Copper Flat Mine Draft Discharge Permit 1840 Technical Comments

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The following comments are provided regarding technical and administrative completeness of the Copper Flat Mine Draft Discharge Permit 1840 (Draft Permit) application, draft permit requirements and conditions, as well as compliance with the technical requirements of New Mexico Copper Rule, 20.6.7 NMAC. These comments are based upon more than 35 years of professional experience in the mining environmental field, as well as significant involvement in both the technical and administrative group efforts in the development of the New Mexico Copper Rule. The comments provided are limited to the proposed Tailings Storage Facility (TSF) that would be located outside of the open pit stormwater capture area (OPSCA).

1 Summary

The risk for groundwater impacts to occur from tailings storage facilities such as that proposed for the Copper Flat Project is well demonstrated and acknowledged. Despite engineered features intended to result in zero discharge of tailings process and seepage water, experience has shown that without exception some level of discharge will occur. Therefore, it is accepted engineering practice to consider and address the potential for unintended or accidental discharges. Typically, the risk to groundwater occurs from unintended and/or untreated discharges that are not captured, such as leakage and/or seepage through a liner. Additionally, in the event of an accidental discharge of tailings resulting from a ruptured pipeline or a catastrophic failure of a TSF, in turn resulting in the release of fluids and deposition of uncontained tailings, impacts to groundwater have the potential to occur. Our comments address the potential from both such occurrences that can result in unaccounted and/or unintended discharges from engineered facilities such as TSFs to groundwater. Our conclusions are summarized as follows:

- Neither the permit application materials or the Draft Permit identify or address TSF liner "seepage" that would be expected to occur from the lined TSF and therefore have not addressed an almost certain "unauthorized discharge." The New Mexico Environment Department (NMED) must require the applicant, New Mexico Copper Corporation (NMCC), to revise the application to identify and include seepage in terms of both liner permeability and potential defects; to conduct an aquifer evaluation to determine the nature and extent of impact to groundwater from TSF seepage; and to propose additional mitigation measures such as a groundwater interception system, as required by the Copper Rule.

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- The TSF was essentially abandoned in the early 1980s and the subsequent owners, including NMCC, have failed to conduct the required monitoring and maintenance. They have further failed to address potential hazards associated with the existing TSF in a timely manner. Given the track record of the project and NMCC, together with the as yet to be filed New Mexico Office of the State Engineer's Dam Safety Bureau (OSE-DSB) application and the potential for the TSF to result in groundwater impacts resulting from a catastrophic failure, the NMED must 1) require NMCC to submit documentation that its proposed TSF complies with OSE-DSB requirements, and 2) delay all discharge permit action until OSE-DSB completes and approves a Dam Permit for the Mine.

- The NMED must require NMCC to provide the basis for the information contained in Part A of the Draft Permit and ensure it is consistent with Part B of same and revise the Draft Permit accordingly. As explicitly required by the Copper Rule, the Copper Flat TSF Report must be revised to include the maximum daily discharge volume and annual volume of tailings as design factors. The Draft Permit must also provide the basis for the maximum discharge figure used which, in addition to the volume of tailings, also includes, impacted stormwater and domestic water (according to the description of process water). The Draft Permit must also identify the annual volume of tailings to be deposited in Part A of the Draft Permit, and the individual basis for the process water, impacted stormwater, and domestic water in Part B of the Draft Permit.

- The Copper Flat TSF Report must be revised to identify the TSF footprint and/or the Draft Permit must identify the source of the information for the footprint. NMCC, OSE-DSB, as well as NMED and the Mining and Minerals Division of the Department of Natural Resources (MMD), should be advised that the information provided does not meet the current standard of care based on industry guidance for geological assessment, including for seismic design as noted. NMED should therefore require NMCC to utilize a 1-in-10,000-year return maximum credible earthquake (MCE) for its seismic analysis and revise the Draft Permit application accordingly.

- While NMED correctly defers to OSE-DSB with respect to stability and associated stormwater control requirements, OSE-DSB regulatory requirements should be provided in the Draft Permit and made a condition of same. Both NMED and MMD must require NMCC to provide the results of a hazard classification and dam breach and flood routing analysis. The analysis would show the distribution of tailings in the event of a catastrophic discharge and whether the TSF poses a hazard to public health or undue risk to property from potential groundwater and surface water impacts resulting from a catastrophic release of tailings and process water. The analysis is also necessary in determining potential impacts in MMD's environmental impact analysis. Additionally, this analysis would ensure the public's right to know what personal risk the discharge permit, mining permit, and dam safety permit, in the event of a catastrophic TSF failure, would entail.

2 TSF Seepage

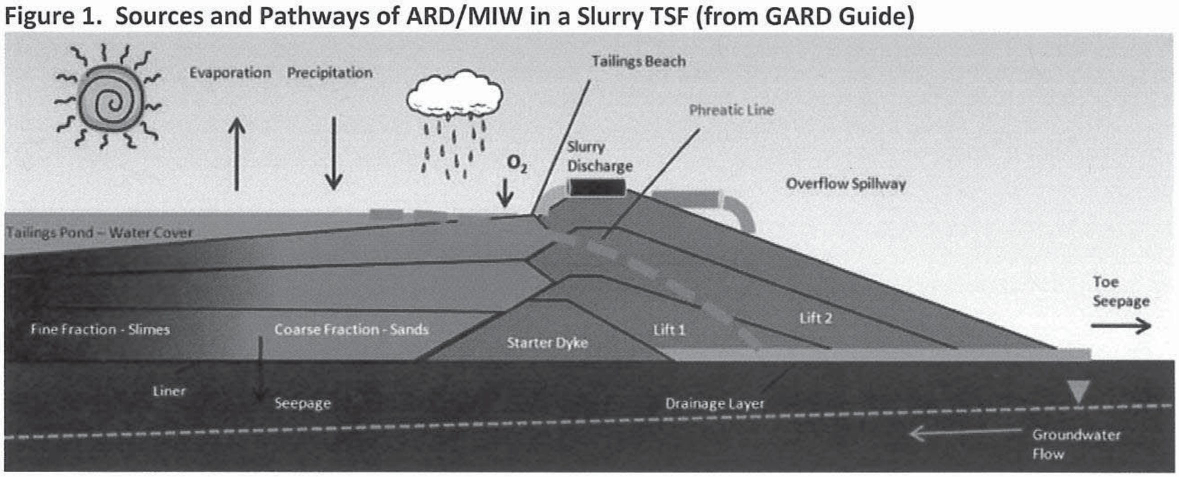
As noted by the mining industry-produced and accepted Global Acid Rock Drainage (GARD) Guide[1], tailings from hardrock mining activities are a primary source of acid rock drainage (ARD) leading to mining influenced water (MIW). As the GARD Guide notes, "Discharges associated with tailings facilities include runoff and seepage for all disposal methods. Runoff and seepage quality are a function of tailings composition, reactivity, and contact time."

