Failure Modes and Effects Analysis
2020 Workshop
Resolution Copper Environmental Impact Statement
Proposed Skunk Camp Tailings Storage Facility

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Excellence Delivered As Promised

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A risk assessment workshop was completed from February 5 to 7, 2020 to review potential failure modes (PFMs) of the proposed Skunk Camp Tailings Storage Facility (TSF) for the Resolution Copper Project and Land Exchange Draft Environmental Impact Statement (DEIS). The Skunk Camp TSF was indicated as the preferred alternative in the DEIS, which also included a mitigation measure (FS-227) to complete a "more robust and refined" Failure Mode and Effects Analysis (FMEA) risk assessment "*with more refined designs and site-specific information,*" to be conducted between the DEIS and the Final EIS to address dam safety comments.

The FMEA was conducted jointly with representatives from USFS, ADEQ, USACE, EPA, Resolution Copper Mining, SWCA, BGC, KCBCL, Golder, Tetra Tech, Inc., and facilitated by Gannett Fleming. The process of the FMEA steps, completed as a group, included:

Prior to the workshop:

1. An informational session was held with the workshop participants via webex on January 17, 2020 to present the proposed Skunk Camp TSF design and FMEA process;
2. Workshop participants were provided with relevant reports and other documentation listed at the end of this report; and
3. Workshop participants brainstormed PFMs and submitted the PFMs to the organizer.

During the workshop, the group:

4. Confirmed the list of PFMs to be reviewed;
5. Evaluated the possibility of each PFM and deciding which PFMs would be developed in the workshop and which PFMs would be considered but not developed;
6. Developed the sequence of events that would result in the PFM;
7. Estimated the likelihood and consequences categories of the PFM;
8. Identified confidence for the likelihood and consequence categories; and
9. Identified additional information needed to build confidence for future design and operations.

A FMEA can be completed at an early design phase, like this project, so that the findings could be incorporated into the final design and operating plans. Specifically, for the proposed Skunk Camp TSF, the FMEA is intended to identify dam safety related PFMs and characterize their risks to aid in developing mitigation strategies (design, operational, etc.) to avoid them. Sixteen PFMs were developed and evaluated for likelihood and consequence:

- Ten PFMs were developed for normal operations: five involved foundation failures, three involved Main Embankment failure and one each involved pipeline failure and surface erosion.
- Three PFMs involved seismic failure modes: each involved liquefaction, one PFM was for a seismic foundation failure, and two involved Main Embankment failure modes.
- Two hydrologic failure modes were developed: one involved high pore pressures in the Main Embankment and one involved diversion ditch failure leading to excessive embankment erosion.

- One failure mode was developed for the Pyrite Cell (PAG) embankment involving foundation failure.

Risk Likelihood and Consequence

The likelihood and consequences categories associated with each PFM were estimated using methods generally conforming to dam safety practice. For dam safety, risk is generally comprised of three parts:

- The likelihood of occurrence of a triggering event (e.g., flood, earthquake, TSF pond elevation, etc.);
- The likelihood of an adverse structural response (e.g., dam failure, damaging spillway discharge, mis-operation, etc.) given the event; and
- The magnitude of the consequences resulting from the adverse event (e.g., life loss, economic damages, environmental damages, etc.) given that it occurs.

For the 2020 Skunk Camp TSF FMEA workshop, the participants estimated the likelihood and consequences categories by utilizing an individual electronic polling method. Following the polling, the participants discussed the results with the intent of moving toward understanding and agreement. The participants then provided (again by individual electronic polling) their confidence for both the likelihood and consequence categories based on whether additional information was necessary or would potentially change the estimated likelihood and consequence. Based on the confidence of the group, and their understanding of the PFM, additional mitigations or studies were identified that could potentially reduce uncertainty and increase the group's confidence in the risk estimate. Where confidence in the estimation was low, additional benefit may come from obtaining more information through additional studies or analyses.

Likelihood of Failure

Likelihood of each PFM was rated on a scale of remote, low, moderate, high or very high. Confidence was rated as low, moderate, and high.

The likelihood descriptions used in the workshop were developed for water dams and levees. Therefore, an additional likelihood description of "Extremely High" was added to capture more frequent events due to the operational nature of tailings storage facilities compared to water dams. The qualitative likelihood descriptors were applied by the workshop participants, followed by discussions to obtain a degree of consensus.

Consequence of Failure

Consequences were rated on a scale of low, significant, high, very high, or extreme. The maximum travel distance downstream based on the failure mechanism, whether the free water pond would be released and was estimated by the group based on professional judgement and experience. The group then used the estimated distance and their judgement to estimate the consequence. The consequence categories assigned to the PFM were primarily environmental, and to a lesser degree economic.

	Factors in Consequence Assessment				*FMEA Risk Categories*	
Potential Failure Modes	Runout limited to embankment slump or failure volume	Tailings runout remains in Dripping Springs Wash with no PAR	Possible higher consequences due to fluid failure and reaching the Gila River	Mainly environmental consequences in Dripping Springs Wash	Likelihood	Consequences
N1 - Weak foundation layer causes Main Embankment to fail		√		√	Low-Mod	Significant
N2 - High pore pressures in the foundation causes Main Embankment to fail		√		√	Low	Significant
N3 - Deviation from Design Construction Geometry or Excessive Raise Rates creates undrained conditions the foundation causes Main Embankment to fail		√		√	Low	Significant
N4 - Terrain Instability (landslide) causes Main Embankment to fail	√			√	Low	Low-Significant
N5 - Geochemical degradation resulting in weak foundation layer causes Main Embankment to fail	√	√		√	Remote - Mod	Significant
N6 - Weak layer in cycloned sand causes Main Embankment to fail	√	√		√	Remote - Low	Low-Significant
N7 - High pore pressures in cycloned sand causes Main Embankment to fail		√	√	√	Remote - Mod	Significant - High
N8 - Deviation from Design Construction Geometry or Excessive Raise Rates creates undrained conditions in the cycloned sand causes Main Embankment to fail	√	√		√	Moderate	Significant
N9 - Internal Erosion through the foundation causes the Starter Dam to fail		√	√	√	Moderate	Significant - High

	Factors in Consequence Assessment				*FMEA Risk Categories*	
Potential Failure Modes	**Runout limited to embankment slump or failure volume**	**Tailings runout remains in Dripping Springs Wash with no PAR**	**Possible higher consequences due to fluid failure and reaching the Gila River**	**Mainly environmental consequences in Dripping Springs Wash**	**Likelihood**	**Consequences**
N10 - Tailings pipeline rupture leads to erosion and causes Main Embankment to fail	√	√	√	√	Moderate	Low-Significant
S1- Earthquake causes undrained conditions in foundation layer causes Main Embankment to fail				√	Low-Mod	Very High
S2 - Earthquake causes terrain instability and abutments causes Main Embankment to fail	√	√		√	Low	Significant
S3 - Earthquake causes undrained conditions in cycloned sand causes Main Embankment to fail				√	Low	Significant - V High
H1 - Storm event causes excess pore pressures in cycloned sand causes Main Embankment to fail			√	√	Remote - Low	High - V High
H2 - Storm event leads to erosion and causes Main Embankment to fail	√	√		√	Remote - Low	Significant
PAG N1 - Weak foundation layer causes Pyrite Cell Embankment to fail			√	√	Low	V High

Conclusions

Of the 16 potential PFMs developed during the FMEA workshop, no unmanageable risks were identified. The risk assessment of the PFMs indicated that risks generally fall within acceptable societal risk levels. Those PFMs with higher risk are those with more fluid tailings behavior, resulting in higher runout, and therefore higher consequences. In summary, the proposed Skunk Camp TSF design evaluated during the risk assessment is robust and addresses the potential PFMs through design, mitigation measures, planned operating procedures, and monitoring.

1. Introduction

1.1. Purpose

The U.S. Department of Agriculture, Forest Service (USFS) Tonto National Forest issued a Draft Environmental Impact Statement (DEIS) for the proposed Resolution Copper Project and Land Exchange in August 2019. As part of the DEIS, the Forest committed to conducting a Failure Mode and Effects Analysis (FMEA) for the Preferred Alternative 6, the proposed Tailings Storage Facility (TSF) at Skunk Camp, to assist in evaluation of potential failure modes and impacts disclosure. Gannett Fleming contracted with BGC Engineering, Inc. (BGC) as an independent subconsultant to conduct a an FMEA workshop for the proposed TSF. The FMEA workshop was held offsite at a conference facility in Phoenix, Arizona to facilitate participation by the Forest, other Federal and State agencies, and the project applicant. The workshop attendees identified potential failure modes (PFM) at the structures and assigned likelihood and consequence to each PFM to determine their associated risk. This session was conducted jointly with representatives from the Forest, U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA(EPA), Arizona Department of Environmental Quality (ADEQ),SWCA Environmental Consultants (SWCA), BGC Engineering Inc. (as a third party contractor to USFS and their subcontractors: BGC) and Gannet Fleming; and Resolution Copper Mining (RCM), LLC (Resolution) and their subcontractors: KCB Consultants Ltd. ((KCBCL),), Golder Associates, Inc. (Golder), Tetra Tech, Inc. (Tetra Tech), and Parsons Behle & Latimer (PBL). The full list of participants is included in Table 1.

The FMEA was performed to determine potential failure modes for the proposed structure; and their likelihood of occurrence, severity of the consequences, level of confidence in the estimates, and the possible controls to reduce the risk of failure. The FMEA was conducted for the KCBCL's Skunk Camp TSF alternative design. The FMEA is intended to inform the requirements to be specified in the Record of Decision (ROD) and ultimately be incorporated into the final plan.

1.2. Project Description

The proposed Preferred Alternative, Skunk Camp TSF is located approximately 14 miles southeast of Superior, Arizona and approximately 5 miles northeast of the Ray Mine in Pinal and Gila Counties, Arizona. The site is located in the Dripping Spring Wash basin and is accessible from Arizona State Highway 77. A general layout of the site is shown in Figure 1. The project is proposed to be an underground copper mine, developed using the block cave mining method near the town of Superior. The mine plan includes generation of approximately 1.37 billion tons of tailings over an estimated 41-year mine life.

A site investigation was conducted by Resolution in 2018 and 2019 to characterize the foundation at the Skunk Camp site. Quaternary alluvium and Quaternary pediment as well as Tertiary conglomerate were identified as the main foundation units below the TSF. In addition to in-situ field tests, laboratory tests were completed to characterize the geotechnical and hydraulic/hydrologic properties of these foundation units. A seismic hazard assessment (SHA) that included desktop reviews and reconnaissance-level fault investigations was also completed by a seismologist; the SHA concluded that the Skunk Camp site has a low seismic hazard and that there are no known active faults. Although no locations were identified within the TSF footprint, potential landslides, rockfalls and other geohazards were also investigated as part of a reconnaissance-level field mapping program. Following review of the site investigation results, KCBCL concluded that no additional design modifications were required and the original design approach remains appropriate to satisfy the design criteria. The design basis and conclusions from the

2018/2019 site investigation informed the FMEA and progression for the failure modes developed in the workshop.

This FMEA was focused on the Forest's preferred TSF location, which is the Skunk Camp (Alternative 6) location as described in the DEIS. Select key elements of the Skunk Camp TSF layout are summarized below:

- The scavenger tailings (Main) embankment is a centerline-raised compacted cyclone sand embankment. A portion of the scavenger tailings stream would be cycloned to create two products: cyclone (underflow) sand used to construct the downstream portion of the embankment; and finer overflow tailings which would be deposited onto the upstream scavenger beach.
- Pyrite tailings will be discharged sub-aqueously from a floating barge or pipelines directly into dedicated potentially acid-generating (PAG) cells, to maintain pyrite tailings saturation during operations as a method to prevent the tailings from becoming acidic.
- Low-permeability, segregated pyrite tailings cells will be contained by downstream-raised embankments incorporating low-permeability layers to manage downstream water quantity and quality. The reclaim pond will be maintained within the pyrite tailings cell.
- Tailings will be piped from the mill to the Skunk Camp TSF site via an approximate 20 mile to 30-25-mile-long pipeline. The pipeline route has not yet been finalized.

The Resolution Copper Project is planned to be an underground copper mine, using the block cave mining method. The proposed mine plan includes generation of approximately 1.37 billion tons of tailings over a 41-year mine life. Processing will generate two physically, mineralogically, and geochemically discrete tailings streams known as "scavenger" tailings and "pyrite" tailings; scavenger tailings will account for approximately 84% of tailings produced by weight and pyrite tailings will account for the remaining 16%. The scavenger tailings are not expected to be acid generating; however, the pyrite tailings have a high-pyrite content and are considered Potentially Acid Generating (PAG).

Select key elements of the Skunk Camp TSF, submitted as the DEIS design (KCBCL 2018), and used as the basis for the FMEA are described below. Key design modifications following comments on the DEIS and used in the workshop are also described below.

The proposed Skunk Camp TSF will be located in the head waters of Dripping Springs Wash upstream of the Gila River. The Dripping Springs Mountains define the western boundary of the proposed site, while the Mescal Mountains and Pinal Mountains define the eastern boundary. The approximate base elevation of the proposed TSF is El. 3,160 ft above sea level (fasl) and the peaks of adjacent mountains are: El. 4,570 fasl at Haleys Mountain (Dripping Springs Mountains), El. 6,570 fasl at El Capitan Mountain (Mescal Mountains), and El. 7,850 fasl at Pinal Peak (Pinal Mountains). Within the proposed TSF area, the drainages are ephemeral and infilled with sand and gravel alluvial deposits. When present, surface water flows in Dripping Springs Wash from northeast to southwest approximately 13 miles to its confluence with the Gila River. The proposed site is located just southwest of the surface water divide between Dripping Springs Wash and Mineral Creek, see Figure 2. The low point along the divide is El. 3,700 fasl. Surface water south of the divide flows through the site as previously described, while surface water north of the divide flows into the Mineral Creek basin, which flows into the Gila River approximately 16 miles downstream of the confluence of Dripping Springs Wash and the Gila River.

The TSF ultimate configuration and post-closure water management plan presented in the DEIS included a closure diversion channel to the north, ultimately diverting the entire TSF catchment towards Mineral

Creek. To address environmental concerns, RCM has updated the closure objective to divert the TSF catchment to the south, towards Dripping Springs Wash, post-closure. To achieve this objective, an update to the tailings staging and deposition plan for the proposed Skunk Camp TSF was completed (KCBCL 2020) and is the ultimate configuration shown on Figure 2.

The Skunk Camp TSF will consist of two pyrite cells (PAG cells) upstream of the scavenger beach contained by a cross-valley embankment (the Main Embankment) as shown in Figure 2. The pyrite cells and scavenger beach have the capacity to store more than the 72-hour Probable Maximum Flood (PMF) from the entire upstream catchment and are designed for the 1 in 10,000 yr earthquake, assuming all potentially liquefiable tailings liquefy.

The pyrite tailings will be deposited subaqueously and kept saturated during operations in low permeability pyrite cells contained by independent downstream raised compacted cycloned sand embankments. Pyrite Cell 1 will receive tailings from startup to Year 15 and will be subsequently covered with scavenger tailings starting in Year 16. Pyrite Cell 2 construction will start prior to Year 15 and will receive pyrite tailings from Year 16 to Year 41. The pyrite cells will also act as the supernatant or reclaim pond for reuse in processing. Slurry bleed water and precipitation runoff from the scavenger tailings beach will be collected in low spots and pumped into the active pyrite cell, such that no permanent pond will be maintained on the scavenger beach.

The Main Embankment will be constructed of compacted cycloned sand underflow (coarser underflow scavenger tailings produced during cycloning) using the centerline construction method up to El. 3,565 feet above sea level (approximately 135 ft below the divide to Mineral Creek). Cyclone overflow (finer scavenger tailings produced during cycloning) and uncycloned scavenger tailings will be deposited upstream of the Main Embankment forming the tailings beach between the Main Embankment and the pyrite cells. Entrained water within the scavenger beach will be minimized by thickening prior to deposition in the TSF and adopting "thin-lift" deposition, allowing time for water to evaporate resulting in a relatively 'dry' tailings beach. The resulting tailings beach at the end of operation is expected to have saturation ranging from less than 80% (at depths from 0 ft to ~100 ft in the near dam area) becoming saturated at a greater distance from the dam where the fines deposit. All tailings is expected to be saturated below 100ft to the base of the tailings, note there is significant uncertainty in this estimate, and as such the saturation (and therefore flowability) should be confirmed in future design stages and site investigations. As the scavenger beach drains down after closure, the saturation will reduce, and tailings will become less saturated with a greater impounded volume as non-flowable (i.e., not susceptible to liquefaction).

Further details of the TSF design are provided in the DEIS design report (KCBCL 2018) and the updated ultimate configuration for the final EIS is included in the Skunk Camp TSF Reclamation Plan (KCBCL 2020d).

The main benefits for the Skunk Camp site are listed below:

- The remote location is far from population centers and close to other mining areas, in an area of low density population, and generally out of public view.
- The site will be on private land.
- The site location will reduce the impact to the National Forest System lands, compared to other options.

- The site has topography that is amenable for cross-valley embankment construction and tailings storage, and potentially favorable foundation for stability, seepage control, and borrow availability.
- The cross-valley embankment configuration requires less embankment fill to retain the tailings, compared to a ring dyke impoundment, thus reducing operational and construction complexity associated with the required embankment raising, compared to other options.
- The Gila River, the downstream receiving water body, is located approximately 13 miles from the TSF.
- The site has relatively low seismic hazard and no known active faults.

1.3. Summary of Key Design Criteria

As part of the assessment, the workshop was informed of the key design criteria as presented in in Appendix I of the DEIS design report (KCBCL 2018). Design standards and minimum factors of safety have been drawn from a variety of guidance sources including the ADEQ Arizona Mining Guidance Manual BADCT (Best Available Demonstrated Control Technology), the Canadian Dam Association (CDA) Guidelines, Federal Emergency Management Agency (FEMA) publications, and United States Army Corps of Engineers (USACE) manuals.

Key risk mitigations incorporated into the design include the selection of the following design criteria:

- The Inflow Design Flood for the Main Embankment and Pyrite Cell embankments will be the Probable Maximum Flood, based on the Probable Maximum Precipitation.
- The Earthquake Design Ground Motions will be based on the 1:10,000 year earthquake
- Minimum factors of safety, deformation limits, and freeboard requirements have been adopted from BADCT, CDA, and other references.

See KCBCL 2018 for further details on the design basis. Additional documents provided to the workshop participants are listed at the end of this report.

2. Failure Modes and Effects Analysis

2.1. FMEA Process

A FMEA is a logical step by step process used to identify PFMs and estimate their associated risk of failure. FMEAs are used by many industries as a part of their quality management system to evaluate new and existing facilities and processes, and to better assess vulnerabilities and risks.

The Quality Assurance and Process Improvement (QAPI) program used in the healthcare industry describes the FMEA process as follows:

> *FMEA is a structured way to identify and address potential problems, or failures and their resulting effects on the system or process before an adverse event occurs. In comparison, a root cause analysis (RCA) is a structured way to address problems after they occur. FMEA involves identifying and eliminating process failures for the purpose of preventing an undesirable event. (CMS, 2014)*

Specifically, for the Skunk Camp TSF, the FMEA is intended to identify PFMs at the TSF and characterize their risks to aid in guiding and prioritizing future engineering design efforts and technical approaches at the facility.

The FMEA conducted for the Skunk Camp TSF would be considered similar in level of rigor to a Semi-Quantitative Risk Analysis (SQRA). In this FMEA, PFMs were identified for the project and risk analysis principles were applied to estimate likelihood and consequence levels within an order of magnitude based on information available for the project. To further evaluate the risks, a Quantitative Risk Analysis (QRA) can be performed; however, a QRA generally requires additional information on loading conditions, structural response given an applied load, detailed consequence evaluations, and significantly more time to evaluate each PFM. Typically, a SQRA (less rigorous) precedes a QRA and only selected "higher risk" PFMs from the SQRA are carried into the QRA.

For the purposes of this FMEA, a failure was considered to be any portion of the tailings embankments or associated structures which are not functioning as intended, and directly resulting in a negative consequence for the impoundment or downstream property. The FMEA focused on physical failures of the TSF such as slope failures, excessive slope erosion, overtopping of the impoundment, and internal erosion; which could result in putting downstream population at risk or significant environmental, financial, external or reputational damage. Regulatory environmental violations incurred due to an uncontrolled release of contaminants to the groundwater or air quality issues (dust control or process releases) were specifically excluded from this FMEA. The FMEA was directed by the Forest to focus exclusively on embankment stability and safety issues. Other aspects of public health, environmental impacts and public safety have been assessed as part of the Forest's NEPA disclosure process, such as air quality potentially impacted by fugitive dust, groundwater quality potentially impacted by seepage, and stormwater quality potentially impacted by contact with tailings. The results of these analyses, and mitigations developed to address them, are documented in the DEIS and in the project record. In addition to this disclosure of impacts as part of the NEPA process, these air and water quality impacts are primarily regulated by the State of Arizona and appropriate permits would be obtained by the mine proponent prior to construction.

This FMEA was conducted in general conformance with dam safety industry standards for risk analysis. Guidelines for risk analysis of dams from the following organizations were reviewed and utilized for the FMEA: Canadian Dam Association (CDA), Federal Energy Regulatory Commission (FERC), USACE, and the United States Bureau of Reclamation (USBR).

The PFMs were evaluated for the following loading conditions:

- **Normal:** Normal, or usual, loading is the condition that can be expected to occur at any time throughout the life of the structure. Activities associated with the expected operations of the proposed Skunk Camp TSF are included under Normal loading. Static conditions, as well as routine operation and construction activities were considered Normal loading.
- **Seismic:** Seismic loading refers to earthquake loading and considers all earthquakes, up to and including the design earthquake (the 1 in 10,000-year return period)[1].
- **Hydrologic:** Hydrologic loading is the occurrence of an extreme flood event. The inflow design flood event for the Skunk Camp TSF is based on the probable maximum precipitation (PMP).

