-induced flow of the tailings, with disastrous consequences. Upstream raising methods are clearly inappropriate in areas of high seismic potential … Upstream embankments, while providing the simplest and least costly raising method, are subject to a number of very critical constraints. Proper use of the method can be justified only when these constraints are thoroughly investigated and satisfied … The fact that so many variables cannot be controlled or easily predicted in advance of operation cannot help but inspire a certain feeling of helplessness among those who would attempt to predict the phreatic surface location within upstream embankments. This uneasiness is often manifested by a preference for other embankment types whose seepage and stability characteristics are more easily predicted and controlled." It should be noted that the susceptibility of upstream dams to failure due to seismic liquefaction had already been established by the mid-1960s (Dobry and Alvarez, 1967) and was the basis for the prohibition against upstream dams in Chile in 1970. The second textbook was Geotechnical Engineering for Mine Waste Storage Facilities (Blight, 2010), which was published 20 years after Vick (1990). Blight (2010) believed that upstream dams were already disappearing and wrote, "This particular method of construction is no longer used in many parts of the world, although it is still used in areas having an arid climate and no seismicity."

Following the Brumadinho disaster, two additional countries prohibited the use of the upstream construction method (ANM, 2019a; Ministerio de Energía y Recursos Naturales No Renovables [Ministry of Energy and Non Renewable Natural Resources] (Ecuador), 2020), so that upstream dams are now prohibited in the four Latin American countries of Brazil, Chile, Ecuador and Peru. Ecuador went further than the other countries in preferring the downstream method and permitting the centerline method only under special circumstances. According to Ministerio de Energía y Recursos Naturales No Renovables (2020), "*Se prohíbe la utilización del método hacia aguas arriba. De manera estandarizada el método de construcción será hacia aguas abajo, incluyendo la presa de arranque. El método de construcción de eje central se aprobará en los casos en que la morfología o espacio del terreno no permitan el crecimiento hacia aguas abajo, siempre y cuando se cumpla con condiciones favorables para la estabilidad física del depósito de relaves*" [The use of the upstream method is prohibited. In a standardized way, the construction method will be downstream, including the starter dike. The centerline construction method will be approved in cases where the morphology or space of the land does not allow for downstream growth, only and when it meets favorable conditions for the physical stability of the tailings deposit]. Brazil also required the safe closure of existing upstream tailings dams by August 2020 (ANM, 2019a), but advanced the deadline for tailings dams storing less than 12 million cubic meters of tailings, 12-30 million cubic meters of tailings, and greater than 30 million cubic meters of tailings to September 2022, September 2025, and September 2027, respectively (ANM, 2019b).

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Some post-Brumadinho guidance documents reinforced previous cautions regarding upstream tailings dams, but did not explicitly call for a prohibition on the upstream construction method. According to Canadian Dam Association (2019), "It is recommended that upstream constructed tailings dams not be built in high seismic areas." According to ICOLD (2022), "ICOLD Bulletin B 121 [ICOLD and UNEP, 2001] discusses a key risk inherent in upstream construction being the potential for tailings in the structural zone to remain saturated at low density, resulting in tailings being in a contractive state, susceptible to static or dynamic liquefaction … The stability of the upstream slope is dependent upon the strength of the impounded tailings [as opposed to dependence only upon the strength of the dikes], which form part of the upstream section … The extent of saturation is sometimes difficult to determine with perched water tables being common due to segregation and layering. Piezometers cannot be relied on to give an accurate picture of the phreatic surface, particularly if vertical drainage is occurring and/or perched water tables are present. Caution should be applied when considering upstream construction, particularly when using fine tailings that have poor drainage characteristics and in climates where drying effects might be limited and/or in areas of moderate seismicity."

Finally, the SME (Society for Mining, Metallurgy and Exploration) Tailings Management Handbook: A Life-Cycle Approach reinforced earlier critiques of the upstream method and even the centerline method in writing, "Upstream construction, and to a lesser degree centerline construction, with the placement of the embankment crest raising on tailings, introduces stability concerns because of the potentially low strength of the saturated tailings during initial covering and the potential for seismically induced strength degradation … Instability and earthquake-related incidents have generally been predominant at upstream and centerline facilities … [The upstream method is] typically more susceptible to instability particularly under earthquake loading" (Snow, 2022). The SME Surface Mining Handbook also concurred in writing, "Upstream dams have a high probability (58%) for damage (Lyu et al., 2019). Historically, downstream and centerline dams are typically more stable and are associated with fewer dam failure events. Downstream or centerline construction is the preferred and recommended method of dam construction" (Mohanty et al. 2023).

On the other hand, Safety First: Guidelines for Responsible Mine Tailings Management (Morrill et al., 2022) followed the regulations in the four Latin American countries and did call for a prohibition on new upstream tailings dams and the safe closure of existing upstream dams. According to Morrill et al. (2022), "Because of the demonstrated risk associated with upstream dam construction, upstream dams must not be built at any new facilities. Upstream construction is especially problematic in areas with moderate or high seismic risk, or in wet climate areas with net precipitation (more precipitation than evaporation), especially as weather events become increasingly severe with climate change … Expansion of existing upstream tailings facilities must cease, and these facilities must be safely closed as soon as possible. This includes dams where companies have been approved for permits that have not begun or are just beginning

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construction. The deadline for safe closure must depend on engineering and the safety of affected communities, rather than economic considerations."

One of the most significant post-Brumadinho developments has been the development of the Global Tailings Portal (UNEP et al., 2026) and its analysis by Franks et al. (2021). For the first time, this analysis quantified the greater risk posed by upstream dams and the gradual disappearance of the upstream construction method for new tailings storage facilities. According to Franks et al. (2021), "Controversy has surrounded the safety of tailings facilities, most notably upstream facilities, for many years but in the absence of definitive empirical data differentiating the risks of different facility types, upstream facilities have continued to be used widely by the industry and a consensus has emerged that upstream facilities can theoretically be built safely under the right circumstances." Franks et al. (2021) showed that the retreat from the upstream construction method was well underway, even by the 1970s (see Fig. 6). According to Franks et al. (2021), "While upstream facilities make up 37 per cent of the total, they have declined from a peak of 85 per cent of new facilities in 1920–1929 to 19 per cent of new facilities in 2010–2019" (see Fig. 6). In addition, upstream facilities made up 45%, 41%, and 32% of total new facilities for the decades 1960-1969, 1970-1979, and 1980-1989, respectively, indicating that it was generally known even in those decades that the benefits of upstream construction did not outweigh the risks. According to Franks et al. (2021), "Owing to their historical popularity, upstream facilities make up 43 per cent of facilities that are inactive, closed or reclaimed. However, in the past twenty years, the number of new downstream and in-pit/natural landform facilities have risen sharply … At present, the number of active downstream facilities (230) marginally exceeds the number of active upstream facilities (224)" (see Fig. 6). At the present time, "Upstream facilities represent a relatively low number of active facilities in North and South America when compared to Africa and Oceania" (Franks et al., 2021). The conclusions by Franks et al. (2021) reinforced the general impression by Blight (2010) and the earlier statement by USEPA (1994) that "most recent dike dams have been built using downstream or centerline methods rather than the upstream method" (USEPA, 1994).

Among other information, the Global Tailings Portal includes the history of stability concerns. The history of stability concerns is a yes or no answer to the question "Has this facility, at any point in its history, failed to be confirmed or certified as stable, or experienced notable stability concerns, as identified by an independent engineer (even if later certified as stable by the same or a different firm)?" (UNEP et al., 2026) with the clarification "We note that this will depend on factors including local legislation that are not necessarily tied to best practice. As such, and because remedial action may have been taken, a 'Yes' answer may not indicate heightened risk. Stability concerns might include toe seepage, dam movement, overtopping, spillway failure, piping etc. If yes, have appropriately designed and reviewed mitigation actions been implemented? We also note that this question does not bear upon the appropriateness of the criteria, but rather the stewardship levels of the facility or the dam" (UNEP et al., 2026). Franks

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et al. (2021) used these responses to establish that upstream dams have increased stability issues, even in cases where the stability issues did not proceed to dam failure (see Fig. 7). According to Franks et al. (2021), "Our findings reveal that in practice active upstream facilities report a higher incidence of stability issues (18.3%) than other facility types, and that this elevated risk persists even when these facilities are built in high governance settings … The likelihood of a stability issue in active upstream facilities is twice that of active downstream facilities … The control tests [age, height, volume, seismic hazard, wind speed, and rainfall] showed that the properties of the upstream samples (notably their distribution of age), have a small effect on the incidence of stability, however the estimated effect is only about one standard error, and is not sufficient to account for their higher than average incidence."

In addition to greater stability issues, Piciullo et al. (2022) have documented the disproportionately large representation of upstream tailings dams among tailings dam failures (see Fig. 8). According to Piciullo et al. (2022), "Joining the databases on failures and existing dams, the fraction of failures as a function of the dam construction method has been computed … we observe that for a relatively high fraction of the incidents in the failure database the construction method was not known … For the tailings dam failures with a documented construction method, a higher frequency (relative to total number of dams in the catalogue of tailings dams) is observed for the upstream method (0.13), followed by the centreline construction method (0.11) and the downstream construction method (0.07) … An analysis with the failure database only … suggests that the downstream method is second in terms of number of failures … The analysis presented in Fig. 13 [Fig. 8 in this memo], using failure and nonfailure databases, shows that the frequency of failures is lower for the downstream method compared to the centreline. This result agrees with the survey carried out by Franks et al., 2021, who highlighted that active upstream facilities show a higher incidence of stability issues than other construction methods."

Set against all of the preceding cautions and prohibitions has been a persistent apology in the mining literature that upstream tailings dams can be safe if they are constructed and operated under ideal conditions (low seismicity and precipitation) and by high-quality personnel who do not make mistakes. The classic paper in this literature is Martin et al. (2002) who wrote, "Upstream dams are not necessarily inherently unstable and dangerous. They can be as safe as other types of dams provided site conditions are favorable and that the rules for their safe design, construction and operation are followed … Conventional upstream dams cannot be considered for areas of moderate to high seismicity. Improved upstream construction, involving a combination of compaction of the outer shell and good internal drainage, can be used in such areas." Martin et al. (2002) then presented ten rules for the safe construction of upstream dams. Of particular note is the rule that "upstream dams should be raised at slopes of 4H:1V or flatter … If an upstream constructed dam is raised at a slope steeper than 4H:1V, the likelihood of a static undrained failure due to minimal trigger is increased" (Martin et al., 2002; see Fig. 9). To

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the list of rules, Martin et al. (2002) added the warning, "Of the 10 rules, a 'score' of 9/10 will not necessarily have a better outcome than 2/10, *as any omission* creates immediate candidacy for an upstream tailings dam to join the list of facilities that have failed due to ignoring some or all of the rules" (emphasis added by Hopkins and Kemp (2021)).