According to the Draft Permit:

> "B100 History and Facility Description, E. A synthetically lined TSF will be constructed in the same location as the historic facility. Tailings slurry (i.e., process water and flotation tailings) containing approximately 29% solids will be gravity conveyed from the Concentrator through the Cyclone Plant to separate the tailings into coarse and fine fractions. The coarse fraction tailings sand cyclone underflow will be deposited at the tailing dam and the fine fraction tailings slime cyclone overflow will be discharged to the interior of the TSF. The TSF will extend approximately 1,000 feet to the east of the former starter dam (the tailings expansion area). A centerline construction method using the cyclone-processed tailings sand for tailings dam construction will be utilized. A starter dam will be constructed using borrow material to provide initial storage capacity and to provide a location for initial discharge of tailings. The use of sand tailings for dam construction are such that the Cyclone Plant will be operated to produce the construction material."

Figure 1 shows the flow paths and geochemical reactions occurring in a subaqueous TSF using a centerline construction method like that proposed for the Copper Flat TSF.

Figure 1. Sources and Pathways of ARD/MIW in a Slurry TSF (from GARD Guide)



The GARD Guide describes the source characterization and potential for discharges from TSFs as follows:

> "A dam is first constructed to impound the tailings and supernatant. For stability reasons, tailings dam embankments are commonly designed to be unsaturated and well drained so if

[1] The International Network for Acid Prevention (INAP), 2009. Global Acid Rock Drainage Guide (GARD Guide).http://www.gardguide.com/

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> they are constructed with sulphide-bearing waste rock or tailings, the tailings dam embankments may be particularly prone to ARD generation. Precipitation onto the surface of the facility contacts the tailings beaches (tailings exposed to atmospheric oxygen), the dam, or falls directly on the tailings pond. During large storm events, discharge through an overflow drain or discharge down the face of the dam may occur. This water may be captured for treatment. Infiltration through the tailings enters into the subsurface or is captured in a seepage collection system. The seepage rate is a function of the permeability of the underlying natural or engineered materials and the infiltration rate through the tailings. During operations, ARD is not normally a concern (except with extremely reactive tailings) because most mill circuits add lime to the tailings. Also, during subaqueous disposal, fresh tailings added to the beaches maintain a relatively high water content for a time. Active management of the tailings pond supernatant (e.g., addition of lime) can be conducted to prevent low pH conditions and mobilization of metals. During post closure, remedial measures that have been designed from the outset are implemented to prevent ARD and improve seepage quality."

The New Mexico Copper Rule addresses TSF seepage and groundwater, as well as various mitigation approaches, as shown in Table 1 attached to these comments. The sequential approach described in the rule assumes that the design process starts with minimal seepage containment such as construction of headwalls, impoundments and diversion structures (NMAC 20.6.7.22 (4)(b). Then, based upon potential groundwater impacts (NMAC 20.6.7.22 (4)(c)), an aquifer evaluation is performed (NMAC 20.6.7.22 (4)(d)(vii). If the design report indicates impacts to groundwater an interceptor system for containment is to be proposed (NMAC 20.6.7.22 (4)(d)(viii)). If the department determines that the proposed seepage collection and interceptor systems evaluated in the previous steps are not capable of meeting groundwater standards, then the department can require additional controls, which may include, but are not limited to, a liner system (NMAC 20.6.7.22 (4)(e)).

The approach taken by NMCC is reflected in the report titled "Feasibility Level Design, 30,000 TPD Tailings Storage Facility" by Golder Associates dated November 30, 2015 and revised June 2016 (Copper Flat TSF Report). The approach has in essence been to skip the steps in NMAC 20.6.7.22 (4)(b)-(d) and propose additional controls in the form of a liner system in the initial application. The liner system proposed by NMCC is described in the Draft Permit as follows:

> "B103 Authorized Mine Units. D. Copper Crushing, Milling, Concentrator, and Tailings Storage Facility. 2. Tailings Storage Facility (TSF) - The lined TSF will be located outside the projected OPSDA and built progressively out in a five-phase process. It is designed to accommodate the volume of tailings generated during the life of the mine. The liner will consist of an 80-millimeter (mil) high-density polyethylene (HPDE) liner placed on a twelve-inch thick liner bedding fill sub base. In Phase 1, the liner bedding fill will consist of a minimum of 12 inches of historic tailings recovered from the north cell of the old starter dam. After Phase 1, liner bedding fill will consist of a twelve-inch layer of crushed and screened native material, or selected local soil. TSF drainage will be collected using an underdrain collection system that incorporates two underdrains that will convey solutions to the TSF Underdrain Collection Pond. Drainage from the TSF impoundment interior will be collected in a continuous underdrain system (impoundment underdrain) constructed over the geomembrane liner. A separate blanket drain system will underlie the tailings dam (dam underdrain). The impoundment underdrain system will be equipped with a shutoff valve at its inlet during the initial years of operation to ensure two feet of freeboard is maintained in the Underdrain Collection Pond. When the valve is closed, the TSF supernatant pool will be used for storage until the TSF underdrain collection pond is pumped

down. The TSF pool, located in the interior of the TSF, will be equipped with four floating-barge pumps with a maximum design capacity of 12,978 gpm. The pumps will convey TSF supernatant process water to the Process Water Reservoir through the 36-inch diameter HDPE water reclaim process water pipeline. Tailing slurry, which is gravity conveyed from the Concentrator, will pass through the Cyclone Plant prior to discharge to the TSF. The Cyclone Plant will separate the tailing slurry into a coarse and fine fraction; the coarse fraction will be used to construct the tailing dam and the fine fraction will be conveyed into the TSF pool."

The New Mexico Copper Rule does not identify specific requirements for TSF liner systems. However, it does have specific requirements for leach stockpiles (NMAC 20.6.7.20) that includes a solution collection system designed to prevent the buildup of head and transmit process fluids out of the pile, a soil liner consisting of a minimum of 12 inches of soil that has a minimum re-compacted in-place coefficient of permeability of $1x10^{-6}$ cm/sec, and a synthetic liner for a leach stockpile shall provide the same or greater level of containment, including permeability, as a 60 mil HDPE geomembrane liner system.

While generally consistent with industry practice, the Copper Flat TSF Report addresses the tailings seepage that will report to the underdrain on top of the liner but does not address seepage through the TSF liner itself. In its technical review, the NMED apparently did not identify the need to include seepage through the liner as a potential discharge. Accordingly, the Draft Permit does not recognize TSF liner seepage in Section B104.

Liners are a recognized means of source control and most state and federal regulations require that the standard of containment is at least equivalent to a constructed liner of 12-18 inches thickness of clay, with a permeability of 10^{-6}cm/s, similar to that required by the New Mexico Copper Rule. However, the fact that all liners leak has been long acknowledged by the U.S. Environmental Protection Agency (EPA) since the 1990s, as well as by industry. For that reason, it is standard practice to recognize both seepage resulting from permeation, but also from liner defects.

Synthetic membranes with low permeation rates such as high-density polyethylene (HDPE) may, under ideal conditions, have hydraulic conductivities as low as 2×10^{-15} m/s, (Giroud and Bonaparte, 1989[2]). However, permeation leakage rates are estimated to be several orders of magnitude less than the rates resulting from geomembrane defects and represent an insignificant component of the total estimated potential leakage.

