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YANKEE DOODLE TAILINGS IMPOUNDMENT
2022 RISK ASSESSMENT REPORT

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Knight Piésold CONSULTING

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EXECUTIVE SUMMARY

Montana Resources, LLP and Atlantic Richfield Company jointly sponsored a risk assessment of the Yankee Doodle Tailings Impoundment (YDTI). The goal of the joint risk assessment was to improve technical alignment and understanding of the key risks associated with potential credible failure modes for the YDTI. The assessment focused on credible failure modes, including foundation and embankment instability, overtopping, and internal erosion and piping while considering relevant hazards for the mine (e.g. seismic events, flood events, and significant operational events). The temporal scope of this risk assessment was focused on near-term operating conditions with the embankments raised to a crest elevation of EL. 6,450 ft while considering continued operations through approximately 2031.

The risk assessment was conducted through a series of meetings. A potential failure modes analysis was initially completed by the risk assessment team to evaluate site-specific potential failure modes for the YDTI and to identify major hazards considered to be of greatest significance that required further assessment. The major hazards identified by the failure modes analysis were then further evaluated using event tree analyses to quantify the risks and determine the main hazards of concern. Potential mitigation measures were then evaluated to identify and prioritize recommended mitigation measures that could further reduce risk associated with the major hazards and enhance safety of the facility.

The hazards identified during the failure modes analysis included the potential for occurrence of earthquakes, severe flooding, fill and foundation material degradation, on-going construction and operations activities, and other geologic and environmental hazards. The major hazards (loading conditions) carried forward for further quantitative risk analysis included severe flooding, earthquakes, construction loading, and material degradation. The highlighted potential failure modes selected for further evaluation using event tree analyses consisted of foundation and slope instability, internal erosion and piping, and undesirable embankment deformation.

The results of the quantitative risk analyses indicate that current normal operating conditions have low risk. The major hazards contributing to the normal operating risk profile include construction-loading, material degradation, and relatively small earthquakes and flooding that are expected to be manageable. The main hazards of concern identified were extreme earthquakes and floods, which have a very low likelihood of occurring. However, these events also have to the potential to result in severe consequences despite their low probability of occurrence. The guiding risk management objective for the YDTI is to continuously expand understanding of the facility and continuously improve management of the facility to enhance safety to the MR workforce, community, and environment. Mitigation measures were evaluated by the risk assessment team with this risk management objective lens.

The recommended actions developed by the risk assessment team were focused on mitigating the likelihood and potential consequences of failure related to low-probability, major hazards such as severe earthquakes and flooding. These recommended actions will also further enhance safety of the facility during normal operating conditions, which already have low risk. The recommendations include actions to enhance stability of the facility, to relocate infrastructure, review and update emergency planning, and to further investigate potential significant areas of uncertainty that could influence dam safety decision making in the future. The best practices employed at the site continue to progressively evolve, taking advantage of the best practicable new technologies and techniques. Risks related to the YDTI will continue to be evaluated periodically and mitigated progressively to enhance dam safety.

TABLE OF CONTENTS

PAGE

TABLES

FIGURES

APPENDICES

ABBREVIATIONS

ACC .... Anaconda Copper Company
AEP .... Annual Exceedance Probability
AR .... Atlantic Richfield Company
APF .... Annualized Probability of Failure
EAP .... Emergency Action Plan
EL. .... Elevation
EMI .... Engineering Management, Inc.
EOR .... Engineer of Record
EPRP .... Emergency Preparedness and Response Plan
ET .... Event Tree
ft .... feet
FMA .... Failure Modes Analysis
GISTM .... Global Industry Standard on Tailings Management
HLA .... Harding Lawson Associates
HsB .... Horseshoe Bend
IECO .... International Engineering Company, Inc.
IRP .... Independent Review Panel
KP .... Knight Piésold Ltd.
MBMG .... Montana Bureau of Mines and Geology
MCA .... Montana Code Annotated
MCE .... Maximum Credible Earthquake
MDEQ .... Montana Department of Environmental Quality
MDNRC .... Montana Department of Natural Resources and Conservation
MR .... Montana Resources, LLP
MSHA .... Mine Safety and Health Administration
Mtons .... million tons
PFMA .... Potential Failure Modes Analysis
PFM .... Potential Failure Mode
PMF .... Probable Maximum Flood
QRA .... Quantitative Risk Assessment
RDS .... Rock Disposal Site
SLWS .... Silver Lake Water System
TAC .... The Anaconda Company
TOMS .... Tailings Operations, Maintenance and Surveillance
USACE .... United States Bureau of Reclamation
USACE .... United States Army Corps of Engineers
WED .... West Embankment Drain
YDTI .... Yankee Doodle Tailings Impoundment

1.0 INTRODUCTION

1.1 GENERAL

Montana Resources, LLP (MR) and Atlantic Richfield Company (AR) jointly sponsored a risk assessment of the Yankee Doodle Tailings Impoundment (YDTI). The goal of the joint risk assessment was to improve technical alignment and understanding of the key risks associated with potential credible failure modes for the YDTI. The assessment focused on credible failure modes, including foundation and embankment instability, overtopping, and internal erosion and piping while considering relevant starting conditions and potential loading conditions (e.g. seismic events, flood events, and significant operational events). The temporal scope of this risk assessment was focused on near-term operating conditions with the embankments raised to a crest elevation of EL. 6,450 ft while considering continued operations through approximately 2031.