Hopkins and Kemp (2021) reacted to the warning by Martin et al. (2002) by writing, "This is a slightly obscure statement that may need to be read twice to reveal its true meaning." (My interpretation is that, from the perspective of Hopkins and Kemp (2021), Martin et al. (2002) described upstream dam construction as if it were a kind of ice climbing expedition in which everything would be fine as long as no mistakes were made.) Morrill et al. (2022) further advanced the critique by writing, "It is theoretically possible to safely construct and operate an upstream tailings dam under the limited conditions of low seismicity, low precipitation and highly-trained personnel. Even under those limited conditions, a very influential tailings industry paper, with many antecedents, has argued that there are ten rules for upstream dams and not a single one can be violated without substantial risk of failure. There is broad consensus within the engineering community, especially in high-risk industries such as aviation and pipelines, that engineered structures should be robust, with multiple back-ups and defense mechanisms. The need to obey ten rules with no margin for error does not constitute a basis for safe design."

In March 2023 the mining industry strongly denounced the upstream method in the SME Surface Mining Handbook and SME Underground Mining Handbook, with no allowance for rules. According to the SME Surface Mining Handbook, "Not mentioned in Table 4 [Tailings storage facility failures by decade from 1950 to December 16, 2020] is the fact that the upstream method of raising the level of the dams has been utilized in many of the most serious failures. This is in spite of the fact that the dangers of failure inherent with the upstream method have been recognized for many decades - see for example, Klohn (1972), who states that the 'history of this method of dam construction is plagued with failures, some of them catastrophic'" (Turek, 2023). According to the SME Underground Mining Handbook, "The industry has only itself to blame because the issues with upstream lifts have been known for decades (Klohn 1972) …" (Darling, 2023).

The insistence that the danger of the upstream construction method has been well-known for over five decades cannot be overemphasized. According to Klohn (1972), "There is a limiting height to which such a dam [constructed using the upstream method] can be raised before a shear failure occurs and the tailings flow out. In regions subject to seismic shocks, failure of this type of dam by liquefaction can occur at very low heights. In fact, the history of this method of dam construction is plagued with failures, some of them catastrophic." According to Klohn (1972), the upstream construction method was "the old method" and was already out-of-date. Klohn (1972) elaborated, "A comparison between a typical water storage dam and two types of tailings dam, one built using the old upstream method of construction and the other built using the downstream method of construction, is most enlightening. An examination of Figure 3, which

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presents a comparison between a water storage dam and the old, upstream-construction type of tailings dam, shows that this type of tailings dam does not meet conventional requirements for slope stability, seepage control (internal drainage) and resistance to earthquake shocks. The factor of safety of the tailings dam is obviously very low even under normal, static conditions of loading. Any change in conditions that would result in saturation of the outer sand dyke could quickly lead to failure by piping or sliding. Potential causes of saturation include such items as: a rise in water levels in the pond, freezing of seepage outlets on the downstream face of the dam, and torrential rainfall. Under earthquake loading the fine, loose tailings in the pond would tend to liquefy and the subsequent high lateral pressures would likely burst the thin, sand-dyke shell. In fact, if, at the time of the earthquake, part of the sand dyke were saturated it would likely fail without the thrust from the liquefied tailings it retains … All upstream methods of tailings dam construction suffer the disadvantage of being built on top of previously deposited, unconsolidated tailings. These tailings have limited shear strength, are loose and usually are saturated. Under static loading conditions there is a limiting height to which such a dam can be built without danger of a shear failure occurring in the downstream direction. This height will depend on the strength of the tailings within the zone of shearing, the downstream slope of the tailings dam and the location of the phreatic line within the dam. Under earthquake loading, this type of dam may be subject to failure by liquefaction, at any height … Upstream dam building is unsuitable for areas where the dam must be designed to resist earthquake shocks. ***Even in non-seismic areas this method of construction is generally unsuitable for all but very minor tailings dams*** … Downstream dam building is the only procedure that permits design and construction of tailings dams to conventionally acceptable engineering standards … All tailings dams located in seismic areas, and all major tailings dams, regardless of their location should be constructed using some form of the downstream method" (emphasis added).

I now turn to the danger of construction using excessively steep embankments. The U.S. Army Corps of Engineers recommends that slopes be no steeper than 1V:5H (11° from the horizontal) to avoid internal erosion in earthen dams or levees. According to USACE (2000), "For sand levees, a 1V on 5H landside slope is considered flat enough to prevent damage from seepage exiting on the landside slope." Safety First: Guidelines for Responsible Mine Tailings Management concurs in writing, "The slope of the outer embankment of the tailings dam must be low enough to keep the annual probability of failure due to piping (also called internal erosion) below an acceptable level. New outer embankments must be constructed with slopes 1V:5H or less, and additional fill must be added to existing outer embankments with a slope steeper than 1V:5H in order to reduce the slope to 1V:5H, as per guidance from the USACE. A proposal to construct or maintain an outer embankment steeper than 1V:5H must be justified in writing to both regulators and the public. The justification cannot be based solely on economic considerations, but must demonstrate that, for a particular design, failure by internal erosion is still sufficiently unlikely even with a steeper slope" (Morrill et al., 2022).

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Gentle slopes can also prevent failure by seismic activity or slope instability. Moreover, a gentle embankment slope could reduce the likelihood of foundation failure by distributing the weight of the dam over a greater area. According to the textbook Geotechnical Engineering for Mine Waste Storage Facilities, "Considering the requirement that the storage capacity for tailings solids of a given site must be maximized, together with the requirements for overall shear stability and the requirement to limit rates of surface erosion, as well as the practical advantage of a slope that can be worked mechanically, an acceptable slope angle for tailings slopes appears to lie in the range of 15-20°. A round figure of 1 vertical on 3 horizontal or 18° appears to be a good compromise" (Blight, 2010).

With regard to the preceding quote from Blight (2010), it should be emphasized that the maximum slope of 1V:3H was not intended to maximize the protection of the environment, but to strike a balance between a need to protect the environment and a need to store the maximum volume of tailings (which might entail reducing the space occupied by the dam in order to create more space for storage behind the dam). By contrast, recommendations from the U.S. Army Corps of Engineers or Safety First are intended to maximize public safety and the safety of the environment. According to the U.S. Army Corps of Engineers, "Since 'Life Safety is Paramount,' it is not appropriate to refer to balancing or trading off public safety with other project benefits. Instead, it is after tolerable risk guidelines are met that other purposes and objectives will be considered" (USACE, 2014). In the same way, Guideline 1 of Safety First: Guidelines for Responsible Mine Tailings Management is "Make safety the guiding principle in design, construction, operation, and closure" (Morrill et al., 2022).

The standards of Blight (2010) and Morrill et al. (2022) refer to tailings dams in general, while the standard of USACE (2000) refers to earthen dams in general. There are also international standards related to the slopes of upstream tailings dams in particular. According to the European Commission, "Key design features to help ensure upstream dam stability include: … • a slope angle of 3:1 (H:V) or flatter, depending on the other measures incorporated into the long-term design; steeper slopes, without an appropriately drained and/or compacted beach, create the potential for spontaneous static liquefaction (Davies et al. 2002)" (Gabarino et al., 2018). An older industry standard (Martin et al., 2002) that the maximum slope for upstream dams should be 1V:4H (14° from the horizontal) was superseded by the current industry standard that upstream dams should be avoided entirely.

The European Commission further called for maximum slopes of 1V:3H not only for upstream dams, but for all tailings dams. According to the European Commission, "In the long term, damage by erosion, temperature and vegetation can be avoided by using stable materials in the construction of the dam and by constructing slopes of a sufficiently low angle. A repose angle of 3:1 (H:V) for the outer surface of the dam is for example considered stable in the long term as such slopes naturally occur in the landscape, according to the MTWR BREF [Management of

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Tailings and Waste Rock - Best Available Techniques Reference Document]" (Garbarino et al., 2018). An example given in the guidance document of the European Commission is that, following the failure of the tailings dam at the Los Frailes mine in Aznalcóllar, Spain, in 1998, the remaining portion of the dam was reconstructed to achieve a slope angle of 1V:3H in order to prevent further failure (Garbarino et al., 2018).

In summary, the existing tailings storage facility on top of which the addition to the Key Mill Tailings Storage Facility would be placed was constructed using methods that were known to be unsafe even at the time of construction. This applies principally to the use of the upstream construction method, which was known to be unsafe even by the early 1970s, and to the use of an embankment slope of 1V:2H, although embankment slopes no steeper than 1V:5H had been recommended by the U.S. Army Corps of Engineers in 2000 (USACE, 2000). It is particularly noteworthy that embankment slopes no steeper than 1V:4H for upstream dams had been recommended by the mining industry in 2002 (Martin et al., 2002).

2) ***Even though the DSEIS assumes that the addition of a filtered tailings storage facility would increase the stability of the existing underlying facility, there are also ways in which the weight of additional tailings could degrade the current state of stability. Moreover, there is no analysis of the current stability of the existing facility. If the objective were to increase the stability of an existing tailings storage facility, placing additional overlying weight would never be suggested as the preferred solution or even as one of the alternative solutions.***

Although the existing tailings storage facility was constructed using unsafe methods, the central assumption of the DSEIS is that the construction of a filtered tailings storage facility on top of the existing facility will improve the stability of the existing facility. The assumption is that weight of the additional tailings would compact the underlying tailings, thus forcing out water that would drain downward through the vertical wick drains that would be constructed (see Fig. 2).

According to the DSEIS, "It is anticipated that the addition of filtered tailings would consolidate the existing conventional mine tailings, and excess pore water pressure would be relieved and conveyed to the NRP [New Reclaim Pond]. The removal of the water in existing tailings would be facilitated through wick drains installed in the existing impoundment. The wick drains provide a passive path of drainage for the pore water that is under pressure (see Figure 4.1-1) [Fig. 2 in this memo]. The removal of this water would reduce the potential for the tailings to liquefy. As the tailings are allowed to consolidate and the water is removed, the potential for liquefaction of the existing conventional mine tailings is expected to be reduced, resulting in increased stability of the facility over time. The additional loading from the Proposed Project in

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combination with new and existing wick drains would accelerate the rate of consolidation" (WSDE, 2026, pdf p. 68).