Seepage from TSF due to geomembrane defects is dependent on the following:

- The area covered by tailings (i.e. the seepage area).
- The pore pressure conditions within the tailings mass and the basin underdrain system.
- The thickness and permeability of the tailings stored within the TSF.
- The permeability of the constructed basin liner and embankment.
- The permeability of the materials underlying the basin liner.
- The hydraulic head within the basin underdrain system over the base of the TSF.

[2] Giroud, J.P. and Bonaparte, R., 1989. *Leakage Through Liners Constructed with Geomembranes – Part II. Composite Liners.* Geotextiles and Geomembranes. Vol. 8 No. 1, 71-111. Great Britain.

The leakage rate through a section of a composite liner system with a single defect in the geomembrane per acre can be evaluated using the following formula presented by Bonaparte (1989):

$$Q = 0.21a^{0.1} h^{0.9} ks^{0.74} A$$

Where:

Q = Steady state leakage through one hole in the geomembrane (m3/s)
a = Area of the hole (m2)
h = Hydraulic head over the section (m)
ks = Hydraulic conductivity of the material underlying the geomembrane (m/s)
A = Geomembrane section area (acres)

This formula is based on "good contact" between the geomembrane and the underlying soil. This is a reasonable assumption for these analyses due to the surcharge pressures applied by the overlying tailings mass. Leakage through a synthetic liner depends on the number and size of defects and the permeability of the subgrade. The hydraulic head acting along the base of the liner is reduced by the underdrainage system but because it is not eliminated, seepage will be expected to occur. For that reason, it is standard practice to include a liner seepage analysis as part of any TSF design report.

Conclusions and Recommendations

The Copper Rule (Section 20.6.7.7.B(51) NMAC) defines "seepage" as "leachate that is discharged from a waste rock stockpile or tailing impoundment and emerges above or at the ground surface or that is present in the vadose zone and may be captured prior to entering ground water." An "unauthorized discharge" "means a release of process water, tailings, leachate or seepage from individual copper mine facility components, impacted stormwater or other substances containing water contaminants not approved by a discharge permit" pursuant to Section 20.6.7.7.B(61) NMAC. Neither the permit application materials or the Draft Permit identify or address TSF seepage that would still be expected to occur from the lined TSF and therefore have not addressed an almost certain "unauthorized discharge." The NMED should have identified this deficiency in its technical completeness review. The NMED must require NMCC to revise the Copper Flat TSF Report to recognize and perform a seepage estimate consistent with current industry practice, which would include a sensitivity analysis given the inherent uncertainty in this type of estimate. The NMED must also require NMCC to perform and submit an aquifer evaluation to determine the nature and extent of impacts to groundwater from TSF seepage, as required by the Copper Rule. Finally, if warranted, the NMED should require NMCC to propose additional mitigation measures, such as a groundwater interceptor system. The draft permit should then be revised accordingly to account for the TSF seepage.

3 TSF Catastrophic Failures

The recent Mount Polley and Samarco/Fundão tailings dam failures highlight the potential for catastrophic failures associated with TSFs, such as that proposed for the Copper Flat Project, and are summarized in Appendix A of these comments. The failures were not the result of a single isolated action or event, but rather resulted from a series of actions any of which by themselves would not result in a catastrophic failure, but as a sequence of events leading to those failures. Also inherent in both catastrophes was a failure to connect hydrologic, stability and operational considerations. For this reason, these comments on the Copper Flat Project Draft Permit focus on the level of interaction between New Mexico regulators required during the design and permitting processes to ensure that there is not undue risk to public health, property or the environment from a catastrophic failure. Given that in New Mexico three separate agencies (NMED, MMD, OSE-DSB) have individual responsibility for various aspects of TSF design, permitting, operations, reclamation and closure there is a greater likelihood for requirements and/or oversight by one agency to inadvertently or unintentionally impact the requirements and/or oversight by the other agencies. This can lead to a greater risk of a catastrophic event unless this potential is clearly acknowledged and a significantly high level of coordination is undertaken by the agencies.

The New Mexico Copper Rule addresses TSF safety in Section 20.6.7.17.C.(1)(d) which requires "An applicant or permittee proposing or required to construct a tailings impoundment shall submit documentation of compliance with the requirements of the dam safety bureau of the state engineer pursuant to Section 72-5-32 NMSA 1978, and rules promulgated under that authority, unless exempt by law from such requirements."

3.1 Applicable New Mexico Office of State Engineer Regulations for TSFs

The OSE-DSB has primary responsibility for the safety of TSFs in New Mexico during the construction and operations phase of the TSF life-cycle. According to the Copper Rule's Section 20.6.7.17.C(1)(d) NMAC, "An applicant or permittee proposing or required to construct a tailings impoundment shall submit documentation of compliance with the requirements of the dam safety bureau of the state engineer pursuant to Section 72-5-32 NMSA 1978, and rules promulgated under that authority, unless exempt by law from such requirements."

Historic records indicate that the Copper Flat Partnership, and its mine owner, Quintana Minerals Corporation, quit operating the mine after less than four months, and subsequently the mine equipment and other liquid assets went into receivership in the 1980s. According to the 2013 Feasibility Study[3], in "mid-March 1982 after a $112 million capital investment, the Copper Flat open pit copper mine began full production at a rated capacity 15,000 tpd, a waste to ore ratio of 1.8:1, and a cut-off grade of 0.25 percent copper. After just 3.5 months of production, the mine shut down on June 30, 1982, due to low copper prices ($0.70/lb) and high interest rates on the CIBC loan." The "Copper Flat mine passed its project stabilization with CIBC during this initial mining period before going into receivership. By late 1985, the surface facilities equipment was sold to the Ok Tedi mine in Papua New Guinea, and the site was reclaimed by CIBC as formally approved by state and federal requirements. The structural foundations, power lines, water wells, and inground infrastructure were left in-place."

The Copper Flat TSF containing 3.5 months of tailings production was also left in place. As noted in a recent communication from the OSE-DSB to NMCC dated September 18, 2017 and attached as Appendix B to these comments, "The dam is currently under a State Engineer Order, dated April 19, 1983 and amended on April 18, 1985, requiring the condition of the dam and monitoring data be reported to the OSE-DSB by March 10 of each year. The last report received by the OSE-DSB was January 31, 1986 (underline added)." At the request of NMCC in 2012 a waiver was granted for performing routine maintenance and monitoring. According to the letter from the OSE-DSB, "The waiver was granted as a mining permit is being sought to reopen the mine which will include removing the existing tailings dam and constructing a new tailings dam approximately 1,000 feet downstream of the existing dam." A recent search of the OSE-DSB files for the Copper Flat Mine revealed that no application for the proposed new TSF had been submitted as of April 1, 2018.

[3] 2013 Feasibility Study. Form 43-101F1 Technical Report, Feasibility Study, Copper Flat Project, New Mexico, USA, M3 for THEMAC Resources, November 21, 2013.

Conclusions and Recommendations

The TSF was essentially abandoned in the early 1980s and the subsequent owners, including NMCC, have failed to conduct the required monitoring and maintenance. NMCC has further failed to address potential hazards associated with the TSF in a timely manner. Given the track record of the project and NMCC, together with the potential impacts to groundwater from a catastrophic event that can only be assessed by OSE-DSB requirements, the NMED must 1) require NMCC to submit documentation that its proposed TSF complies with OSE-DSB requirements, and 2) delay all discharge permit action until OSE-DSB completes and approves a Dam Permit for the Mine.