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[1] *The MCE is typically associated with a well-known seismic source such as a known fault. The MCE was calculated using a deterministic analysis (DSHA) for the closest active faults and was compared with the 10,000-year return period from a probabilistic analysis (PSHA). The PSHA results were higher than the DSHA results, so the 10,000-year return period event was adopted in place of the MCE. This is a typical approach in low-seismicity regions.*

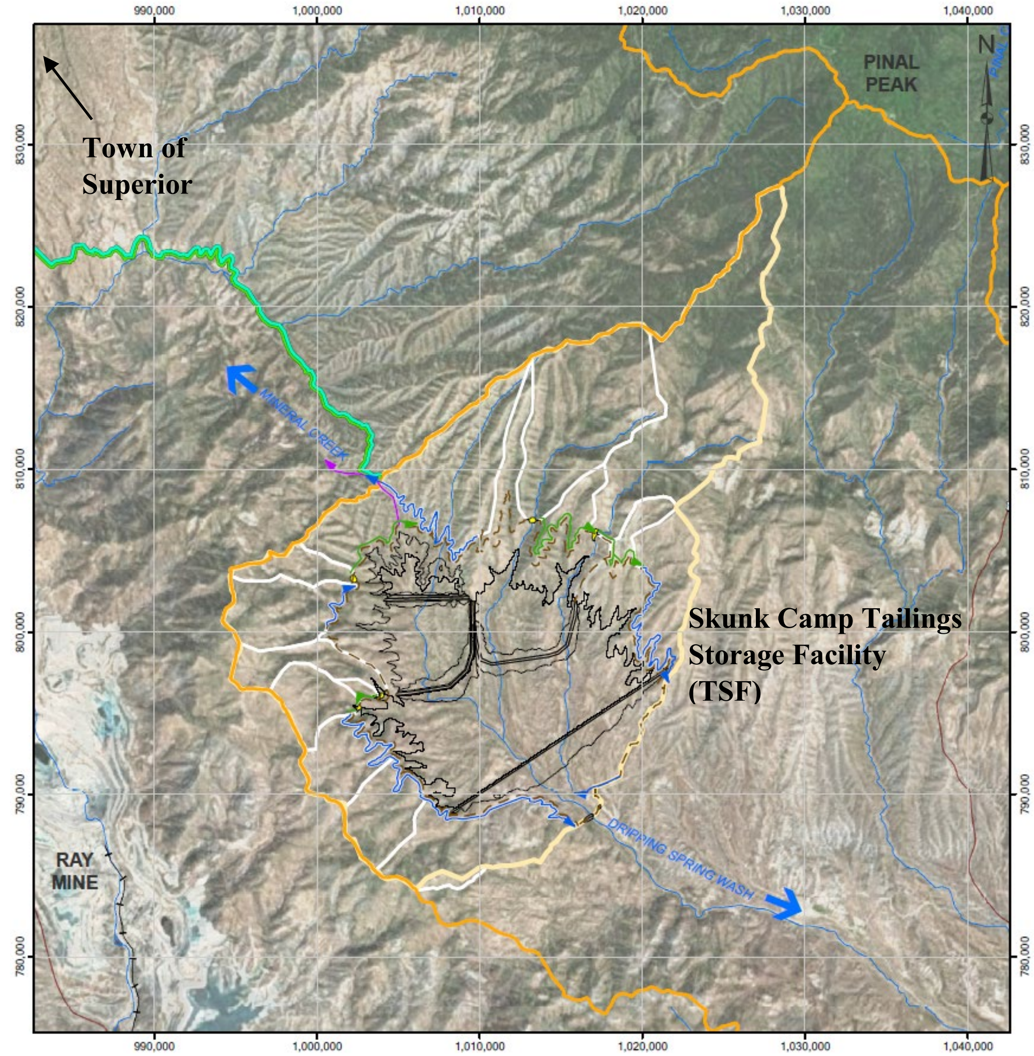


Figure 1: Site Location and Layout

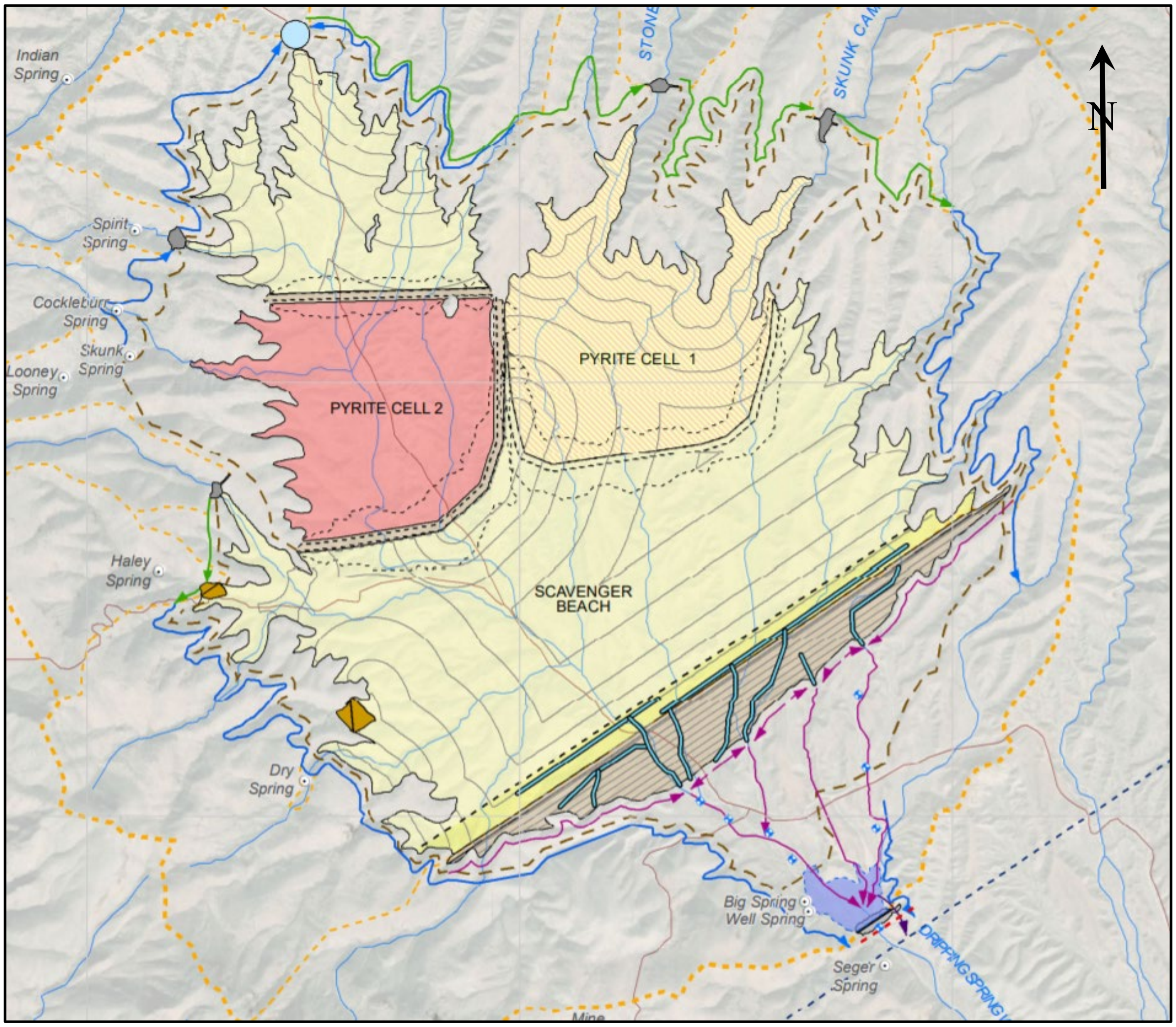


Figure 2: Skunk Camp Site with Project Features

2.2. FMEA Workshop

The FMEA workshop was held at the Radisson Sky Harbor conference center between February 5 and 7, 2020. During the FMEA workshop, a list of PFMs was brainstormed and screened by the group. The PFMs that were considered plausible were developed and evaluated using the collective experience and judgment of the group, as is typical of conducting a FMEA. A list of FMEA participants is provided in Table 1.

Table 1: FMEA Workshop Participants

Name	Affiliation	Participant Role
Wayne Harrison	ADEQ	State Agency
Hugo Hoffman	EPA	Federal Agency
Patty McGrath	EPA	Federal Agency
Michael Langley	USACE	Federal Agency
Mary Rasmussen	USFS	Federal Agency
Peter Werner	USFS	Federal Agency
Lee Ann Atkinson	USFS	Federal Agency
Judd Sampson	USFS	Federal Agency
Chris Garrett	SWCA	Consultant
Donna Morey	SWCA	Consultant
Charles Coyle	SWCA	Consultant
Nick Enos	BGC	Consultant
Michael Henderson	BGC	Consultant
Troy Meyer	BGC	Consultant
Trevor Crozier	BGC	Consultant
Vicky Peacey	Resolution	Owner
Jason Nielson	Resolution	Owner
Cameo Flood	Tetra Tech	Consultant
Jim Butler	PBL	Consultant
Kate Patterson	KCBCL	Consultant
Len Murray	KCBCL	Consultant
Jared Whitehead	KCBCL	Consultant
Joergen Pilz	Golder	Consultant
Dean Durkee	Gannett Fleming	Facilitator
Matt Balven	Gannett Fleming	Facilitator
Tyler Moore	Gannett Fleming	Facilitator

During the FMEA workshop, the attendees were provided a summary presentation of the proposed TSF design. The first task performed during the FMEA workshop was to develop a list of brainstormed (potential) PFMs. Following development of the initial list, PFMs that were submitted by FMEA attendees through questionnaires prior to the workshop were reviewed and added to the list if not already identified by the group. The list of PFMs was then screened by the group to determine which PFMs to carry forward to the FMEA and which ones to screen out. PFMs were briefly discussed and categorized as either: 1) carried forward or 2) considered but not developed. Those not carried forward were PFMs that were postulated but were determined to be not physically possible or so unlikely as to be unnecessary for further evaluation (estimated annual probability of occurrence on the order of $1x10^{-9}$ or less). The PFMs not carried forward are listed in Section 2.5.

PFMs that were carried forward, were each developed and further analyzed by the group. Development of each PFM consisted of listing the sequence of events in a step by step progression from the initial loading to the failure event. Relevant information for each PFM was discussed, captured and input into the following categories for documentation on the PFM notes:

- Additional Information
- Positive and Adverse Factors
- Potential Surveillance and Monitoring
- Data Information Needs
- Potential Risk Reduction Measures

The final step in development of each PFM was to estimate the likelihood and consequences of the PFM. The process for estimating the likelihood and consequences associated with each PFM is further discussed in the following section.

2.3. Estimation of Likelihood and Consequence

The likelihood and consequence(s) associated with each PFM were estimated using methods generally conforming to dam safety practice in the United States. Dam safety references used for developing the workshop processes include the *Best Practices in Dam and Levee Safety Risk Analysis* (USACE/BOR, 2015) and the Draft *Risk-Informed Decision Making (RIDM) Risk Guidelines* (FERC, 2016). Risk has many different definitions depending on the context, but for dam safety considerations, risk can be defined as *"a measure of the probability and severity of an adverse effect to life, health, property, or the environment"*. This definition of risk was considered by all participants during the polling for risk analysis estimates.

For dam safety, risk is generally comprised of three parts:

- The likelihood of event occurrence (e.g., flood, earthquake, reservoir elevation, etc.)
- The likelihood of an adverse structural response (e.g., dam failure, damaging spillway discharge, incorrect operation, etc.) given the load, and
- The magnitude of the consequences resulting from the adverse event (e.g., life loss, economic damages, environmental damages, etc.) given that it occurs.

For the 2020 FMEA workshop, the participants estimated the likelihood and consequences by utilizing an electronic polling method. Relevant design information and site characterization information for the failure modes were discussed by the group first prior to additional discussion about the likelihood and consequence of the particular failure mode. Participants of the discussion where then polled anonymously using an online survey tool. Following the polling, the participants discussed the results with the intent of moving toward consensus. The participants then provided their confidence for both the likelihood and consequence categories based on whether additional information was necessary or would potentially change the estimated likelihood and consequence. Based on the confidence of the group, and their understanding of the failure mode, additional future studies were identified that could potentially reduce uncertainty and increase the group's confidence in the risk estimate. Where confidence in the estimation was low, additional benefit may come from obtaining more information through additional studies or analyses. Much of the additional information will come in future stages of design, during construction, and over the operation of the facility.

The criteria used to assign the likelihood and consequence values is provided in Sections 2.3.1 and 2.3.2.

2.3.1. Likelihood of Failure

The Annual Probability of Failure (APF) is used to describe the likelihood of a PFM occurring. The APF is estimated using the frequency of the initiating condition (i.e., the 100-yr flood or the 10,000-yr seismic event), and the likelihood of failure given the load. For normal conditions, the probability of the load is assumed to be 1.

The likelihood descriptions used during the FMEA workshop were based on the criteria presented in USACE/BOR (2019). Since the USACE/BOR (2019) likelihood descriptions were developed with water dams and levees in mind, an additional likelihood description of "Extremely High" was added to capture more frequent events due to the operational nature of tailings storage facilities compared to water dams. Table 2 shows the likelihood descriptions used for the Skunk Camp FMEA. Although the USACE/BOR procedures provide a range of annual probability of failures[2], these annualized probabilities were not calculated during the FMEA workshop, rather the qualitative likelihood descriptors were applied by the participants using individual polling during the workshop, followed by discussions once the likelihood estimates had been electronically tabulated to obtain a degree of consensus

Table 2: Failure Likelihood Descriptions

Likelihood	Annual Failure Likelihood	Descriptor of Evidence
Remote	$< 1x10^{-6}$	The annual failure likelihood is more remote than 1/1,000,000. Several events must occur concurrently or in series to cause failure, and most, if not all, have negligible likelihood such that failure likelihood is negligible.
Low	$1x10^{-5}$ to $1x10^{-6}$	The annual failure mode likelihood is between 1/100,000 and 1/1,000,000. The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to initiation. Or, a flood or earthquake with a return period much more than 100,000-years Annual Exceedance Probability (AEP) would likely trigger the potential failure mode.
Moderate	$1x10^{-4}$ to $1x10^{-5}$	The annual failure likelihood is between 1/10,000 and 1/100,000. The fundamental condition of defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward less likely than more likely. Or, a flood or earthquake with a return period more remote than 10,000-years AEP would likely trigger the potential failure mode.

[2] The Annual Probability of Failure (APF) is used to describe the likelihood of a PFM occurring. The APF is estimated using the frequency of the initiating condition (i.e., the 100-yr flood or the 10,000-yr seismic event), and the likelihood of failure given the load. For normal conditions, the probability of the load is assumed to be 1.

Likelihood	Annual Failure Likelihood	Descriptor of Evidence
High	$1x10^{-3}$ to $1x10^{-4}$	The annual failure likelihood is between 1/1,000 and 1/10,000. The fundamental condition or defect is known to exist, indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward more likely than less likely. Or, a flood or earthquake with a return period between 1,000 and 10,000 years would likely trigger the potential failure mode.
Very High	> $1x10^{-3}$	The annual failure likelihood is more frequent (greater) than 1/1000. There is direct evidence or substantial indirect evidence to suggest it has initiated or is likely to occur in the near future. Or, a flood or earthquake with a return period between 100 and 1,000 years would likely trigger the potential failure mode.

2.3.2. Consequence of Failure

Prior to the FMEA, the Draft EIS disclosed the potential consequences of an embankment failure at the Skunk Camp location (BCG, 2018) using an empirical method to predict the volume of material released during a hypothetical failure, based on the total facility volume (Rico empirical method after Rico et al., 2007). This method also estimates the maximum travel distance downstream based on the release volume and the maximum embankment height. It is important to note that this method does not consider embankment type, design features used to address failure modes, foundation conditions, operational approaches, or any other site-specific aspects. In general, the group classified the potential runout distances, as:

- Localized erosion or minor failure that requires maintenance but has no serious consequences;
- Runout limited to a soil slump with limited failure volume - a "soil slump" like failure with limited runout of a few hundred to a few thousand feet;
- Tailings runout remains in Dripping Springs Wash with no PAR (Public at Risk) - a tailings runout failure of less than 4 miles and remaining within the wash;
- Tailings runout remains in Dripping Springs Wash with some PAR (Public at Risk) - a tailings runout failure of greater than 4 miles and remaining within the wash;
- Possible higher consequences due to fluid failure and reaching the Gila River - a potentially longer, fluid like runout travelling down Dripping Springs Wash and making its way to the Gila River.

For the FMEA, the group estimated potential runouts for each PFM based on professional judgement of combined experience of the group related to similar facilities. As an example, for PFMs that did not release a pond and the scavenger tailings are not completely saturated, the group considered runouts generally defined as "between the mine property boundary and about 4 miles downstream of the embankment" for the purposes of the FMEA. After conclusion of the FMEA meeting, Resolution commissioned a further assessment of the potential runout from KCBCL (2020), in order to clarify and validate the scenario assumed during the FMEA. This additional assessment is pending. There was also a distinction made between potential impacts to the downstream environment above the confluence with the Gila River, and potential impacts to the Gila River. Each PFM was viewed in terms of the expected runout distance (or potential residual downstream impacts to environment) for that particular PFM.

The group then used the estimated runout and their judgement and experience to estimate the consequence. Consequence classifications considered generalized Potential Loss of Life (PLL) using the criteria in Table 3 and other Non-Life Loss consequences (environmental, economic, etc.) in Table 4. The PLL consequence categories shown in Table 3 are based on the categories provided in the “Best Practices in Dam and Levee Safety Risk Analysis” [1]. There is not a nearby downstream population at risk (PAR) and it became evident during the workshop that the Non-Life Loss consequences generally controlled the consequence level, with environmental impacts being the driving factor. A semi-quantitative approach was taken and estimates were made using broad range of Non-Life Loss consequences, along with order of magnitude estimates of PLL. The consequence selected for each failure mode was generally dictated by the environmental consequences and is noted in the rationale for the consequence levels. Where PLL was considered possible, it is also discussed in the consequence rationale, but was never considered higher than Category 2. During the workshop, Category 1, Category 2, etc. consequence levels were used, as summarized in Table 3 and Table 4.

Table 3: Life Loss Consequence Descriptions (modified after USACOE)

Life Safety Consequence Classification	Incremental Life Loss	Descriptor of Evidence
Category 1	< 1	Downstream discharge results in limited property and/or environmental damage. Although life-threatening releases occur, direct loss of life is unlikely due to severity or location of the flooding, or effective detection and evacuation.
Category 2	1 to 10	Downstream discharge results in moderate property and/or environmental damage. Some direct loss of life is likely, related primarily to difficulties in warning and evacuating recreationists/travelers and small population centers
Category 3	10 to 100	Downstream discharge results in significant property and/or environmental damage. Large direct loss of life is likely, related primarily to difficulties in warning and evacuating recreationists and/or travelers and smaller population centers, or difficulties evacuating large population centers with significant warning time
Category 4	100 to 1,000	Downstream discharge results in extensive property and/or environmental damage. Extensive direct loss of life can be expected due to limited warning for large population centers and/or limited evacuation routes

Life Safety Consequence Classification	Incremental Life Loss	Descriptor of Evidence
Category 5	> 1,000	Downstream discharge results in extremely high property and/or environmental damage. Extremely high direct loss of life can be expected due to limited warning for very large population centers and/or limited evacuation routes

Table 4: Non-Life Loss Consequence Descriptions

Consequence Classification	Environmental and Cultural Impact	External Infrastructure and Economics
Category 1	Minimal short-term loss (less than 5 years); no long-term loss	Low economic losses; area contains limited infrastructure or services
Category 2	No sizeable loss or deterioration of primary ecological functions; loss of marginal habitat/flora/fauna only; restoration or compensation in kind highly possible	Loss of recreational facilities, seasonal workplaces, or infrequently used transportation routes
Category 3	Significant loss or deterioration of important fish or wildlife habitat; restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, or commercial facilities
Category 4	Significant loss or deterioration of critical fish or wildlife habitat; restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Category 5	Major loss of critical fish or wildlife habitat; restoration or compensation in kind impossible	Extreme economic losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

It should be recognized that the Non-Life Loss consequences are not to be used in place of, or in any way equated to, the Life Loss classification, and are not to be used to arrive at a value for human life. They are, however, used as a separate portrayal of risks based on environmental, economic, or business impacts of a PFM. Table 4 assumes the highest consequence score. For example, if the environmental and cultural impact is Category 4, and the external infrastructure and economics impact score is Category 1, the overall Non-Life Loss consequence score would be Category 4.

2.3.3. Confidence

A qualitative "confidence" estimate was taken from the group following estimation of likelihood and consequence for each PFM. The intent of the confidence estimate was to determine the degree of uncertainty the group believed there was associated within the risk classification. The qualitative confidence options were low, moderate, and high. Confidence descriptors were provided to all participants of the workshop during polling and descriptions of confidence are listed below for reference.

- Low Confidence – The individual/team is not confident in the order of magnitude for the assigned category, and it is entirely possible that additional information could change the estimate.
- Moderate Confidence – The individual/team is relatively confident in the order of magnitude for the assigned category, but key additional information might possibly change the estimate.
- High Confidence – The individual/team in confident in the order of magnitude for the assigned category and it is unlikely that additional information would change the estimate.

If the confidence is low, then the estimate likely falls within a broader range of possibilities. However, if the confidence is high, the estimate can be considered "tighter" or within a smaller range of possible outcomes. For risk estimates with low confidence, additional studies and analysis may be required to better define the risk associated with the PFM. Whereas PFMs with high confidence may not need additional information to better define risk, and additional work can focus directly on reducing the risk. The FMEA was performed on the Skunk Camp TSF design presented in the DEIS, so there are limitations related to the level of design and the amount of studies completed. Additional studies, such as more site investigations, will help reduce uncertainty and increase confidence as they are completed and as the design becomes final.

2.4. FMEA Results

A total of sixteen plausible PFMs were developed during the FMEA Workshop:

- Fifteen (15) of these PFMs were for the Scavenger (Main) TSF
- One (1) was for the Potential Acid Generating (PAG) TSF
- For the Main TSF:
  - Ten (10) PFMs were developed under normal loading conditions;
  - Three (3) for seismic loading; and
  - Two (2) for hydrologic loading.

The one PFM for the PAG TSF is under normal loading conditions.

The PFM workshop notes for each of the individual plausible PFMs are provided in Appendix A. The PFM notes reflect the record of the workshop dialog. The PFM notes include the following elements and decision factors:

- a description of the development of the PFM,
- positive and adverse factors,
- surveillance and monitoring,
- data information needs,
- potential risk reduction measures, and the
- likelihood and consequence values.

Table 5 summarizes the plausible PFMs identified and developed.

Table 5: Summary of Potential Failure Modes

Loading Cond.	PFM	FMEA Workshop Description	Simplified Definition
Normal	N-1	Slope Instability through the Foundation at the Main Embankment due to a Weak Foundation Layer	Weak foundation layer causes Main Embankment to fail
	N-2	Slope Instability through the Foundation at the Main Embankment due to High Porewater Pressures	High pore pressures in the foundation causes Main Embankment to fail
	N-3	Slope Instability through the Foundation at the Main Embankment due to Deviation from Design Construction Geometry or Excessive Raise Rates	Deviation from Design Construction Geometry or Excessive Raise Rates creates undrained conditions causing the Main Embankment to fail
	N-4	Slope Instability through the Foundation at the Main Embankment due to Terrain Instability at the Abutments	Terrain Instability (landslide) causes Main Embankment to fail
	N-5	Slope Instability through the Foundation at the Main Embankment due to Geochemical Changes in the Foundation Over Time	Geochemical degradation resulting in weak foundation layer causes Main Embankment to fail
	N-6	Slope Instability through the Embankment at the Main Embankment due to a Weak Layer in the Embankment	Weak layer in cyclone sand causes Main Embankment to fail
	N-7	Slope Instability through the Tailings Embankment at the Main Embankment due to High Porewater Pressure in the Embankment	High pore pressures in cyclone sand causes Main Embankment to fail
	N-8	Slope Instability through the Tailings Embankment at the Main Embankment due to Deviation from Design Geometry or Excessive Raise Rates	Deviation from Design Construction Geometry or Excessive Raise Rates create undrained loading conditions in the cyclone sand, causing Main Embankment to fail
	N-9	Internal Erosion through the Foundation at the Starter Dam	Internal Erosion through the foundation causes the Starter Dam to fail
	N-10	Pipeline Rupture at the Main Dam Leads to Erosion and Dam Release of Tailings	Tailings pipeline rupture leads to erosion and causes tailings to be released
Seismic	S-1	Slope Instability through the Foundation at the Main Dam due to Strength Loss during a Seismic Event	Earthquake causes undrained conditions in foundation layer causes Main Embankment to fail
	S-2	Slope Instability through the Foundation at the Main Dam due to Terrain Instability at the Abutments during a Seismic Event	Earthquake causes terrain instability and abutments causes Main Embankment to fail
	S-3	Slope Instability through the Tailings Embankment during a Seismic Event	Earthquake causes undrained conditions in cyclone sand causing Main Embankment to fail

Loading Cond.	PFM	FMEA Workshop Description	Simplified Definition
Hydrologic	H-1	Slope Instability at the Main Dam due to High Porewater Pressure in the Embankment following a Hydrologic Event	Storm event causes excess pore pressures in cyclone sand causes Main Embankment to fail
	H-2	A Diversion Ditch Fails during a Storm Event leading to Erosion of the Main Embankment	Storm event leads to erosion and causes Main Embankment to fail
PAG Cell PFM			
Normal	PAG N-1	Slope Instability through the Foundation at the PAG Dam due to a Weak Foundation Layer	Weak foundation layer causes Pyrite Cell Embankment to fail

For each of the plausible PFMs, the group assigned likelihood and consequence values based on the criteria outlined in Section 2.3.

The likelihood and consequence values for each PFM are plotted on a risk matrix to show the relative risk associated with the PFM (Figure 2). The y-axis of the risk matrix represents the likelihood value and the x-axis the consequence value. PFMs considered low risk would plot towards the lower left corner, and those with higher likelihood move upward on the plot and those with higher consequence move to the right.

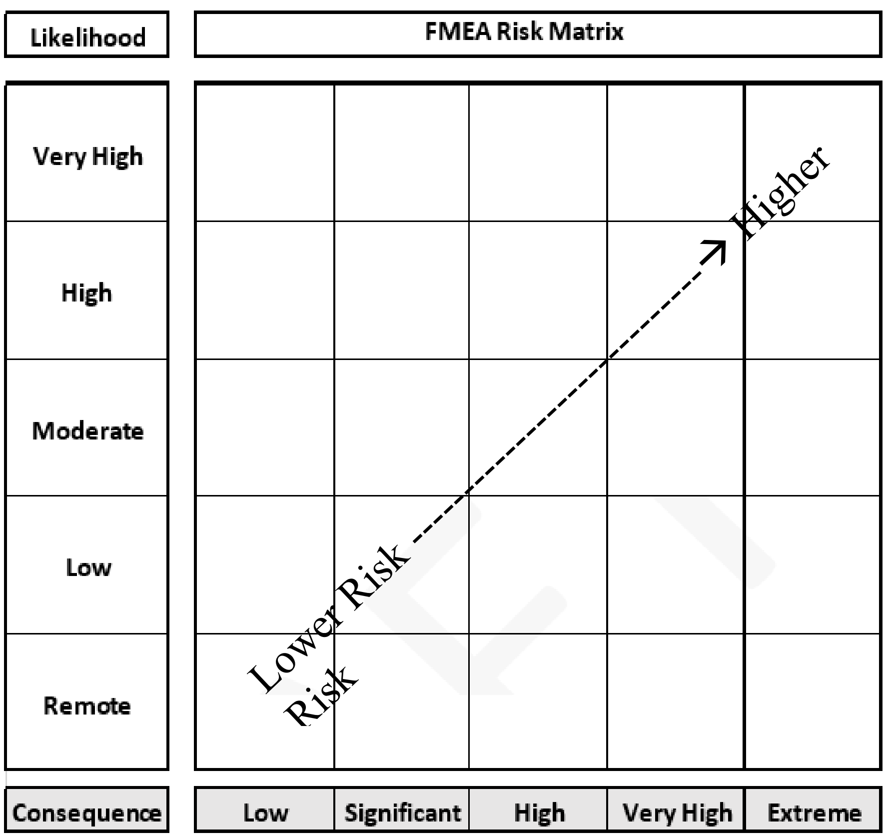


Figure 3: Risk Matrix for the FMEA

The 2020 Skunk Camp TSF FMEA workshop identified sixteen plausible PFMs that were assigned likelihood and consequence. These PFMs and their Risk Matrix with assigned likelihood and consequence are discussed below, organized by loading condition. The estimates for likelihood and consequence were developed by blind polling as well as discussion of the initial poll results, following the polling. On the Risk Matrices, a box has been placed where the PFM likelihood and consequences intersect. Some of the failure modes straddle two classifications (such as low to moderate) and some extend over three classifications based on the groups estimates (such as low to high). The PFM notes developed during the 2020 FMEA workshop, which provide more information for each PFM, are provided in Appendix A.