There are three concerns related to the central assumptions. The first concern is that, although there are reasons as to why additional weight could improve stability, there are also reasons as to why additional weight could degrade the current state of stability. The primary reason is even expressed in the DSEIS. According to the DSEIS, "Liquefaction can also be a concern under other loading conditions that lead to increases in pore water pressure, such as placing additional weight on top of the existing TSF … Adding the weight of the new filtered tailings above the saturated existing tailings would compress the existing tailings and can cause a buildup [of] porewater pressure in the tailings under the additional load" (WSDE, 2026, pdf pp. 66-67). Thus, the assumption that the addition of the weight of a filtered tailings stack will improve the stability of the underlying tailings facility is equivalent to the assumption that the rate of drainage of both existing and anticipated excess pore water pressure will exceed the rate of buildup of additional excess pore water pressure (due to the weight of additional tailings).

The second concern is that, although the DSEIS includes stability analyses of the existing tailings facility plus an additional filtered tailings stack, there are no analyses of the current stability of the existing tailings storage facility alone. Thus, it is not known how further construction, such as the installation of the vertical wick drains (see Fig. 2), could impact the stability or potentially initiate the collapse of the existing tailings storage facility.

The third concern is that there are ways of improving the stability of tailings storage facilities that were originally constructed using unsafe methods. A partial list of possible approaches includes the following:

1) removal of some or all of the tailings to a safe location, such as an abandoned open pit
2) installation of pumps to remove any surface water
3) installation of vertical or horizontal drains to facilitate reducing pore water pressure and lowering the water table
4) construction of a buttress to reduce the slope of the outer embankment
5) construction of a secondary dam downstream to contain the collapse of the existing tailings facility

The important point is that, although the placement of additional weight on top of the existing tailings facility could improve stability, as suggested in the DSEIS, since the placement of additional weight could also de-stabilize a tailings facility, no one would ever propose the placement of additional weight as the preferred solution or even as one of the alternative solutions, if the purpose of the project were to stabilize an existing tailings storage facility (as opposed to a project for which the purpose is to mine more gold).

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3) ***The strength parameters for the existing tailings are far greater than what would be standard in the mining industry, so that all of the stability analyses are highly questionable.***

According to NewFields (2025), the peak undrained strength ratio of the existing slurry tailings was assumed to be 0.32 (see Fig. 10). The peak undrained strength ratio is a dimensionless number that indicates the resistance of the tailings to liquefaction. The assumed peak undrained strength ratio is far higher than what is typically measured or assumed in the mining industry, so that all of the stability analyses should be regarded as highly questionable. The peak undrained strength ratio is also related to the fraction of stored tailings that will be released following failure of the tailings storage facility, in that a higher peak undrained strength ratio would correspond to a larger release of tailings. The underestimation of the volume of released tailings and the consequences of tailings facility failure are further discussed under Point #5.

According to Martin et al. (2002), a typical range for peak undrained strength ratio is 0.2-0.3 (see Fig. 11). The context for the range given by Martin et al. (2002) was to argue that tailings dams can be safely constructed and operated using the upstream method, as long as ten rules are followed, including constructing the outer embankment with a slope no steeper than 1V:4H (see Fig. 9) and using carrying out the stability analyses using reasonable values for the peak undrained strength ratio. Thus, since the existing Key Mill tailings facility was constructed using an outer embankment slope of 1V:2H (see Fig. 3) and since the stability has been evaluated assuming a peak undrained strength ratio of 0.32 (see Fig. 10), both of the preceding rules have been violated.

As a second example, Olson and Stark (2003) back calculated peak undrained strength ratios from case histories of liquefaction failures. According to Olson and Stark (2003), "Strength ratios mobilized during the static liquefaction flow failures ranged from approximately 0.24 to 0.30 and are correlated to corrected cone and standard penetration resistances." Based on 33 case studies of both static and seismic liquefaction, Olson and Stark (2003) found best estimates of peak undrained strength ratios in the range 0.16-0.32 with both arithmetic mean and median (50th percentile) of 0.24 (see Fig. 12).

The choice of the peak undrained strength ratio is supposed to be conservative, that is, it should err on the side of underestimating, not overestimating, stability and resistance to liquefaction. According to Padovani and Bretas (2023), "For the peak shear strength, the calculated frequency distribution (histogram) per layer was evaluated, being considered as representative those that correspond to the 20- 30% percentile. The adopted criteria is consistent with the 20th percentile suggested by Jefferies & Been (2015) [2016]." For the 33 case histories presented by Olson and Stark (2003), the 20th and 30th percentiles for the peak undrained strength ratios are 0.21 and 0.22, respectively.

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In summary, despite the fact that the DSEIS considered only the stability of the existing tailings facility plus an overlying filtered tailings stack and not the stability of the existing tailings facility alone, the stability and resistance to liquefaction of the combination of the existing tailings facility plus an overlying filtered tailings stack has been overestimated.

4) ***The claim in the DSEIS that filtered tailings are non-liquefiable is inconsistent with both industry and FEMA guidance.***

The DSEIS states repeatedly that the proposed filtered tailings stack cannot undergo liquefaction. According to the DSEIS, "For the Proposed Project, as part of the filtered tailings processing, water is removed from the filtered tailings and then the filtered tailings are transported to the TSF and placed in layers and compacted to densify them. The placed filtered tailings are not liquefiable due to their low moisture content and higher density … The Proposed Project would add approximately 5.5 MT of filtered tailings that are relatively dry, not prone to liquefaction, and would accelerate consolidation of the existing tailings in the TSF … Given that the placed filtered tailings are not liquefiable, and consolidation of the existing tailings would not be as extensive, the overall seismic stability of the TSF under the No Action Alternative would not improve as much as it would under the Proposed Project" (WSDE, 2026).

The same assumption that the filtered tailings cannot liquefy is repeated throughout the consulting reports that accompany the DSEIS. According to NewFields (2023), "The filtered tailings will be compacted and will not be liquefiable." According to NewFields (2025), "Filtered Tailings – Represents tailings that are dewatered, placed in lifts, and compacted. These tailings have higher associated densities, lower moisture contents, and are considered non-liquefiable … The filter stack is comprised of non-liquefiable tailings."

The claim in the DSEIS and the accompanying consulting reports is not correct and is inconsistent with both industry guidance and FEMA guidance. A more accurate claim would be that filtered tailings will not liquefy if all of the processes of filtering, stacking, compacting, and draining the tailings are carried out perfectly, so that the tailings remain unsaturated and compacted into a dilative state. For clarification, compaction into a dilative state means that the tailings will tend to expand, rather than contract, in response to disturbance. The tendency of saturated tailings to contract in response to disturbance is the pre-condition for the phenomenon of liquefaction. It is important to note that filtered tailings do not need to be fully saturated for liquefaction to occur. In the context of filtered tailings, the FEMA Tailings Dam Safety Best Practices stated: "The degree of saturation that can result in contractive behavior in loose stacked tailings is often taken as a value exceeding 80 to 85 percent" (FEMA, 2025).

As opposed to the perfect execution of all of the processes involved in filtered tailings technology, any of the following could set the stage for liquefaction:

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1) The tailings leave the filter presses with excessive water content for maximum compaction.
2) Attempts to field-dry excessively wet tailings are unsuccessful due to insufficient space for drying.
3) The tailings become re-wetted by precipitation after filtering, but before stacking and compaction.
4) Tailings are inadequately compacted either because they are too wet or because the compaction was not carried out properly.
5) Inadequate initial compaction means that the tailings will continue to compact due to the additional weight of overlying layers. Further compaction will decrease pore sizes, so that tailings that were unsaturated now become saturated.
6) Inadequate drainage systems mean that saturated tailings remain saturated.
7) High precipitation together with inadequate drainage conditions result in the re-saturation of tailings that were previously unsaturated.

The industry guidance document Guidelines for Tailing Piles and Tailing & Overburden Piles summarizes the preceding list of imperfect execution of filtered tailings technology and its consequences in the following way: "The risk associated with liquefaction of tailings when stacked without proper compaction control is one of the fundamental aspects that must be considered … The option of disposing tailings in a pile, whether PDR [Tailings Disposal Piles] or PDER [Overburden and Tailing Disposal Piles], should only be considered when the resulting structure is stable considering the most critical possible scenarios. One of the main concerns associated with the disposal of tailings in piles is the possibility of liquefaction of these materials, because, due to their geotechnical characteristics, they can generate excess pore pressure if they present contractive behavior. For this reason, it is necessary to ensure that the disposed materials are not susceptible to liquefaction, ensuring that they (i) exhibit dilative behavior – which can be achieved through rigorous compaction processes – and (ii) are not saturated … Another condition that needs to be met so that there is no risk of liquefaction of the materials disposed in the pile, is the unsaturated condition. Projects must be developed to provide drainage conditions that prevent the saturation of materials. However, this is a condition that must be constantly monitored once the structure is constructed, and for existing structures, as there may be a risk of material saturation, either due to design or construction flaws, or unexpected conditions" (AECOM, 2023).

The FEMA guidance document Tailings Dam Safety Best Practices is the most detailed in describing all of the circumstances that could lead to liquefaction of a filtered tailings stack. According to FEMA (2025), "However, consistently achieving a moisture content low enough to achieve the necessary inherent stability is challenging and not always achieved with current technology … However, if the filtered tailings facility contains any zones of uncompacted tailings that may become saturated or nearly saturated, the stability of the stack needs to consider the lower strength of the uncompacted zone and the potential for static or dynamic liquefaction … 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 … Filtered tailings facilities are frequently referred to colloquially as a 'dry stack', but this term is a misnomer and can be misleading because the tailings are not truly dry, and saturated conditions can result, especially in the bottom portions of the stack. 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 … If significant zones of filtered tailings remain or become saturated, loss of strength and/or liquefaction due to static and seismic loads can occur … These two general failure scenario categories can also apply to filtered tailings facilities that do not include free water storage … Further, it is not necessary for the full stack to be saturated; it may be sufficient if the bottom layers are saturated and give way under the weight above. If the bottom fails, it acts as a lubricating layer and the material above it may be carried along on top of a liquefied layer at the bottom … However, the extent and reliability of filter cake dewatering depends on the processing technology employed, as well as the tailings particle size distribution, mineralogy and shape, and clay content. Additionally, climatic conditions can require drainage to be collected on the tailings surface and make it challenging to maintain the filtered tailings in a state suitable for compaction … Consolidation will also occur in a partially saturated deposit—such as the initial condition of filtered tailings in most 'dry-stack' facilities—as successive layers of tailings are placed, which increases the applied stresses, which in turn compresses the air voids, potentially causing the voids to become fully saturated. Consolidation may occur over an extended time after filling of the tailings deposit ends, causing the tailings surface to settle and release water from the pores into the surrounding environment. The process occurs in both hydraulic fills (slurry deposits) and filtered tailings facilities."