The best practices employed at the site continue to progressively evolve, taking advantage of the best practicable new technologies and techniques. The design, construction, operation, maintenance, and surveillance of the YDTI involves a multidisciplinary team of professionals. The team works closely together to achieve the fundamental objective of ongoing continuous improvement of the safety of the impoundment. Risks related to the YDTI will continue to be evaluated periodically and mitigated progressively to enhance dam safety.

The principal objectives of this risk assessment were as follows:

- Identify and analyze risks associated with the YDTI for near-term operating conditions
- Evaluate risk in terms of likelihood and resulting consequences using event tree analyses
- Reach consensus on the main hazards of concern and recommended mitigation measures to further enhance safety of the facility
- Identify any suggested changes to surveillance and monitoring protocols to detect deviations related to critical potential failure modes
- Identify uncertainty resulting from insufficient or incomplete data, which impacts the assessment of potential failure modes, and develop plans to collect additional data to reduce the uncertainty

MR is the current operator of the YDTI and is responsible for the continued construction and safe operation of the YDTI. Knight Piésold Ltd. (KP) is the designer of the Elevation (EL.) 6,450 ft lift of the YDTI embankments and actively monitors ongoing construction activities performed by MR and operational performance of the YDTI. Construction of the EL. 6,450 ft lift of the embankment is underway and expected to be completed in 2023. The Engineer of Record (EOR) for the YDTI is currently Mr. Daniel Fontaine, P.E. of KP, who accepted the role of EOR on September 10, 2021. Mr. Ken Brouwer, P.E. of KP had previously held the role of EOR since September 2015. The former EOR, Mr. Brouwer, remains available to the KP and MR team as a Principal technical reviewer and was a participant in this risk assessment.

MR is currently using the YDTI with AR as part of a treatment system (the Pilot Project) that introduces flows from the Berkeley Pit into the mine site water management systems and facilitates the treatment and release of water from the YDTI. Goals of the Pilot Project include progressively reducing the YDTI supernatant pond volume to approximately 15,000 acre-ft and limiting further rise of the Berkeley Pit water surface elevation. AR continues to share certain environmental remediation accountabilities associated with the YDTI. AR also retained independent experts in dam safety and tailings dam engineering to participate in the risk assessment.

1.2 GUIDING RISK MANAGEMENT OBJECTIVE

MR developed the following guiding statement to document their risk management philosophy for the YDTI:

> *"Montana Resources risk management objective for the YDTI is consistent with our core safety values, which includes a philosophy that no incident is acceptable, and every incident is preventable. Montana Resources is committed to continuously expanding our understanding of the facility and continuously improving our management of the facility to ensure that the YDTI is fully protective of our workforce, community, and environment in which we operate and that there is never an unplanned discharge from the facility."*

1.3 PROJECT BACKGROUND

MR operates an open pit copper and molybdenum mine in Butte, Montana. MR has owned and operated the mine site since the 1980's and is currently mining the Continental Pit at a nominal concentrator throughput rate of approximately 49,000 tons per day. Tailings produced from the process are stored in the YDTI. The YDTI was originally constructed beginning in 1962 and the embankments have been continuously constructed using rockfill from the Berkeley Pit (until 1982) and from the Continental Pit (beginning in 1986). An amendment to the operating permit was approved in August 2019 to allow for continued use of the YDTI, which is being facilitated by continued construction of the embankment to a crest elevation of 6,450 ft and operation of the West Embankment Drain (WED).

The YDTI comprises a valley-fill style impoundment created by a continuous rockfill embankment that for descriptive purposes is divided into three embankment sections: the North-South Embankment, the East-West Embankment, and the West Embankment. The embankments are raised using a combination of downstream and centreline construction methods. The current maximum embankment height is approximately 800 ft along the southern end of the impoundment upstream of the Horseshoe Bend (HsB) area. The HsB area is shaped like an inverted 'U', bounded to both the east and west by historically leached mine rock and to the north by the East-West Embankment. The HsB area contains infrastructure related to YDTI seepage collection and historical mine leach operations along with miscellaneous mine buildings, including the truck maintenance workshop. The project arrangement is shown on Figure 1.1.

The MR facilities, mine operations, and YDTI operational procedures are described in additional detail in the MR report entitled '*Yankee Doodle Tailings Impoundment – Tailings Operations, Maintenance and Surveillance (TOMS) Manual*' (MR/KP, 2022). Additional details related to the facility development history, previous risk analysis studies, summary of recent relevant trends, and other reference information are included in Appendix A.

NOTES:

1. COORDINATE SYSTEM AND ELEVATIONS ARE BASED ON ANACONDA MINE GRID.
2. AERIAL IMAGERY PROVIDED BY MONTANA RESOURCES, LLC ON JULY 20, 2022.

SCALE A: 1500 | 0 | 1500 | 3000 | 4500 | 6000 | 7500 ft

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	REVIEWED
0	07JUL'23	ISSUED WITH REPORT	DDF	RMM	KJB

MONTANA RESOURCES, LLC

YANKEE DOODLE TAILINGS IMPOUNDMENT

PROJECT ARRANGEMENT

Knight Piésold CONSULTING

P/A NO.	REF NO.
VA101-126/27	1

FIGURE 1.1 REV 0

SAVED: M:\1\01\00126\27\A\Acad\FIGS\A09, 5/15/2023 10:23:33 AM, ELEE PRINTED: 7/5/2023 8:42:38 AM, FIG 1.1, RMCLELLAN
XREF FILE(S): Tailings and Reclaim Pipelines; 5ft_01_2022-07-18 IMAGE FILE(S): 5ft_01_2022-07-18

1.4 RISK ASSESSMENT PROCESS

1.4.1 GENERAL

The risk assessment was conducted through a series of virtual and in-person meetings following the process illustrated in Figure 1.2. Initial meetings focused on developing the assessment process and terms of reference, discussion of supporting information to improve technical alignment, and selecting the risk assessment team. A potential failure modes analysis was then completed by the risk assessment team to evaluate site-specific potential failure modes for the YDTI and to identify major hazards considered to be of greatest significance that required further assessment. The major hazards identified by the failure modes analysis were then further evaluated using event tree analyses to estimate the probability of occurrence of an adverse outcome and to determine the main hazards of concern. Potential mitigation measures were then evaluated to identify and prioritize recommended mitigation measures that could further reduce risk associated with the major hazards and to enhance safety of the facility.