2.4.1. Factors Common to all PFM Cases

Once all the results were tabulated, it was found that a number of factors supporting the Likelihood and Consequence categories were common to more than one of the PFMs. Similarly, there were common factors in the group confidence ratings and potential risk reduction measures. These factors are summarized in Table 5, and described in further detail below.

Key Positive Factors in Likelihood Ratings

Design

- The design meets or exceeds the minimum industry standard FoS ≥ 1.5 (Factor of Safety) for static conditions and FoS ≥ 1.2 for seismic conditions.
- The ability to flatten the slopes from the design of 3H:1V to 4H:1V is feasible as there are both sufficient materials available and real estate beyond the toe of the embankment to reduce the slope angle. The potential to flatten the slopes does not mean that the design is too steep, just that this design option is available should adverse conditions be encountered.
- Centerline construction methods will be used for the Main Embankment along with hydraulic cell deposition of cyclone sands. The potential for a continuous poorly compacted layer using these methods is remote and has not been observed in practice.

Geologic Foundation Conditions

- The foundation conditions are generally favorable for the cross valley Main Embankment construction. Foundation of the embankments include relatively shallow alluvium, Gila Conglomerate and Quaternary Pediment, site investigations show that these units are favorable for stability or can be removed easily. The site is also relatively remote from seismic sources with relatively low ground acceleration values.
- During design, thorough foundation investigations will be completed, which are likely to detect the presence of weak foundation layers, if present.
- The design also used a lower bound weakened strength under assumed saturated conditions of the Gila formation.
- In terms of landslide potential at the abutments or around the tailings impoundment perimeter, no landslides have been mapped or are known to exist at the site.

Drainage Conditions

- Thickened tailings deposition will be used for placement of the impoundment tailings. The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and relatively high permeability foundation; all which reduce the infiltration and potential for high pore pressures to develop. The flow failure potential of partially saturated thickened tailings is considerably less than standard hydraulic deposited tailings that have a high saturation and typically a large reclaim pond.
- The embankment designs incorporate underdrainage to promote drainage of the cycloned sands and reduce the phreatic surface.

Management Considerations

- Construction of the embankments will involve a thorough Quality Control testing and Quality Assurance (QC/QA) program to confirm that materials are placed in accordance with specifications.
- An Operations, Maintenance and Surveillance (OMS) manual will be developed which describes management accountabilities, maintenance procedures and surveillance techniques. The OMS will include the geotechnical monitoring plan to facilitate the observational method.
- An Emergency Action Plan (EAP) will be prepared to reduce consequences and provide direction during emergency events.

Other special considerations are summarized under the individual PFM descriptions that follow.

Key Adverse Factors in Likelihood Ratings

Geologic Foundation Conditions

- The foundation could be variable and the variability may not be detected, as this is a possibility that must be considered.
- The Quaternary pediment that is present on ridgetop and have the potential to have low strength. The current design assumes removal of the pediment. There is potential that not all the low strength material is removed.
- It was raised that there may be paleo-channels in the alluvium and may result in unknown seepage pathways.
- The inactive Dripping Springs Fault runs down the center of the wash and it is not known whether the fault will behave as an aquitard or seepage pathway.

Construction Related Factors

- Geochemical alternation may reduce the permeability of the foundation and underdrains, thereby impeding drainage and leading to elevated pore water pressures.
- The proposed TSF construction will span over a 40+ time period with potential changes in ownership, regulatory processes, oversight, commodity costs and other considerations. This time period could result in changes or omissions in the construction and/or operations.

- There could be higher ARD content in the cyclone sands due to issues with the pyrite separation circuits, changes in ore and other factors, which may result in geochemical degradation.
- The cyclone performance must meet the design requirements and changes in the ore, grind and other factors could change the drainage and shear strength properties of the cyclone sands.
- There is a potential for uncompacted zones, especially near the hydraulic cell decant areas, where fines may collect, impeding drainage and compaction.

Management Considerations

- Construction of the tailings embankment is a 41-year project, with potential changes in ownership, operations, and personnel.
- There is a potential for regulatory changes and lack of regulatory capacity or experience of staff.
- There is minimal dam safety oversight of tailings dams or embankments in Arizona.
- Fluctuation in the cost of copper can cause a temporary cessation in operations.
- There is a potential shortage of qualified staff to operate a tailings facility.
- Potential upsets in production, or errors or omissions in quality control and assurance program(s).

Other Factors

- Wildfire could impact erodibility, slope stability and debris flow potential, adversely impacting slope stability around the impoundment and embankment abutments.

A number of factors not common to all PFMs are presented under the individual PFM descriptions.

Key Factors in Consequence Ratings

The consequences of geotechnical instability or runout fell into three categories at this stage of the design:

- Geotechnical instability may result in limited runout, such as a soil slope / slump failure, which may extend from a few hundred to a few thousand feet from the failure. This failure type represents the lowest consequence and may remain on the TSF property itself.
- The tailings may runout a limited distance and remain within Dripping Springs Wash. The nearest public at risk (PAR) is approximately 4 miles from the impoundment, with the potential exception of operators on site. Tailings runout of less than 4 miles would have environmental consequences resulting in damage to vegetation, habitat and potentially surface and groundwater.
- Instability occurring at times where the decant pond is close to the embankment, such as during startup, may have the highest consequences due to the fluid nature of the saturated tailings and presence of free water. This type of runout is rated as the highest consequence.

- In each of the cases evaluated, the consequences were rated primarily as environmental damage versus potential loss of life (PLL).

PLL factors originally considered in the PFM analyses were therefore not utilized in the actual ratings of the different failure modes.

Group Confidence Rating

The group confidence ratings generally fell into the low to moderate rating based on the individual electronic poling results.

- The Low likelihood or consequence categories was generally a result of uncertainty in the PFM credibility, analyses had not been completed to clarify a technical aspect of the PFM and/or additional information could come to light that could change the estimated likelihood or consequence or result in the PFM being so unlikely that is would not be considered.
- Most of the likelihood and consequence factors were rated as Moderate. In terms of consequence, it seemed clear that some environmental damage would occur as a result of a failure. However, further dam break or runout type analyses could add additional information to the inundation zone and lead to a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures

Potential risk reduction measures also had a large number of approaches that were common across all of the PFMs. These included:

- Flatten or reduce the slopes. Although this was considered a positive factor it is also a mitigation measure and was included as a risk reduction measure. The ability to flatten the slopes from the design of 3H:1V to 4H:1V is feasible as there are both sufficient materials available and real estate beyond the toe of the embankment to reduce the slope angle.
- Thorough foundation investigations are planned and also present a risk reduction measure to identify potential weak layers, paleo-channels and complete characterize the foundation for design.
- For those cases where high pore water pressures could lead to instability, pressure relief wells could be installed to reduce foundation or cycloned sand pore water pressures and improve stability.
- Diversion berms, deflection dikes or other means could be installed to direct a potential failure away from critical infrastructure or habitat.
- A geotechnical monitoring program will be part of the OMS manual and both the instrumentation and monitoring program are risk reduction measures. Instrumentation may also lead to design improvements. The geotechnical monitoring may be divided into:
    - Installation of piezometers to measure pore pressures
    - Installation of inclinometers, survey prisms and other movement detection devices
    - Aerial or satellite-based monitoring systems
- Preparation of the OMS and EAP documents, the periodic updates and drills associated with those plans are risk reduction measures

- The high-quality QC/QA program is also a risk reduction measure (in addition to being a positive factor to likelihood)
- Land acquisition downstream of the facility could be considered a risk reduction measure because consequences can be more controlled within property limits.

Other individual mitigation measures are described under the individual PFM descriptions that follow.

Closure Considerations

Each PFM was evaluated for differences or changes that may occur under closure conditions.

- The group considered that an active monitoring period would be required to evaluate each PFM through the initial active closure monitoring period.
- The group agreed that a minimum active monitoring period of at least 30 years would be required, although actual conditions may lengthen this period of time significantly.
- Drainage tended to reduce the likelihood and consequence of various PFMs related to high pore pressure or water surface conditions.
- Individual PFMs were rated whether the likelihood or consequences would be the same or less during closure versus the operation condition evaluated

The applicability of these factors to each PFM is summarized in Appendix A. Factors that are not common to a number of PFMs are described individually in subsequent descriptions of the individual PFMs.

2.4.2. Normal Loading Conditions (Scavenger Tailings)

N-1: Slope Instability through the Foundation at the Main Embankment due to a Weak Foundation Layer

The group estimated the likelihood of this PFM as low to moderate and the consequences as significant.

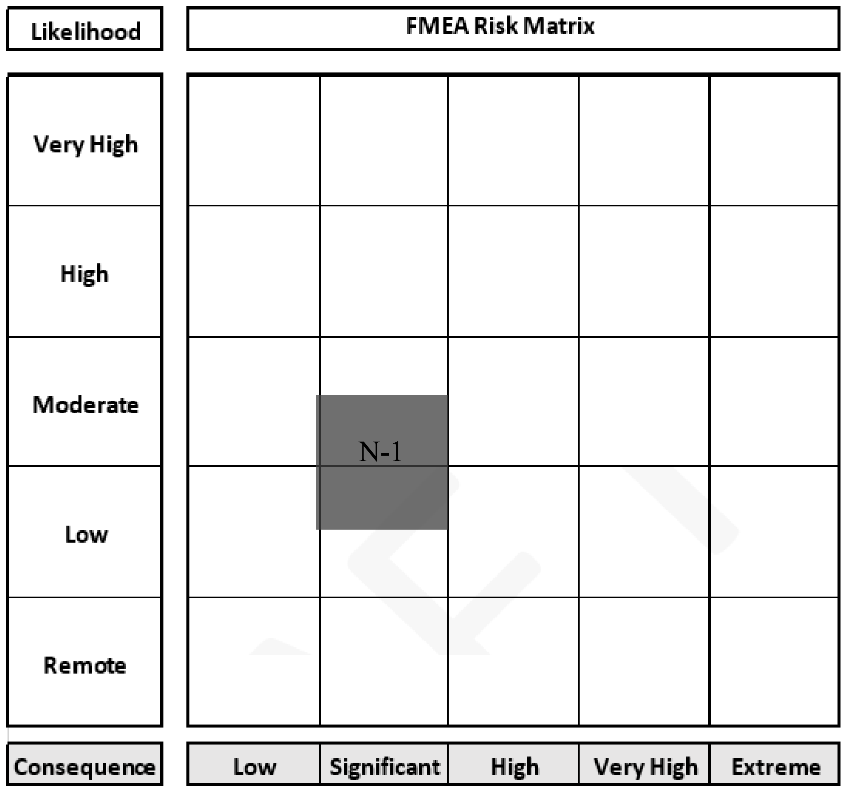


Figure 4: Risk Matrix for N-1

Risk Matrix Justification

This failure consists of a slope failure initiated through the foundation under the following conditions:

- An undetected weak layer is present in the foundation below the Main Embankment.
- The upper portion of the alluvium and Gila in the foundation below the Main Embankment will be saturated from operations.

The failure progression is as follows:

- As the embankment is raised, a slip surface develops because the shear strength in the postulated weak foundation layer is exceeded.
- The embankment begins to move (fail) on the weak layer.
- The slope failure surface progresses upstream into the impoundment.
- Embankment freeboard is lost and tailings are released downstream.

Low to moderate likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- Water balance is net negative and climate is arid/desert.
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The site is considered a suitable for a tailings embankment; with a relatively permeable foundation, low seismicity, negative water balance, dense granular soils, and well understood geology.
- There has been a site investigation at the site location and additional investigations will be performed. If weak material is encountered in the investigation or during construction, it is proposed that the weak material be removed.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankments; all of which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- The foundation conditions are heterogeneous and potentially highly variable.
- There is a surficial Quaternary pediment layer with potential low strength zones present at the ground surface in some areas of the site (note that, it is intended to be removed as a part of foundation preparation for the embankment).
- The alluvium and upper Gila are likely to become saturated from tailings deposition
- There is a potential for paleo channels in the foundation which are potential seepage paths.

The potential consequence of this failure mode was rated significant with the following justification:

- The runout with this type of failure is not expected to extend very far. The nearest Population at Risk (PAR) is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was low. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures

- Flatten the slopes to improve slope stability.
- Perform additional foundation investigations to identify weak layers.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an Emergency Action Plan (EAP) and early warning system.

Post Closure Considerations

- There will be a post-closure monitoring period. According to ADEQ, 30 years is common following closure. There are other factors that could change and possibly significantly extend the monitoring period.
- There is an active closure period following operations, and before passive closure.
- After closure, the tailings will drain down which should lower the consequence. Also, the likelihood should be similar or become less likely.
- Overall the risk of this failure mode is expected to be the same or less in closure than during operations.

N-2: Slope Instability through the Foundation at the Main Embankment due to High Porewater Pressures

The group estimated the likelihood of this PFM as low and the consequences as significant.

Likelihood	FMEA Risk Matrix				
Very High					
High					
Moderate					
Low		N-2			
Remote					
Consequence	Low	Significant	High	Very High	Extreme

Figure 5: Risk Matrix for N-2

Risk Matrix Justification

This failure is similar to N-1, except that it is initiated due to high porewater pressures in the foundation.

The failure progression is as follows:

- Porewater pressures increase within the foundation due to either:
  - the foundation having a lower permeability than expected in design, or
  - a failure to pump water from the downstream foundation during operation
- A slip surface develops in the foundation due to the elevated pore pressures
- The embankment begins to move (fail) due to the continued excess pore pressures.
- The slope failure surface progresses upstream into the impoundment.
- Embankment freeboard is lost and tailings are released downstream.

Low likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The site is considered a suitable for a tailings embankment; with a relatively permeable foundation, low seismicity, negative water balance, dense granular soils, and well understood geology.
- The groundwater table prior to construction is low with no artesian pressures, and shallow pumping wells will be installed in the alluvium downstream of the impoundment to pump back seepage water back during operation.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all of which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- The foundation conditions are heterogeneous and potentially highly variable.
- The Dripping Springs Fault extends across the impoundment (which may act as a conduit or barrier to seepage).
- There is potential for geochemical sealing of the underdrains which could reduce underdrain performance.
- The alluvium and upper Gila are likely to become saturated from tailings deposition
- There is a potential for paleo channels in the foundation which are potential seepage paths.

The potential consequence of this failure mode was rated significant with the following justification:

- The runout with this type of failure is not expected to extend very far. The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash and not extend to the Gila River.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve slope stability.
- Perform additional foundation investigations to identify weak layers.
- If there were lower permeability units identified in the additional site investigation, the design

should be modified to account for lower permeability unit(s).

- An instrumentation monitoring plan (with established threshold levels) with associated action plans / alarms for threshold exceedance
- Additional extraction / pressure relief wells could be installed to reduce pore pressures.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- Overall the risk of this failure mode is expected to be the same as during operations or less.
- The tailings are draining and consolidating after closure.
- Could have backup of water behind the cutoff wall if the shallow pumping wells are turned off. May need to remove the cutoff wall at time of closure to prevent backup of water once pumps are turned off.

N-3: Slope Instability through the Foundation at the Main Embankment due to Deviation from Design Construction Geometry or Excessive Raise Rates

The group estimated this PFM as low likelihood with a significant consequence.

Likelihood	FMEA Risk Matrix				
Very High					
High					
Moderate					
Low		N-3			
Remote					
Consequence	Low	Significant	High	Very High	Extreme

Figure 6: Risk Matrix for N-3

Risk Matrix Justification

This failure occurs due to excess pore pressures developing in the foundation leading to a slope failure through the foundation.

The failure progression is as follows:

- Excess pore pressures develop in the foundation caused by either:
  - A temporary deviation from design (example: oversteepening of hydraulic cells slopes), or
  - A local area of high construction raise rates is required (due to unforeseen circumstances),
- A slip surface develops in the foundation due to the elevated pore water pressures
- The embankment begins to move (fail) due to the excess pore water pressures
- The slope failure surface progresses upstream into the impoundment.
- Embankment freeboard is lost and tailings are released downstream.

The group estimated this failure mode to have low likelihood of occurrence based on key factors listed below.

Key Positive Factors

- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The site is considered a suitable for a tailings embankment; with a relatively permeable foundation, low seismicity, negative water balance, dense granular soils, and well understood geology.
- The groundwater table prior to construction is low with no artesian pressures, and shallow pumping wells will be installed in the alluvium downstream of the impoundment to pump back seepage water back during operation.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all of which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- The foundation conditions are heterogeneous and potentially highly variable.
- There is a surficial Quaternary pediment layer with potential low strength zones present at the ground surface in some areas of the site (note that, it is intended to be removed as a part of foundation preparation for the embankment).
- The alluvium and upper Gila are likely to become saturated from tailings deposition

The potential consequence of this failure mode was rated significant with the following justification:

- The runout with this type of failure is not expected to extend very far. The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve slope stability.
- Perform additional foundation investigations to identify less permeable layers.
- Prepare an operating plan that establishes a maximum rate of rise.

- Install more shallow pumping wells in the foundation.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- This is an operational failure mode and will not be applicable following closure.

N-4: Slope Instability through the Foundation at the Main Embankment due to Terrain Instability at the Abutments

The group estimated this PFM low likelihood with a low to significant consequence.

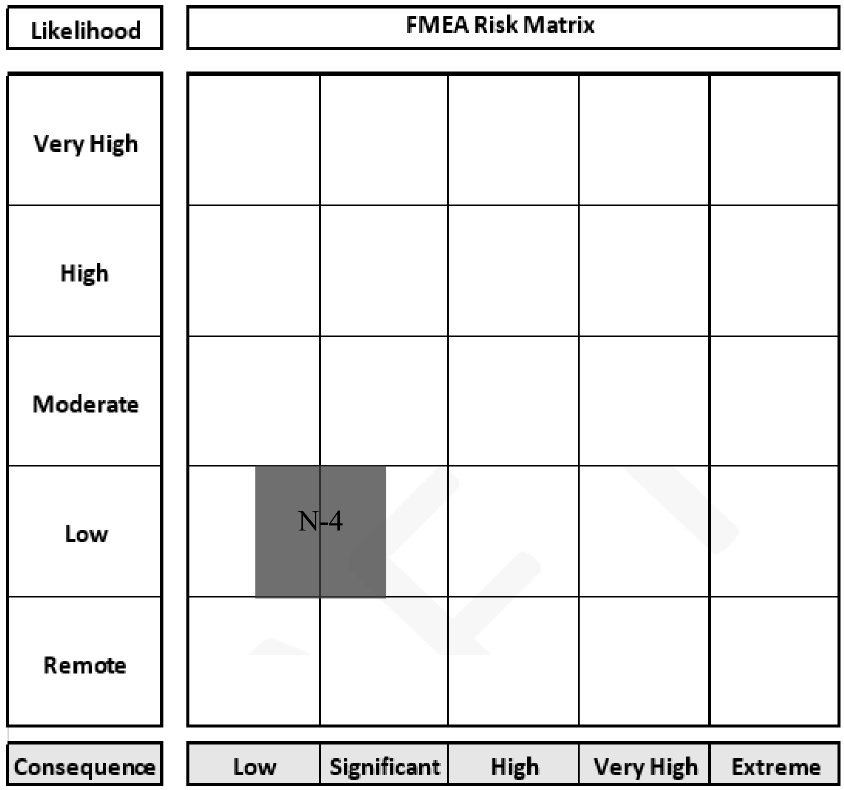


Figure 7: Risk Matrix for N-4

Risk Matrix Justification

This failure is due to reactivation of a preexisting (ancient) landslide on the rim or abutment of the tailings impoundment. For this to occur, an undetected existing landslide would need to be present at the impoundment (specifically near the abutments of the Main Embankment).

The failure progression is as follows:

- The toe of the existing landslide deposit within the foundation become saturated by the new tailings impoundment or seepage from diversion ditches.
- The landslide is reactivated and the movement causes the Main Embankment to deform which in turn leads to a slope failure.
- As the landslide progresses, embankment freeboard is lost and tailings are released downstream

Low likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- There are no mapped landslides at the site.

- Large, major landslides in Arizona are generally slow moving so there is likely to be sufficient time to implement appropriate mitigation measures.
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all of which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- Wildfire in the area could exacerbate the potential for landslides by increasing infiltration.
- The foundation conditions are heterogeneous and potentially highly variable.
- Ancient landslides can be difficult to detect due to subtle landforms.
- If a landslide was detected, it is difficult to stabilize
- The alluvium and upper Gila are likely to become saturated, and there is a potential for paleo channels in the foundation which are potential seepage paths.

The potential consequence of this failure mode was rated low to significant with the following justification:

- This is expected to be a slower moving failure than the previous slope failure PFMs (N-1, N-2, N-3), and there may be time to provide additional warning and preparation.
- The slope failure through the embankment may be limited to the upper portion of the embankment because the landslide is more likely to impact the embankment near the abutments where there is less buttressing effect on the landslide.
- The runout with this type of failure is not expected to extend very far. The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.
- The landslides can be difficult to detect, there are subtle landforms, and if a landslide was detected, it is difficult to stabilize.

Confidence

Confidence in the estimate for likelihood was low to moderate. A site investigation and reconnaissance has been performed and did not identify any ancient landslides; however, it is not uncommon for ancient landslides to be overlooked.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Install a liner in the diversion channels or relocate ditches away from impoundment.
- Perform in-situ mitigation of any active landslides.
- Buttress any identified landslides to prevent movement.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- The likelihood and consequence for this failure mode is generally the same or less risk during post-closure than for during operations.

N-5: Slope Instability through the Foundation at the Main Embankment due to Geochemical Changes in the Foundation Over Time

The group estimated this PFM remote to moderate likelihood with a significant consequence.

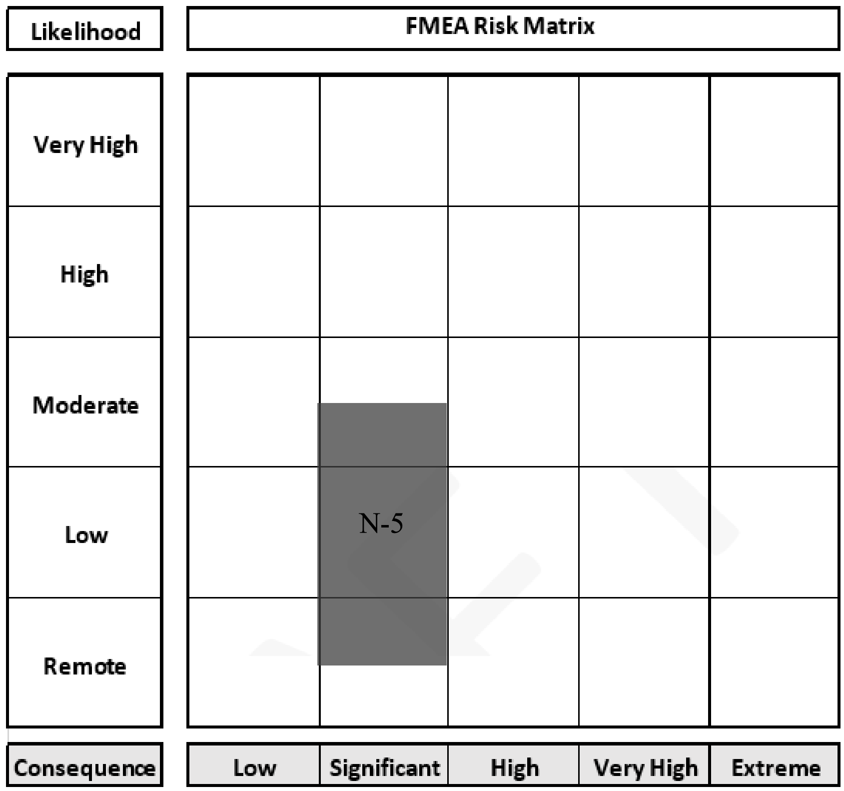


Figure 8: Risk Matrix for N-5

Risk Matrix Justification

This failure occurs due to geochemical changes in the foundation over time during operation of the TSF, leading to a slope failure through the foundation.

The failure progression is as follows:

- Over time, the impacted water from the tailings impoundment chemically reacts with the foundation materials and changes the shear strength and/or the permeability of the foundation.
- The reduced foundation strength or increased pore pressures due to "plugging" of foundation pore space results in a slip surface developing through the foundation.
- The embankment begins to move (fail) due to reduced shear strength of the materials (N1) or excess pore water pressures (N2)
- The slope failure surface progresses upstream into the impoundment
- Embankment freeboard is lost and tailings are released downstream

Remote to moderate likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- The design assumes that the upper portion of the Gila would be weakened, so a lower residual strength value was used for the upper portion of the Gila in the stability analysis.
- There are many other tailings impoundments in Arizona on Gila foundation materials, and there is no evidence in geochemical degradation of the Gila at the other sites.
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all of which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- There is a potential for variability or mischaracterization in the ore material so that more acid generating tailings may end up in the scavenger (Main) tailings impoundment.
- The foundation conditions are heterogeneous and potentially highly variable.
- The alluvium and upper Gila are likely to become saturated, and there is a potential for paleo channels in the foundation which are potential seepage paths.