Numerous industry and academic publications have also warned of the possibility of liquefaction of a filtered tailings stacks. According to Crystal et al. (2018), "If the [filtered] tailings become and/or remain saturated, they can be susceptible to pore pressure increases and associated strength reductions as well as static and seismic liquefaction." According to Andrade et al. (2025), "The degree of compaction (DC) was found to play a crucial role in determining the mechanical behavior of the filtered tailings. Samples with lower compaction levels showed a reduction in post-peak shear strength during undrained tests, making them more susceptible to liquefaction. Therefore, ensuring adequate compaction is crucial to preventing the liquefaction of filtered tailings and maintaining the stability of the embankments." According to Cabrera and Villanueva (2025), "Filtered tailings remoulded using the moist-tamping method exhibited sand-like behaviour when subjected to triaxial compression testing. That is, strain-hardening, and

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strain-softening behaviours were observed in the results depending on the density level and effective confining stress. Contractive tailings samples were observed to exhibit strain-softening behaviour at large deformations, with a consequent loss of strength under undrained conditions. This indicates that this material is susceptible to flow liquefaction at very high saturation levels."

In summary, the blanket statement in the DSEIS that "filtered tailings are not liquefiable" (WSDE, 2026) is not correct. The statement is essentially equivalent to claiming that failure of the proposed filtered tailings storage facility is impossible. Any implication that failure of a proposed project is impossible should be immediate grounds for dismissal of the proposal.

5) ***Although the dam breach analysis assumes a loss of 3-6% of the stored tailings, the minimum loss during any previous tailings storage facility failure has been 9%. The average loss has been 45% of the stored tailings and there are at least four documented examples of the loss of 100% of the stored tailings.***

The most important control on the consequences of failure of a tailings storage facility is the volume of released tailings. For the failure of the combined existing tailings facility plus an overlying filtered tailings stack, NewFields (2025) assumed release of 3% of the stored tailings during a flood-induced failure and release of 6% of the stored tailings during a fair-weather failure (see Fig. 13). According to NewFields (2025, pdf p. 7), "NewFields' estimated release volumes for the FTS fall within the range of similar historic failures. The flood-induced release estimate is within the lower bounds of historic failures, which is consistent with the assumed tailings densification caused by the load applied from the filtered tailings. It is our opinion that the release volumes presented herein are reasonable estimates."

In fact, the release volumes assumed by NewFields (2025) are completely inconsistent with past failures of tailings storage facilities. Table 1 in this memo shows the storage and release volumes of 28 failures of tailings storage facilities that were compiled by Larrauri and Lall (2018), which is supplemented by five additional case studies from Center for Science in Public Participation (2025). To the best of my knowledge, Table 1 includes all failures of tailings storage facilities for which the tailings storage and release volumes are known. The minimum release volume has been 9% of the stored tailings, while the average release volume has been 45% of the stored tailings (see Table 1). There are 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 1).

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In summary, all of the analyses of the consequences of failure of the Key Mill Tailings Storage Facility represent considerable underestimates. The correct and conservative approach would have been to assume the loss of 100% of the stored tailings.

The dam break assessment by NewFields (2025) does consider the possibility of the release of a greater fraction of the stored tailings. According to NewFields (2025, pdf p. 21), "Sensitivity Case 2 increases the fair-weather breach volume by 25%, to represent the potential impact of more conservative breach parameters. Varying breach inputs, and by extension the release volume, impacts the inundation area, with effects more pronounced in areas close to the beach location. Altering the breach released volume increases its peak discharge by 12%, which in turn influences the velocity and flow depth of the fluidized tailings within areas close to the facility." However, increasing the assumed fair-weather breach volume of 6% (see Fig. 13) by 25% results in a release volume of only 7.5% of the stored tailings, which would still be less than the smallest fraction of released tailings (9%; see Table 1) that has ever occurred for any tailings storage facility failure.

6) ***The dam breach analysis report does not include even the most basic information that would be required to either confirm or challenge the analysis, such as the height of the existing facility.***

Typically, an EIS includes the input data that were used to carry out the analyses, so that the public could either confirm or challenge the analyses. However, the dam breach analysis by NewFields (2025) does not include even the most basic information that could be used to verify or challenge the predictions of the consequences of failure of the tailings facility, such as the height of the existing tailings facility. In a similar way, the omission of basic information such as the height of the existing tailings facility makes it impossible to either confirm or challenge the various stability analyses.

From another perspective, although computational methods for dam breach analyses can produce very detailed predictions, such as flow depths, flow velocities, and the arrival times of the tailings flood, the disadvantage of these computational methods is that they require a very large number of input parameters. Many of these parameters are poorly known, 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

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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 computational models are continually updated through calibration as more observations become available that can be compared with predictions.

The problem with computational models for tailings dam breach analyses is that the models are never calibrated. Such models could be calibrated only if a minor failure had already occurred for a particular tailings dam and the observations from that minor failure were being used to calibrate a model for a future major failure. I am not aware of any computational model that has ever been calibrated under the preceding circumstances. Thus, in all cases, computational models for tailings dam 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, computational tailings dam breach analyses should have a low level of confidence almost by definition.

Because of the low level of confidence in the predictions of the consequences of tailings facility failures based on computational models with their intensive input parameters, a common strategy for building confidence or exposing the true lack of confidence is the comparison of the predictions of a computational model with the predictions of an empirical or statistical model developed from past tailings dam failures. An example of a statistical model of past tailings dam failures was developed by Larrauri and Lall (2018). The statistical model predicts the initial runout of tailings following dam failure based upon the height of the facility and the volume of stored tailings. However, without even knowing the height of the existing tailings facility, not even a comparison with the simplest statistical model is possible and the public is left with no confidence in the reliability of the dam breach analysis for the proposed expansion of the Key Mill Tailings Storage Facility.

This concludes my comments. Please let me know if I can help with anything else.

Best wishes,

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Table 1. Empirical measurements of past tailings storage facility failures: Storage volume and release volume

No.	Mine	Year	Storage Volume (Mm^3)	Release Volume (Mm^3)	Fraction (Release/ Storage)
Dataset of Larrauri and Lall (2018)					
1	(unidentified), Southwestern USA	1973	0.5	0.17	0.34
2	Aitik mine, Sweden (Boliden Ltd.)	2000	15	1.8	0.12
4	Bafokeng, South Africa	1974	13	3	0.23
5	Balka Chuficheva, Russia	1981	27	3.5	0.13
6	Bellavista, Chile	1965	0.45	0.07	0.16
7	Bonsal, North Carolina, USA	1985	0.038	0.011	0.29
8	Cerro Negro No. (3 of 5)	1965	0.5	0.085	0.17
9	Cerro Negro No. (4 of 5)	1985	2	0.5	0.25
10	Churchrock, New Mexico, United Nuclear	1979	0.37	0.37	1.00
11	Cities Service, Fort Meade, Florida	1971	12.34	9	0.73
12	Deneen Mica Yancey County, North Carolina, USA	1974	0.3	0.038	0.13
13	El Cobre New Dam	1965	0.35	0.35	1.00
14	El Cobre Old Dam	1965	4.25	1.9	0.45
15	Fundão-Santarem, Minas Gerais, Brazil (Samarco)	2015	55	32	0.58
18	Hokkaido, Japan	1968	0.3	0.09	0.30
19	Imperial Metals, Mt Polley, British Columbia, Canada	2014	74	23.6	0.32
22	Los Frailes, near Seville, Spain (Boliden Ltd.)	1998	15	6.8	0.45
23	Los Maquis No. 3	1965	0.043	0.021	0.49
24	Merriespruit, South Africa (Harmony)-No. 4A Tailings Complex	1994	7.04	0.6	0.09
25	Mochikoshi No. 1, Japan (1 of 2)	1978	0.48	0.08	0.17
27	Olinghouse, Nevada, USA	1985	0.12	0.025	0.21
28	Omai Mine, No. 1, 2, Guyana (Cambior)	1995	5.25	4.2	0.80
29	Prestavel Mine-Stava, North Italy, 2, 3 (Prealpi Mineraria)	1985	0.3	0.2	0.67
30	Sgurigrad, Bulgaria	1996	1.52	0.22	0.14
31	Stancil, Maryland, USA	1989	0.074	0.038	0.51
32	Taoshi, Linfen City, Shanxi province, China (Tahsan Mining Co.)	2008	0.29	0.19	0.66

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34	Tyrone, New Mexico (Phelps Dodge)	1980	2.5	2	0.80
35	Veta de Agua (Chile)	1985	0.7	0.28	0.40
	Additional Data Points[1]				
	Williamson, Tanzania (Petra Diamonds)	2022	25.76	12.8	0.50
	Jagersfontein, South Africa (De Beers)	2022	22	6	0.27
	Brumadinho, Mina Córrego do Feijão, Minas Gerais, Brazil (Vale)	2019	12	9.57	0.80
	Hector Mine Pit Pond, Minnesota, USA	2018	0.185	0.123	0.66
	Dahegou Village, Luoyang, Henan Province, China (Luoyang Xiangjiang Wanji Aluminum Co., Ltd.)	2016	2	2	1.00
				Average	0.45
				Minimum	0.09
				Maximum	1.00

[1]Center for Science in Public Participation (2025)

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Table 1.4-1. TSF height by phases of development