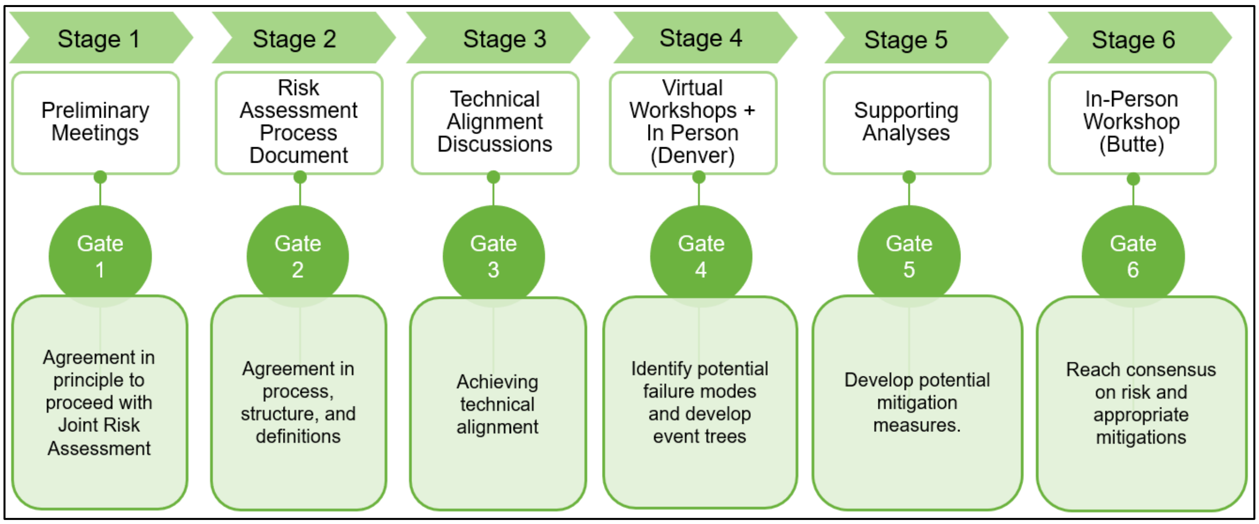


Figure 1.2 Risk Assessment Process Overview

1.4.2 PARTICIPANTS

The following people regularly participated in the analysis of YDTI risks and attended the various risk assessment meetings and workshops:

- Peter K. Robertson, Ph.D., P.Eng. – Independent Facilitator
- Daniel Fontaine, P.E. of KP – EOR of the YDTI
- Ken Brouwer, P.E., Tom Kerr, P.E., Kevin Davenport, P.Eng., and Jason Gillespie, P.Eng. of KP
- Brian Hippley, Ph.D., P.E. of AECOM, Richard Davidson, P.E., and Norbert Morgenstern, Ph.D., P.Eng

The following people helped prepare materials for and/or regularly attended and observed the meetings and workshops:

- Mark Thompson and Mike Harvie of MR
- Loren Burmeister and Chris Greco of AR
- Roanna Dalton, P.Eng. and Ethan Alban, E.I.T. of KP

1.4.3 LEGISLATED REQUIREMENTS AND GUIDING DOCUMENTS

The jurisdiction for the YDTI resides with the Montana Department of Environmental Quality (MDEQ). The laws governing tailings storage facility design, operation and reclamation are contained within sections of Montana Code Annotated (MCA) Title 82 Chapter 4 Part 3 (MCA, 2019). The State laws in Montana governing tailings storage facility design, operation and reclamation form the primary requirements that needed to be addressed while updating the risk assessment for the YDTI.

There were also many available national and international guidance documents related to risk assessment and dam safety management, including some updated and newly emerging international best practice guidelines for tailings management that were reviewed when developing the updated risk assessment framework for the YDTI. The goal was to incorporate international best practices to the extent practicable while taking into consideration site-specific conditions and concerns. The procedures outlined in the Best Practices in Dam and Levee Safety Risk Analysis by the U.S. Department of the Interior Bureau of Reclamation (USBR, 2019) were considered to be the best practices for dam risk analyses in the U.S. at the time of the study. The risk assessment process generally followed the USBR best practice guidelines while considering other international guidelines.

Parties to the risk analysis strived to comply with the Global Industry Standard on Tailings Management (GISTM) (GTR, 2020) where reasonable and appropriate. The GISTM suggests that risk assessments should be performed by a qualified multi-disciplinary team using best practice methodologies every three years, and more frequently whenever there is a material change to the tailings facility or to the social, environmental, and local economic context of the site. The GISTM also suggests that risk assessments be provided to senior independent reviewers and that unacceptable tailings facility risks are addressed with urgency.