The potential consequence of this failure mode was rated significant with the following justification:

- The runout with this type of failure is not expected to extend very far. The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was low to moderate. The confidence in the likelihood for this failure mode was low to moderate because there is limited information on the potential chemical degradation of the foundation and use of the PAG cells is new in the Gila. This will take time to develop and is difficult to predict at this time.

Confidence in the consequence estimate was low to moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences. Additionally, there is less certainty regarding the potential for chemical degradation of the foundation and how that may impact stability.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve stability.
- Perform additional foundation investigations to identify less permeable layers.
- Treatment of higher acid zones with neutralizing material (e.g., limestone).
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- This is a potentially long-term developing failure mode. Monitoring of water quality will need to continue into post-closure..
- The geochemical reactions can take a long time to develop.

N-6: Slope Instability through the Embankment at the Main Embankment due to a Weak Layer in the Embankment

The group estimated this PFM remote to low likelihood with a low to significant consequence.

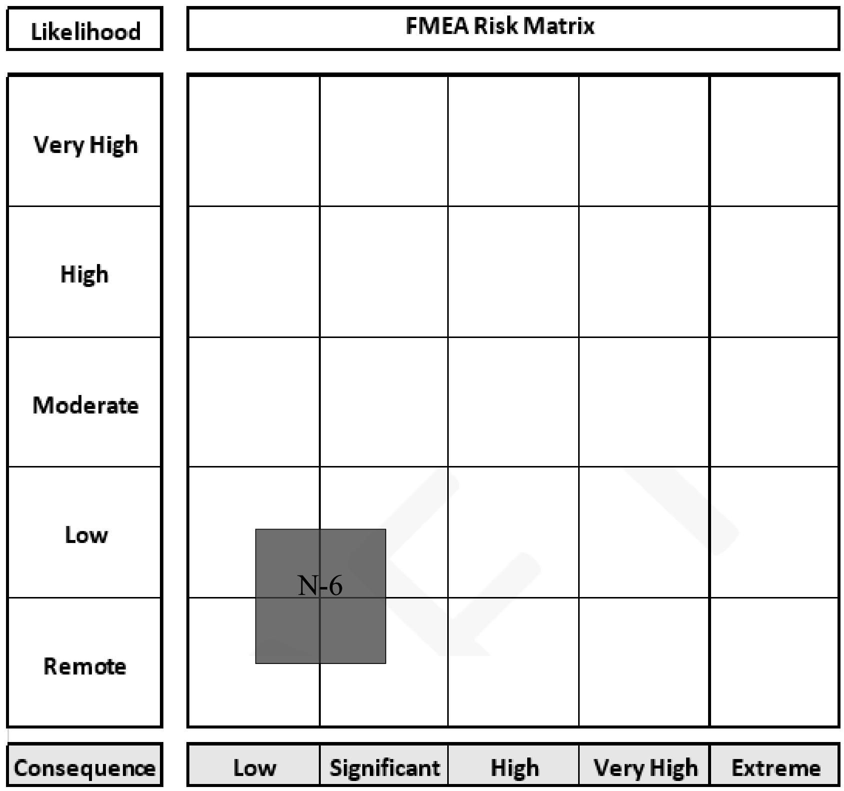


Figure 9: Risk Matrix for N-6

Risk Matrix Justification

This failure consists of a slope failure through the tailings embankment due to a weak layer in the embankment.

The failure progression is as follows:

- A continuous weak zone is created through the Main Embankment by either:
    - Placement of out-of-specification (e.g., fine-grained) material in multiple parallel cells at the same elevation, or
    - Inadequate compaction in multiple parallel cells for an extended period of time.
- The weak layer goes unnoticed as the embankment is raised, and a slip surface develops because the shear strength of the weak layer is exceeded
- The slope failure surface progresses upstream into the impoundment
- Embankment freeboard is lost and tailings are released downstream

Low to moderate likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- The centerline construction method with cellular placement of cycloned sand makes it unlikely that a continuous fines layer or uncompacted zone extending upstream to downstream at the same elevation can be constructed.
- The individual cells are of limited size and extent (approximately 300 ft by 100 ft) and are generally not all raised in parallel at the same time.
- There is a QA/QC program developed for the placement of the embankment materials.
- A series of operational errors or upsets would need to occur to generate this situation and there is a lot of industry experience with centerline tailings embankment construction where this has not happened.
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- Construction of the Main Embankment is a 40-year project, with multiple changes in ownership, operations, and personnel.
- There is a potential for finer material to be washed onto the surface of the embankment during a storm and create a more continuous weak layer.
- A shutdown could create a less dense layer that is not adequately recompacted (reworked).
- The cyclones for centerline construction have to operate in a specific range for adequate performance.

The potential consequence of this failure mode was rated significant with the following justification:

- The runout with this type of failure is not expected to extend very far. The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was moderate to high. Based on the proposed construction method, the development of a continuous weak layer is very unlikely, and additional information is not likely to change that.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve slope stability.
- Develop a QA/QC program for the tailings construction.
- Install wick drains / horizontal drains in the embankment for drainage.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- This condition should improve with time, so the risk post-closure is expected to be less.

N-7: Slope Instability through the Tailings Embankment at the Main Embankment due to High Porewater Pressure in the Embankment

The group estimated this PFM remote to moderate likelihood with a significant to high consequence.

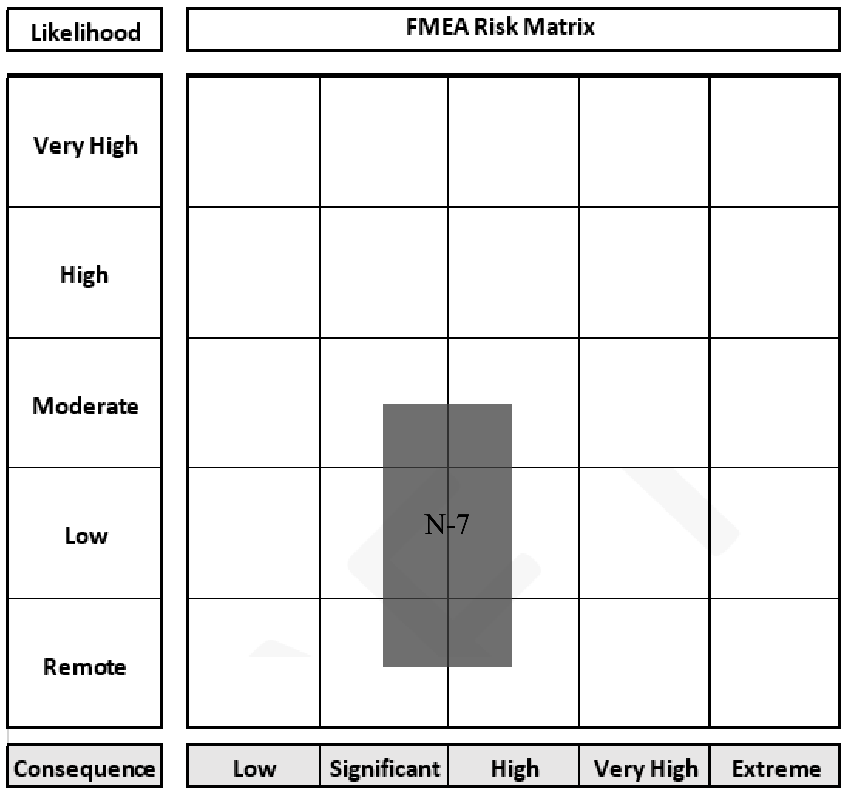


Figure 10: Risk Matrix for N-7

Risk Matrix Justification

This failure consists of a slope failure through the tailings embankment due to high porewater pressure in the embankment. N-7 is closely related to N-6.

The failure progression is as follows:

- During hydraulic fill placement, excessive fine or out of specification material is placed in multiple parallel hydraulic cells at the same elevation.
- The placement of the material goes unnoticed and creates a low permeability zone through the embankment.
- The embankment develops a high phreatic surface and seepage develops on the downstream slope through the layer of out of specification material.
- Static liquefaction occurs in the layer and a slip surface rapidly develops because the liquefied shear strength in the embankment layer is exceeded
- The slope failure surface progresses upstream into the impoundment
- Embankment freeboard is lost and tailings are released downstream

A remote to moderate likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- Inspections will be performed that could observe seepage on the downstream slope and initiate intervention.
- Similar to N-6, a series of operational errors or upsets would need to occur to generate this situation and there is a lot of industry experience with centerline tailings embankment construction where this has not happened.
- The operational issues that may lead to this failure are most likely to occur early in tailings construction, these issues would most likely be worked out in operations before the embankment is at higher elevations (later in construction).
- The starter dam may provide passive resistance against the development of this failure mode early in construction.
- There is a QA/QC program developed for the placement of the embankment materials.
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all of which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- Construction of the tailings embankment is a 40-year project, with multiple changes in ownership, operations, and personnel.
- It is possible the grind from the mill could change and finer tailings could be deposited.
- There is a potential for there to be an elevated pond level near the embankment (more likely in early years of operations).
- The underdrain system could become plugged over time and would be difficult to repair.
- There is a potential for uncompacted layers to develop during cellular construction.

The potential consequence of this failure mode was rated significant to high with the following justification:

- The runout with this type of failure is not expected to extend very far. The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. It was not clear how additional saturation of the slope may contribute to higher consequences. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve stability.
- Install wick drains / horizontal drains in the embankment for drainage.
- Develop and follow a Tailings Operation and Maintenance (O&M) Manual.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- There will not be water introduced through operations following closure, but there will be surface water routed over the pond in closure. The risk remains post-closure.

N-8: Slope Instability through the Tailings Embankment at the Main Embankment due to Deviation from Design Geometry or Excessive Raise Rates

The group estimated this PFM moderate likelihood with a significant consequence.

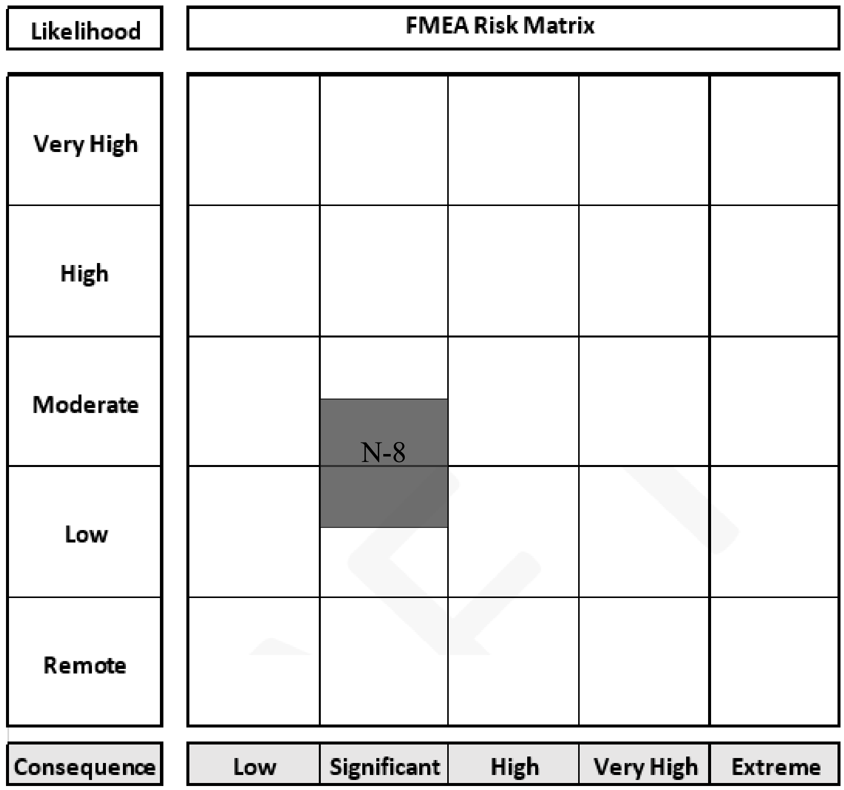


Figure 11: Risk Matrix for N-8

Risk Matrix Justification

This failure consists of a slope failure through the tailings embankment due to excess pore pressures resulting from deviations from the design geometry or excessive raise rates. This PFM is closely related to N-3, except the failure occurs through the embankment (versus the foundation).

The failure progression is as follows:

- Excess pore pressures develop in the Main Embankment caused by either:
    - A temporary deviation from design (example: oversteepening of hydraulic cells slopes), or
    - A local area of high construction raise rates is required (due to unforeseen circumstances),
- A slip surface develops in the foundation due to the elevated pore water pressures
- The embankment begins to move (fail) due to the excess pore water pressures
- The slope failure surface progresses upstream into the impoundment.

- Embankment freeboard is lost and tailings are released downstream.

As a result, the slope is constructed excessively steep and is less stable than designed. A slope failure develops through the embankment that extends back into the impoundment releasing tailings downslope.

A low to moderate likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- This type of embankment slope failure has never been observed in centerline constructed cyclone sand embankments
- There will be a Tailings O&M Manual.
- There is a management of change procedure (per ICMM).
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- Construction of the tailings embankment is a 40-year project, with multiple changes in ownership, operations, and personnel.
- There is a potential for regulatory changes and lack of regulatory capacity or experience of staff.
- There is no dam safety oversight of tailings dams or embankments in Arizona.
- Fluctuation in the cost of copper can cause a break in operations.
- There can be a shortage of qualified staff to work on tailings dams.
- Upsets in production, or errors or omissions in quality control and assurance program(s).

The potential consequence of this failure mode was rated significant with the following justification:

- The runout with this type of failure is not expected to extend very far. However, considering the saturated slope associated with this failure the runout could extend further than for the other failure modes.
- The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage, and with the further runout the environmental damage could be high. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

The confidence in the likelihood estimate during the 2020 workshop was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve slope stability.
- Comply with the Arizona Aquifer Protection Permit (APP).
- Implement change of management procedures.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- The risk associated with this failure mode will remain the same or less post-closure.

N-9: Internal Erosion through the Foundation at the Starter Dam

The group estimated this PFM moderate likelihood with a significant to high consequence.

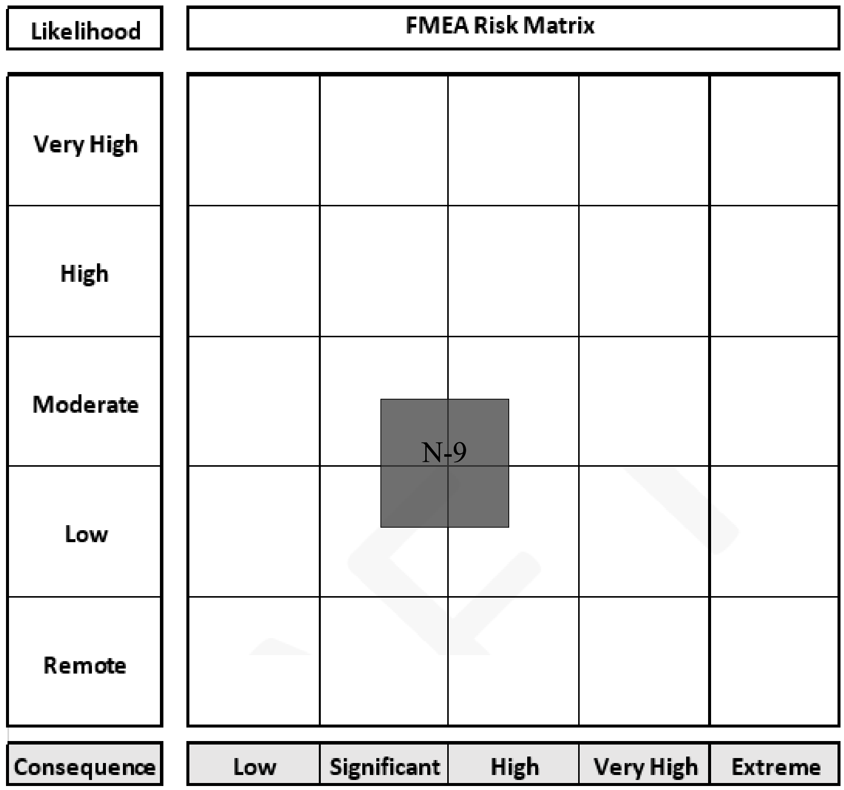


Figure 12: Risk Matrix for N-9

Risk Matrix Justification

This PFM consists of an internal erosion failure through the foundation at the starter dam for the Main TSF, during the first 5 years of operation. Many internal erosion failure modes were discussed, but under most normal operation scenarios for the impoundment, the pond is located too far from the exterior slope to consider internal erosion a plausible failure. However, during approximately the first 5 years of operation a pond will be maintained against the starter dam. The group felt the most plausible internal erosion failure scenario was internal erosion of embankment material from the Main Embankment starter dam into a defect in the foundation.

The failure progression is as follows:

- The Main Embankment starter dam and foundation materials are filter incompatible (in other words, particles from the starter dam can wash into the voids of the foundation materials)
- Internal erosion of embankment material from the starter dam into a defect in the foundation occurs
- The erosion continues, leading to a sinkhole on the slope of the Main Embankment
- The sinkhole enlarges and a breach of the starter dam occurs

- The pond and impounded tailings are released

A low to moderate likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- Under most normal operation scenarios for the impoundment after the first few years, the pond is located too far from the exterior slope to consider internal erosion a credible failure
- The starter dam will be designed to be filter compatible with the tailings
- The starter dam will have a trapezoidal cross-section (longer seepage path)
- Underdrains are proposed for below the starter dam and cyclone sand embankment and the foundation is highly permeable
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond during startup
- Cyclone sand placed on the downstream side of the starter dam, will act as a downstream filter
- Instrumentation and monitoring will facilitate observational method (there are not brittle materials at this site, thus more slowly developing failure)

Key Adverse Factors

- Could just develop a concentrated leak through the foundation defect and may not be able to hold the pond.
- There is a potential for unknown or undiscovered variability in the foundation (paleo channel, coarse material, fractured Gila) that may be difficult to detect during start up.
- Startup conditions are inherently complex.
- Startup conditions typically use more water and it is harder to control the water balance.

The potential consequence of this failure mode was rated significant to high with the following justification:

- Because the starter dam will impound a larger pond, closer to the exterior slope during initial operation, the consequences from this failure were seen as potentially greater than for the previously postulated failures that occur later in operation.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage, and with the further runout the environmental damage could be high. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

The confidence in the likelihood estimate during the 2020 workshop was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses would better characterize the inundation zone providing a better understanding of the consequences.

Potential Risk Reduction Measures and Additional Information

- Install a cutoff wall in the alluvium under the embankment to reduce foundation seepage.
- Add a filter along the foundation contact to prevent internal erosion from initiating.
- Install backup pumps to lower the pond level.
- Develop a contingency plan for this scenario.
- Maintain pond management and control of the water balance.
- Perform QA/QC during construction and operations.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- The risk is not relevant during post-closure.

N-10: Pipeline Rupture at the Main Dam Leads to Erosion and Dam Release of Tailings

The group estimated this PFM to have a moderate likelihood with a low to significant consequence.

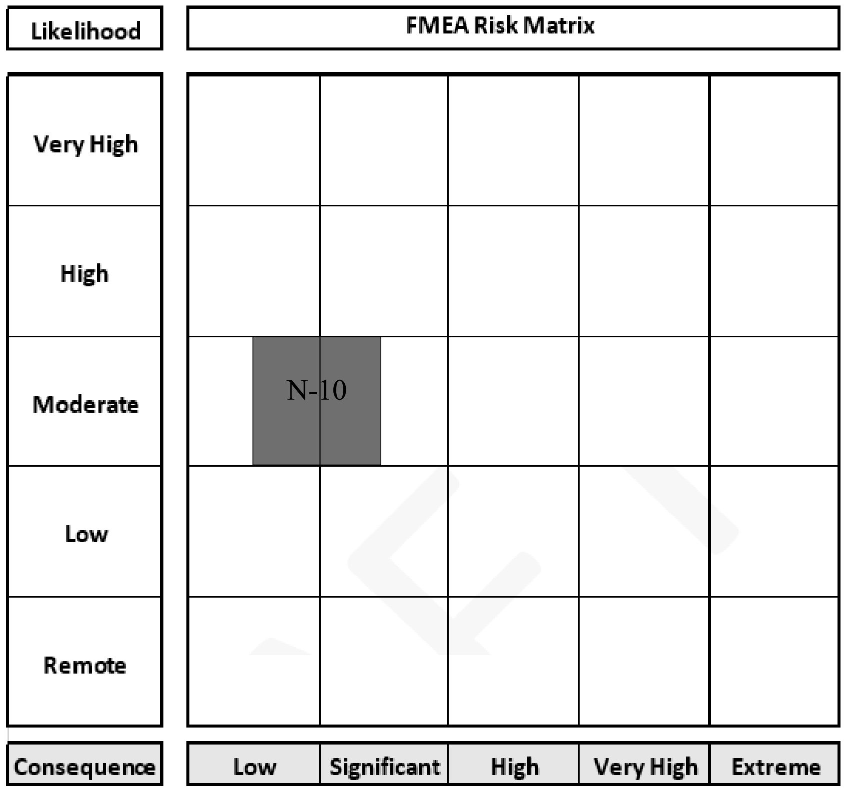


Figure 13: Risk Matrix for N-10

Risk Matrix Justification

This failure mode consists of rupture of a pipeline at the Main Embankment which leads to erosion of the slope and release of tailings. This PFM differs from other failure modes as the failure itself is expected to be a "V" shaped erosional feature.

The failure progression is as follows:

- A cyclone sand pipeline ruptures near the crest of the embankment.
- Cyclone sand and water are released onto the slope.
- Erosion of the slope develops rapidly and continues unnoticed.
- Enough erosion occurs on the slope to retrogress back into the impoundment
- A failure of the embankment occurs and tailings are released downstream.

A moderate likelihood was estimated by the group based on key factors listed below.

Key Positive Factors

- The embankment crest is 150 feet wide, so a lot of erosion would need to occur before reaching the impounded tailings.
- Operators will be able to see a pipe break.
- Monitoring would detect a loss in pipeline pressure.
- Pipeline preventative maintenance is planned.
- Response to this failure is covered in the O&M Manual.
- The cycloned sand slurry requires pumping to reach the construction cells and flow can be more quickly controlled or stopped in the event of a break (compared to a gravity feed system). The pipes are generally discharging into the construction cells, so tailings from a rupture lower on the embankment would be released into and contained by the cells.

Key Adverse Factors

- The tailings sand is very erodible.
- This type of pipeline break does occur due to wear and other factors.
- Operations occur at night and a break may be harder to detect.
- The cyclone sand is abrasive and will wear out the pipelines.
- Construction of the tailings embankment is a 40-year project, with potential multiple changes in ownership, operations, and personnel.

The potential consequence of this failure mode was rated low to significant with the following justification:

- The expected release from this failure would be less than that from other similar PFMs (N-1, N-2, N-3).
- If there is less erosion and the failure does not result in a full breach of the embankment, the consequences are expected to be less.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage, and with the further runout the environmental damage could be high. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

The confidence in the likelihood estimate during the 2020 workshop was moderate. Rupture of tailings delivery lines do occur, but it was considered unlikely for a rupture of the pipeline to lead to a significant embankment failure. However, the impoundment has not been constructed at this time so there is little information on actual operations and the potential for a rupture to go unnoticed.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although the extent of the consequences would depend on how long the erosion occurs and the magnitude of the embankment failure.

Potential Risk Reduction Measures and Additional Information

- Relocate the pipeline from the slope of the embankment to the abutment and the downstream toe of the embankment.
- Use steel pipeline in critical locations.
- Install automatic shutoff valves on the pipe.
- Plan pipeline distribution routing to keep the cyclone sand pipeline and the overflow sand pipelines separate, so rupture of one does not impact the other.
- Develop an operational plan for moving the pipelines.
- Perform regular inspection and maintenance on the pipelines.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- The risk is not relevant during post-closure.

2.4.3. Seismic Loading Conditions

S-1: Slope Instability through the Foundation at the Main Dam due to Strength Loss during a Seismic Event

The group estimated this PFM low to moderate likelihood with a very high consequence.