Phase	Activity	Authorized height (feet-amsl)	Associated storage capacity (MT)	Cumulative storage capacity (MT)	Remaining capacity (MT)	Liner	Groundwater drainage	Surface water drainage
I/II	Initial construction of the TSF (starter dike)	3,220	2.5 MT of conventional tailings, then 1.1 MT of conventional tailings	3.6 MT of conventional tailings	0 MT	Single VLDPE liner	Under liner, drainage material: a layer of free-draining sand and gravel over native soils/bedrock with perforated HDPE pipes	Upgradient ditch that discharged surface and stormwater onto the TSF impoundment
III	TSF Modifications - downstream raise	3,245	3.2 MT of conventional tailings	6.8 MT of conventional tailings	0 MT	Same as Phase I/II (extended)	Same as Phase I	Same as Phase I
IV	TSF Modifications – upstream raise	3,257	1.7 MT of conventional tailings	8.5 MT of conventional tailings	0 MT	Double VLDPE liner (on slopes). Smooth single VLDPE geomembrane (on floor). GCL between, liner cushion and drainage material.	Same as Phase I. Vertical wick drains and collector pipes at TSF surface.	Upgradient stormwater diversion channels
V	TSF Modifications – upstream raise	3,285	4.7 MT of conventional tailings OR 3.7 MT of conventional tailings and 1 MT of filtered tailings)[a]	13.2 MT (11.5 MT of conventional tailings and 1 MT of filtered tailings)	0.70 MT of conventional tailings OR 1 MT of filtered tailings**	Same as Phase IV (Basin Liner), and GCL on LLDPE textured liner with cushion (Upstream Liner)	Same as Phase IV	Same as Phase IV

Figure 1a. The filtered tailings storage facility would be constructed on top of an existing tailings storage facility that was constructed using the upstream method (compare Fig. 2 with Fig. 4a). The upstream construction method was known to be unsafe even three decades prior to the use of the method at the Key Mill Tailings Storage Facility. See continuation of table in Fig. 1b. Table from WSDE (2026, pdf p. 22).

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Phase	Activity	Authorized height (feet-amsl)	Associated storage capacity (MT)	Cumulative storage capacity (MT)	Remaining capacity (MT)	Liner	Groundwater drainage	Surface water drainage
VI	Proposed Action	3,360	5.5 MT of filtered tailings	18.7 MT (12.2 MT of conventional tailings and 6.5 MT of filtered tailings)	6.5 MT of filtered tailings	Double-sided HDPE liner	Vertical wick drains in TSF	Upgrade Phase IV upgradient stormwater diversion channels. Emergency spillway.

** Note: The remaining capacity to reach the current authorized height depends on the type of tailings. If the Proposed Action (Phase VI) is not approved, EBMC is authorized to have a remaining capacity of placing conventional tailings, the TSF has a remaining capacity of 0.70 MT conventional tailings. If placing filtered tailings, the TSF has a remaining capacity of 1 MT filtered tailings.

Figure 1b. The filtered tailings storage facility would be constructed on top of an existing tailings storage facility that was constructed using the upstream method (compare Fig. 2 with Fig. 4a). The upstream construction method was known to be unsafe even three decades prior to the use of the method at the Key Mill Tailings Storage Facility. See beginning of table in Fig. 1a. Table from WSDE (2026, pdf p. 23).

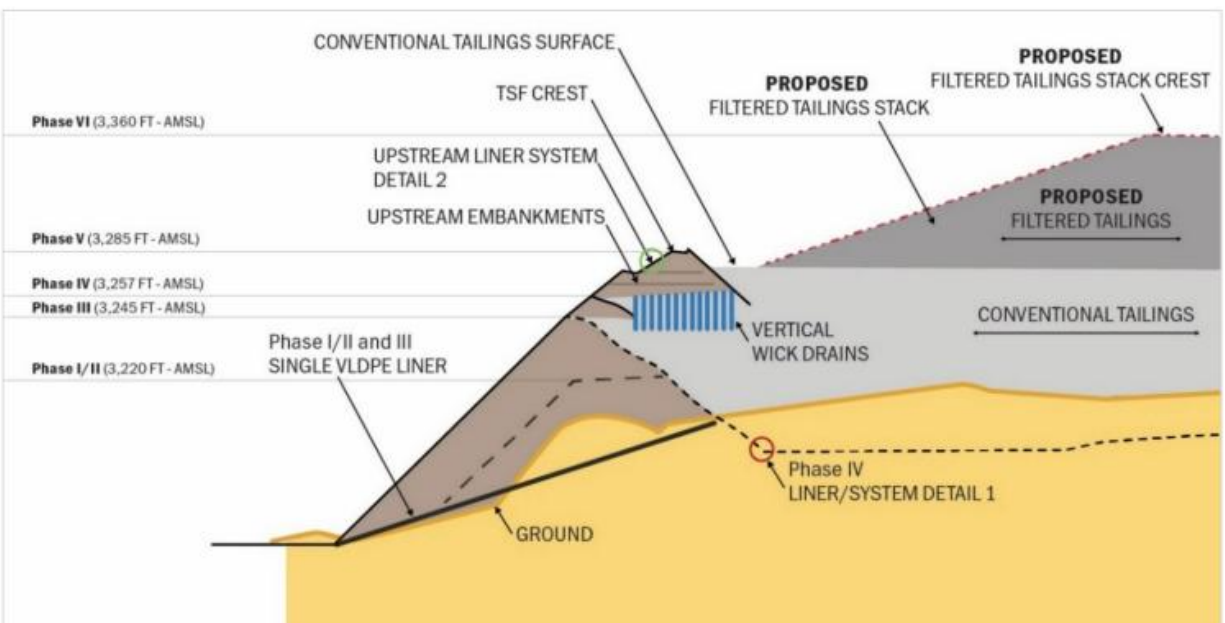

Figure 1.4-1. Phases of stack height raises of the Key Mill TSF

Figure 2. The filtered tailings storage facility would be constructed on top of an existing tailings storage facility that was constructed using the upstream method (compare with Fig. 4a). The upstream construction method was known to be unsafe even three decades prior to the use of the method at the Key Mill Tailings Storage Facility. Figure from WSDE (2026, pdf p. 21).

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Table 2.1 - TSF and FTS Facility Configuration

Element	Value
TSF Crest elevation (ft-amsl)	3285
TSF Crest Width (ft)	30
TSF Exterior Embankment Slope (xH:1V)	2
TSF Tailings Elevation (ft-amsl)	3281.6
Existing (Slurry) Tailings Storage (Mcy)	9.95
FTS Crest Elevation (ft-amsl)	3360
FTS Placement Slope (xH:1V)	4-6
FTS Tailings Storage Capacity (Mcy)	4.1

Figure 3. The filtered tailings storage facility would be constructed on top of an existing tailings storage facility that was constructed using the upstream method (see Figs. 1a-b, 2) with the excessively steep slope of 1V:2H (1 meter vertical for two meters horizontal). The construction of outer embankments with such excessively steep slopes was known to be unsafe at the time of construction of these embankments at the Key Mill Tailings Storage Facility. Table from NewFields (2025, pdf p. 3).

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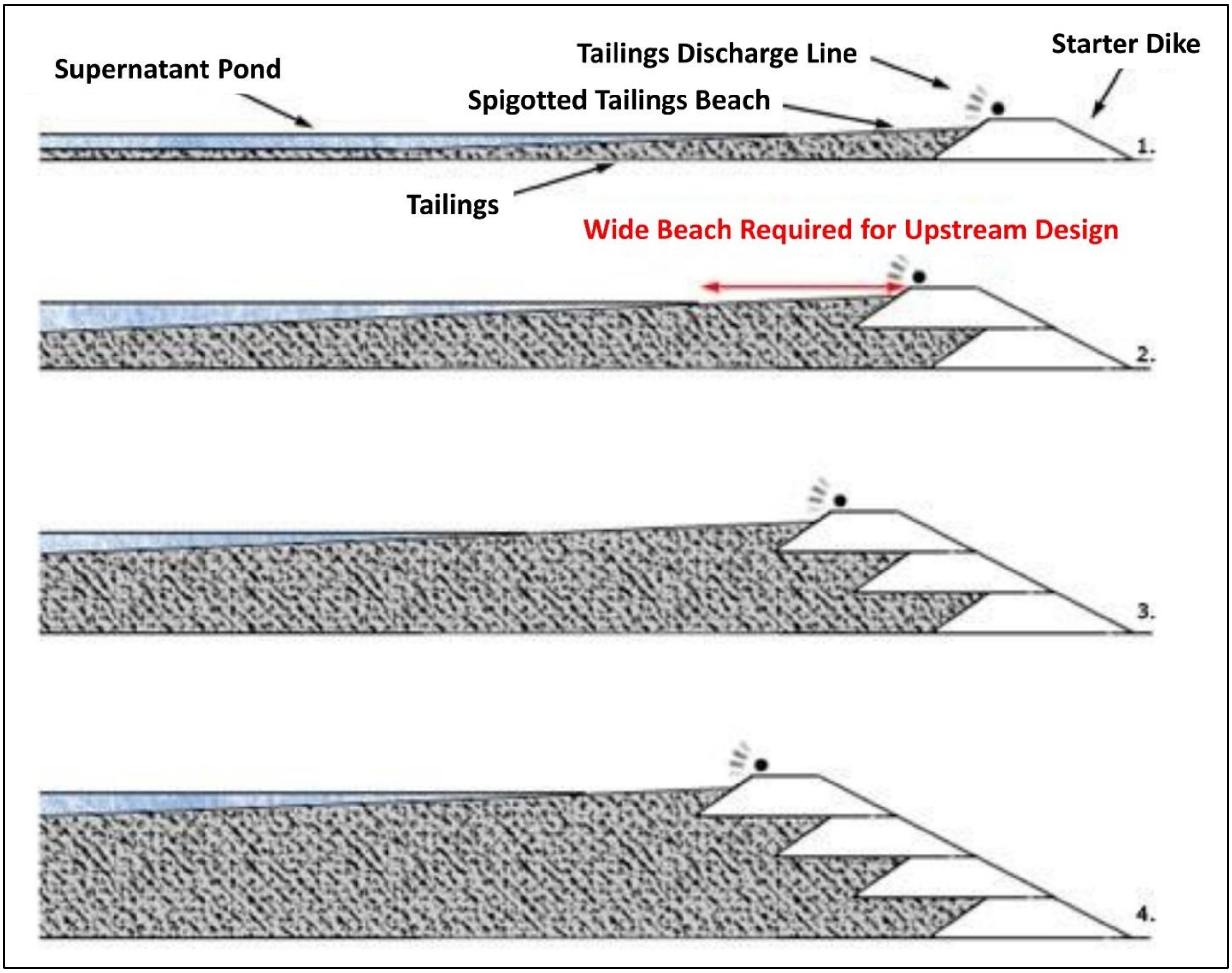

Figure 4a. In the upstream construction method, successive dikes are built in the upstream direction as the level of stored tailings increases. Dikes can be constructed with mine waste rock, natural soil, natural rock fill, or the coarser fraction of tailings (with proper compaction). The advantage of the method is its low cost because very little material is required for the construction of the dam. The disadvantage is that the dam is susceptible to failure due to seismic or static liquefaction because the non-compacted wet tailings are below the dam. For this reason, the upstream construction method is illegal in Brazil, Chile, Ecuador and Peru. Dams constructed by this method are also susceptible to flood failure when the beach is too narrow due to an insufficient amount of sand in the discharged tailings or excessive water in the settling pond. Figure from TailPro Consulting (2026).