1.5 INDEPENDENT REVIEW PANEL

An Independent Review Panel (IRP) consisting of three independent tailings facility review experts is required by State law for the YDTI. The IRP is responsible for review of the amendment application design documents, the underlying analysis, and assumptions for consistency with State law. The IRP accepted the adequacy of the EL. 6,450 ft raise design in 2017 and highlighted their requirements for on-going information updates to be addressed during annual updates and periodic reviews (as outlined in MCA 82-4-380). The first periodic review of the YDTI was completed in 2020 (IRP, 2020). The following three international experts constitute the current IRP for the YDTI:

- Dr. Dirk Van Zyl, P.E. – Tailings and Geotechnical Specialist
- Dr. Leslie Smith, P.Geo. – Hydrogeology Specialist
- Mr. Jim Swaisgood, P.E. – Dam and Seismic Specialist

A fourth international expert was also engaged to provide additional YDTI oversight and review beginning in 2019. Tailings and geotechnical specialist, Dr. Peter K. Robertson, participates with the IRP and EOR in update meetings and reviews documents concerning the YDTI. Dr. Robertson also participated in the risk assessment as the facilitator, as noted previously.

The IRP did not directly participate in the preparation of the risk assessment; however, the IRP members were informed of the planned process, presented the results of the risk assessment periodically during the process, and will be provided a copy of this risk assessment report for their review and comment.

2.0 POTENTIAL FAILURE MODES ANALYSIS

2.1 GENERAL

The Potential Failure Modes Analysis (PFMA) consisted of identifying, describing, and performing an initial screening assessment to evaluate site-specific potential failure modes for the YDTI. The PFMA was conducted by virtual meetings on July 6-7 and August 16, 2021. The PFMA considered the following:

- Relevant initiating events (e.g. flood events, earthquake events, embankment construction loading, material degradation, and operational upsets or malfunctions)
- The associated potential failure mechanism (e.g. overtopping, embankment deformation, slope instability, and internal erosion and piping)
- Step-by-step progression towards failure and location considered
- The resulting impacts (e.g. a description of the potential physical impacts)
- Potential for intervention

The PFMA process resulted in differentiation between those potential failure modes (PFMs) that were considered to be not credible or have negligible contribution to the risk profile and those that potentially contribute the most to the risk profile, in the opinion of the risk assessment team. The PFMs were assigned to the categories summarized in Table 2.1 below based on the consensus of the risk assessment team.

Table 2.1 Categories for Prioritization of Potential Failure Modes

Category	Assessment Priority	Description
1	Highlighted	Failure mode of greatest significance considering need for awareness, potential for occurrence, magnitude of consequences and likelihood of adverse response. Physical possibility evident, fundamental flaws or weakness identified and conditions and events leading to failure seemed reasonable and credible
2	Considered, but not Highlighted	Judged to be lesser significance and likelihood. Reason for lesser significance is noted and summarized in the documentation.
3	More Information or analyses needed	Lacked information for confident judgement of significance and action or analyses recommended. Need for action to be highlighted.
4	Ruled Out	Failure mode unlikely to occur or non-credible.

Note(s):

1. Categories adopted for the PFMA were simplified from those suggested by guidance from the Federal Energy Regulatory Commission (FERC, 2017) and the Montana Department of Natural Resources and Conservation (MDNRC, 2011).

2.2 MAJOR HAZARDS IDENTIFIED

The major hazards identified during the PFMA included the potential for occurrence of earthquakes, severe flooding, fill and foundation material degradation, on-going construction and operations activities, and other geologic and environmental hazards.

A summary of the potential failure modes assessed for each embankment limb and the associated categorization of the failure modes is shown in Table 2.2. A one-page summary for each potential failure mode was prepared during the PFMA workshops to document the reasoning of the risk assessment team and are included in Appendices B1 to B3. Each one-page summary includes a table of factors that would make the failure mode more likely and less likely to occur. Detailed summary tables from the failure mode screening also are provided in each appendix.

Table 2.2 Summary of Potential Failure Modes Analysis Results

Embankment	Number of Potential Failure Modes Evaluated	Summary Information Location	Category			
			1	2	3	4
East-West Embankment	22	Appendix B1	13	5	1	3
North-South Embankment	17	Appendix B2	3	4	1	9
West Embankment	10	Appendix B3	-	4	3	3
Total	**49**	**-**	**16**	**13**	**5**	**15**

Note(s):

1. All Category 1 failure modes that were 'highlighted' for further assessment were directly incorporated into the development of event tree analyses.
2. Six potential failure modes that were not initially 'highlighted' as Category 1 were also incorporated into the event trees where the failure modes fit logically within the event tree structure as a variation of the embankment behavior or potential consequences of failure.

The major hazards (loading conditions) carried forward for further assessment included severe flooding, earthquakes, construction loading, and material degradation. The highlighted potential failure modes resulting from these major hazards and selected for further evaluation using event tree analyses consisted of foundation and slope instability, internal erosion and piping, undesirable embankment deformation, and overtopping. The structure of the event trees developed for this risk assessment and the basis for incremental probability assignments are further described in the next section.

The PFMs that were not carried forward into the event tree analysis portion of the study were generally related to geological hazards (e.g. fires, drought, heavy winds, etc.), operational upsets (e.g. tailings line failures, power loss, etc.), or flood-induced embankment overtopping. The reason for screening each out from further consideration is documented in the associated PFMA summary information included in Appendix B. The Category 3 PFMs generally related to the potential for landslides along Rampart Mountain impacting the YDTI embankments (3 PFMs) or the long-term performance risks for the West Embankment Drain associated with the potential for severe earthquakes or long-term exposure to acidic drainage (2 PFMs). These PFMs were judged to potentially require further consideration in the future and some opportunities for additional data collection were noted in the PFMA documentation. No PFMs considered along the West Embankment were 'highlighted' for further consideration and therefore no event trees were developed/conducted for the West Embankment.