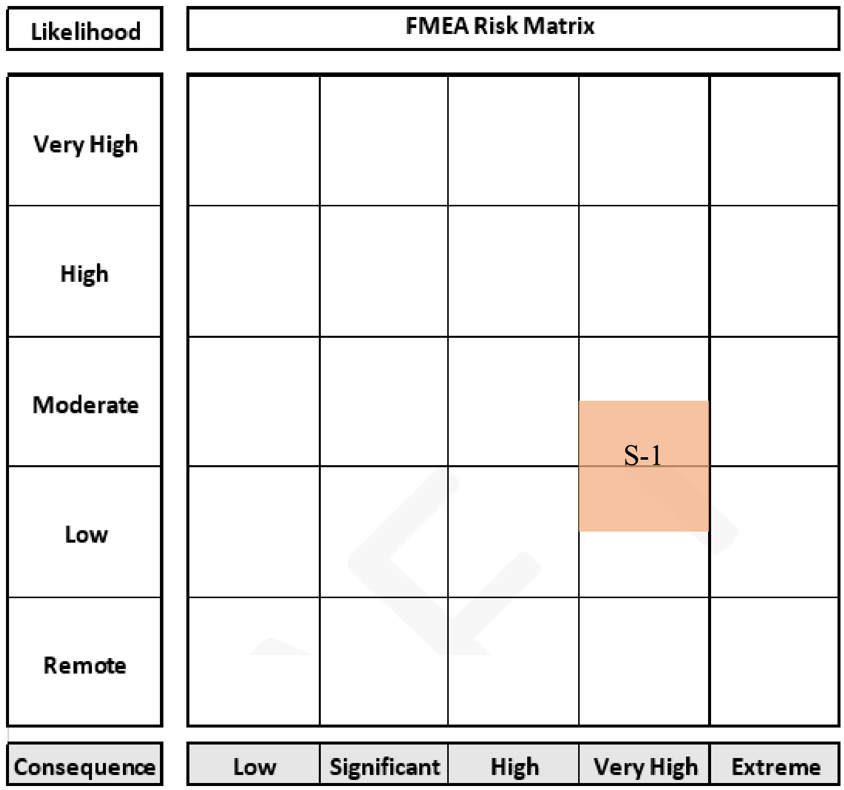


Figure 14: Risk Matrix for S-1

Risk Matrix Justification

This PFM is very close to the N-1 and N-2 failure modes with the addition that the trigger is seismicity (an earthquake). This PFM assumes a zone of liquefiable material is present within the Main Embankment or a layer within the foundation is liquefiable.

The failure progression is as follows:

- The lower portion of the embankment, alluvium and upper portion of the underlying Gila formation will be saturated from operations for liquefaction to occur.
- An earthquake triggers liquefaction of a layer in either the embankment or foundation
- The shear strength of the liquefiable layer is exceeded
- The embankment begins to move (fail) on the liquefied layer.
- The slope failure surface progresses upstream into the impoundment.
- Embankment freeboard is lost and tailings are released downstream

The above are expected to occur more rapidly than under the normal loading case.

The justification used for the low to moderate likelihood was based on the factors listed below.

Key Positive Factors

- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials. Stability analysis assumes all the impounded tailings have been liquefiedSimplified deformation analysis using pseudostatic coefficient, ka = 0.6 x Peak Ground Acceleration for failure modes not involving liquefiable materials, analysis showed deformation on the order of inches.
- The site is considered suitable for a tailings embankment; with a relatively permeable foundation, low seismicity, negative water balance, dense granular soils, and well understood geology. Additionally, the alluvium is not continuous across the embankment foundation.
- Site investigations have shown that the alluvium and Gila are dense. Typical SPT values of 40 to 50 blows per foot (bpf), lowest values ~25 bpf (for dry conditions). The likelihood of liquefiable materials present in either the embankment or foundation is low.
- There has been a site-specific Seismic Hazard Analysis (SHA) performed indicating relatively low seismicity and the design criteria include a return period of 1 in 10,000 years. Proposed treatment or removal of potentially weak (or liquefiable) foundation material, if encountered
- The cycloned sand Main Embankment will be raised using the centerline method and with compacted hydraulic cells
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures

Key Adverse Factors

- The Gila is considered a weak rock, so amplification of the accelerations should be applied to the ground motion.
- There is a potential for the Gila to soften over time with wetting.
- The foundation conditions are heterogeneous and potentially highly variable.
- There is a surficial Quaternary pediment layer with potential low strength zones present at the ground surface in some areas of the site (note that, it is intended to be removed as a part of foundation preparation for the embankment).
- The alluvium and upper Gila are likely to become saturated from tailings deposition
- Construction of the tailings embankment is a 40-year project, with potential multiple changes in ownership, operations, and personnel
- There is a potential for unknown or undiscovered paleo channels (potential seepage pathways) in the foundation
- There is a potential for concurrent failure of both the PAG cell embankments during a seismic event, this would increase the consequences

The potential consequence of this failure mode was rated very high with the following justification:

- The runout for failure is expected to be similar for the normal case, but some of the group felt it may extend further due to the liquefaction of the tailings.

- Both a potential for loss of life and environmental damage contributed to the consequence estimate. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected. It is also possible that a failure of the embankment would runout to the Gila River and would impact the water quality in the river.
- Potentially higher consequences could occur if the PAG cell embankment was to fail concurrently with the Main Embankment.

Confidence

Confidence in the likelihood estimate was moderate. The seismic analysis for the embankment conservatively assumed the impounded tailings will liquefy during an earthquake. There is some uncertainty on whether the foundation materials are actually potentially liquefiable. Additional site investigation may provide information that could change the likelihood estimate.

The confidence in the consequence estimate during the 2020 workshop was moderate. It seems clear that some environmental damage would occur as a result of this failure. It was not clear how additional saturation and liquefaction of the slope may contribute to higher consequences. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes.
- Perform additional foundation investigation to further characterize the potential for liquefaction.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- Drain down of the impoundment may improve the condition post-closure but should still be monitored following closure.

S-2: Slope Instability through the Foundation at the Main Dam due to Terrain Instability at the Abutments during a Seismic Event

The group estimated this PFM to have a low likelihood with a significant consequence.

Likelihood	FMEA Risk Matrix				
Very High					
High					
Moderate					
Low		S-2			
Remote					
Consequence	Low	Significant	High	Very High	Extreme

Figure 15: Risk Matrix for S-2

Risk Matrix Justification

This failure is a variation of N-4 with a seismic trigger reactivating a preexisting (ancient) landslide on the rim or abutment of the tailings impoundment. For this to occur, an undetected existing landslide would need to be present at the impoundment (specifically near the abutments of the Main Embankment).

The failure progression is as follows:

- The toe of the existing landslide deposit within the foundation become saturated by the new tailings impoundment or seepage from diversion ditches.
- The landslide is reactivated and the movement causes the Main Embankment to deform which in turn leads to a slope failure.
- As the landslide progresses, embankment freeboard is lost and tailings are released downstream

A low likelihood was estimated by the group based on key factors listed below.

Key Positive Factors

- There are no mapped landslides at the site.
- Large, major landslides in Arizona are generally slow moving so there is likely to be sufficient time to implement appropriate mitigation measures.
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials. Stability analysis assumes all the impounded tailings have been liquefied.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- Wildfire in the area could exacerbate the potential for landslides by increasing infiltration.
- The foundation conditions are heterogeneous and potentially highly variable.
- The alluvium and upper Gila are likely to become saturated, and there is a potential for paleo channels in the foundation which are potential seepage paths.
- The landslides can be difficult to detect, there are subtle landforms, and if a landslide was detected, it is difficult to stabilize.

The potential consequence of this failure mode was rated significant with the following justification:

- The slope failure through the embankment may be limited to the upper portion of the embankment because the landslide is more likely to impact the embankment near the abutments where there is less buttressing effect on the landslide.
- The runout with this type of failure is not expected to extend very far. However, considering the saturated slope associated with this failure the runout could extend further than for the other failure modes.
- The nearest PAR is approximately 4 miles from the impoundment, with the potential exception of operators on site.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was low to moderate. A site investigation and reconnaissance has been performed and did not identify any ancient landslides; however, it is not uncommon for ancient landslides to be overlooked.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Install a liner in the diversion channels or relocate ditches away from impoundment.
- Perform in-situ mitigation of any active landslides.
- Buttress any identified landslides to prevent movement.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- Risk for this failure mode is considered similar under post-closure condition. May be slightly less due to drained down conditions.
- Preventative maintenance should be performed at the impoundment, including during post-closure. InSAR could be used to monitor for slope movements, continuing during post-closure.
- Site inspections should be continued following closure.

S-3: Slope Instability through the Tailings Embankment during a Seismic Event

The group estimated this PFM low likelihood with a significant to very high consequence.

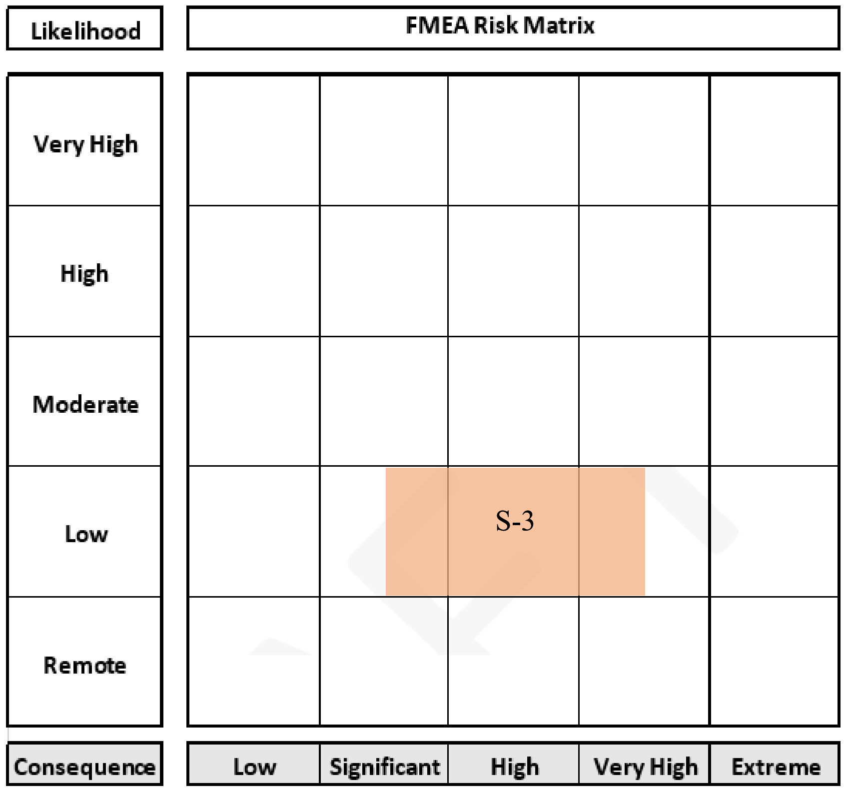


Figure 16: Risk Matrix for S-3

Risk Matrix Justification

This PFM consists of a slope failure through the tailings embankment due to liquefaction in the embankment during an earthquake. This PFM is the seismic version of N-6, requiring similar conditions, but with a seismic trigger (liquefaction).

The failure progression is as follows:

- Perched water is present in the embankment which causes saturated zones.
- During an earthquake the saturated zones liquefy, reducing the shear strength of this layer within the Main Embankment
- The shear strength of the liquefied tailings is exceeded, and a slip surface develops
- The slope failure surface progresses upstream into the impoundment
- Embankment freeboard is lost and tailings are released downstream

A low likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- Inspections will be performed that could observe seepage on the downstream slope and initiate intervention.
- The operational issues that may lead to this failure are likely to occur early in tailings construction and would likely be resolved in operations before the embankment is at higher elevations (later in construction).
- The starter dam may resist this failure mode in early years of operations.
- There is a QA/QC program developed for the placement of the embankment materials.
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials. Stability analysis assumes all the impounded tailings have been liquefied.
- A simplified deformation analysis using pseudostatic coefficient, ka = 0.6 x Peak Ground Acceleration for failure modes not involving liquefiable materials.
- The thickened tailings reduce process water into the impoundment, there are operational controls in place to maintain a minimal pond, and an underdrain system will be constructed beneath the embankment; all which reduce the infiltration and potential for high pore pressures to develop.

Key Adverse Factors

- Construction of the Main embankment is a 40-year project, with multiple changes in ownership, operations, and personnel.
- There is a potential for finer material to be washed onto the surface of the embankment during a storm or during shutdown and create a more continuous less permeable or weak layer.
- There is a potential for a temporary shutdown, potentially creating an inadequately prepared layer in the embankment.
- The embankment sand is of a grain size that is potentially liquefiable.
- There is a potential for concurrent failure the PAG cell embankment(s) during a seismic event, this would increase the consequences.

The potential consequence of this failure mode was rated significant to very high with the following justification:

- The runout for failure is expected to be similar for the normal case, but some of the group felt it may extend further due to the liquefaction of the tailings, and could impact the Gila River.
- Both a potential for loss of life and environmental damage contributed to the consequence estimate. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.
- Potentially higher consequences could occur if the PAG cell embankment was to fail concurrently with the Main Embankment.

Confidence

Confidence in the estimate for likelihood was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. It was not clear how additional saturation and liquefaction of the slope may contribute to higher consequences. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve slope stability.
- Install wick drains / horizontal drains in the embankment for drainage.
- Develop and follow a Tailings Operation and Maintenance (O&M) Manual.
- Prepare and exercise an Emergency Action Plan (EAP).
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop and early warning system in additional to the EAP.

Post Closure Considerations

- The risk for this failure mode should decrease in post-closure condition. The impoundment will drain down over time.

2.4.4. Hydrologic Loading Conditions

H-1: Slope Instability at the Main Dam due to High Porewater Pressure in the Embankment following a Hydrologic Event

The group estimated this PFM remote to low likelihood with a high to very high consequence.

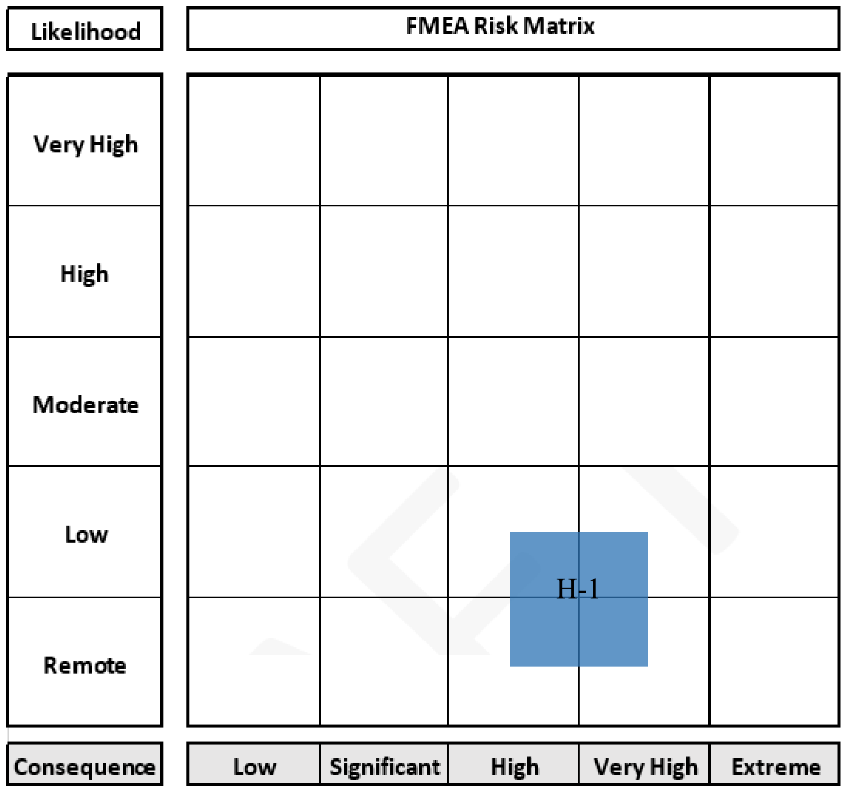


Figure 17: Risk Matrix for H-1

Risk Matrix Justification

This failure consists of a slope failure through the tailings embankment due to high porewater pressure in the embankment during the first 5 years of operation.

The failure progression is as follows:

- A storm causes a rise in the pond level
- A high phreatic surface develops in the embankment and seepage develops on the downstream slope.
- Either an erosion gully on the downstream slope develops, retrogressing back towards the impoundment, or
- The elevated pore water pressures cause a slip surface to develop along a low strength layer in the embankment
- The above causes a slope failure through the embankment

- The slope failure surface progresses upstream into the impoundment
- Embankment freeboard is lost and tailings are released downstream

. The failure mode is considered most plausible during the first 5 years of operation because a larger pond will be maintained in the impoundment during early operation. In later years of operation, the pond will be small and maintained a large distance from the exterior of the impoundment, even under a PMF condition.

A remote to low likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- There will be instrumentation and monitoring of the embankment pore pressure
- The design downstream slope angle is 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring).
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- The cycloned sand Main Embankment will be raised using the centerline method and with compacted hydraulic cells There is a QA/QC program developed for the placement of the embankment materials.
- The flood / high pond is a temporary condition.
- There are reclaim pumps and stand-by pumps on site to pump out the pond.

A low likelihood was selected by the group based on key factors listed below.

Key Adverse Factors

- There is potential for there to be an elevated pond level near the embankment.
- The drains could become plugged over time, be difficult to repair (less likely in the first 5 years).
- There is a potential for uncompacted layers in the cellular construction.
- This is similar to a first filling.
- It will take time to pump the pond down.
- The tailings will be in a less consolidated state.
- Climate change could make the potential flooding worse.

Due to the presence of the pond the potential consequence of this failure mode was rated high to very high with the following justification:

- Because the starter dam will impound a larger pond, closer to the exterior slope during initial operation, the consequences from this failure were seen as potentially greater than for the previously postulated failures that occur later in operation. There will also be additional water in the impoundment from the flood.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage, and with the further runout the environmental damage could be high to very high.
- A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood. Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Flatten the slopes to improve stability.
- Develop and follow a Tailings Operation and Maintenance (O&M) Manual.
- Prepare and exercise an Emergency Action Plan (EAP).
- Increase the diversion channel design criteria to convey storms larger than the 100-yr event.
- Make additional pumps available and develop plan for removing water in the event of large forecasted storms.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- The risk is not applicable in the post-closure condition.

H-2: A Diversion Ditch Fails during a Storm Event leading to Erosion of the Main Embankment

The group estimated this PFM to have a remote to low likelihood with a significant consequence.

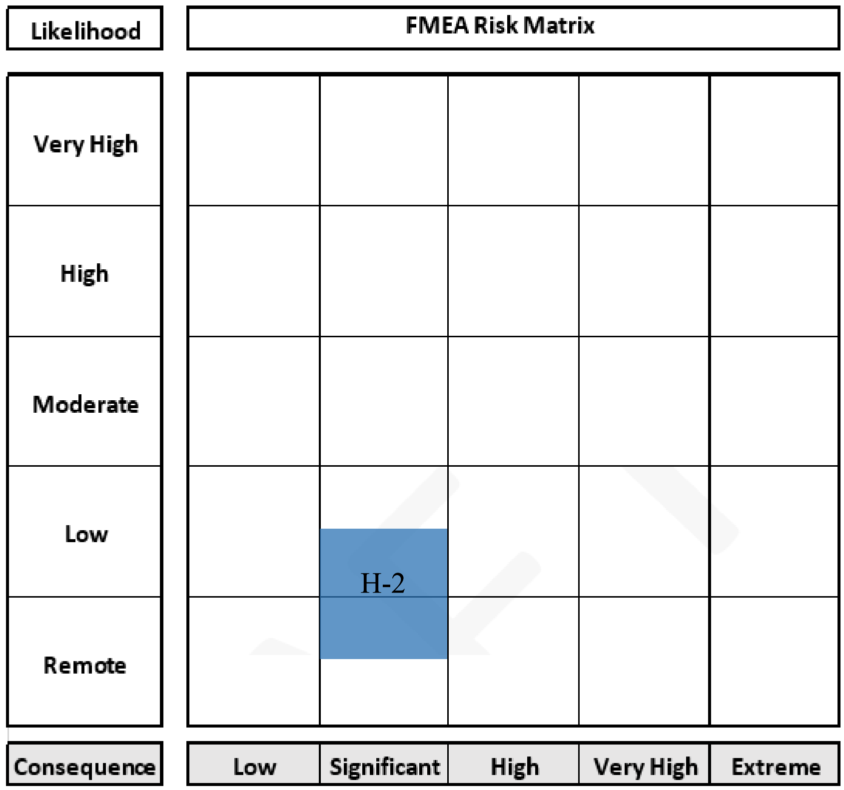


Figure 18: Risk Matrix for H-2

Risk Matrix Justification

This failure mode consists of erosion of the embankment due to a diversion channel failure during a storm.

The failure progression is as follows:

- A flood occurs with the diversion channels flowing full
- A section of a diversion channel fails near the abutment of the Main Embankment
- Water is released on to the groin of the embankment and onto the slope
- Erosion of the slope develops rapidly and continues unnoticed
- Enough erosion occurs on the slope to lead to a failure of the Main Embankment and tailings are released downstream

A low likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- A scour assessment will be completed for the channels, and a portion of the channels maybe be armored (there is an allowance to armor the channels at this stage of the project).
- The channels are largely in the Gila which is erosion resistant.
- The channels are in cut, so there is potentially additional freeboard.
- The exposure length of the channel that would impact the embankment is short.

Key Adverse Factors

- The sand is erodible.
- Operations occur at night and erosion may go unnoticed for a period of time.
- Construction of the tailings embankment is a 40-year project, with potential multiple changes in ownership, operations, and personnel.

The potential consequence of this failure mode was rated significant with the following justification:

- The release from this failure is expected to be less than that from other embankment PFMs because it is not expected to result in a full breach.
- The tailings from this failure are expected to stay in the Dripping Springs Wash.
- The primary concern is environmental damage, and with the further runout the environmental damage could be high. A failure will impact Dripping Springs Wash, and habitat and vegetation damage would be expected.

Confidence

Confidence in the estimate for likelihood was moderate. It appears to be a plausible failure mode, but there is still uncertainty in the design of the channels adjacent to the embankment and the potential for a failure to occur directly adjacent to the embankment.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although the extent of the consequences would depend on how long the erosion occurs and the magnitude of the embankment failure.

Potential Risk Reduction Measures and Additional Information

- Develop and use a Tailings O&M Manual.
- Increase the diversion channel design criteria to convey storms larger than the 100-yr event.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- The channel will be relocated for post-closure conditions. The channel location during post-closure will be designed to convey the PMF and will be further from the embankment. Risk should be lower during post-closure but should continue to monitor and maintain.

2.4.5. PAG Loading Conditions

PAG N-1: Slope Instability through the Foundation at the PAG Dam due to a Weak Foundation Layer

The group estimated this PFM to have a low likelihood with a very high consequence.

FMEA Risk Matrix

Likelihood					
Very High					
High					
Moderate					
Low				PAG N-1	
Remote					
Consequence	Low	Significant	High	Very High	Extreme

Figure 19: Risk Matrix for PAG N-1

Risk Matrix Justification

This failure consists of a slope failure initiating through the foundation at the PAG Embankment under the following conditions:

- An undetected weak layer is present in the foundation below the Main Embankment.
- The upper portion of the alluvium and Gila in the foundation below the Main Embankment will be saturated from operations.

The failure progression is as follows:

- As the PAG embankment is raised, a slip surface develops because the shear strength in the weak foundation layer is exceeded due to either an unidentified weak layer or high pore pressures developing (or both).
- The embankment begins to move (fail) on the weak layer.
- The slope failure progresses upstream into the PAG impoundment

- Embankment freeboard is lost, releasing water and tailings into the Main (scavenger) impoundment.
- The Main Embankment is overtopped and fails, releasing both PAG and scavenger tailings downstream.

This PFM was postulated to occur in the first 5 to 10 years of operation of the PAG Cell 1, because this was considered the timeframe that the PAG Embankment would store enough water relative to the Main impoundment to cause a cascading failure. At other times there would be enough storage in the Main impoundment to capture all the PAG Embankment release or eventually the PAG Embankment will be buttressed or covered by the scavenger tailings.

A low likelihood was selected by the group based on key factors listed below.

Key Positive Factors

- The design downstream slope angle is 2.5H:1V with a design FoS greater than 1.5 for slope failure under static conditions.
- Proposed removal of near-surface weak foundation materials (e.g., Quaternary pediment), if encountered
- PAG embankment is progressively buttressed by scavenger tailings
- Low-permeability liner reduces the potential for high water pressures in the foundation
- Instrumentation and monitoring are planned for the PAG Embankment
- The design is for two PAG cells working in succession to limit pond size
- The pyrite tailings may plug defects in the liner (~85% fines)

Key Adverse Factors

- The foundation is heterogeneous and potentially highly variable.
- The downstream toe of the PAG Embankment will be saturated by pond water from the scavenger beach
- The embankments will be constructed such that it allows for a cascading failure (PAG into Main Impoundment)
- Requires strict operational control and planning / sequencing
- Installing the liner in the basin will be difficult, potential for damage and leakage through the liner
- A free pond is maintained in the PAG pond during operations
- In the first 5-10 years the Main Impoundment is not able to store the PAG contents
- The release from the PAG Embankment into the Main Impoundment could create a wave

The potential consequence of this failure mode was rated very high with the following justification:

- There is more water in the PAG Embankment that will be released and will result in further runout, thus failure releases are expected to reach the Gila River.
- Pyrite tailings will have higher environmental consequences. The estimate is based primarily on the environmental and economic damages.
- The potential for direct loss of life is considered very low to remote, but there may be some indirect loss of life.

Confidence

Confidence in the estimate for likelihood was moderate. Based on the design and available information this failure is unlikely; however, at this stage of the project, additional information could come to light that could change the estimated likelihood.