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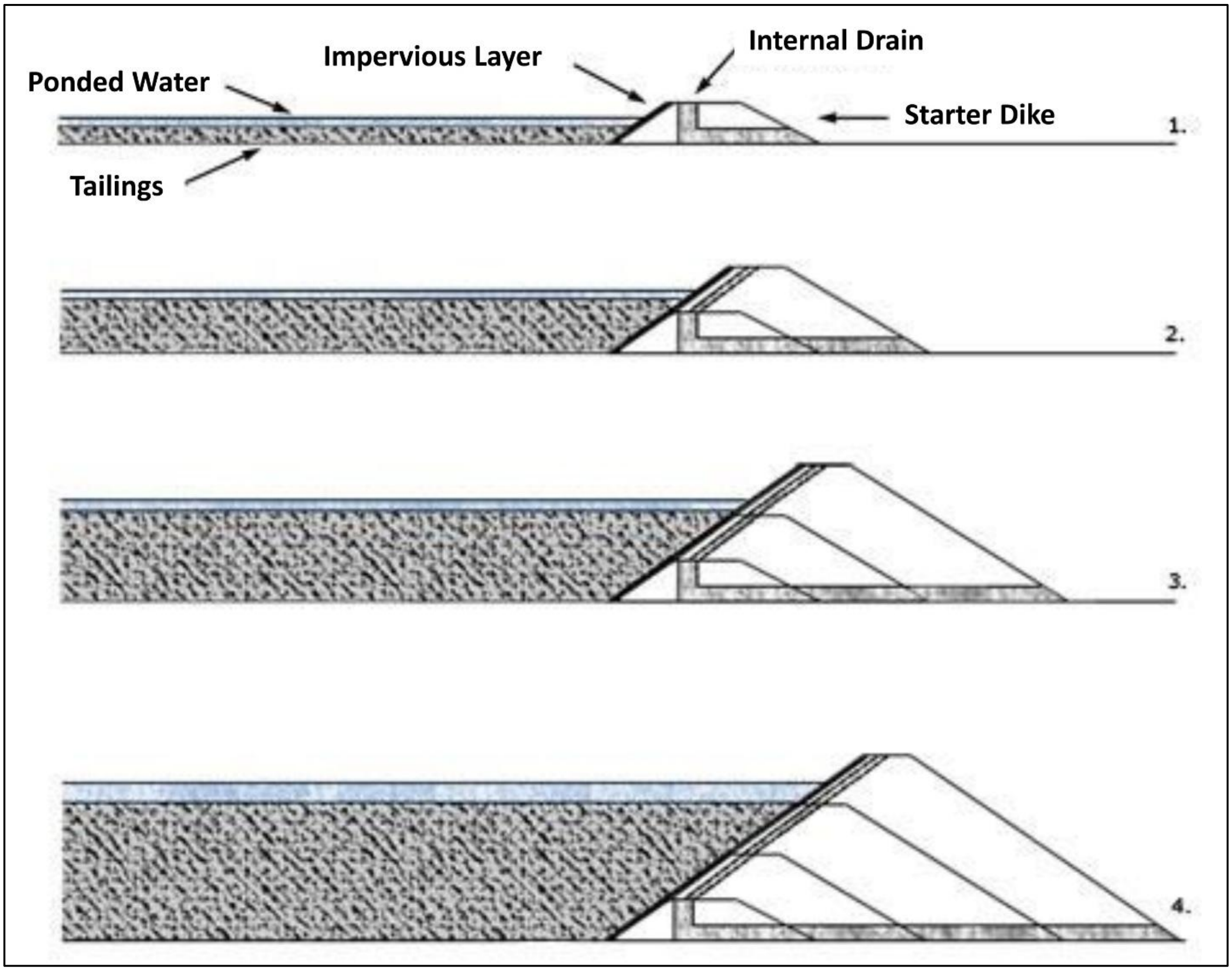

Figure 4b. In the downstream construction method, successive dikes are constructed in the downstream direction as the level of stored tailings increases. Dikes can be constructed from mine waste rock, natural soil, natural rock fill, or the coarser fraction of tailings (with proper compaction). The resistance to seismic and static liquefaction is high because there are no uncompacted tailings below the dam. The disadvantage of the method is its high cost due to the amount of material required to build the dikes (compare the dike volumes in Figs. 4a and 4b). Figure from TailPro Consulting (2026).

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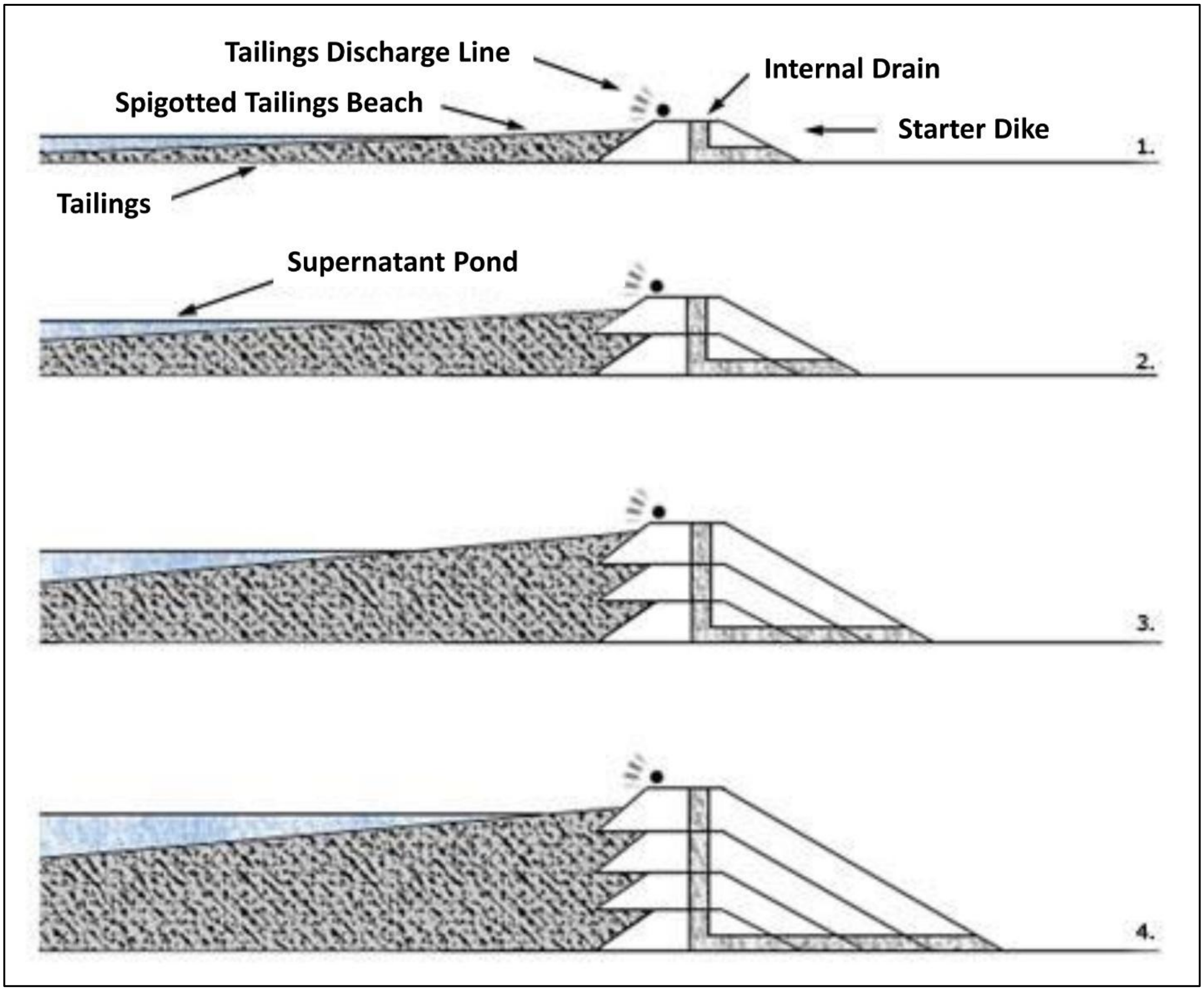

Figure 4c. In the centerline construction method, successive dikes are constructed by placing construction material on the beach and on the slope downstream of the previous dike. The central lines of the rises coincide as the dam is built upwards. Dikes can be constructed from mine waste rock, natural soil, natural rock fill, or the coarser fraction of tailings (with proper compaction). The centerline method is intermediate between the upstream and downstream methods (see Figs. 5a-b) in terms of cost and risk of failure. The resistance to seismic and static liquefaction is moderate because there are still some uncompacted tailings below the dikes. It is still necessary to maintain a suitable beach to avoid flooding the dam. Figure from TailPro Consulting (2026).

Figure 5. The failure of the upstream tailings dam at the Córrego do Feijão mine near Brumadinho, Brazil, on January 25, 2019, which resulted in 272 deaths, including the deaths of 258 mineworkers, was a watershed moment in the global awareness of the danger of the upstream construction method. However, in the five decades preceding the Brumadinho disaster, there were already numerous cautions and prohibitions regarding the use of the upstream method in guidance documents and regulations. Photo from Robertson et al. (2019).