3.0 QUANTITATIVE RISK ANALYSIS

3.1 GENERAL

Event tree analysis is a commonly used quantitative risk analysis tool to identify, characterize, and estimate risk associated with dam safety. Each event tree typically begins with an initiating event (or hazard) and graphs the sequences of subsequent hypothetical events that ultimately could lead to failure. The probability of an outcome of a pathway (at an end node) depends on all events along the pathway to the left with cumulative probability represented by the product of the branch probabilities along the pathway. The cumulative probability calculated for each pathway represents the Annualized Probability of Failure (APF) for that individual potential failure mode.

Event trees were developed for PFMs that were highlighted as risk-drivers during the PFMA. The risk analyses were performed using the PrecisionTree add-in to Microsoft Excel (part of the DecisionTools Suite), which is an effective tool for visualizing event trees, assigning probabilities to event tree branches, and automating the probability calculations to estimate the APF for the various failure modes.

3.2 EVENT TREE ANALYSIS

Five generalized event trees were developed for the risk analysis to facilitate evaluation of the major hazards identified during the PFMA. Examples of each generalized event tree showing the event tree structure are included in Appendix C1 for reference. The generalized event trees used in the risk analysis were as follows:

- Event Tree 1 (ET1): Flood-induced instability
- Event Tree 2 (ET2): Flood-induced piping/internal erosion
- Event Tree 3 (ET3): Earthquake-induced deformation
- Event Tree 4 (ET4): Construction loading-induced instability
- Event Tree 5 (ET5): Material strength degradation instability

The thirteen (13) highlighted PFMs for the East-West Embankment and four (4) additional PFMs not initially highlighted were combined and evaluated with these five event trees (ET1 to ET5). The three (3) highlighted PFMs for the North-South Embankment were combined with two (2) additional PFMs not initially highlighted and evaluated using ET1, ET2, and ET3. This resulted in the evaluation of eight (8) event trees for the quantitative risk analysis portion of the risk assessment. The results of the these are presented in Appendix C3.

The event tree analyses were performed by the risk assessment team during several in-person meetings, which occurred on May 25-26, 2022 in Denver, Colorado and June 29-30, 2022 in Butte, Montana, and a virtual meeting that occurred on June 13, 2022. Attendees were also able to join the in-person meetings virtually depending on scheduling and personal travel restrictions.

The criteria for estimating the probability values and potential consequences of failure used during the event tree analyses are summarized in Appendix C2. These criteria were used to guide discussion and to reach consensus on the probability assignments made by the risk assessment team. The individual probability estimates were added to the event tree in real time during the meetings and are not reproduced in this report for ease of presentation. The overall results of the assessment were portrayed on visualization plots and reviewed by the group to confirm they were reasonably representative of the consensus opinion of the team.

3.3 SELECTED FORMAT FOR PORTRAYING RISK

The risk analysis process described above produced estimates of risk for individual potential failure modes. These estimates were based on the way the potential failure modes were evaluated, including interpretation of an array of input data, technical analyses, and resulting subjective estimates of the likelihood and potential consequences of failure. The reference subjective consequence criteria developed for the risk analysis are described in Appendix C2 and included in Table 3.1.

Table 3.1 Subjective Consequence Criteria

Subjective Consequence Criteria		
Category	**Impact to Mine Operations**	**Life Safety Risks**
Catastrophic/Extreme	Potential to render key site facilities inoperable and cause off-site damages	On-site worker and off-site public safety risks
Major	Potential impact on precipitate plant, maintenance workshop, and Booster Pump Houses	Potential impacts to permanent on-site workers
Moderate	Potential impact on operability of pipelines, mine haul ramps, and #3 Booster Pump House	Potential impacts to transient on-site workers
Minor/Low	No facilities impacted; resulting failure investigations may impact operations or have no impact to daily operations	Minimal to no on-site worker safety risk

A graphical technique was selected for results presentation in this report. This graphical technique uses a color-coding scheme to highlight zones of lower and higher risk as illustrated in Figure 3.1. In general terms, risk is higher when the likelihood and consequence of failure is higher, and risk is lower when the likelihood and consequence is lower. Each branch of the event trees ends with the potential consequence category (either Minor, Moderate, Major or Extreme based on the reference consequence criteria) and an estimate of the cumulative annualized probability of failure (the APF), which collectively create a data point. These data points were then plotted on the color-coded matrix below to portray the individual risks. The results were then reviewed by the risk assessment team to determine the main hazards of concern. Failure modes that plot within the lower, left side of the color-coded chart were estimated to be lower risk whereas failure modes that plot moving upwards and to the right indicate relatively higher risk.

Likelihood	Subjective Consequence Category			
	Minor	Moderate	Major	Extreme
High (APF = 10^{-2})				
Moderate (APF = 10^{-3})				
Low (APF = 10^{-4})				
Very Low (APF = 10^{-5})				
(APF = 10^{-6})				
Remote (APF = 10^{-7})				
(APF = 10^{-8})				