3.2 Copper Rule Requirements and OSE-DSB Requirements

The discharge permit requirements for Copper Mines pertaining to TSFs are provided in NMAC 20.6.7.22 REQUIREMENTS FOR COPPER CRUSHING, MILLING, CONCENTRATOR, SMELTING AND TAILINGS IMPOUNDMENT UNITS, which includes Section A.4 addressing engineering design requirements for new TSFs. The requirements are shown in Table 1 attached to these comments.

The OSE-DSB requirements for TSF safety as addressed by NMAC 19.25.12 DAM DESIGN, CONSTRUCTION AND DAM SAFETY are also identified in Table 1.

As part of their permit application package to NMED, NMCC submitted the previously discussed Copper Flat TSF Report by Golder. Agency review comments on the application materials do not indicate the submittal has been reviewed by the OSE-DSB. As will be discussed further in the following comments, various aspects of NMED's Copper Rule for Discharge Permits and OSE-DSB requirements overlap or otherwise have common implications that either should result in significant comment from OSE-DSB or would result from submittal of the same document directly to OSE-DSB. In a similar fashion, these overlaps highlight why it is highly risky to permit the TSF under NMED regulations without consideration of OSE-DSB requirements.

3.2.1 Tailings Discharge Description

As shown in Table 1 attached to these comments, the Copper Rule requires that NMCC provide the "annual volumes and daily maximum design rates of tailings deposited in the impoundment." Also, as indicated current OSE-DSB requirements are for dam safety in general and non-specific for mine tailings other than for closure. Most existing U.S. regulations and guidance for dam safety is similarly intended for water storage dams and not mine tailings storage facilities. Aspects in which mining TSFs are different from water storage dams include:

- TSFs are constructed, operated and closed by mine owners focused on extraction for a profit and not necessarily for public benefit or on TSF safety.
- TSFs are designed to retain solids (that may or may not be contaminated) and/or process solutions (that may or may not be contaminated).
- TSFs can contain large quantities of fluids and solids that if released can cause significant environmental damage and result in loss of human life.
- TSFs are built during the development and operation of mines and remain as part of the landscape becoming a permanent feature that must perform as designed after closure of the mine indefinitely (e.g. in perpetuity).

- TSFs, if they contain contaminated substances (fluids and/or solids), have no minimum size where the consequences of failure would be generally acceptable.
- Many TSFs are built in stages over the mine life, rather than built in a single stage prior to decommissioning.
- The condition of TSFs is continually changing so safety must be continually re-evaluated rendering TSF management more onerous. A steady-state condition is only achieved some time after the mine operations cease.
- TSF decommissioning cannot be accomplished by breaching and removal but instead typically requires a transition period and long-term monitoring and maintenance.
- TSFs are not generally viewed as an asset but instead as a liability and thus may warrant a lower standard of care from their owners.
- TSF owners typically rely on consultants rather than in-house expertise leading to the potential for poor communication and lack of project continuity.

Water storage dam safety principles are applicable to TSFs. However, because of the important differences, design reports typically reference both U.S. federal and state regulations in addition to guidance documents such as the Canadian Dam Association's Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams.[4] The Copper Flat TSF Report does not reference the CDA Technical Bulleting on Mining Dams.

As indicated in Table 1 attached to these comments, the Copper Flat TSF Report (p. 19) provides the required information in the TSF design factors in terms of tailings specific gravity, tailings solids content and production rate, to calculate the daily maximum design rate and annual volume of tailings.

According to "Part A GENERAL INFORMATION A100 Introduction B. Pursuant to this Discharge Permit, the permittee is authorized to discharge a maximum of 25,264,000 gallons per day (gpd) of mine tailings, process water, impacted stormwater, and domestic wastewater to a lined tailing impoundment." The DP does not identify how the maximum discharge rate is calculated. The DP also does not identify the annual volume of tailings. B104 Authorized Discharges indicates "A. The permittee is authorized to discharge a maximum of 25,246,000 gpd of tailing slurry from the Concentrator to the Cyclone Plant and then the TSF via gravity through the Concentrator Whole Tailings Transport pipeline" and according to "J. The permittee is authorized to discharge a maximum of 10,000 gpd of treated effluent from the domestic wastewater treatment and disposal facility to the TSF." The permit does not identify the discharge of impacted stormwater, but by calculation it would appear to be 10,000 gpd. The permit should provide the basis for the information contained in Part A and it should be consistent with Part B.

According to B104 Authorized Discharges "A. The permittee is authorized to discharge a maximum of 25,246,000 gpd of tailing slurry from the Concentrator to the Cyclone Plant and then the TSF via gravity through the Concentrator Whole Tailings Transport pipeline." However, this description is incorrect. As noted by the Golder Report, "The tailings delivery and distribution system design consists of pipeline system that delivers whole tailings from the processing plant to the tailings storage facility. Whole tailings will be separated into fine material and sand material in the cyclone plant. The sand fraction will be transported to the TSF and used for dam construction while fine material will be deposited into the TSF."

[4] CDA. 2014. *Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams.* www.cda.ca

Conclusions and Recommendations

The NMED must require NMCC to provide the basis for the information contained in Part A and ensure it is consistent with Part B and revise the Draft Permit accordingly. As explicitly required by the Copper Rule, the Copper Flat TSF Report must be revised to include the maximum daily discharge and annual volume of tailings as design factors. The Draft Permit must also provide the basis for the maximum discharge figure used which, in addition to the volume of tailings, also includes, impacted stormwater and domestic water (according to the description process water). The Draft Permit must also identify the annual volume of tailings to be deposited in Part A and the individual basis for the process water, impacted stormwater, and domestic water in Part B.

The following revision must also be made to B104 Authorized Discharges: A. The permittee is authorized to discharge a maximum of 25,246,000 gpd of tailing slurry from the Concentrator *to the TSF via gravity through the Concentrator Whole Tailings Transport pipeline* to the Cyclone Plant *and then the sand fraction will be transported to the TSF and used for dam construction while fine material will be deposited into* the TSF ~~via gravity through the Concentrator Whole Tailings Transport pipeline~~."

3.2.2 Topography, geology, footprint

The NMED Copper Rule requires that a description be provided of the TSF topography, geology and footprint. However, as previously discussed, OSE-DSB requirements are significantly more detailed and require a geological assessment for all dams classified as high or significant hazard potential. The geological assessment may be a stand-alone document or part of the geotechnical investigation or seismic study. The geological assessment is required to address a number of factors as noted in Table 1 attached to these comments: regional geologic setting; local and site geology; geologic suitability of the dam foundation; slide potential of the reservoir rim and abutment areas; and seismic history and potential.

The Copper Flat TSF Report provides a brief description of the site topography (p.4) and a more detailed description of the TSF Area Subsurface Conditions (p. 5-6), consisting of a description of the geology and observations from the site geotechnical program. However, the report does not identify the size of the TSF footprint other than to suggest "At final build-out with an impoundment floor area of 321 acres, total drainage collected in the impoundment underdrain will be on the order of 66 gallons per minute (gpm)." The report also includes information on site investigations (Section 3), including information on foundation materials.