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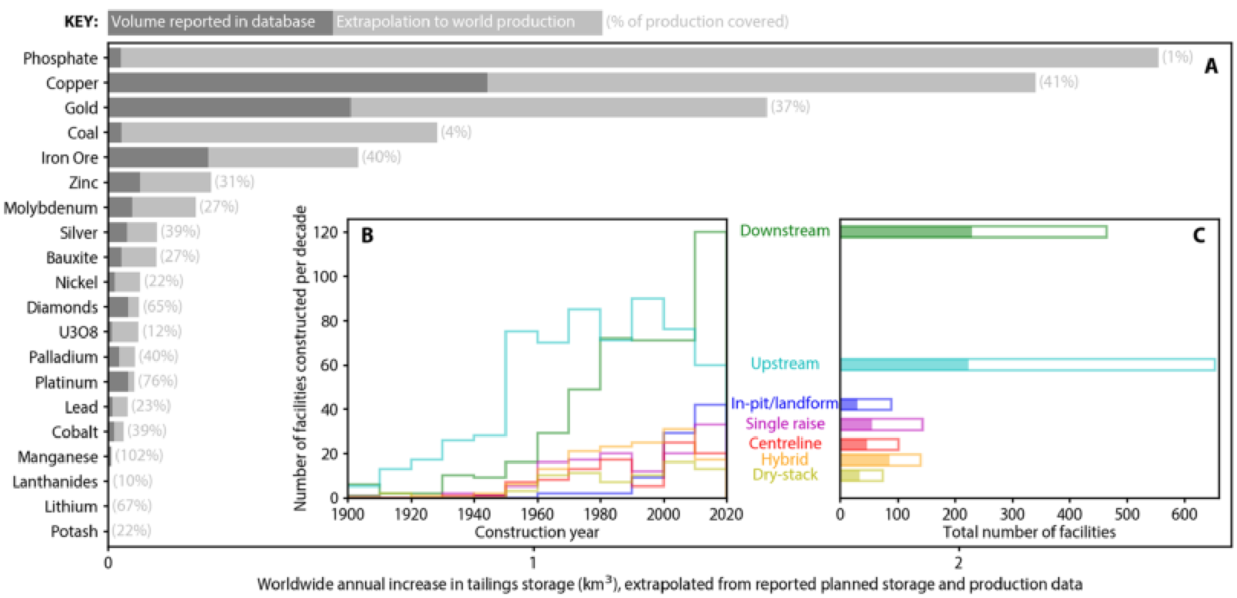

Figure 1. Tailings storage. (**A**) Tailings storage volume increase per year over the 2019–2023 period for a range of commodities as reported in the dataset and extrapolated to world production. (**B**) Number of reported facilities constructed per decade by raise type. (**C**) Reported tailings facilities by raise type. Shading indicates active facilities.

Figure 6. According to Franks et al. (2021), “while upstream facilities make up 37 per cent of the total, they have declined from a peak of 85 per cent of new facilities in 1920–1929 to 19 per cent of new facilities in 2010–2019 (Fig. 1B).” In addition, upstream facilities made up 45%, 41%, and 32% of total new facilities for the decades 1960-1969, 1970-1979, and 1980-1989, respectively, indicating that it was generally known by the 1970s that the benefits of upstream construction did not outweigh the risks. Figure from Franks et al. (2021).

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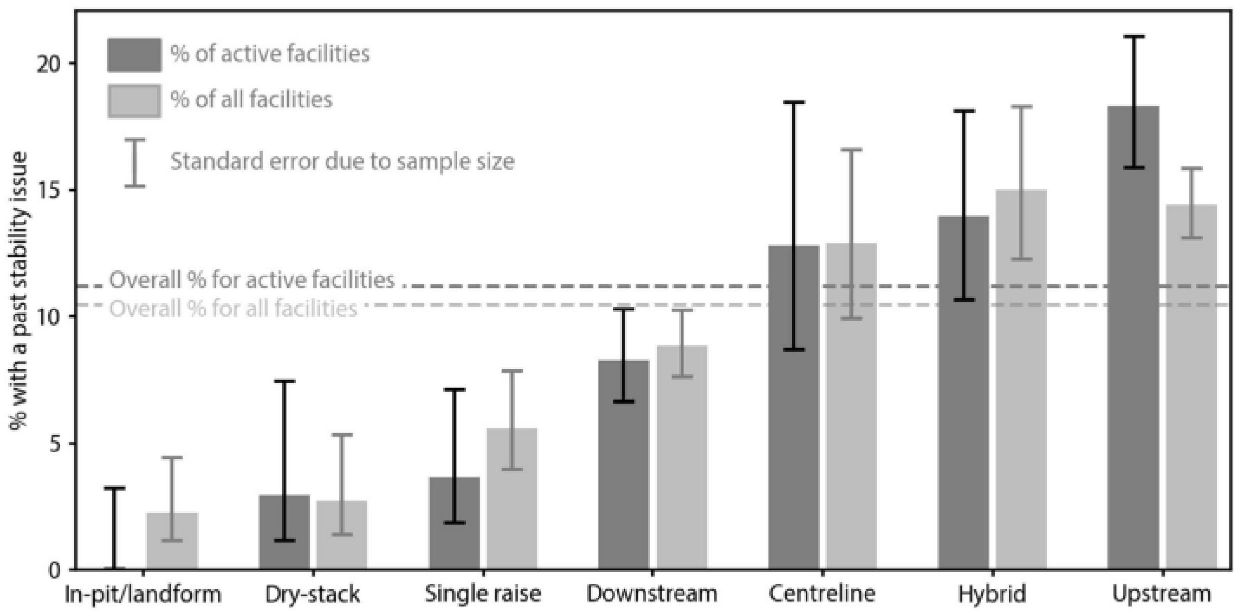

Figure 3. Stability of tailings facilities. Proportion of facilities with a stability issue by raise type. Error bar lengths are binomial confidence intervals for the subsample represented by each bar, showing ± 1 standard error (approximately 68%).

Figure 7. According to Franks et al. (2021), "Our findings reveal that in practice active upstream facilities report a higher incidence of stability issues (18.3%) than other facility types, and that this elevated risk persists even when these facilities are built in high governance settings … The likelihood of a stability issue in active upstream facilities is twice that of active downstream facilities … The control tests [age, height, volume, seismic hazard, wind speed, and rainfall] showed that the properties of the upstream samples (notably their distribution of age), have a small effect on the incidence of stability, however the estimated effect is only about one standard error, and is not sufficient to account for their higher than average incidence." The stability issue was an answer to the particular question "Has this facility, at any point in its history, failed to be confirmed or certified as stable, or experienced notable stability concerns, as identified by an independent engineer (even if later certified as stable by the same or a different firm)?" with the clarification "We note that this will depend on factors including local legislation that are not necessarily tied to best practice. As such, and because remedial action may have been taken, a 'Yes' answer may not indicate heightened risk. Stability concerns might include toe seepage, dam movement, overtopping, spillway failure, piping etc. If yes, have appropriately designed and reviewed mitigation actions been implemented? We also note that this question does not bear upon the appropriateness of the criteria, but rather the stewardship levels of the facility or the dam" (Franks et al., 2021). Figure from Franks et al. (2021).

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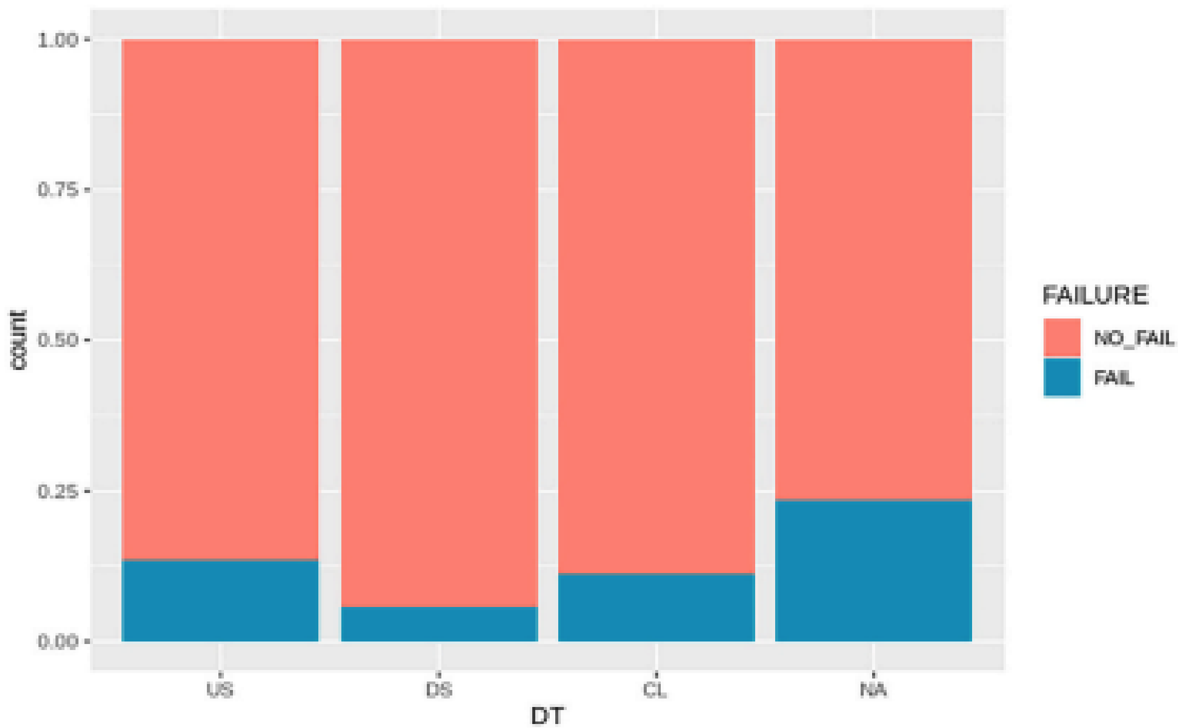

Fig. 13. Fraction of dams in the failure dataset to the total number of dams in both datasets as a function of the dam construction method. US = upstream; DS = downstream, CL = centreline; NA = not known.

Figure 8. By comparing datasets on global tailings dam failures (Center for Science in Public Participation, 2025) with global tailings dams (Franks et al., 2021; UNEP et al., 2026), Piciullo et al. (2022) showed a disproportionately large representation of upstream tailings dams among tailings dam failures. DT = Dam Type, US = Upstream, DS = Downstream, CL = Centerline. Figure from Piciullo et al. (2022).