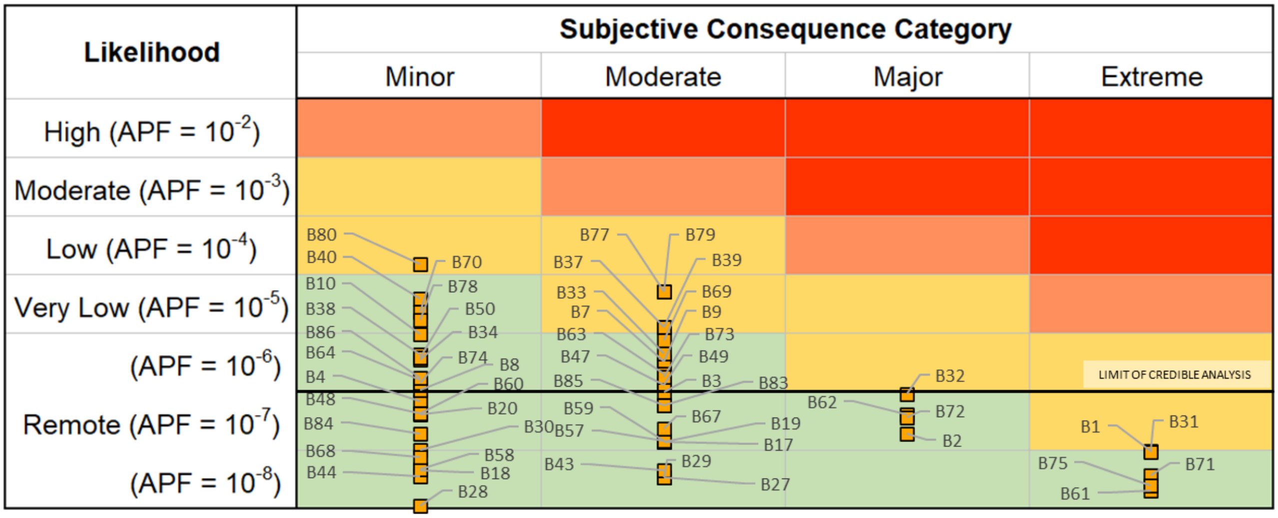
Figure 3.1 Risk Portrayal Template

3.4 SUMMARY OF RESULTS

3.4.1 GENERAL

The results generally indicate across all failure modes that probability of an adverse outcome decreases with increasing consequence severity. The estimated probabilities for the individual branches of each event tree vary by several orders of magnitude with one or more branches generally contributing the most to the risk profile (risk drivers) for each event tree and the others being less consequential. A typical example of the event tree analysis results for the East-West Embankment earthquake-induced deformations (EW-ET3) is shown on Figure 3.2. Each data point (identified in this event tree by B##) represents an individual branch of the event tree, which allows identification of the branch of the event tree. The individual results for each event tree analysis are presented in Appendix C3 using the color-coded chart scheme shown above. The results are organized by event tree with one chart provided for each embankment and failure mode. Figure 3.2 below is copied from Figure C3.3 in Appendix C3.

An extensive summary of all branches of the event trees is not included in this report for ease of presentation and brevity but the complete results are available in the event trees with discussions captured in the meeting records for future reference. A calculated probability of 10^{-6} (i.e. one in a million) was generally viewed as a limiting value whereby values lower than this threshold have very low probability but the calculated values and differences cannot be quantified with great credibility. The calculated values are presented for completeness but could be interpreted to mean less than one in a million.



Note(s):

1. Figure 3.2 is a copy of Figure C3.3 in Appendix C3 provided as an example. Please refer to Appendix C3 for more details and summaries from other event trees.

Figure 3.2 East-West Embankment Earthquake-Induced Deformation (EW-ET3)

Additional summary plots representing cumulative values for each consequence category are provided in Figures 3.3 and 3.4. The cumulative results shown in Figure 3.3 represent the sum of all branches for each major hazard (i.e. results for both embankment sections evaluated were combined), and the results shown in Figure 3.4 represent the sum of all branches within each event tree (i.e. results organized by embankment and major hazard).

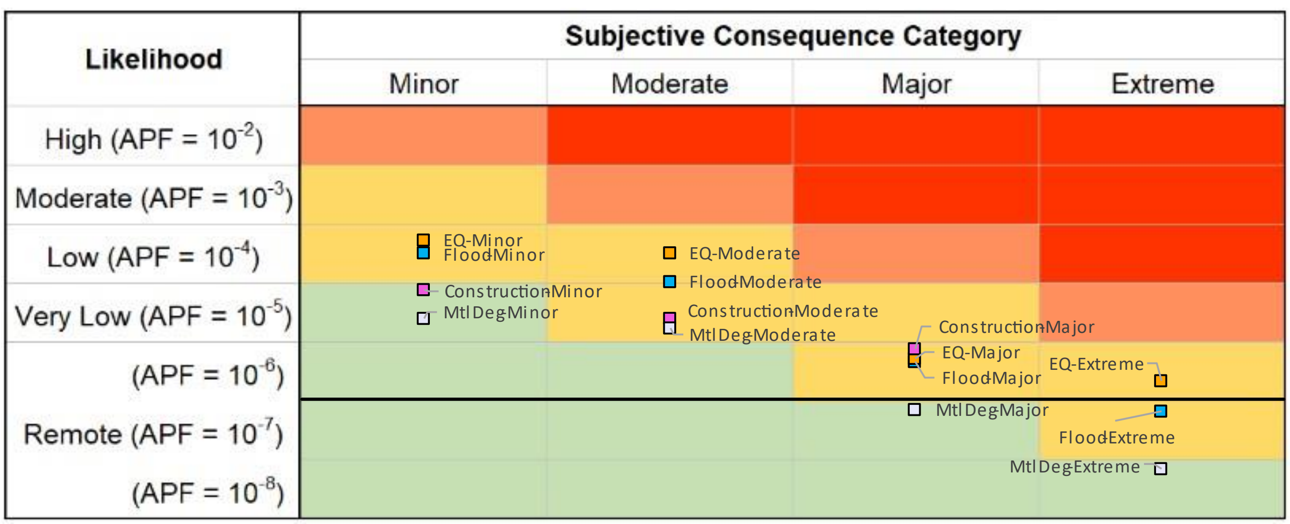


Figure 3.3 Risk Summary by Embankment and Major Hazards (Cumulative APF)