The Seismic Design Criteria (p. 41) are also discussed in the report. The report identifies the requirements of the OSE-DSB as the basis for the seismic criteria: "The NMDSB requires that structures such as the Copper Flat TSF be designed to withstand the seismic loading from the Maximum Design Earthquake (MDE) with a 2 percent probability of exceedance in 50 years (approximately 2,475-year return frequency). The peak ground acceleration (PGA) for the Copper Flat property was obtained using the US Seismic "Design Maps" Web Application developed by the United States Geological Survey (USGS) Geologic Hazards Science Center (USGS, 2011). Considering the 2009 National Earthquake Hazards Reduction Program provisions for a Site Class C and a site location of 32.96° North latitude and 107.5° West longitude, the resulting PGA for the 2,475-year return MDE is approximately 0.13 times gravitational acceleration (0.13g)."

Although the Copper Flat TSF Report identifies the OSE-DSB requirements it is clear the contents of the report would not meet those requirements. Based on our review and a comparison to the current standard of care based on industry practice for TSFs, the information provided in the report is not adequate to assess the geologic setting or corresponding risks related to the foundation or seismic risk.

Though OSE-DSB's regulations are more stringent than NMED's, this particular regulation is not consistent with current dam safety and TSF standard of care such as that contained in CDA 2014 or Montana's SB 409. MCA 82-4-376. Tailings storage facility (2)(i) requires "for a new tailings storage facility, an analysis showing that the seismic response of the tailings storage facility does not result in the uncontrolled release of impounded materials or other undesirable consequences when subject to the ground motion associated with the 1-in-10,000-year event, or the maximum credible earthquake, whichever is larger."

The use of a 2,475-year return is significantly less conservative than that required by Montana and other current guidance for TSFs and presents a significant risk of underestimating both the probability and magnitude of a catastrophic failure associated with a TSF embankment failure. Based on our experience we would expect that a more conservative risk assessment would result in a significantly higher gravitational acceleration of approximately 0.25g or greater as compared to the current 0.13g value used in the assessment contained in the Copper Flat TSF Report.

Conclusions and Recommendations

Though the DP application briefly addresses topography and geology of the TSF, the draft DP is silent on those subjects.

According to the Draft Permit, "C105 Copper Crushing, Milling, Concentrator, and Tailings Storage Facility Units C. Tailings Storage Facility 4. Pursuant to Subparagraph (a) of 20.6.7.22.C(1) NMAC, the TSF shall not exceed the footprint (564 acres) or location and configuration as shown in Drawing 12 in Appendix J of the document titled Feasibility Level Design, 30,000 TPD Tailings Storage Facility and Tailings Distribution and Water Reclaim Systems Copper Flat Project Sierra County, New Mexico Golder Associates Inc., Revised, November 2016 (i.e., Appendix A the Revised Application) and as shown on Figure 1 of this Discharge Permit." The Copper Flat TSF Report must be revised to identify the size of the TSF footprint (as noted, 321 acres is the size of the "impoundment area" identified in the TSF Report) and/or the DP should identify the source of the information for the footprint.

NMCC, OSE-DSB, as well as NMED and MMD, should be advised that the information provided does not meet the current standard of care based on industry guidance for geological assessment, including for seismic design as noted. NMED should therefore require NMCC to utilize a 1-in-10,000-year return MBE for its seismic analysis and revise its DP application accordingly.

3.2.3 Stormwater

As shown in Table 1 of these comments, the Copper Rule requires that stormwater run-on be diverted and/or contained to minimize contact between stormwater run-on and the tailing material. The Copper Rule also requires NMCC to disclose and consider the amount, intensity, duration and frequency of precipitation; watershed characteristics including the area, topography, geomorphology, soils and vegetation of the watershed; and run-off characteristics of the watershed including the peak rate, volumes and time distribution of run-off events. While no specific stormwater criteria are provided under the Copper Rule for TSFs, the general engineering requirements for impoundments are for a "100-year return interval storm event" while maintaining "two feet of freeboard" and "peak flow from a 100-year return interval storm event" while maintaining at least "six inches of freeboard" for conveyances.

Also shown in Table 1 of these comments are the OSE-DSB requirements for stormwater that include: Hydrologic analysis, Spillway design flood, Incremental damage assessment, Spillway capacity, Spillway design, Outlet works capacity, Outlet works design and Freeboard. The OSE-DSB requirements are based on Section 19.25.12.10 NMAC (Hazard Potential Classification), which is a rating for a dam based on the potential consequences of failure. "No allowances for evacuation or other emergency actions by the population are to be considered" and "the hazard potential classification is not a reflection of the condition of the dam." The classification is based on the following definitions:

> **A. Low hazard potential**: Dams assigned the low hazard potential classification are those dams where failure or misoperation results in no probable loss of life and low economic or environmental losses. Losses are principally limited to the dam owner's property.
>
> **B. Significant hazard potential**: Dams assigned the significant hazard potential classification are those dams where failure or misoperation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas but could be located in populated areas with significant infrastructure.
>
> **C. High hazard potential**: Dams assigned the high hazard potential classification are those dams where failure or misoperation will probably cause loss of human life.

The classification is based on a dam breach and flood routing analysis that includes a table of results for the flood routing for the sunny day failure, and the failure and no failure scenarios for multiple flood events, up to and including, the spillway design flood as defined in Subparagraph (a) through (d) of Paragraph (3) of Subsection C of 19.25.12.11 NMAC; the table of results for all critical locations downstream shall include the depth of flow in feet, velocity of flow in feet per second, rate of flow in cubic feet per second and the incremental impacts; and dam failure inundation maps downstream of the dam for the sunny day failure and failure during the spillway design flood event showing the depth of flow in feet, average velocity in feet per second and rate of flow in cubic feet per second at critical locations downstream. The spillway design flood requirements for Dams classified as large, with a significant hazard potential rating shall have spillways designed to pass a flood resulting from 75 percent of the probable maximum precipitation and Dams classified as high hazard potential, regardless of size, shall have spillways designed to pass a flood resulting from the probable maximum precipitation.

According to the Copper Flat TSF Report (p. 41), the proposed TSF "can be classified as having a significant hazard potential." The report provides no basis for this assessment, such as a classification evaluation including dam breach and flood routing analysis. However, even though the report suggests a significant hazard potential, it uses the design event for a high hazard potential (p. 33): "the TSF will be required to contain inflows and direct precipitation associated with the 72-hour PMP of 26 inches. Diversion ditches constructed for impoundment run-on control have been sized to carry the peak discharge associated with the prescribed PMP event using a rainfall intensity versus time distribution defined in Hydrometeorological Report 55A (US Department of Commerce, 1998)."

Conclusions and Recommendations

The Draft Permit does not identify the hazard classification or design storm requirements for the TSF or any suggestion of the freeboard requirements. According to C105 Copper Crushing, Milling, Concentrator, and Tailings Storage Facility Units C. Tailings Storage Facility 2, "Prior to discharging to the TSF, the permittee shall ensure that berms and/or the dam structure of the TSF will have the capacity for such discharges while maintaining appropriate safety measures in accordance with the regulations of the Dam Safety Bureau of the Office of the State Engineer and Paragraph (d) of 20.6.7.17.C(1) NMAC."