Confidence in the consequence estimate was moderate. It seems clear that some environmental damage would occur as a result of this failure. Although further embankment break or runout type analyses could add additional information to the inundation zone and a better understanding of the magnitude of consequences.

Potential Risk Reduction Measures and Additional Information

- Overbuild the Main Embankment to contain the potential release from the PAG Embankment
- Evaluate the required water depth on the pond to maintain saturation / prevent oxidation
- Perform foundation treatment
- Reconfigure the PAG cells to reduce the volume in each of the cells and prevent potential overtopping of the Main Embankment.
- Install diversion berms downstream to catch, slow down, or divert a tailings release.
- Purchase downstream properties.
- Develop an EAP and early warning system.

Post Closure Considerations

- The risk is not applicable in the post-closure condition.

2.5. Potential Failure Modes Not Developed in the FMEA

Additional PFMs were postulated during the brainstorming and FMEA workshop but were not carried forward to full development because they were found to be so unlikely as to be considered non-plausible. These failure modes were not carried forward to the FMEA for further discussion and estimation of likelihood and consequences. The failure modes that were not carried forward are listed below along with a justification for not discussing them further.

PFM	Justification for Not Developing
Static slope failure through the tailings embankment due to insufficient material to construct the embankment design.	*This is not an operational concern, it was determined there will be sufficient cyclone sand and if there is not, tailings deposition rates could be adjusted until there is additional borrow material available.*
Static slope failure of the tailings embankment due to physical or chemical degradation of the embankment.	*This was suggested because a similar failure occurred at Brumadinho. However, based on the ore and design, and the climate, this is not expected to be an issue at this site. However, clogging of the drains could be an issue and is addressed in a separate failure mode.*
Inadequate beach distance and supernatant pool saturates the embankment which leads to a slope failure and a release of tailings.	*This failure mode was not developed on its own but was considered as a factor in failure mode N-7 (Embankment failure due to rise in the phreatic surface).*
Saturation at the toe of the natural slope in the (Gila Conglomerate) causes impoundment or abutment slope failure causing a seiche wave and overtopping.	*This failure mode is not possible, there is not enough water in the main embankment to generate a wave that can overtop the embankment.*
Inadequate beach development occurs due to spigotting or operations allowing for the free water reclaim pond to impound against the cyclone sand embankment, causing excess seepage and an elevated phreatic surface that expresses on the downstream slope of the embankment.	*The centerline raise method of construction is less sensitive to plunge pool development, which is typically associated with depositional issues that are more commonly associated with the upstream raise method of construction. This failure mode was considered as a factor for failure mode N-7.*

PFM	Justification for Not Developing
Mill grind is finer than anticipated which leads to a finer tailings beach and an upstream failure of the embankment raise and a release of tailings.	*This is an operational failure mode and would not lead to a embankment safety incident, because it is not likely the failure plane would extend through the embankment and release tailings. The consequences of this failure would not be significant and are covered in the tailings O&M Manual.*
Poor compaction and an elevated water content in the cyclone sands leads to static liquefaction of a portion of the embankment fill causing slope failure and a release of tailings.	*This potential failure mode was covered under failure of embankment due to a rise in the phreatic surface (N-7).*
Failure due to internal erosion or piping of the embankment.	*This was determined not to be possible. The embankment sand would not hold a crack and would also not hold a roof. This failure would require a pond against the cyclone sand for a long time to develop a phreatic surface which is very unlikely to occur. Erosion could be initiated at the downstream slope, but the sand would collapse on its self.*
A storm event exceeding the diversion design capacity causes overtopping in the diversion ditch in proximity to the embankment abutment which leads to overtopping of the embankment.	*The tailings impoundment has the capacity to store the entire PMF for the whole catchment. It should be noted that climate change could impact future storm events and storage. A separate failure mode initiated by releases from the diversion ditch onto the downstream groin of the embankment was considered (PFM H-1)*
Blockage of the closure channel results in the overtopping of the closed impoundment.	*Because of the climate in Arizona, this condition seems unlikely to occur. The impoundment can store the PMF inflow and does not overtop the embankment.*
Tailings surface settlement during closure cause the surface grade of the tailings beach to route water towards the embankment, instead of towards the closure surface diversion channel (upslope of the tailings impoundment), which results in overtopping of the embankment and deep erosion gullying.	*This failure mechanism would require a lot of settlement and was not considered likely to go unnoticed and advance to the state described in the PFM description. It should be noted that there is still a need to discuss drainage maintenance and monitoring for settlement in the closure plan.*

PFM	Justification for Not Developing
A slope failure along the pipeline corridor prevents reclaim water from being pumped back to the mill after a major storm event. A storm event has raised reclaim pond levels and there is nowhere (or way) to remove the water from the pond(s) due to landslide shutting down the return water pipeline for an extended period of time. A second storm then overtops the facility.	*This failure mode would require sequential extreme events which is not considered r plausible. Evaluations should still be done to consider how long operations can be maintained if the reclaim pipeline is out of service on site.*
A storm event larger than the design storm event could overtop the embankment during the early stages of embankment construction due to inadequate freeboard.	*The starter dam is designed to store rain in excess of the PMF, so larger storms are not considered plausible.*
Failure of the Pyrite Acid Generating (PAG) cell into the main scavenger embankment causes overtopping of the main embankment.	*This failure mode was not considered because there is sufficient volume in the main embankment to contain all of the PAG water. During the initial years of operation, this could be a concern and is covered in failure mode PAG N-1.*
Groundwater induced subsidence from the seepage control mitigation measures in the compressible alluvium creates aquifer compaction and differential settlement beneath the embankment resulting in tensile stress and deformation in the embankment, leading to a slope failure and a release of tailings.	*This failure mode does not seem likely as the alluvium in this region is at a maximum depth of 70 feet and is not saturated at this site.*
Saturation of compressible alluvium from seepage, settlement and consolidation of the compressible alluvium under normal loading of the tailings and the embankment, resulting in differential settlement and deformation of the embankment, leading to a slope failure and a release of tailings.	*Historically, the alluvium has not been saturated at this site. Additionally, there is a limited thickness of alluvium.*

PFM	Justification for Not Developing
Tailings raise rate is too high which induces a static liquefaction condition in soft contractile zones, leading to a slope failure and a release of tailings.	*The impoundment design itself assumed some liquefaction would occur. Embankment material will be constructed in cells to a non-dilative density. Drains would need to not be working as well for this failure to occur because at least partial level of saturation is needed in order to initiate static liquefaction. Quality control of the embankment should be maintained during construction to ensure that compaction is adequate.*
Liner leakage causes higher than anticipated seepage gradients into the scavenger impoundment area which leads to a high phreatic surface and instability.	*This failure mode is unlikely to occur. There is approximately 5 to 10 feet of water in the Pyrite cell as well as a long beach on the scavenger pond. Both of these are unlikely to create instability in the main embankment.*
Available cyclone sand volumes are less than expected which limits the ability to respond to elevated pore pressures by flattening the downstream slope of the embankment for mitigation resulting in embankment failure.	*This failure mode would require significant incorrect assumptions in design and is unlikely to occur. However, there is a need to identify borrow material or stockpile additional material if it is needed on site.*
Unknown mine workings lead to seepage of tailings, which creates piping and internal erosion.	*There are currently no mine workings under this site.*
Poor water management of the mine leads to overtopping of the embankment.	*It is possible to limit the amount of fresh water the mill receives if there is a water balance issue on site.*
An earthquake causes failure of appurtenant structures, such as pipeline alignment, abutment failure or impoundment failure. However, failure of the appurtenant structures causes the inability to remove water from the impoundment resulting in insufficient freeboard, which results in overtopping.	*It was not considered possible for this to lead to a embankment failure, but there is a need to evaluate how long mine operations can be maintained if the reclaim pipeline is out of service.*
Slope failure during to an earthquake due to cracking through the foundation specifically due to fault offset.	*This failure mode is not considered plausible. A recent evaluation done by Lettis states that there is no evidence of fault offset in the quaternity alluvium, suggesting no recent fault displacement. However, a report generated by M&A in 2018 referenced a 1970s USGS map that suggested there was offset in the quaternity alluvium. It may be an option to perform a fault trench in order to reconcile the difference in opinion between the old and new reports.*

3. Conclusions

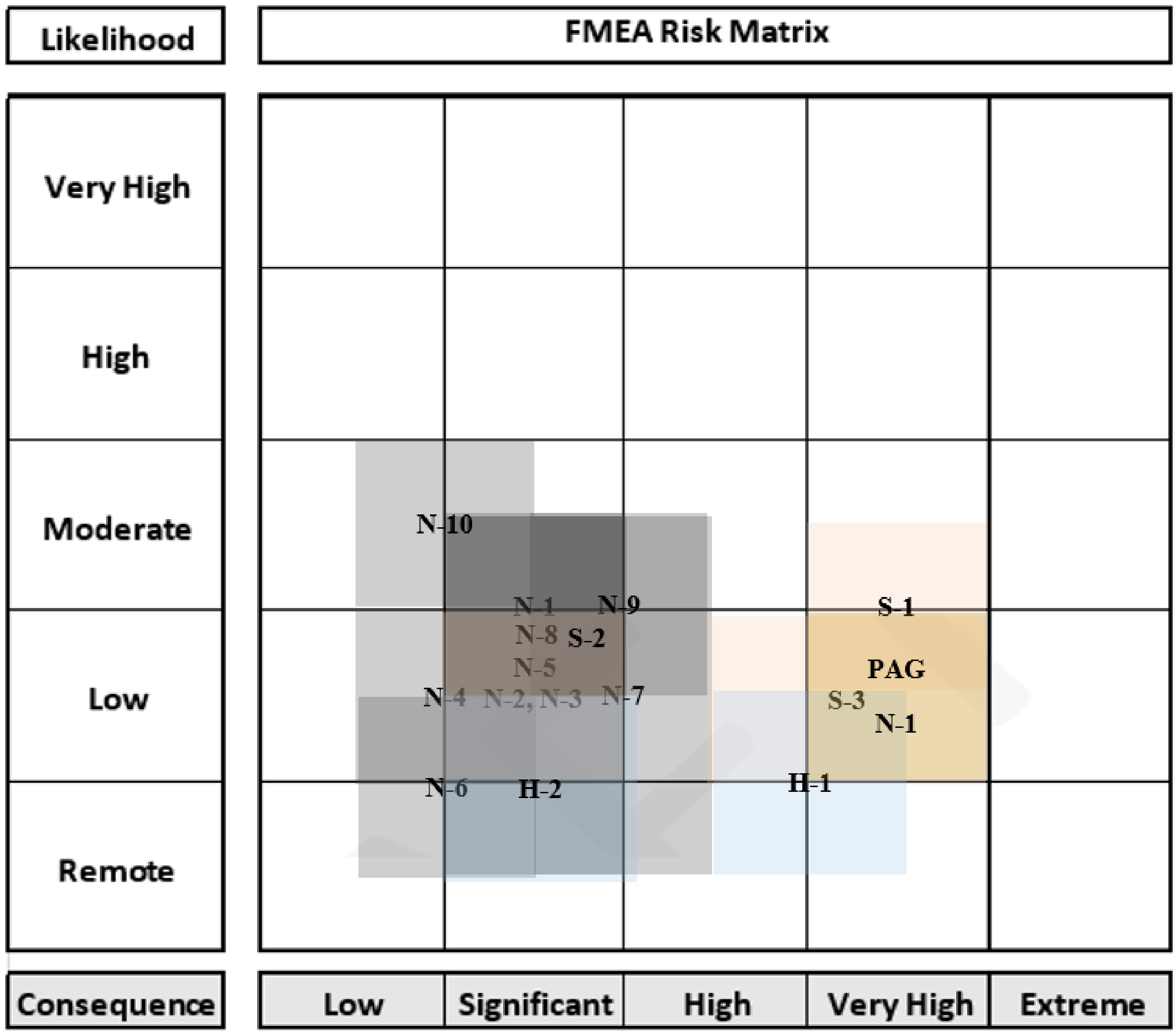
A total of sixteen potential PFMs were developed during the FMEA session. For the Main Embankment; ten were developed under normal loading conditions, three for seismic loading; two for hydrologic loading. One additional PFM was developed under normal conditions for the Pyrite Cell Embankment (PAG Cells). As summarized in Table 2 and Table 6, the Main Embankment PFMs generally included causes of failures relating to weak layers, excess pore pressures or slope failures at the dam abutments. The PFMs were similar (i.e., same failure mode but different triggering events), the positive factors, adverse factors and consequences also tended to fall into similar groupings. In terms of mitigation measures, most of the measures identified by the group are part of future design and planning efforts.

Following the workshop, a recent CDA publication (CDA, 2020, TDBA) was used to assess whether all appropriate failure modes were evaluated during the workshop. Although the FMEA workshop preceded publication of the CDA document, the workshop results indicate that each of the PFMs identified by CDA (shown **bolded**) was evaluated, showing the thoroughness and reasonableness of the workshop outcomes as follows:

- **Foundation failure modes** - seven of the PFM cases involved foundation failure modes (N-1 through N-5, S1 and PAG-N1)
- **Liquefaction failure modes** – each of the three seismic PFMs (S-1 through S-3) involved liquefaction.
- **Surface erosion** – two of the PFMs involved surface erosion (N-10 and H-2)
- **Piping and internal erosion** – one of the cases (N-9) involved internal piping and erosion
- In addition, six PFMs involved embankment failure modes (N-6 to N-8 and S-2 to H-1), which is not identified by CDA

In terms of failure mechanisms, practically all of the PFMs involved settlement of the crest during operating conditions due to a global instability, seismic event, construction deficiencies, or weak foundation. In addition, two of the PFMs involved deep erosion channels or downcutting of the embankment by surface water (or tailings pipe discharge).

Figure 4 presents a summary of the 2020 Skunk Camp TSF PFMs plotted on the risk matrix. The majority of the PFMs plot on the lower left of the risk matrix. Of the sixteen potential PFMs developed during the FMEA workshop, no unmanageable risks were identified. The risk assessment of the PFMs indicated that risks generally fall within acceptable societal risk levels. Those PFMs that plot towards the right on the chart are considered higher risk and reflect more fluid tailings behavior with higher runout and consequences. This plot location indicates that a better understanding of the failure modes is needed to assess the likelihood and tailings runout behavior under these scenarios and to assess the consequences. In general, the risk matrix indicates that the proposed Skunk Camp TSF design evaluated during the risk assessment is robust and addresses the potential PFMs through design, mitigation measures or planned operating procedures.



Note: The location ranges of the failure modes are approximate and intended to provide a relative location of the risk for all the failure modes discussed during the workshop. For the specific classification of each PFM, please refer to that PFM in Section 2.4 of the report. PFMs N-5, N-7, S-3 were classified over a range of categories and are plotted near the center of the range on this matrix.

Figure 20: Summary of Results on Risk Matrix

The workshop notes for the individual PFMs are provided in Appendix A, it should be noted these worksheets in this appendix are the workshop notes and may not be technically accurate or consistent but represent the workshop record. The PFM workshop notes include a description of the PFM development, positive and adverse factors, surveillance and monitoring, data information needs, potential risk reduction measures, and the likelihood and consequence classifications.

3.1. Data Information Needs

The 2020 FMEA identified and discussed the need for additional information to better understand and assign likelihood and consequence to many PFMs, but a thorough vetting or scoping of specific data needs was not performed. The listed data needs should not be seen as recommendations. With further review, some of these items may be considered unnecessary, or additional needs may be identified.

- **Perform Breach and Runout Analyses**: Complete breach and runout analysis to improve consequence definitions. (All failure modes)
- **Perform additional foundation characterization:** Several failure modes involved unknown or undesirable foundation conditions. We understand additional foundation investigation is planned for the site, based on the findings the design may be modified. The additional information and potential design changes may change the likelihood and/or consequence estimates made during this FMEA and increase the confidence in the estimates. (N-1, N-2, PAG N-1)
- **Perform geohazard evaluation of the site:** Perform a geohazard evaluation to identify existing landslides and other potential geohazards that may develop at the site. Evaluate the potential for landslides to develop in the Gila formation at the site and in the region. (N-4)
- **Perform Comprehensive Geochemical Compatibility Testing:** Perform additional geochemical testing to identify area of incompatibility. (N-5)
- **Additional PAG Liner Design:** Conduct additional design analysis for the PAG cell liner. Permeability and seepage rates through the liner should be determined as well. (N-9)
- **Specific Post-Closure Risk Analysis:** This workshop focused on failure of the facility during operations with a discussion of how closure of the facility would affect the risk of the individual failure modes. Additional work could be performed to further evaluate the specific risks following closure of the facility. (All failure modes)

3.2. Potential Surveillance & Monitoring

The 2020 FMEA identified and discussed potential surveillance and monitoring items for the PFMs. These are not recommendations but are items that the group suggested could be considered to monitor for the PFMs discussed. The specific PFMs the item applies to are listed in parentheses following the suggestion. Many of these items are already planned for the TSF.

- **Develop an OMS manual, as planned**. The 40 plus years of TSF construction requires a high degree of consistency in OMS.
- **Install appropriate instrumentation in the embankment and establish a surveillance and monitoring plan:** To monitor pore pressures and potential changes and movements in the TSF, instrumentation was suggested and is planned for the TSF. Instrumentation suggested includes piezometers and inclinometers, as well as use of surveying and InSAR monitoring to track movements over time. Suggested surveillance and monitoring also includes establishing an embankment inspection program including post event inspections following storms and earthquakes. Proposed surveillance and monitoring plan would include piezometer threshold levels and appropriate associated responses. (All PFMs)
- **Monitoring of pipelines:** Tailings delivery pipelines are prone to rupture over time. The pipelines should be regularly inspected. A flowmeter could be installed near the end of the pipe to provide indication of a break in the pipe if the flow is unexpectedly interrupted. (N-10)
- **Installation of seismic monitoring equipment:** Seismic monitoring equipment such as a seismograph or strong motion accelerometers could be installed at the site to identify earthquakes at the site and provide information on the level of shaking. (S-1, S-2, S-3)

- **Perform periodic subsurface investigation of the TSF during operation:** Subsurface investigation on the tailings impoundments should be considered at a regular interval to evaluate the material properties and the water levels and degree of saturation in the impoundments. (N-6)
- **Monitor the grind from the mill:** The gradation of the grind produced by the mill should be regularly monitored and evaluated. If the grind becomes excessively fine, it could impact stability and drainage in the impoundments. (N-6)
- **Perform water quality monitoring and geochemistry testing:** Water quality monitoring should be performed for the water within the impoundments. The geochemistry of the tailings and water should be evaluated prior to placement and following placement to evaluate changes and to allow comparisons to the model. (N-5)
- **Monitor pond levels and storm forecasts:** Instrumentation at the ponds could include electronic pond level monitoring so that the pond levels can be monitored remotely in real time. Additionally, weather forecasts should be monitored to identify potential large storms before they occur so that the site can prepare and make any necessary operational changes prior to the storms. (H-1, H-2)

3.3. Potential Risk Reduction Measures

The 2020 FMEA identified the following risk reduction measures items for the PFMs, sorted by design considerations, future planned work, and contingencies that could be implemented, if needed. These are items that could reduce the likelihood and/or consequence of the failures. These are not recommendations but are items suggested by the group during the workshop. The specific PFMs the item applies to are listed in parentheses following the suggestion. Many of these items are already planned for the TSF.

Future Design Considerations:

- If there were lower permeability units identified in the additional site investigation, the design will be modified to account for lower K-unit (N-2)
- Install a liner in the diversion channels or relocate ditches away from impoundment (N-4)
- Comply with the Aquifer Protection Plan (APP) (N-8)
- Add a filter along the foundation contact (N-9)
- Add backup pumps to lower the pond level (N-9)
- Use steel pipeline in critical locations (N-10)
- Automatic shutoff valves on the pipe (N-10)
- Pipeline distribution routing, keep the cyclone sand pipeline and the overflow sand pipelines separate, so rupture of one does not impact the other (N-10)
- Increase the density specification or frequency of testing in the lower 20 feet of the embankment, that is where saturation is most likely (S-3)
- If a landslide is identified, realign the dam to avoid potential landslide damage (S-2)
- Enlarge the diversion channels to convey storms large than the 100-year storm (H-1, H-2)

- Make additional pumps available and develop plan for removing water in the event of the large forecasted storms (H-1, H-2)
- Overbuild the Main Embankment to contain the potential release from the PAG
- Perform foundation treatment for the PAG Cells (PAG N-1)
- Reconfigure the PAG cells to reduce the volume in each of the cells, to prevent potential overtopping of Main Dam (PAG N-1)

Future Planned Work or Activity:

- Develop an Emergency Action Plan (EAP) and early warning system (N-1, N-2, N-3, N-4, N-5, N-6, N-7, N-8, N-9, N-10, S-1, S-2, S-3, H-1, H-2)
- Establish threshold levels for the piezometers (N-2)
- Prepare an operating plan that establishes a maximum rate of rise (N-3)
- Develop a QA/QC program for tailings construction (N-6, N-9, S-3)
- Develop a tailings Operations & Maintenance (O&M) Manual (N-7, H-1, H-2)
- Implement change of management procedures (N-8)
- Develop a contingency plan in the event of seepage and internal erosion (N-9)
- Maintain pond management, and control the water balance (N-9)
- Develop an Operational plan for moving the pipeline (N-10)
- Purchase downstream properties (S-1)

Contingencies That Could be Implemented, if Needed:

- Flatten the slopes or buttress slopes (N-1, N-2, N-5, N-6, N-7, N-8, S-1, S-3, H-1, H-2)
- Install diversion berms downstream to catch, slow down, or divert a tailings release (N-1, N-2, N-3, N-4, N-5, N-6, N-7, N-8, N-9, N-10, S-1, S-2, S-3, H-1, H-2)
- Install additional extraction / pressure relief wells (N-2, N-3)
- Perform in-situ mitigation of any active landslides (N-4, S-2)
- Buttress the landslides to prevent movement (N-4)
- Treatment of higher acid zones with limestone (N-5)
- Install wick drains / horizontal drains (N-6, N-7, S-3)
- Install a cutoff wall in the alluvium under the embankment (N-9)
- Relocate the pipeline from the slope of the dam to the abutment and the downstream toe of the dam (N-10)

4. References

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[15] Lettis Consultants International, Inc. (LCI), "Site-Specific Seismic Hazard Analyses and Development of Time Histories for Resolution Copper's Proposed Skunk Camp Tailings Storage Facility, Southern Arizona – Final Report," 2020.

[16] Montgomery & Associates (M&A), "Skunk Camp Investigations: Results of Site Reconnaissance," 2018.

APPENDIX A

PFM Workshop Notes

PFM No. N-1	Slope Instability through the Foundation at the Main Embankment due to a Weak Foundation Layer		
PFM Load	Normal		

PFM Description

- ➢ The Main Embankment is under normal operating conditions
- ➢ There is an unknown weak layer in the foundation (Alluvium or Gila)
- ➢ The alluvial foundation and the upper portion of the Gila is saturated
- ➢ The shear strength of the foundation layer is exceeded (could be inherently weak layer or excess pore pressures develop)
- ➢ A slope failure through the weak layer in the foundation occurs
- ➢ The slope failure extends back into the impounded tailings
- ➢ Tailings are released downstream

Additional Information

- Design static FoS ≥ 1.5
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction
- Proposed removal of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method
- Available locally sourced construction material if adequate cyclone sand cannot be produced

Positive Factors (makes PFM less likely to occur)

- Design static FoS ≥ 1.5
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction
- Proposed removal of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- It is a good site for a tailings embankment – free draining foundation, low seismicity, negative water balance, dense granular soils, well understood geology
- Centerline construction method with compacted raises
- The geometry of the embankment is linear, no saddle dams are needed

Adverse Factors (makes PFM more likely to occur)

- The foundation conditions are heterogeneous and potentially highly variable.
- There is a surficial Quaternary pediment layer with potential low strength zones present at the ground surface in some areas of the site (note that it is intended to be removed as part of the foundation preparation).
- The alluvium and upper Gila are likely to become saturated
- Construction of the tailings embankment is a 40-year project, with multiple changes in personnel
- There is a potential for paleo channels in the foundation, potential seepage paths

PFM No. N-1	Slope Instability through the Foundation at the Main Embankment due to a Weak Foundation Layer

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the foundation
- Survey / remote sensing of the impoundment
- InSAR monitoring

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done prior to detailed design. Based on results of the additional site investigation the design may be modified.

Potential Risk Reduction Measures

- Flatten the slopes
- Additional foundation investigation
- Develop an Emergency Action Plan (EAP) and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low to Moderate

Estimate: 1-Remote, 9-Low, 7-Moderate, 1-High, 4-Abstain

Rationale:

Low – Agreed with the description, cannot be ruled out. No compelling evidence that there is a weak layer.

Moderate – Fundamental condition or defect is known to exist. There are measures in place to prevent the failure from happening.

Confidence:

Estimate: Moderate

Consequence: Significant

Estimate: 1-Low, 12-Significant, 4-High, 2-Very High, 0-Extreme, 3-Abstain

Rationale:

Significant – It is in the 0.04 to 0.06 slope range, and do not expect the runout to go very far. There is population at risk about 4 miles away

Confidence:

Estimate: Moderate

Post Closure Considerations:

- There will be a post-closure monitoring period. According to ADEQ, 30 years is common following closure. There are other factors that could change and possibly significantly extend the monitoring period.
- There is an active closure period following operations, and before passive closure.
- After closure, the tailings will drain down which should lower the consequence. Also, the likelihood should be similar or become less likely.
- Overall the risk of this failure mode is expected to be the same or less in closure as for in operations.