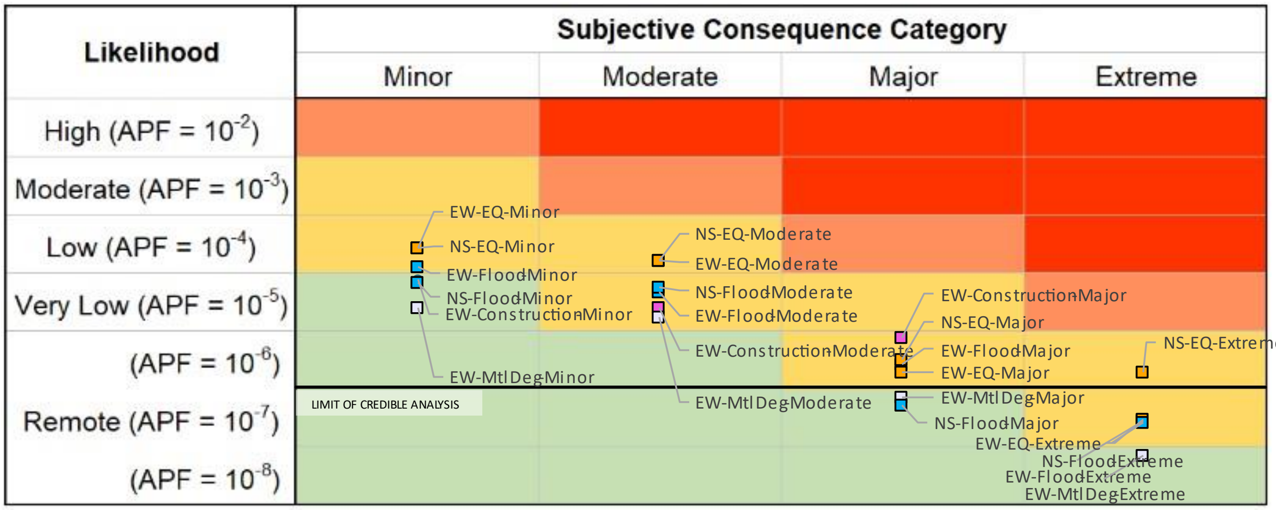


Figure 3.4 Risk Assessment Summary by Major Hazard (Cumulative APF)

A discussion of the risk drivers for each of the major hazards is provided below to inform the identification of the main hazards of concern and key uncertainties identified by the risk assessment team that influence the results of the assessment.

3.4.2 EARTHQUAKES

The potential for adverse embankment deformation due to a severe earthquake was identified to be one of the main hazards of concern during the risk assessment. A summary of the risk driver branches of these event trees and the estimated probabilities associated with them are summarized in Table 3.2 for the event tree branches that were defined as falling under the Extreme consequence category. The results of the earthquake event trees for the East-West Embankment and North-South Embankment are presented on Figures C3.3 and C3.8, respectively, in Appendix C3.

The primary risk driver for the Extreme (and Major) consequence categories was the potential for foundation and/or slope instability due to the MCE occurring at the site resulting in high excess pore pressure generation in the saturated zones of tailings, embankment fill and the foundation. Lesser contributors to the risk profile included less severe earthquakes and/or lesser excess pore pressure response in the zones of saturation. The risk profile for the 'Minor' and 'Moderate' consequence categories was primarily controlled by embankment settlement and lateral displacement with commensurate cracking. The primary factor influencing the probability estimates was the very low likelihood of these severe earthquake events occurring.

Table 3.2 Earthquake Hazard Risk Drivers (Extreme Consequence)

Branch(es)	Probability of Extreme Consequence	Description
NS-I1	1.7E-06	North-South Embankment slope/foundation instability; 84th-percentile Maximum Credible Earthquake (MCE) with high excess pore pressures.
B-1	9.5E-08	East-West Embankment slope/foundation instability; 84th-percentile MCE with high excess pore pressures.
B-31	9.0E-08	East-West Embankment slope/foundation instability; 50th-percentile (median) MCE with high excess pore pressures.
NS-I31	9.0E-08	North-South Embankment slope/foundation instability; 50th-percentile (median) MCE with high excess pore pressures.
Remaining Branches	1.9E-07	Other lesser contributors to the risk profile include slope/foundation instability for less severe earthquakes and/or pore pressure response and failure modes driven by crest settlement, lateral displacement, and commensurate cracking.
Total	**2.1E-06**	Estimated cumulative APF for earthquake-induced deformations with extreme consequences.

Note(s):

1. Primary risk drivers estimated for the Major consequence category are generally consistent with those listed for the Extreme consequence category in the table above.
2. Primary risk drivers estimated for the Moderate and Minor consequence categories typically related to the potential for settlement and lateral displacement with commensurate cracking.

The highest estimated individual probability for ‘Major’ and ‘Extreme’ consequences for this major hazard was on the order of 10^{-6} or approximately one in a million. However, it was generally recognized that there may be an order of magnitude of uncertainty in this estimate based on the current knowledge base, particularly along the North-South Embankment where there is limited knowledge about the engineering properties of the historical dump leach materials and their variability within the foundation of the embankment. This uncertainty is reflected in the branch probabilities assigned in the North-South Embankment event tree (N-S ET3). Consensus was not fully reached by the risk assessment team on the probability assignments for this failure mode; however, it was generally agreed that the uncertainty in engineering properties related to the historical leach materials in this area and the corresponding seismic response of the North-South Embankment warranted further study. This consensus of the team is reflected in the recommended actions provided in Section 4 of this report, including the priorities for on-going site investigations in the area as well as the relative prioritization of slope flattening and buttressing along the North-South Embankment as rockfill becomes available from mining.