While NMED correctly defers to OSE-DSB with respect to stability and associated stormwater control requirements, OSE-DSB regulatory requirements should be provided in the Draft Permit and made a condition of the permit. Both NMED and MMD must require NMCC to provide the results of a hazard classification and dam breach and flood routing analysis for the following reasons. First, the analysis would show the distribution of tailings in the event of a catastrophic discharge and whether the TSF poses a hazard to public health or undue risk to property from potential groundwater and surface water impacts resulting from a catastrophic release of tailings and process water. Second, the analysis is also necessary in determining potential impacts in MMD's environmental impact analysis. Additionally, this analysis would ensure the public's right to know what personal risk the discharge permit, mining permit and OSE-DSB permit, would entail.

Table 1. Comparison of NM Copper Rule, OSE-DSB Requirements and NMCC Submittal

Description	NMAC 20.6.7.22 GENERAL ENGINEERING AND SURVEYING REQUIREMENTS (4) New tailings impoundments	NMAC 19.25.12 DAM DESIGN, CONSTRUCTION AND DAM SAFETY 19.25.12.11 DESIGN OF A DAM C. Design report:	NMCC Feasibility Study
Tailings discharge description	(d) (i) The annual volumes and daily maximum design rates of tailings or other discharge approved by the department to be deposited in the impoundment.		Varies, Net tailings to the TSF from 9,182 to 10,704 kilotons per year (25,156 to 29,326 tons per day). Tailings S.G 2.64. 29.2 percent solids by weight. (p. 19)
Topography, geology, footprint	(d) (ii) The topography of the site where the impoundment will be located. (iii) The geology of the site. (iv) The design footprint of the tailing impoundment.	(9) Geological assessment. A geological assessment of the dam and reservoir site is required for all dams classified as high or significant hazard potential. The geological assessment may be included in the geotechnical investigation or seismic study, or may be submitted as a separate document. The geological assessment shall address regional geologic setting; local and site geology; geologic suitability of the dam foundation; slide potential of the reservoir rim and abutment areas; and seismic history and potential.	Section 2.0 Site Description At final build-out with an impoundment floor area of 321 acres, total drainage collected in the impoundment underdrain will be on the order of 66 gallons per minute (gpm). (p. 24)
Stormwater	(4) Impacted stormwater management plans and specifications. An applicant shall submit stormwater management plans and specifications to limit run-on of stormwater and manage impacted stormwater in a manner which prevents water pollution that may cause an exceedance of the applicable standards. The plans and specifications shall be submitted with an application for a new or renewed discharge permit, or as	(1) Hazard potential classification (2) Hydrologic analysis (3) Spillway design flood. (4) Incremental damage assessment. (5) Spillway capacity. (6) Spillway design (7) Outlet works capacity. (8) Outlet works design (15) Freeboard	The TSF will be required to contain inflows and direct precipitation associated with the 72-hour PMP of 26 inches. Diversion ditches constructed for impoundment runon control have been sized to carry the peak discharge associated with the prescribed PMP event using a rainfall intensity versus time distribution defined in Hydrometeorological Report 55A (US Department of Commerce, 1998). (p. 33)

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	applicable with an application for a modified discharge permit, and shall include the following information. (a) A scaled map of the copper mine facility showing: (i) the property boundaries of the copper mine facility and the mining areas; (ii) all existing and proposed structures; (iii) existing and proposed final ground surface contours outside of the open pit surface drainage area at appropriate vertical intervals; and (iv) existing and proposed stormwater containment and conveyance structures, including construction materials, size, type, slope, capacity and inlet and invert elevation (or minimum and maximum slopes) of the structures, as applicable. (b) A description of existing surface water drainage conditions. (c) A description of the proposed post-development surface water drainage conditions. (d) Supplemental information supporting the stormwater management plan including the following information: (i) hydrologic and hydraulic calculations for design storm events; (ii) hydraulic calculations demonstrating the capacity of existing and proposed stormwater impoundments; (iii) hydraulic calculations demonstrating the capacity of existing and proposed conveyance channels to divert stormwater or contain and transport runoff to stormwater impoundment(s); and (iv) a list of tools and references used to		

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	develop the hydrologic and hydraulic calculations such as computer software, documents, circulars, and manuals. (e) A plan to manage impacted stormwater, and to divert run-on of non-impacted stormwater where practicable. The plan shall include, as necessary, design, construction, and installation of stormwater run-on and run-off diversion structures, collection of impacted stormwater, and a description of existing surface water drainage conditions. The plan shall consider: (i) the amount, intensity, duration and frequency of precipitation; (ii) watershed characteristics including the size, topography, soils and vegetation of the watershed; and (iii) runoff characteristics including the peak rate, volumes and time distribution of runoff events.		
Seepage	(b) Seepage from the sides of a tailing impoundment shall be captured and contained through the construction of headwalls, impoundments and diversion structures as applicable. (d) (v) The design of tailing seepage collection systems, to be proposed based on consideration of site-specific conditions.	(11) Seepage and internal drainage. (16) Erosion protection.	*The TSF report does not provide an estimate of seepage from the impoundment. The TSF report addresses seepage from the tailings into the TSF underdrain that lies above the liner, but otherwise appears to assume that no additional seepage will occur through the liner.*
Groundwater	(c) Ground water impacted by the tailing impoundment in excess of applicable standards shall be captured and contained through the construction of interceptor systems designed in accordance with Subparagraph (d) of Paragraph (4) of Subsection A of 20.6.7.22 NMAC.		*Report assumes no groundwater discharge.*

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	(d) (vii) An aquifer evaluation to determine the potential nature and extent of impacts on ground water from the tailings impoundment based on the proposed tailings impoundment design. The aquifer evaluation shall include a complete description of aquifer characteristics and hydrogeologic controls on movement of tailing drainage and ground water impacted by the tailings impoundment. (viii) A design report for a proposed interceptor system for containment and capture of ground water impacted by the tailings impoundment based on the aquifer evaluation required in Subparagraph (d) of Paragraph (4) of Subsection A of this section. The design report shall include, at a minimum construction drawings and interceptor system performance information, recommended equipment including pumps and meters, recommended pump settings and pumping rates, methods for data collection, and a demonstration that the permittee has adequate water rights to operate the system as designed. The design report shall include a demonstration that interceptor system design will capture ground water impacted by the tailings impoundment such that applicable standards will not be exceeded at monitoring well locations specified by 20.6.7.28 NMAC. The interceptor system shall be designed to maximize capture of impacted ground water and minimize the extent of ground water impacted by the tailings		