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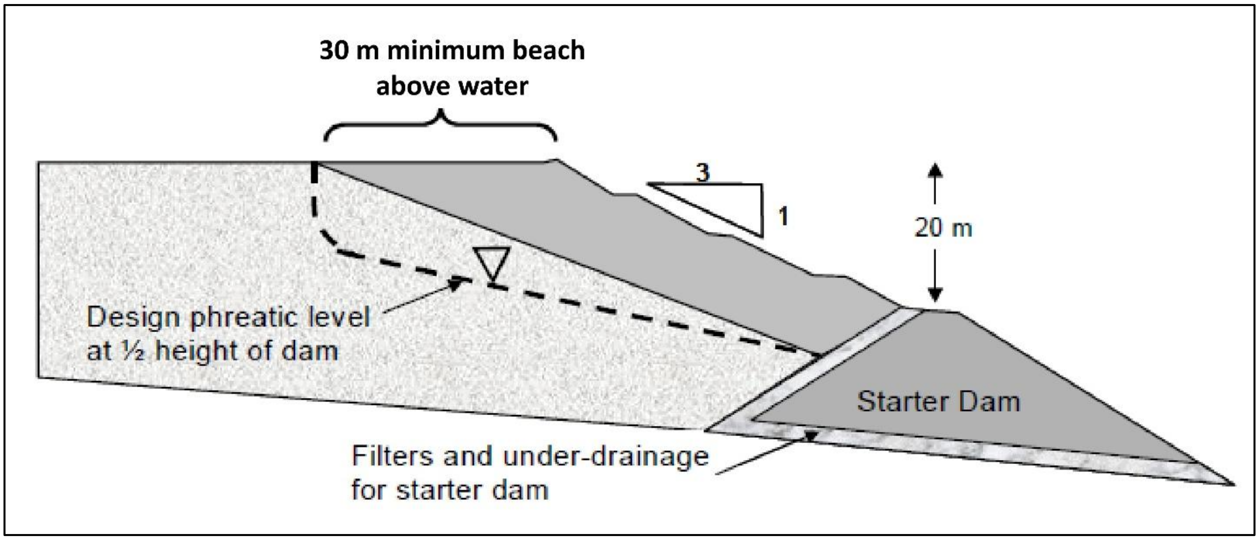

Figure 9. Martin et al. (2002) listed ten rules for the safe construction of upstream dams with the warning that "of the 10 rules, a 'score' of 9/10 will not necessarily have a better outcome than 2/10, as any omission creates immediate candidacy for an upstream tailings dam to join the list of facilities that have failed due to ignoring some or all of the rules." It should be noted that, at the present time, "There is broad consensus within the engineering community, especially in high-risk industries such as aviation and pipelines, that engineered structures should be robust, with multiple back-ups and defense mechanisms. The need to obey ten rules with no margin for error does not constitute a basis for safe design" (Morrill et al., 2022). Some of the ten rules by Martin et al. (2002) are illustrated in the above figure, which is intended to show an off-the-shelf design that fulfills four out of the ten rules. In particular, the embankment slope of 3H:1V violated the rule that "upstream dams should be raised at slopes of 4H:1V or flatter" (Martin et al., 2002). Figure from Martin et al. (2002).

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Table 3.2 – Tailings Release Volume Estimating Methodologies and Angles

Scenario	Slurry Tailings		Filtered Tailings Drained Strength (degrees)	Failure Slopes (%)	
	Peak Undrained Strength (Su/σ')	Residual Undrained Strength (Su/σ')		Slurry Tailings	Filtered Tailings
Fair-weather	0.32	0.10	34	6	n/a
Flood-induced				18	70

Figure 10. According to NewFields (2025), the peak undrained strength ratio of the existing slurry tailings was assumed to be 0.32. The peak undrained strength ratio is a dimensionless number that indicates the resistance of the tailings to liquefaction. The assumed peak undrained strength ratio is far higher than what is typically measured or assumed in the mining industry (compare with Figs. 11-12), so that all of the stability analyses should be regarded as highly questionable. The peak undrained strength ratio is also related to the fraction of stored tailings that will be released following failure of the tailings storage facility. Table from NewFields (2025, pdf p. 7).

Table 1 – Analytical Approaches for Upstream Tailings Dams

Approach		Conditions Suitable for Application of Approach	Typical Range of Shear Strengths
ESA	Effective stress analysis	Tailings unsaturated and/or dilatant under shear.	c' = 0 ϕ' = 30 to 36°
USA-D	Undrained strength analysis for ductile materials, and/or peak undrained shear strength	Tailings saturated and contractant under shear. Potential for triggering of undrained loading exists.	Undrained strength ratio (S_u/p') = 0.2 to 0.3
USA-SS	Undrained shear strength analysis based on steady state shear strength		Undrained strength ratio (S_u/p') = 0.06 to 0.15

Figure 11. According to Martin et al. (2002), a typical range for peak undrained strength ratio is 0.2-0.3. The context for the range given by Martin et al. (2002) was to argue that tailings dams can be safely constructed and operated using the upstream method, as long as ten rules are followed, including constructing the outer embankment with a slope no steeper than 1V:4H (see Fig. 9) and using carrying out the stability analyses using reasonable values for the peak undrained strength ratio. Thus, since the existing Key Mill tailings facility was constructed using an outer embankment slope of 1V:2H (see Fig. 3) and since the stability has been evaluated assuming a peak undrained strength ratio of 0.32 (see Fig. 10), both of the preceding rules have been violated. Table from Martin et al. (2002).

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Table 2. Back Calculated Shear Strengths and Strength Ratios from Flow Failure Case Histories

Case History	Prefailure geometry strength ratio			Prefailure geometry shear strength			Weighted average prefailure vertical effective stress (kPa)	Weighted average prefailure vertical total stress[a] (kPa)
	Best estimate	Lower bound	Upper bound	Best estimate (kPa)	Lower bound (kPa)	Upper bound (kPa)		
1	0.265	0.247	0.28	16.1	15.0	16.8	59.7	—
2	0.26	0.26	0.30	37.6	37.6	41.9	141.6	—
3	0.27	0.255	0.295	76.6	71.8	80.7	294.3	—
4	0.228	0.207	0.249	15.4	12.7	18.0	68.4	84.3
5	0.24	0.21	0.26	3.8	2.2	4.4	15.1	—
6	0.255	0.23	0.285	82.9	69.9	89.6	319.7	—
7	0.225	0.172	0.25	6.0	3.9	6.75	26.5	37.8
8	0.32	0.30	0.34	17.7	15.7	18.1	55.4	89.1
9	—	—	—	—	—	—	—	—
10	0.21	0.19	0.24	10.9	10.0	11.9	51.7	59.4
11	—	—	—	—	—	—	—	—
12	0.24	0.225	0.27	5.3	4.5	5.7	20.9	23.9
13	0.25	0.2	0.29	9.0	8.5	11.1	34.8	42.9
14	0.195	0.155	0.21	11.7	10.3	12.7	59.9	70.2
15	—	—	—	—	—	—	—	—
16	0.265	0.195	0.30	35.9	32.3	38.6	135.8	—
17	0.27	0.24	0.30	21.1	18.0	23.9	73.8	116.1
18	0.22	0.16	0.25	16.0	10.5	18.7	69.2	110.0
19	0.21	0.17	0.23	2.7	2.7	4.0	12.7	—
20	0.21	0.19	0.23	4.2	4.0	4.8	19.8	—
21	0.20	0.165	0.23	4.8	4.2	5.7	24.7	—
22	0.16	0.115	0.205	4.8	4.3	5.3	30.2	36.9
23	0.28	0.22	0.37	16.8	13.9	18.9	59.9	—
24	0.20	0.155	0.27	9.3	6.7	13.4	46.0	101.0
25	0.25	0.195	0.30	12.9	7.7	15.6	51.4	58.4
26	0.26	0.245	0.32	10.1	9.1	12.2	39.7	57.6
27	—	—	—	—	—	—	—	—
28	0.245	0.22	0.275	10.1	8.6	10.5	40.4	—
29	0.215	0.20	0.235	12.2	12.0	12.9	56.4	64.8
30	0.18	0.155	0.21	8.9	8.6	9.6	48.9	78.8
31	0.30	0.28	0.32	31.6	30.4	32.3	106.0	170.4
32	0.24	0.21	0.32	15.8	14.8	18.7	66.6	81.7
33	0.25	0.25	0.255	13.1	13.0	13.4	52.3	71.1

[a]Determined for seismic loading-induced flow failures only.

Figure 12. According to NewFields (2025), the peak undrained strength ratio of the existing slurry tailings was assumed to be 0.32 (see Fig. 10). By comparison, Olson and Stark (2003) back calculated peak undrained strength ratios from case histories of liquefaction failures. Based on 33 case studies of both static and seismic liquefaction, Olson and Stark (2003) found best estimates of peak undrained strength ratios in the range 0.16-0.32 with both arithmetic mean and median (50^{th} percentile) of 0.24 and with 20^{th} and 30^{th} percentiles of 0.21 and 0.22, respectively. Table from Olson and Stark (2003).

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Table 3.3 – Release Volumes

Scenario	Facility Volume (Myd^3) [Note 1]	Released Volumes (Myd^3) [Note 2]					Percent Mobilized (%) Note 3
		Eroded Embankment	Stormwater	Mobilized Tailings		Total	
				Slurry	Filtered		
Fair-weather	14.05	0.11	0.0	0.77	0.0	0.88	6
Flood-induced	14.28	0.06	0.24	0.12	0.06	0.48	3

Notes:

1. **The facility volume represents the total volume of tailings (slurry and filtered) and water stored in the facility at the time of the breach.**
2. **The released volume from the facility represents the summation of tailings volume, supernatant pond volume, and eroded embankment.**
3. **The percent mobilized represents the percent of total tailings and water contained within the facility that are released during the breach and does not include the eroded embankment volume.**

Figure 13. The most important control on the consequences of failure of a tailings storage facility is the volume of released tailings. For the failure of the combined existing tailings facility plus an overlying filtered tailings stack, NewFields (2025) assumed release of 3% of the stored tailings during a flood-induced failure and release of 6% of the stored tailings during a fair-weather failure. The release volumes assumed by NewFields (2025) are completely inconsistent with past failures of tailings storage facilities. Table 1 shows the storage and release volumes of 28 failures of tailings storage facilities that were compiled by Larrauri and Lall (2018), which is supplemented by five additional case studies from Center for Science in Public Participation (2025). The minimum release volume has been 9% of the stored tailings, while the average release volume has been 45% of the stored tailings, and there are four documented examples of total losses of tailings (see Table 1). Table from NewFields (2025, pdf p. 7).