PFM No. N-2	**Slope Instability through the Foundation at the Main Embankment due to High Porewater Pressures**		
PFM Load	Normal		

PFM Description

- The Main Embankment is under normal operating conditions
- The alluvial foundation and the upper portion of the Gila is saturated
- The foundation and impoundment do not drain as expected in design (lower permeability, failure to pump water, etc.)
- High pore pressures develop in the foundation
- A slope failure through the foundation develops
- The slope failure extends back into the impounded tailings
- Tailings are released downstream

Additional Information

- Design static FoS ≥ 1.5
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction
- Proposed removal of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high water pressures
- Instrumentation and monitoring to facilitate observational method
- Available locally sourced construction material if adequate cyclone sand cannot be produced

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high water pressures
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design (Rio Tinto D-5 Standard)
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- It is a good site for a tailings embankment – free draining foundation, low seismicity, negative water balance, dense granular soils, well understood geology. The water table (prior to tailings construction) is low, there are no current signs of artesian pressures
- There will be shallow pumping wells downstream in the alluvium to pumpback seepage water
- The alluvium is free draining and orders of magnitude higher permeability than the tailings
- Centerline construction method with compacted raises
- There will be piezometers in the impoundment and foundation with threshold levels and alarms

PFM No. N-2	Slope Instability through the Foundation at the Main Embankment due to High Porewater Pressures

Adverse Factors (makes PFM more likely to occur)

- The foundation conditions are heterogeneous and potentially highly variable
- There is a surficial Quaternary pediment layer with potential low strength zones present at the ground surface in some areas of the site (note that it is intended to be removed as part of the foundation preparation).
- The alluvium and upper Gila are likely to become saturated
- Construction of the tailings embankment is a 40-year project, with multiple changes in personnel and operations
- There is a potential for paleo channels in the foundation, potential seepage paths
- The Dripping Springs Fault extends across the impoundment (undetermined if it its conduit or barrier to seepage)
- There is a potential for geochemical sealing of the underdrains

Potential Surveillance & Monitoring

- Piezometers, inclinometers, and other instrumentation in the foundation
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Perform periodic embankment safety inspections

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done prior to detailed design. Based on results of the additional site investigation the design may be modified.

Potential Risk Reduction Measures

- Flatten the slopes
- Additional foundation investigation
- If there were lower permeability units identified in the additional site investigation, the design will be modified to account for lower K-unit
- An instrumentation monitoring plan (with established threshold levels) with associated action plans / alarms for threshold exceedance
- Install additional extraction / pressure relief wells
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low

Estimate: 3-Remote, 11-Low, 1-Moderate, 1-High, 4-Abstain

Rationale:

Low – Everything points to good foundation drainage. Cannot be ruled out, but no compelling evidence.

Moderate – There was a lack in subsurface information, low confidence in the likelihood estimate.

Confidence:

Estimate: Moderate

Consequence: Significant

Estimate: 3-Low, 12-Significant, 3-High, 0-Very High, 0-Extreme, 3-Abstain

Rationale:

Significant – Underlying assumption is that the failure stays within the Dripping Springs Wash corridor.

Confidence:

Estimate: Moderate

PFM No. N-2	Slope Instability through the Foundation at the Main Embankment due to High Porewater Pressures

Post Closure Considerations:

- There will be a post-closure monitoring period. According to ADEQ, 30 years is common following closure. There are other factors that could change and possibly significantly extend the monitoring period.
- There is an active closure period following operations, and before passive closure.
- After closure, the tailings will drain down which should lower the consequence. Also, the likelihood should be similar or become less likely.
- Overall the risk of this failure mode is expected to be the same or less in closure as for in operations.
- The tailings are draining down after closure
- Could have backup of water behind the cutoff wall if the shallow pumping wells are turned off
- May need to remove the cutoff wall at time of closure to prevent backup of water once pumps are turned off

PFM No. N-3	Slope Instability through the Foundation at the Main Embankment due to Deviation from Design Construction Geometry or Excessive Raise Rates		
PFM Load	Normal		

PFM Description

- The Main Embankment is under normal operating conditions
- The alluvial foundation and the upper portion of the Gila is saturated
- The construction of the tailings impoundment deviates from design, by either constructing embankment too steep or building at too high of a raise rate
- Excess stresses / pore pressures develop in the foundation
- A slope failure through the foundation develops
- The slope failure extends back into the impounded tailings
- Tailings are released downstream

Additional Information

- Design static FoS ≥ 1.5
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction
- Proposed removal of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method
- Available locally sourced construction material if adequate cyclone sand cannot be produced

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- The design indicates a factor of safety (FoS) greater than 1.5 for slope failure under static conditions.
- Proposed removal of potentially weak foundation material, if encountered
- The groundwater table prior to construction is low with no artesian pressures, and shallow pumping wells will be installed in the alluvium downstream of the impoundment to pump back seepage water back during operation.
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design (Rio Tinto D-5 Standard)
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- It is a good site for a tailings embankment – free draining foundation, low seismicity, negative water balance, dense granular soils, well understood geology. The alluvium is dense, granular soil.
- There will be shallow pumping wells downstream in the alluvium to pumpback seepage water
- Centerline construction method with compacted raises
- The design is fairly insensitive to raise rates

Adverse Factors (makes PFM more likely to occur)

- The foundation conditions are heterogeneous and potentially highly variable
- There is a surficial Quaternary pediment layer with potential low strength zones present at the ground surface in some areas of the site (note that, it is intended to be removed as a part of foundation preparation for the embankment)
- The alluvium and upper Gila are likely to become saturated
- Construction of the tailings embankment is a 40-year project, with potential multiple changes ownership, personnel, and operations
- There is a potential for paleo channels in the foundation, potential seepage paths
- There is a minimal pond near the DS toe of the PAG cells, the size of the ponds is reliant on operations

PFM No. N-3	Slope Instability through the Foundation at the Main Embankment due to Deviation from Design Construction Geometry or Excessive Raise Rates

Potential Surveillance & Monitoring

- Piezometers, inclinometers, and other instrumentation in the foundation
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Perform periodic embankment safety inspections

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction

Potential Risk Reduction Measures

- Flatten the slopes
- Additional foundation investigation
- Prepare an operating plan that establishes a maximum rate of rise
- Install more shallow pumping wells in the foundation
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low

Estimate: 0-Remote, 13-Low, 5-Moderate, -High, 1-Abstain

Rationale:

Low – Same as N-2

Moderate – Seemed to be more likely than others due to human factors involved.

Confidence:

Estimate: Moderate

Consequence: Significant

Estimate: 1-Low, 12-Significant, 5-High, 0-Very High, 0-Extreme, 1-Abstain

Rationale:

Significant – Mostly environmental concerns. There is some risk of life loss for operators.

Confidence:

Estimate: Moderate

Post Closure Considerations:

- This is an operational failure mode. This is not applicable to post-closure.

PFM No. N-4	Slope Instability through the Foundation at the Main Embankment due to Terrain Instability at the Abutments		
PFM Load	Normal		

PFM Description

- The Main Embankment is under normal operating conditions
- There are preexisting ancient landslides, not previously identified, adjacent to the tailings impoundment
- Due to deposition of tailings and seepage the potential ancient landslide becomes saturated
- A potential ancient landslide mobilizes
- The landslide intersects and damages the embankment
- Results in slope failure of the embankment
- Tailings are released downstream

Additional Information

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Proposed remediation of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method

Positive Factors (makes PFM less likely to occur)

- The design indicates a FoS greater than 1.5 for slope failure under static conditions
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Proposed remediation of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design (Rio Tinto D-5 Standard)
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- It is a good site for a tailings embankment – free draining foundation, low seismicity, negative water balance, dense granular soils, well understood geology
- Centerline construction method with compacted raises
- There are no mapped landslides at the site
- Large major landslides observed in Arizona are generally slow moving so there is likely to be sufficient time to implement appropriate mitigation measures

Adverse Factors (makes PFM more likely to occur)

- The foundation conditions are heterogeneous and potentially highly variable
- The alluvium and upper Gila are likely to become saturated
- Construction of the tailings embankment is a 40-year project, with multiple changes in ownership, operations, and personnel
- There is a potential for paleo channels in the foundation, potential seepage paths
- The diversion ditches are water sources and excavation could intersect the toe of an ancient landslide
- Wildfire in the area could exacerbate the potential for landslides by increasing the infiltration
- If a landslide was detected, it is difficult to stabilize
- Ancient landslides can be difficult to detect, there are subtle landforms

PFM No. N-4	**Slope Instability through the Foundation at the Main Embankment due to Terrain Instability at the Abutments**

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the foundation
- Survey / remote sensing of the impoundment and surrounding area
- InSAR monitoring
- Observe the ditches during site inspection
- Post storm special inspections

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction
- Evaluate potential for landslides within the Gila Conglomerate in this region
- Perform more detailed geohazards evaluation

Potential Risk Reduction Measures

- Install a liner in the diversion channels or relocate ditches away from impoundment
- Perform in-situ mitigation of any active landslides
- Buttress the landslides to prevent movement
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low

Estimate: 2-Remote, 12-Low, 3-Moderate, 1-High, 1-Abstain

Rationale:

Low – Unlikely to get a landslide, and can do mapping to find landslides.

Moderate – Missing ancient landslides

Confidence:

Estimate: Low to Moderate

Consequence: Low to Significant

Estimate: 8-Low, 10-Significant, 1-High, -Very High, -Extreme, -Abstain

Rationale:

Low to Significant – Slow moving failure, would likely have time to provide warning.

Confidence:

Estimate: Moderate

Post Closure Considerations:

- The likelihood and consequence for this failure mode is generally the same or less risk during post-closure than for during normal operations.

PFM No. N-5	**Slope Instability through the Foundation at the Main Embankment due to Geochemical Changes in the Foundation Over Time**		
PFM Load	Normal		

PFM Description

- ➢ The Main Embankment is under normal operating conditions
- ➢ The alluvial foundation and the upper portion of the Gila is saturated
- ➢ Over time the impacted water from the tailings chemically reacts with the foundation materials
- ➢ The geochemical changes reduce the shear strength and changes the permeability in the foundation
- ➢ A slope failure occurs due to the reduced strength
- ➢ The slope failure extends back into the impounded tailings
- ➢ Tailings are released downstream

Additional Information

- The Gila contains calcite which can dissolve or react with acid seepage
- Design static FoS ≥ 1.5
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction
- Proposed removal of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method
- Available locally sourced construction material if adequate cyclone sand cannot be produced

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- The design indicates a FoS greater than 1.5 for slope failure under static conditions
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design (Rio Tinto D-5 Standard)
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- It is a good site for a tailings embankment – free draining foundation, low seismicity, negative water balance, dense granular soils, well understood geology
- Centerline construction method with compacted raises
- Assumed the surficial Gila would be weakened, so have used weakened residual strength in the stability analysis (used 25^{o} friction angle based on residual strength lab testing)
- There has been geochemical modeling at the project, there is information on potential dissolution
- There is benchmarking across AZ of many tailings impoundments constructed on Gila without evidence of geochemical degradation

Adverse Factors (makes PFM more likely to occur)

- The foundation conditions are heterogeneous and potentially highly variable
- There is a weak pediment layer (intended to be removed)
- The alluvium and upper Gila are likely to become saturated
- Construction of the tailings embankment is a 40-year project, with multiple changes in personnel
- There is a potential for paleo channels in the foundation, potential seepage paths
- There is a potential for variability or mischaracterization in the ore so that more acid generating tailings may end up in the scavenger tailings impoundment

PFM No. N-5	Slope Instability through the Foundation at the Main Embankment due to Geochemical Changes in the Foundation Over Time

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the foundation
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Water quality monitoring
- Compare input geochemistry of PAG with model and routine sampling tailing prior to placement and post-placement

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before construction
- Additional detailed design of PAG liner
- Perform a comprehensive geochemical compatibility evaluation

Potential Risk Reduction Measures

- Flatten the slopes
- Additional foundation investigation
- Treatment of higher acid zones with limestone
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Remote to Moderate

Estimate: 4-Remote, 7-Low, 4-Moderate, 1-High, 2-Very High, 1-Abstain

Rationale:

Remote -

Low – Conservative assumptions used in the analysis. Case studies in the area don't suggest this is an issue.

Moderate – Focused on the mechanisms that could lead to geochemical changes. Liners do leak, and the potential is there for geochemical changes. There are no separate pyrite facilities in the Gila.

Confidence:

Estimate: Low to Moderate

Consequence: Significant

Estimate: 2-Low, 13-Significant, 3-High, 0-Very High, 0-Extreme, 1-Abstain

Rationale:

Significant – Same as N-1

Confidence:

Estimate: Low to Moderate

Post Closure Considerations:

- This is a potentially long-term developing failure mode. Will need to continue to monitor water quality for this post-closure.
- The geochemical reactions can take a long time to develop.

PFM No. N-6	Slope Instability through the Embankment at the Main Embankment due to a Weak Layer in the Embankment		
PFM Load	Normal		

PFM Description

- The Main Embankment is under normal operating conditions
- Excessive fines are deposited in multiple, parallel cells at the same elevation in the tailings embankment
- The fine layer goes unnoticed and is left in-place creating a weak zone in the embankment
- The shear strength of the fine layer is exceeded
- A slope failure develops through the embankment
- The slope failure extends back into the impounded tailings
- Tailings are released downstream

Additional Information

- The design indicates an FoS greater than 1.5 for slope failure under static conditions
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high phreatic surface
- Instrumentation and monitoring to facilitate observational method
- Available locally sourced construction material if adequate cyclone sand cannot be produced
- The embankment is centerline construction with cellular compacted placement

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- The design indicates an FoS greater than 1.5 for slope failure under static conditions
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high phreatic surface
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- There is a QA/QC program for placement and compaction of the embankment
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- Centerline construction method with compacted raises
- Due to the cellular construction it unlikely to have a continuous fines layer upstream to downstream at the same elevation
- There is a lot of local experience the centerline tailings construction

Adverse Factors (makes PFM more likely to occur)

- Construction of the Main Embankment is a 40-year project, with multiple changes in ownership, operations, and personnel
- There is a potential for finer material to be washed onto the surface of the embankment during a storm and create a more continuous weak layer
- A shutdown could create a less dense layer that is not adequately recompacted (reworked)
- The cyclones have to operate in a specific range for adequate performance

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the embankment
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Perform CPT investigations during at various times during construction
- Monitor grind from the mill to evaluate for finer materials

Data Information Needs

- None identified

<table>
<tr><th>PFM No. N-6</th><th>Slope Instability through the Embankment at the Main Embankment due to a Weak Layer in the Embankment</th></tr>
<tr><td colspan="2">Potential Risk Reduction Measures
• Develop a QA/QC program for tailings construction
• Install wick drains / horizontal drains
• Flatten the slopes or buttress the slope
• Develop an EAP and early warning system
• Install diversion berms downstream to catch, slow down, or divert a tailings release</td></tr>
<tr><td colspan="2">Likelihood: Remote to Low
Estimate: 8-Remote, 9-Low, 3-Moderate, 0-High, 0-Abstain
Rationale:
Low – Takes several unlikely events to occur. Would need to deposit fine material in several cells, not observe or remove the material, and then do that again at the same elevation several times.
Remote –

Confidence:
Estimate: Moderate to High</td></tr>
<tr><td colspan="2">Consequence: Low to Significant
Estimate: 12-Low, 8-Significant, -High, -Very High, -Extreme, -Abstain
Rationale:
Significant –

Confidence:
Estimate: Moderate</td></tr>
<tr><td colspan="2">Post Closure Considerations:
• This condition should improve with time, so the risk post-closure is expected to be less.</td></tr>
</table>

PFM No. N-7	**Slope Instability through the Tailings Embankment at the Main Embankment due to High Porewater Pressure in the Embankment**		
PFM Load	Normal		

PFM Description

- The Main Embankment is under normal operating conditions
- The phreatic surface rises in the embankment
- There is a layer in the embankment that was not compacted to specified density
- Seepage develops on the downstream slope of the embankment
- Static liquefaction is triggered in the loose layer due to rate of rise
- Static liquefaction results in a slope failure extending back into the impounded tailings
- Tailings are released downstream

Additional Information

- The design indicates an FoS greater than 1.5 for slope failure under static conditions
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- A preliminary tailings characterization has been completed for Skunk Camp, additional characterization will be ongoing during construction
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high phreatic surface
- Instrumentation and monitoring to facilitate observational method
- Available locally sourced construction material if adequate cyclone sand cannot be produced

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- The design indicates an FoS greater than 1.5 for slope failure under static conditions
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- A series of operational errors or upsets would need to occur to generate this situation and there is a lot of industry experience with centerline tailings embankment construction where this has not happened.
- Underdrainage (drain system and permeable alluvial foundation) beneath embankment footprint to reduce potential for high phreatic surface
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- Centerline construction method with compacted raises
- There is QA/QC on the fill construction
- Inspections are performed that could observe seepage on the downstream slope and initiate intervention
- The operational issues that may lead to this failure are most likely to occur early in tailings construction, these issues would most likely be worked out in operations before the embankment is at higher elevations (later in construction)
- The starter dam may resist this failure mode early on

Adverse Factors (makes PFM more likely to occur)

- It possible the grind from the mill could change and finer tailings are deposited
- There is a potential for there to be an elevated pond level near the embankment (more likely in early years of operation)
- The underdrain system could become plugged over time, be difficult to repair
- There is a potential for uncompacted layers in the cellular construction
- Construction of the tailings embankment is a 40-year project, with multiple changes in ownership, operations, and personnel

PFM No. N-7	Slope Instability through the Tailings Embankment at the Main Embankment due to High Porewater Pressure in the Embankment

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the embankment
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Perform visual inspections for seepage on the downstream slope

Data Information Needs

- None identified

Potential Risk Reduction Measures

- Flatten the slopes
- Install wick drains or horizontal drains
- Tailings O&M manual
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Remote to Moderate

Estimate: 5-Remote, 8-Low, 5-Moderate, -High, 1-Abstain

Rationale:

Remote to Low – Would have to ignore a lot of adverse conditions that could be observed for this to occur.

Moderate – There is uncertainty as to what time in the construction this would occur.

Confidence:

Estimate: Moderate

Consequence: Significant to High

Estimate: 3-Low, 8-Significant, 7-High, 1-Very High, -Extreme, 1-Abstain

Rationale:

Significant –

High – Environmental consequences were the driver. Thought the runout may go further due to the saturated slope.

Confidence:

Estimate: Low to Moderate

Post Closure Considerations:

- There will not be water introduced through operations, but there will be surface water routed over the pond in closure. The risk remains post-closure.

PFM No. N-8	Slope Instability through the Tailings Embankment at the Main Embankment due to Deviation from Design Geometry or Excessive Raise Rates		
PFM Load	Normal Operational		

PFM Description

- The Main Embankment is under normal operating conditions
- The construction of the tailings impoundment deviates from design
- The embankment slope is over steepened
- The operating factor of safety is reduced
- A slope failure develops through the embankment
- The slope failure extends back into the impounded tailings
- Tailings are released downstream

Additional Information

- The design indicates an FoS greater than 1.5 for slope failure under static conditions
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method
- Available locally sourced construction material if adequate cyclone sand cannot be produced

Positive Factors (makes PFM less likely to occur)

- This type of embankment slope failure has never been observed in centerline constructed cyclone sand embankments
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- The design indicates an FoS greater than 1.5 for slope failure under static conditions
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)
- Centerline construction method with compacted raises
- There will be a tailings O&M plan
- There is a management of change procedure (ICMM)
- It would require operating out of design considerations for a long period of time without correcting it

Adverse Factors (makes PFM more likely to occur)

- Construction of the tailings embankment is a 40-year project, with potential multiple changes in ownership, operations, and personnel
- Regulatory change or capacity and experience of staff
- Some of the technical review items on positive factors are not required by AZ, and are not required to be followed
- There is no dam safety oversight of tailings embankments or dams in AZ
- Fluctuation in the cost of copper can cause a break in operations
- Shortage of qualified staff to work on tailings embankments
- Upsets in production, or errors or omissions in quality control and assurance program(s)

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the embankment
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Could perform radar for real-time monitoring
- Perform regular inspections (internal and regulatory)
- Perform Dam Safety Reviews

<table>
<tr><th>PFM No. N-8</th><th>Slope Instability through the Tailings Embankment at the Main Embankment due to Deviation from Design Geometry or Excessive Raise Rates</th></tr>
<tr><td colspan="2">Data Information Needs
• None identified</td></tr>
<tr><td colspan="2">Potential Risk Reduction Measures
• Flatten the slopes
• Compliance with the APP
• Implement change of management procedures
• Develop an EAP and early warning system
• Install diversion berms downstream to catch, slow down, or divert a tailings release</td></tr>
<tr><td colspan="2">Likelihood: Low to Moderate
Estimate: 3-Remote, 9-Low, 8-Moderate, -High, -Abstain
Rationale:
Low – A lot of things have to happen and go unnoticed for this to occur
Moderate –

Confidence:
Estimate: Moderate</td></tr>
<tr><td colspan="2">Consequence: Significant
Estimate: -Low, 12-Significant, 8-High, -Very High, -Extreme, -Abstain
Rationale:
Significant –

Confidence:
Estimate: Moderate</td></tr>
<tr><td colspan="2">Post Closure Considerations:
• This risk will not increase in post-closure.</td></tr>
</table>

PFM No. Main N-9	Internal Erosion through the Foundation at the Starter Dam		
PFM Load	Normal		Plausible

PFM Description

- The Main Embankment is under normal operating conditions during startup conditions (first 5 years)
- There is a pond behind the starter dam
- The alluvial foundation and the upper portion of the Gila is saturated
- There is an upstream to downstream defect in the foundation under the embankment (paleo-channel, coarse zone in the alluvium, factures in the Gila, etc.)
- Internal erosion of embankment material is initiated into the defect
- The seepage and embankment material are discharging beyond the downstream toe of the dam
- The seepage increases as embankment material is piped through the defect
- Piping progresses upwards through the embankment
- A sinkhole develops on the downstream slope of the embankment
- The sinkhole continues to enlarge until it breaches the starter dam
- The pond and tailings are released downstream

Additional Information

- The starter dam has a maximum height of approx. 150 feet
- The starter dam is sized to contain two years of tailings plus the PMF
- The starter dam slope is 3H:1V, constructed of compacted Gila
- The foundation has underdrainage and the foundation is permeable
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond
- Instrumentation and monitoring to facilitate observational method

Positive Factors (makes PFM less likely to occur)

- Under most normal operation scenarios for the impoundment after the first few years, the pond is located too far from the exterior slope to consider internal erosion a credible failure
- Designed downstream slope angle of 3H:1V
- The starter dam will be designed to be filter compatible with the tailings
- The starter dam will have a trapezoidal cross-section (longer seepage path)
- Underdrains are proposed for below the starter dam and cyclone sand embankment and the foundation is highly permeable
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond
- Cyclone sand will be placed on the downstream side of the starter dam, will act as a downstream filter
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- There is a QA/QC program for placement and compaction of the embankment
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the embankment is in operation (ICMM guidelines)

Adverse Factors (makes PFM more likely to occur)

- Could just develop a concentrated leak through the foundation defect and may not be able to hold the pond
- There is a potential for variability in the foundation (paleo channel, coarse material, fractured Gila) that may be difficult to detect during startup
- Startup conditions are inherently complex
- Startup conditions typically use more water and it is harder to control the water balance

PFM No. Main N-9	Internal Erosion through the Foundation at the Starter Dam

Potential Surveillance & Monitoring

- Perform routine inspection and visual observation

Data Information Needs

- More understanding of the starter impoundment conditions
- Better geologic characterization of the foundation

Potential Risk Reduction Measures

- Install a cutoff wall in the alluvium under the embankment
- Add a filter along the foundation contact
- Backup pumps to lower the pond level
- Have contingency plan developed
- Pond management, control the water balance
- QA/QC during construction and operations
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low to Moderate

Estimate: 2-Remote, 8-Low, 7-Moderate, 2-High, 1-Abstain

Rationale:

Low – The starter dam is a downstream dam and is built to have a water against it. Considering the permeability of the foundation it is hard to envision a pond developing behind the dam.

Moderate – Defect of coarse alluvium is known to exist.

High – There is indirect evidence to suggest it is plausible. Weighed it to be more likely than

Confidence:

Estimate: Moderate

Consequence: Significant to High

Estimate: 2-Low, 7-Significant, 9-High, 2-Very High, -Extreme, -Abstain

Rationale:

High – Release would likely go far because of the water in the impoundment.

Significant –

Confidence:

Estimate: Moderate

Post Closure Considerations:

- This condition is not relevant to post-closure.