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	impoundment.		
Additional Controls/Liners	(e) If the department determines that the proposed tailings impoundment, seepage collection and interceptor systems when constructed and operated in accordance with the design plan specified in this paragraph would cause ground water to exceed applicable standards at monitoring well locations specified by 20.6.7.28 NMAC, the department shall require additional controls, which may include but are not limited to, a liner system as additional conditions in accordance with Subsection I of 20.6.7.10 NMAC.	17) Geotextile design	
Stability/Safety	(d) Dam safety. An applicant or permittee proposing or required to construct a tailings impoundment shall submit documentation of compliance with the requirements of the dam safety bureau of the state engineer pursuant to Section 72-5-32 NMSA 1978, and rules promulgated under that authority, unless exempt by law from such requirements.[5]	(1) Hazard potential classification (2) Hydrologic analysis (3) Spillway design flood. (4) Incremental damage assessment. (5) Spillway capacity. (6) Spillway design (7) Outlet works capacity. (8) Outlet works design (9) Geological assessment (10) Geotechnical investigation. (11) Seepage and internal drainage. (12) Stability analysis. (13) Seismic design and analysis (14) Dam geometry. (15) Freeboard (16) Erosion protection. (17) Geotextile design	

[5] NMAC 20.6.7.33 CLOSURE REQUIREMENTS FOR COPPER MINE FACILITIES B. Slope stability. At closure, tailing impoundment(s) not regulated by the office of the state engineer, leach stockpile(s) or waste rock stockpile(s) shall be constructed to promote the long-term stability of the structure. Closure of all critical structures at a copper mine facility shall be designed for a long-term static factor of safety of 1.5 or greater and non-critical structures shall be designed for a long-term static factor of safety of 1.3 or greater. The units being closed shall also be designed for a factor of safety of 1.1 or greater under pseudostatic analysis. A stability analysis shall be conducted for the unit and shall include evaluation for static and seismic induced liquefaction.

		(18) Structural design. (19) Utilities design (20) Miscellaneous design I. Operation and maintenance manual: An operation and maintenance manual is required for dams classified as high or significant hazard potential. The operation and maintenance manual identifies activity necessary to address the continued safe operation, maintenance and overall performance of the dam. Any restrictions imposed by the design shall be addressed in the operation and maintenance manual. The operation and maintenance manual shall conform to the requirements set forth in 19.25.12.17 NMAC. J. Emergency action plan: An emergency action plan is required for dams classified as high or significant hazard potential. The emergency action plan identifies potential emergency conditions at a dam and specifies preplanned actions to be followed to minimize property damage and loss of life. The emergency action plan shall conform to the requirements set forth in 19.25.12.18 NMAC.	

Appendix A

TSF FAILURE CASE STUDIES

This appendix summarizes the causes of two recent TSF catastrophic failures (Mount Polley and Fundão). As both of these recent significant TSF failures demonstrate, minimization and/or prevention of catastrophic consequences requires detailed and strict attention to not only design, but also other factors such as operations. The following summarizes the causes and recommendations as reported by Independent Engineering Review Panels that were explicitly formed to investigate each failure.

Mount Polley, British Columbia, Canada

In August 2014, the Mount Polley Mine tailings facility breached, resulting in a catastrophic release of tailings that was previously considered unlikely due to the circumstances of it occurring in what is touted as one of the more progressively regulated jurisdictions (British Columbia) at a mine operated by a rising and supposedly highly capable Canadian based mining company (Imperial Metals) and designed and inspected by leading engineering firms (Knight Piésold and AMEC). Additionally, the failure was not triggered by seismic or hydrologic events, but instead occurred as a nearly instantaneous event under "Sunny Day" conditions. The event resulted in a loss of about 17 million cubic meters of water and 8 million cubic meters of tailings/materials which were deposited in a drainage basin including two lakes downstream of the TSF, but fortunately did not result in loss of human life. The event was considered by the industry and associated engineering consultants as a highly significant event.

The Mount Polley Independent Expert Engineering Investigation and Review Panel (Panel), consisting of three leading experts in the geotechnical stability of mine tailings facilities, was convened by the BC Government to investigate the cause of the failure and to address the minimization and elimination of the risk of similar failures from tailings facilities. The Panel Report[6] was issued in January 2015. The following was excerpted from the report.

Failure Cause

The Panel made the following conclusions as to the failure mechanisms involved in the Mount Polley TSF failure:

- The breach of the TSF perimeter embankment was caused by shear failure of dam foundation materials when the loading imposed by the dam exceeded the capacity of these materials to sustain it. The failure occurred rapidly and without precursors. They also concluded that the dominant contribution to the failure resided in the design. The design did not take into account the complexity of the sub-glacial and pre-glacial geological environment associated with the Perimeter Embankment foundation. As a result, foundation investigations and associated site characterization failed to identify a continuous glaciolacustrine layer in the vicinity of the breach and to recognize that it was susceptible to undrained failure when subject to the stresses associated with the embankment.

[6] Morgenstern, N.R., S.G. Vick, and Dirk Van Zyl. 2015. *Independent Expert Engineering Investigation and Review Panel, Report on Mount Polley Tailings Storage Facility Breach.* Province of British Columbia. January 30. https://www.mountpolleyreviewpanel.ca/final-report

- The specifics of the failure were triggered by the construction of the downstream rockfill zone at a steep slope of 1.3 horizontal to 1.0 vertical. This was justified by design analyses without questioning its reasonableness. Had the downstream slope in recent years been flattened to 2.0 horizontal to 1.0 vertical, as proposed in the original design, failure would have been avoided. The slope was on the way to being flattened to meet its ultimate design criteria at the time of the incident.
- A lack of foresight in planning for dam raising contributed to the failure. Successfully executing the raising plan required intimate coordination of impoundment water-level projections, production and transport of mine waste for raising, and seasonal constraints on construction. This made the tailings dam contingent at the same time on the water balance, the Mine plan, and the weather. But instead of projecting these interactions into the future, they were evaluated a year at a time, with dam raising often bordering on ad hoc and only responding to events as they occurred. The effects were twofold: a near overtopping failure in May of 2014, and restrictions on mine waste availability that produced the over-steepened slopes and deferred buttress expansion.
- The Observational Method was adopted as a design philosophy, but misapplied. For reasons not unrelated to planning shortcomings, instrumentation was relied upon to substitute for definitive input parameters and design projections. But the Mount Polley dam was ill-suited to this approach, for both practical and strategic reasons. The steep slopes and constant construction activity on the Perimeter Embankment prevented installation of instruments at optimal locations. More importantly, the instrumentation program was incapable of detecting critical conditions because, once again, the critical materials and their critical mode of undrained behavior were not recognized.
- High impoundment water levels were a major cause of chronic problems in maintaining a tailings beach around the perimeter of the dam. At the breach section, water was in direct contact with the upstream zone of tailings fill when failure occurred. This increased the piezometric level in the upstream zone above what it would have been had a wide tailings beach been present. The Panel's analyses show that this had some influence on dam stability, although it was not the dominant factor.
  - The high water level was the final link in the chain of failure events. Immediately before the failure, the water was about 2.3 m below the dam core. The Panel's excavation of the failure surface showed that the crest dropped at least 3.3 m, which allowed overflow to begin and breaching to initiate. Had the water level been even a meter lower and the tailings beach commensurately wider, this last link might have held until dawn the next morning, allowing timely intervention and potentially turning a fatal condition into something survivable.
  - Finally, the quantity of water had a great deal to do with the quantity of tailings released after the breach developed. It was water erosion that transported the bulk of the tailings, and these fluvial processes ended when the supply of water was exhausted. Had there been less water to sustain them, the proportion of the tailings released from the TSF would have been less than the one-third that was actually lost.

Recommendations

The Panel included recommendations that are grouped into the following seven areas and discussed in the sections below:

1. Implement Best Available Practices (BAP) and Best Available Technologies (BAT) using a phased approach,

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2. Improve corporate governance,
3. Expand corporate design commitments,
4. Enhance validation of safety and regulation of all phases of a TSF,
5. Strengthen current regulatory operations,
6. Improve professional practice, and
7. Improve dam safety guidelines

Implement Best Available Practices (BAP) and Best Available Technologies (BAT) using a phased approach. The Panel recommended using Best Available Practices (BAP) to address existing TSFs and recommended using Best Available Technology (BAT). They further recommended applying BAT principles to closure of active impoundments to eliminate risk. The Panel identified the three principles of BAT, as: no surface water; unsaturated conditions, and; achieve dilatant conditions by compaction. The Panel further identified backfilling of mined out pits or underground workings as being the most direct method, but otherwise identified "filtered tailings" technology as the primary BAT. In doing so, the Panel suggested that "There are no overriding technical impediments to more widespread adoption of filtered tailings technology" and "While economic factors cannot be neglected, neither can they continue to pre-empt best technology."

Improve corporate governance. The Panel recommended that corporations operating TSFs should be required to be a member of the Mining Association of Canada (MAC) or be obliged to commit to an equivalent program for tailings management, including the audit function. The MAC, in response to issues presented by TSFs worldwide owned by Canadian based corporations, developed guidelines for tailings management that are considered worldwide as best management practice (BMP). This includes: A Guide to the Management of Tailings Facilities; Developing an Operation, Maintenance and Surveillance Manual for Tailings and Water Management Facilities, and; A Guide to the Audit and Assessment of Tailings Facility Management.

Expand corporate design commitments. The Panel recommended that new TSFs "should be based on a bankable feasibility study and consider all technical, environmental, social and economic aspects of the project in sufficient detail to support an investment decision" and should contain a failure modes and effects analysis, cost/benefit analysis of BAT tailings and closure options with the caveat the cost/benefit should not super-cede safety considerations, and detailed and declared Quantitative Performance Objectives (QPOs).

Enhance validation of safety and regulation of all phases of a TSF. The Panel recommended that Independent Expert Review Panels (IERPs) be utilized together with QPOs to improve safety and regulation of all phases of TSFs.

Strengthen current regulatory operations. The Panel recommended that inspections be performed at all existing TSFs to ascertain whether they may be a risk and require appropriate actions due to specific failure modes: filter adequacy; water balance adequacy; undrained shear failure of silt and clay foundations.

Improve professional practice. The Panel encouraged the Association of Professional Engineers and Geoscientists of BC to develop guidelines that would lead to improved site characterization for tailings dams with respect to the geological, geomorphological, hydrogeological and possibly seismotectonic characteristics.

Improve dam safety guidelines. The Panel, recognizing limitations of current Canadian Dam Association guidelines, recommended that dam safety guidance be developed specific to the conditions encountered with TSFs in BC and incorporated as a statutory requirement.

Fundão, Brazil

The Fundão dam began operating in 2008 and was designed to contain a total of 79.6 million cubic meters of fine tailings (mud) and 32 million cubic meters of sandy tailings during what was supposed to be a 25-year lifespan. In November 2015, Fundão contained 56.4 million cubic meters of iron ore tailings deposited in merely seven years of operation and was undergoing further expansion. On 05 November 2015 a total collapse of the dam took place and about43 million m3of tailings (80% of the total contained volume) were released, generating mud waves 10 m high, killing 19 people, and causing damage to downstream water courses 548 km downstream and beyond (Carmo et al. 2017).

The investigation of the Fundão Tailings Dam failure was commissioned by BHP Billiton Brasil Ltda., Vale S.A. and Samarco Mineração S.A. The firm of Cleary Gottlieb Steen & Hamilton LLP (CGSH) was engaged to conduct the Investigation with the assistance of a panel of experts. The Fundão Tailings Dam Review Panel (Panel) included four members, all specialist geotechnical engineers in water and tailings dams: Norbert R. Morgenstern (Chair), Steven G. Vick, Cássio B. Viotti, and Bryan D. Watts. The Panel Report[7] was issued in August 2016. The following was excerpted from the report.

Failure Cause

The Panel made the following conclusions as to the failure mechanisms involved in the Fundão TSF failure:

- The original design concept for the Fundão Dam employed an unsaturated sand zone to support the weak slimes zone. Unsaturated sand is not amenable to liquefaction and hence the original design was robust in this regard. However, difficulties were encountered in executing the design and a modified design was put forward and adopted. As part of this modification, a change in the design concept was also adopted and saturated conditions were permitted to develop in the sand.
- The flowslide required three conditions to develop: (1) saturation of the sand; (2) loose uncompacted sand; and (3) a trigger mechanism. Depositing sand tailings by hydraulic means resulted in loose conditions. The growth in the saturated conditions is well-documented. Hence, all the conditions prevailed for liquefaction to develop resulting in a flowslide, provided it was triggered.
- Eyewitness accounts revealed that the flowslide initiated on the left abutment, where the dam had been set back from its former alignment. Studies of the depositional history associated with the growth of the Fundão Dam revealed that slimes encroached into the area preserved for sand deposition alone. The design incorporated a 200-meter zone separating the two deposits but historical information reveals that slimes had encroached into the area on a number of occasions. The presence of slimes introduces a barrier to downward drainage and a zone of

[7] Morgenstern, N.R., S.G. Vick, C.B. Viotti, B.D. Watts. 2016. *Fundão Tailings Dam Review Panel Report on the Immediate Causes of the Failure of the Fundão Dam*. August 25, 2016. http://fundaoinvestigation.com/the-panel-report/

potential weakness that might affect stability. Deposition in the area of the right abutment was almost slimes free.

- The setback was implemented to accommodate repairs to a deficient conduit at the base of the impoundment as well as the construction of additional horizontal blanket drains to facilitate subsequent dike-raising. This change in geometry resulted in substantial embankment loading over slimes-rich deposits. This distinguishes the left abutment area from the right and accounts for the location of flowslide initiation.
- The Panel concluded that lateral extrusion initiated the failure. The lateral extrusion mechanism develops as the dam increases in height, loading the slimes-rich zone vertically which tends to extrude or spread laterally, rather like squeezing toothpaste from a tube. This results in stress changes in the overlying sands which reduce their confinement, leading to collapse.
    - This mechanism for collapse was modelled by tests in the laboratory and by computational modeling that predicted to an acceptable degree that collapse should have occurred about the time that the dam was raised to the height that was attained on November 5, 2015.
- The role of the earthquakes that occurred just prior to collapse was also investigated quantitatively. Calculations with recommended design motions reveal that about 5 mm of displacement may have been induced in the slimes. Given the proximity of the dam to collapse due to prior construction loading, this likely accelerated the failure process that was already well-advanced.