PFM No. Main N-10	Pipeline Rupture at the Main Dam Leads to Erosion and Dam Release of Tailings		
PFM Load	Normal		Plausible

PFM Description

- The Main Dam is under normal operating conditions
- The cyclone sand pipeline extends down the downstream slope of the embankment
- Cyclone pipeline ruptures near the crest of the dam
- The cyclone sand/water is released on the downstream slope
- The downstream slope is eroded rapidly and goes unnotticed
- Erosion continues, head cutting towards the crest of the dam
- The embankment fails and tailings are released downstream

Additional Information

- Cyclone sand delivery is a 24-hr operation
- Thickened tailings to reduce process water inputs to the TSF impoundment (60% solids)
- Operational controls to maintain minimal pond

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V
- The dam crest is 150 feet wide
- Operators will be able to see a pipe break
- Monitoring would detect a loss in pipeline pressure
- Pipeline preventative maintenance is planned
- Response to this failure is covered in the O&M plan
- The cyclone sand slury requires pumping to reach the construction cells and flow can be more quickly controlled or stopped in the event of a break (compared to a gravity feed system)
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the dam is in operation (ICMM guidelines)
- The pipes are generally discharging into the construction cells, so tailings from a rupture lower on the dam would be released into and controlled by the cells

Adverse Factors (makes PFM more likely to occur)

- The sand is erodible
- This type of pipeline break does occur due to wear and other factors
- Operations occur at night and a break may be harder to detect
- The cyclone sand is abrasive, and will wear out the pipelines
- Construction of the tailings dam is a 40-year project, with potential multiple changes in ownership, operations, and personnel

Potential Surveillance & Monitoring

- Perform routine inspection and visual observation of the pipeline
- Install a flowmeter at the end of the pipe to monitor flow
- Piezometers in the sand on the DS slope to monitor for saturation

Data Information Needs

- None identified.

PFM No. Main N-10	Pipeline Rupture at the Main Dam Leads to Erosion and Dam Release of Tailings

Potential Risk Reduction Measures

- Relocate the pipeline from the slope of the dam to the abutment and the downstream toe of the dam
- Use steel pipeline in critical locations
- Automatic shutoff valves on the pipe
- Pipeline distribution routing, keep the cyclone sand pipeline and the overflow sand pipelines separate, so rupture of one does not impact the other
- Operational plan for moving the pipeline
- Develop an EAP and early warning system
- Perform regular inspection and maintenance on the pipelines
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Moderate

Estimate: 3-Remote, 6-Low, 10-Moderate, 0-High, 0-Very High, 0-Abstain

Rationale:

Low –

Moderate – Pipeline breaks have happened before. High probability of initiation, but hard to see it go to failure.

Remote –

Confidence:

Estimate: Moderate

Consequence: Low to Significant

Estimate: 7-Low, 8-Significant, 4-High, -Very High, -Extreme, 1-Abstain

Rationale:

High – Release of tailings would be a large environmental consequence.

Significant – Similar consequence as for the first failure modes for slope failure.

Confidence:

Estimate: Moderate

Post Closure Considerations:

- This condition is not relevant to post-closure.

PFM No. S-1	Slope Instability through the Foundation at the Main Dam due to Strength Loss during a Seismic Event		
PFM Load	Seismic		

PFM Description

- ➢ The Main Dam is under normal operating conditions
- ➢ The alluvial foundation and the upper portion of the Gila is saturated
- ➢ A major seismic event occurs
- ➢ The impounded tailings liquefy due to the earthquake
- ➢ Liquefaction occurs in the alluvium / Gila foundation, and the foundation is reduced to residual shear strength
- ➢ The shear strength of the alluvium foundation layer is exceeded
- ➢ A slope failure through the foundation occurs
- ➢ The slope failure extends back into the impounded tailings
- ➢ Tailings are released downstream

Additional Information

- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials
- Simplified deformation analysis using pseudostatic coefficient, ka = 0.6 x Peak Ground Acceleration for failure modes not involving liquefiable materials
- Maximum downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Foundation geological properties and seismic hazard assessment from similar nearby sites used in preliminary analysis
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before final design
- Proposed removal of potentially weak foundation materials, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrains through dam footprint to reduce the potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials
- Simplified deformation analysis using pseudostatic coefficient, ka = 0.6 x Peak Ground Acceleration for failure modes not involving liquefiable materials, analysis showed deformation on the order of inches.
- The site is considered suitable a tailings embankment; with relatively permeable foundation, low seismicity, negative water balance, dense granular soils, and well understood geology.
- Proposed removal of potentially weak foundation material, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the dam is in operation (ICMM guidelines)
- It is a good site for a tailings dam – free draining foundation, low seismicity, negative water balance, dense granular soils, well understood geology
- Centerline construction method with compacted raises
- Alluvium is not continuous across the dam
- There has been a site-specific SHA performed indicating relatively low seismicity and the design criteria include a return period of 1 in 10,000 years. Proposed treatment or removal of potentially weak (or liquefiable) foundation material, if encountered
- Site investigations has shown that the alluvium and Gila are dense. Typical N_{1-60}-values of 40 to 50 bpf, lowest values ~25 bpf (for dry conditions)
- Stability analysis assumes all the impounded tailings have been liquefied

PFM No. S-1	**Slope Instability through the Foundation at the Main Dam due to Strength Loss during a Seismic Event**

Adverse Factors (makes PFM more likely to occur)

- The Gila is considered a weak rock, so amplification of the accelerations should be applied to the ground motion
- There is a potential for the Gila to soften overtime with wetting
- The foundation conditions are heterogeneous and potentially highly variable
- There is a surficial Quaternary pediment layer with potential low strength zones present at the ground surface in some areas of the site (note that, it is intended to be removed as a part of foundation preparation for the embankment)
- The alluvium and upper Gila are likely to become saturated with tailings deposition
- Construction of the tailings dam is a 40-year project, with potential multiple changes in ownership, operations, and personnel
- There is a potential for paleo channels in the foundation, potential seepage paths
- There is a potential for concurrent failure of the PAG cell dams during a seismic event, this would increase the consequences

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the foundation
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Install seismograph / accelerometer at the dam
- Slope radar
- Perform post-earthquake inspections as part of O&M plan

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before final design

Potential Risk Reduction Measures

- Flatten the slopes
- Additional foundation investigation to further characterize the potential for liquefaction
- Install diversion berms downstream to catch, slow down, or divert a tailings release
- Purchase downstream properties
- Develop an EAP and early warning system

Likelihood: Low to Moderate

Estimate: 4-Remote, 9-Low, 8-Moderate, 0-High, 0-Abstain

Rationale:

Low to Moderate – Likelihood could not be more likely than earthquake event.

Remote – Stringent design criteria, not a high seismic area.

-The likelihood would go down if we were to consider the PAG cell dam failing concurrently with the Main Dam

Confidence:

Estimate: Moderate

Consequence: Very High

Estimate: -Low, 2-Significant, 3-High, 12-Very High, 4-Extreme, -Abstain

Rationale:

Sig – While the tailings "liquefy" they are not actually flowing and will settle out about the same as for the normal case.

Very High – Because the tailings are liquefied, they will flow further and there is no warning in this scenario. Not extreme, because there is not a big population center. Considered both environmental consequences and potential life loss in the consequence estimate.

-The consequence estimate would increase if we were to consider the PAG cell dam failing concurrently with the Main Dam

Confidence:

Estimate: Moderate

PFM No. S-1	Slope Instability through the Foundation at the Main Dam due to Strength Loss during a Seismic Event
Post Closure Considerations: • Drain down of the impoundment may improve the condition post-closure but will still need to monitor following closure.	

PFM No. S-2	**Slope Instability through the Foundation at the Main Dam due to Terrain Instability at the Abutments during a Seismic Event**		
PFM Load	Seismic		

PFM Description

- The Main Dam is under normal operating conditions
- There is are preexisting ancient landslides, not previously identified, adjacent to the tailings impoundment
- Due to deposition of tailings and seepage the potential ancient landslide becomes saturated
- A major seismic event occurs
- The impounded tailings liquefy due to the earthquake
- A potential ancient landslide mobilizes
- The landslide intersects and damages the embankment
- Results in slope failure of the embankment
- Tailings are released downstream through the upper portion of the dam

Additional Information

- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials
- Simplified deformation analysis using pseudostatic coefficient, ka = 0.6 x Peak Ground Acceleration for failure modes not involving liquefiable materials
- Maximum downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Foundation geological properties and seismic hazard assessment from similar nearby sites used in preliminary analysis
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before final design
- Proposed removal of potentially weak foundation materials, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrains through dam footprint to reduce the potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design (Rio Tinto D-5 Standard)
- A third-party review will be conducted every 2 years once the dam is in operation (ICMM guidelines)
- It is a good site for a tailings dam – free draining foundation, low seismicity, negative water balance, dense granular soils, well understood geology
- Centerline construction method with compacted raises
- There are no mapped landslides at the site
- Large, major landslides in Arizona are generally slow moving so there is likely to be sufficient time to implement appropriate mitigation measures
- With the cuts for the diversion channels, there will be opportunity to observe the geology
- There will be thorough investigation of the area near the dam, so it is unlikely a landslide will go undetected

PFM No. S-2	Slope Instability through the Foundation at the Main Dam due to Terrain Instability at the Abutments during a Seismic Event

Adverse Factors (makes PFM more likely to occur)

- Wildfire in the area could exacerbate the potential for landslides by increasing the infiltration
- The foundation conditions are heterogeneous and potentially highly variable
- The alluvium and upper Gila are likely to become saturated
- Construction of the tailings dam is a 40-year project, with potential for multiple changes in ownership, operations, and personnel
- There is a potential for paleo channels in the foundation, potential seepage paths
- The diversion ditches are water sources and excavation could intersect the toe of an ancient landslide
- If a landslide was detected, it is difficult to stabilize
- The landslides can be difficult to detect, there are subtle landforms

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the foundation
- Survey / remote sensing of the impoundment and surrounding area
- InSAR monitoring
- Observe the ditches during site inspection
- Post-earthquake special inspections

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before final design
- Evaluate potential for landslides within the Gila Conglomerate in this region
- Perform more detailed geohazards evaluation

Potential Risk Reduction Measures

- Perform in-situ mitigation of any active landslides
- If a landslide is identified, realign the dam to avoid potential landslide damage
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low

Estimate: 3-Remote, 12-Low, 5-Moderate, -High, -Abstain

Rationale:

Low – There will be more investigation done, so the dam would likely be relocated if a major concern for liquefaction was identified.

Moderate –

Confidence:

Estimate: Low to Moderate

Consequence: Significant

Estimate: 2-Low, 12-Significant, 5-High, 1-Very High, -Extreme, -Abstain

Rationale:

Low –

Significant – It is more likely to develop higher up on the embankment, not likely to involve water, so less runout.

High – there is little notification time in the event of an earthquake

Confidence:

Estimate: Moderate

PFM No. S-2	Slope Instability through the Foundation at the Main Dam due to Terrain Instability at the Abutments during a Seismic Event
Post Closure Considerations: • Risk for this failure mode is considered similar under post-closure condition. May be slightly less due to drained down conditions. • Preventative maintenance should be performed at the impoundment, including during post-closure. InSAR could be used to monitor for slope movements, continuing during post-closure. • Site inspections should be continued following closure.	

PFM No. S-3	Slope Instability through the Tailings Embankment during a Seismic Event		
PFM Load	Seismic		

PFM Description

- ➢ The Main Dam is under normal operating conditions
- ➢ There are perched zones of saturated material in the embankment, near the foundation
- ➢ A major seismic event occurs
- ➢ The impounded tailings are liquefied due to the earthquake
- ➢ Liquefaction occurs in the saturated zone, and a portion of the embankment is reduced to residual shear strength
- ➢ The shear strength of the liquefied embankment is exceeded
- ➢ A slope failure develops through the embankment
- ➢ The slope failure extends back into the impounded tailings
- ➢ Tailings are released downstream

Additional Information

- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials
- Simplified deformation analysis using pseudostatic coefficient, ka = 0.6 x Peak Ground Acceleration for failure modes not involving liquefiable materials
- Maximum downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Foundation geological properties and seismic hazard assessment from similar nearby sites used in preliminary analysis
- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done before final design
- Proposed removal of potentially weak foundation materials, if encountered
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrains through dam footprint to reduce the potential for high groundwater pressures
- Instrumentation and monitoring to facilitate observational method

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Design post-seismic FoS ≥ 1.2 for failure modes involving potentially liquefiable materials
- Simplified deformation analysis using pseudostatic coefficient, ka = 0.6 x Peak Ground Acceleration for failure modes not involving liquefiable materials, shows the embankment deformation in on the order of inches
- Designed downstream slope angle of 3H:1V, with contingency to extend to 4H:1V, if necessary
- Thickened tailings to reduce process water inputs to the TSF impoundment
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high phreatic surface
- Instrumentation and monitoring to facilitate observational method (there are not brittle materials at this site, more slowly developing failure)
- There is a QA/QC program for placement and compaction of the embankment
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the dam is in operation (ICMM guidelines)
- Centerline construction method with compacted raises
- CPTs will be performed during operation to identify weak / saturated layers as the dam is built

Adverse Factors (makes PFM more likely to occur)

- Construction of the Main Embankment is a 40-year project, with multiple changes in ownership, operations, and personnel
- There is a potential for finer material to be washed onto the surface of the embankment during a storm or during shutdown and create a more continuous less permeable or weak layer
- There is a potential for a temporary shutdown, potentially creating an inadequately prepared layer in the embankment
- The embankment sand is of a grain size that is potentially liquefiable
- There is a potential for concurrent failure of the PAG cell dams during a seismic event, this would increase the consequences

Potential Surveillance & Monitoring

PFM No. S-3	Slope Instability through the Tailings Embankment during a Seismic Event

- Piezometers and other instrumentation in the embankment
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Perform CPT investigations during at various times during construction
- Monitor grind from the mill to evaluate for finer materials

Data Information Needs

- Perform a dam breach or runout analysis.

Potential Risk Reduction Measures

- Develop a QA/QC program for tailings construction
- Install wick drains / horizontal drains
- Flatten the slopes or buttress the slope
- Increase the density specification or frequency of testing in the lower 20 feet of the embankment, that is where saturation is most likely
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low

Estimate: 2-Remote, 14-Low, 3-Moderate, 0-High, 0-Abstain

Rationale:

Low –

Remote –

-The likelihood would go down if we were to consider the PAG cell dam failing concurrently with the Main Dam

Confidence:

Estimate: Moderate

Consequence: Significant to Very High

Estimate: 1-Low, 4-Significant, 7-High, 6-Very High, 1-Extreme, -Abstain

Rationale:

Low – Lower likelihood of this happening, but not expecting a long runout.

Significant –

High to Very High – Expect it to be a larger failure and with liquefaction of the tailings, expect a further runout.

-The consequence estimate would increase if we were to consider the PAG cell dam failing concurrently with the Main Dam

Confidence:

Estimate: Moderate

Post Closure Considerations:

The risk for this failure mode should go down in post-closure condition. The impoundment will drain down overtime.

PFM No. H-1	Slope Instability at the Main Dam due to High Porewater Pressure in the Embankment following a Hydrologic Event		
PFM Load	Hydrologic		

PFM Description

- ➢ A storm event up to the PMF occurs in the first 5 years of operation
- ➢ The pond level rises in the Main Impoundment
- ➢ With the high pond level, the phreatic surface rises in the embankment
- ➢ A slope failure develops through the embankment section
- ➢ The slope failure extends back into the impounded tailings
- ➢ The pond and tailings are released downstream

Additional Information

- Design static FoS ≥ 1.5 (normal conditions)
- Designed downstream slope angle of 3H:1V
- Operational controls to maintain minimal pond to reduce infiltration
- Underdrainage beneath embankment footprint to reduce potential for high phreatic surface
- Instrumentation and monitoring to facilitate observational method

Positive Factors (makes PFM less likely to occur)

- Designed downstream slope angle of 3H:1V with a contingency to flatten to 4H:1V if necessary (this condition would be identified through monitoring)
- The design indicates a FoS greater than 1.5 for slope failure under static conditions
- Underdrainage (drain system and permeable alluvial foundation) beneath embankment footprint to reduce potential for high phreatic surface
- Instrumentation and monitoring of the embankment pore pressure
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the dam is in operation (ICMM guidelines)
- The cyclone sand Main Embankment will be raised using the centerline method and with compacted hydraulic cells
- There is QA/QC on the fill construction
- The OMS manual will have procedures for flooding
- The starter dam is large, limited tailings embankment above the starter dam early on
- Less impounded tailings in first 5 years (smaller consequence)
- The stability and seepage analyses will factor into the design of the dam, will design for the critical case
- The flood / high pond is a temporary condition
- There are reclaim pumps and stand-by pumps on site to pump out the pond

Adverse Factors (makes PFM more likely to occur)

- There is a potential for there to be an elevated pond level near the embankment
- The drains could become plugged over time, be difficult to repair (less likely in the first 5 years)
- There is a potential for uncompacted layers in the cellular construction
- This is similar to a first filling
- It will take time to pump the pond down
- The tailings will be in a less consolidated state
- Climate change could make the potential flooding worse

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the embankment
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Post-storm inspections
- Monitor the pond elevation
- Monitor weather / storm forecasting

Data Information Needs

Perform a dam breach or runout analysis.

Potential Risk Reduction Measures

PFM No. H-1	**Slope Instability at the Main Dam due to High Porewater Pressure in the Embankment following a Hydrologic Event**

- Flatten the slopes
- Tailings O&M manual
- Increase the diversion channel design capacity to convey storms large than the 100-yr event
- Make additional pumps available and develop plan for removing water in the event of large forecasted storms
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Remote to Low

Estimate: 9-Remote, 10-Low, 1-Moderate, -High, -Abstain

Rationale:

Remote – Adding several steps on top of a PMF. The facility is designed to contain the PMF. Multiple low likelihood events.

Low –

Moderate –

Confidence:

Estimate: Moderate

Consequence: High to Very High

Estimate: 1-Low, 2-Significant, 6-High, 10-Very High, 1-Extreme, -Abstain

Rationale:

Significant –

High to Very High – It's a large starter dam, and there is more water than for the other failure modes. The water/tailings will flow further. There will be large enviro, economic and there are PLL consequences.

Confidence:

Estimate:

Post Closure Considerations:

- Not applicable to post-closure condition. Happens in first 5 years.

PFM No. H-2	**A Diversion Ditch Fails during a Storm Event leading to Erosion of the Main Dam Embankment**		
PFM Load	**Hydrologic**		
PFM Description			

PFM No. H-2	A Diversion Ditch Fails during a Storm Event leading to Erosion of the Main Dam Embankment

- A storm event up to the PMF occurs
- Runoff from the storm is collected in the diversion channels
- The diversion channels fail near an abutment of the dam
- The flow from the failed channel is directed to the groin of the Main Dam embankment
- Erosion is initiated at the groin
- Erosion continues through the embankment
- Headcut continues through the embankment until the dam is breached
- The impoundment is breached, and the pond and tailings are released

Additional Information

- The channels are designed to carry at least the 100-yr storm
- Slopes in the channels are 2H:1V
- Cut into Gila, which is erosion resistant

Positive Factors (makes PFM less likely to occur)

- A scour assessment will be completed, a portion of the channels maybe be armored (there is an allowance to armor the channels at this stage)
- The channels are largely in the Gila which is erosion resistant
- The channels are in cut, so there is potentially additional freeboard
- The exposure length of the channel that would impact the dam is short
- Resolution has employed an Independent Technical Review Board (ITRB) to review the tailings design
- A third-party review will be conducted every 2 years once the dam is in operation (ICMM guidelines)

Adverse Factors (makes PFM more likely to occur)

- The sand tailings in the embankment are erodible
- Operations occur at night and erosion may go unnoticed for a period of time
- The terrain slopes back toward the groin of the dam
- The design of the channels could be challenging due to the multiple turns in the terrain
- The channels are designed for a relatively small storm (100-yr)

Potential Surveillance & Monitoring

- Piezometers and other instrumentation in the embankment
- Survey / remote sensing of the impoundment
- InSAR monitoring
- Post-storm inspections
- Monitor the pond elevation
- Monitor weather / storm forecasting

Data Information Needs

- None identified

Potential Risk Reduction Measures

- Flatten the slopes
- Tailings O&M manual
- Increase the diversion channel capacity to convey storms large than the 100-yr event
- Make additional pumps available and develop plan for removing water in the event of large forecasted storms
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Remote to Low

Estimate: 2-Remote, 16-Low, 2-Moderate, 0-High, 0-Abstain

Rationale:

Low – Lees likely to fail due to failure of a channel than for a slope failure through the embankment. A number of unlikely events have to occur at the right place at the right time.

PFM No. H-2	A Diversion Ditch Fails during a Storm Event leading to Erosion of the Main Dam Embankment
Moderate – **Confidence:** Estimate: Moderate	
Consequence: Significant Estimate: 7-Low, 9-Significant, 4-High, 0-Very High, 0-Extreme, 0-Abstain Rationale: Low to Significant – Will learn about the performance of the diversion channels early on and can address issues before there is major failure. High – Water will be in the channel, will carry tailings/water further. Expect environmental damage, not life loss. **Confidence:** Estimate: Moderate	
Post Closure Considerations: • The channel will be relocated for post-closure conditions. The channel location during post-closure will be designed to convey the PMF and will be further from the embankment. Risk should be lower during post-closure, but should continue to monitor and maintain	

PFM No. PAG N-1	Slope Instability through the Foundation at the PAG Dam due to a Weak Foundation Layer		
PFM Load	Normal		

PFM Description

- The PAG Dam is under normal operating conditions, in the first 5 to 10 years (PAG Cell 1)
- There is an unknown weak layer in the foundation (Alluvium or Gila)
- The alluvial foundation and the upper portion of the Gila is saturated
- The shear strength of the foundation layer is exceeded (could be inherently weak layer or high pore pressures develop)
- A slope failure through the weak layer in the foundation occurs
- The slope failure extends back into the impounded tailings
- Tailings are released downstream into the Main Impoundment
- The Main Embankment is overtopped and erosion initiates on the embankment
- The erosion progresses and the embankment fails
- PAG and scavenger tailings are released downstream from the Main Dam

Additional Information

- Design static FoS ≥ 1.5
- Downstream raised dams with maximum slope angle of 2.5H:1V
- There has been a preliminary site investigation that has been incorporated into design, additional investigations will be conducted prior to final design
- Proposed removal of near-surface weak foundation materials, if encountered
- Progressively buttressed by scavenger tailings pond
- Low-permeability liner reduces the potential for high water pressures in the foundation
- Instrumentation and monitoring are planned for the PAG
- PAG cell embankments fully covered and supported by scavenger tailings at closure
- These tailings are potentially acid generating (PAG)

Positive Factors (makes PFM less likely to occur)

- Design static FoS ≥ 1.5
- Downstream raised dams with maximum slope angle of 2.5H:1V
- Proposed removal of near-surface weak foundation materials, if encountered
- PAG Embankment is progressively buttressed by scavenger tailings
- Low-permeability liner reduces the potential for high water pressures in the foundation
- Instrumentation and monitoring are planned for the PAG
- The design is for two PAG cells working in succession to limit pond size
- The pyrite tailings will plug defects in the liner (~85% fines)

Adverse Factors (makes PFM more likely to occur)

- The foundation is heterogeneous and potentially highly variable
- The downstream toe of the PAG dam will be saturated by pond water from the scavenger beach
- The dams are constructed that allows for a cascading failure (PAG into Main Impoundment)
- Requires strict operational control and planning / sequencing
- Installing the liner in the basin will be difficult, potential for damage and leakage through the liner
- A free pond is maintained in the PAG pond during operations
- In the first 5-10 years the Main Impoundment is not able to store the PAG contents
- The release from the PAG into the Main Impoundment could create a wave

PFM No. PAG N-1	**Slope Instability through the Foundation at the PAG Dam due to a Weak Foundation Layer**

Potential Surveillance & Monitoring

- Piezometers and additional embankment instrumentation
- Perform inspection of the embankment
- Survey and remote sensing / InSAR monitoring

Data Information Needs

- A preliminary site investigation has been completed for Skunk Camp, additional site investigations will be done prior to detailed design. Based on results of the additional site investigation the design may be modified.
- Perform a "cascading" runout analysis for failure of the PAG Cells and then failure of Main Impoundment.

Potential Risk Reduction Measures

- Overbuild the Main Embankment to contain the potential release from the PAG
- Evaluate the required water depth on the pond to maintain saturation / prevent oxidation
- Perform foundation treatment
- Reconfigure the PAG cells to reduce the volume in each of the cells, to prevent potential overtopping of Main Dam
- Develop an EAP and early warning system
- Install diversion berms downstream to catch, slow down, or divert a tailings release

Likelihood: Low

Estimate: -Remote, 14-Low, 5-Moderate, -High, 1-Abstain

Rationale:

Low – There is a robust design, multiple events have to happen, and there are a limited number of years where failure results in overtopping the Main Dam.

Moderate –

Confidence:

Estimate:

Consequence: Very High

Estimate: -Low, -Significant, 3-High, 12-Very High, 5-Extreme, -Abstain

Rationale:

Very High – There is more water in the PAG that will be released and will result in further runout. Expect it will reach the Gila River. It is pyrite tailings which have a higher environmental consequence. The estimate is based primarily on the environmental and economic damages. The potential for direct loss of life is considered small, but there may be some indirect loss of life.

Confidence:

Estimate: Moderate

Post Closure Considerations:

- This failure mode is not a concern post closure.