3.4.3 FLOODS

The potential for adverse facility response due to severe flooding was identified to be another main hazard of concern during the risk assessment. A summary of the risk profile for these event trees, including flood-induced instability and flood-induced piping/internal erosion, as represented by the event tree branches that were defined as falling under the Extreme consequence category, is provided in Table 3.3. The estimated risk profile for severe flooding was more evenly distributed within the individual branches than for the earthquake hazard. The results of the flood event trees for the East-West Embankment are presented on Figures C3.1 and C3.2, and the flood event results for the North-South Embankment are presented on Figures C3.6 and C3.7 in Appendix C3.

Table 3.3 Flood Hazard Risk Profile by Flood Event (Extreme Consequence)

Branch(es)	Probability of Extreme Consequence	Description
Combined PMF event	3.5E-07	Slope/foundation instability and internal erosion/piping; Probable Maximum Flood (PMF)
Combined 1 in 1,000-year event	2.0E-07	Slope/foundation instability and internal erosion/piping; 1 in 1,000-year wet month
Total	**5.7E-07**	Estimated cumulative APF for flood-induced failure modes with extreme consequences.

Note(s):

1. The relative distribution of the risk profile estimated for the Major consequence category is generally consistent with those listed for the Extreme consequence category in the table above.
2. The relative contribution of the 1 in 1,000-year event to the risk profile estimated for the Moderate and Minor consequence categories is larger than for the Extreme and Major categories reaching approximately 50% of the cumulative APF.

The risk profile organized by failure mode, including flood-induced instability and flood-induced piping/internal erosion, is summarized in Table 3.4.

Table 3.4 Flood Hazard Risk Profile by Failure Mode (Extreme Consequence)

Branch(es)	Probability of Extreme Consequence	Description
Foundation / Slope Instability	4.4E-07	Slope/foundation instability; PMF and 1 in 1,000-year wet month
Internal Erosion / Piping	1.3E-07	Internal erosion / piping; PMF and 1 in 1,000-year wet month
Total	**5.7E-07**	Estimated cumulative APF for flood-induced failure modes with extreme consequences.

Note(s):

1. The relative distribution of the risk profile estimated for the Major consequence category is generally consistent with those listed for the Extreme consequence category in the table above.
2. The relative contribution of the internal erosion and piping failure to the risk profiles estimated for the Moderate and Minor consequence categories was negligible and approximately 50%, respectively.

The primary risk driver for the Major and Extreme consequence categories was the potential for an adverse response due to severe, low-probability flooding, which could result in rising pore pressures in the tailings, embankment fill and foundation materials potentially leading to foundation or slope instability. The PMF generally contributed more to the risk profile than the 1 in 1,000-year return period event due to the relative size and expected proximity of the supernatant pond to the embankment under these conditions despite the lower likelihood of this more severe flood occurring. The relative contribution of the 1 in 1,000-year return period event for the Moderate and Minor consequence categories increased progressively. Lesser contributors to the risk profile for all consequence categories included the potential for internal erosion and piping under PMF conditions. The potential for internal erosion and piping for 1 in 1,000-year return period event did not contribute significantly to the risk profile due to the availability of on beach water storage within the facility without reaching the embankment.

It was recognized by the team that there is uncertainty related to the potential piezometric response within the tailings, embankment and foundation materials as a result of severe flooding, and this was identified as a topic for future evaluation. There was discussion and consensus within the risk assessment team that limiting the level and/or duration of inundation in the facility associated with severe flooding would be a beneficial mitigation measure. It was generally recognized that the current and continued pond inventory management activities (i.e. reducing normal operations water storage within the facility) will increase available storage on beach within the facility in the short-term, and the capability to discharge water from the facility and prevailing water balance deficit conditions were positive attributes for the overall risk profile during operations.

A closure spillway is planned at the end of operations, which will provide passive control of the maximum ponding level in the long-term. Several additional potential mitigations for future assessment were noted during the workshops, including developing water management action plans under flood conditions and the potential inclusion of interim emergency spillways in future designs. These mitigations for future assessment are included in Section 4.

3.4.4 CONSTRUCTION LOADING

The potential for embankment instability due to construction loading was assessed while considering the trigger-action response plans developed for the focused construction monitoring for the EL. 6,450 ft lift of the East-West Embankment. The assessment highlighted significant and widespread pore pressure increases would be indicative of higher risk as indicated in the summary provided in Table 3.5. The results presented in Table 3.5 are for the Moderate consequence category. The Moderate consequence category was selected for the results presented in Table 3.5 because there were no event tree branches falling under the Extreme consequence classification, and the Major consequence category only included scenarios with considerable and widespread changes to pore pressure as a result of construction loading, which were not observed during monitoring of response to EL. 6,450 ft lift construction. The results of the construction loading event tree for the East-West Embankment are presented on Figure C3.4 in Appendix C3.

Detailed monitoring is underway to identify changing pore pressure conditions as well as monitoring of embankment deformations. This hazard was generally recognized by the team to be well managed and was not considered to be a main hazard of concern for the current risk assessment.

Table 3.5 Construction-Loading Hazard by Response (Moderate Consequence)

Pore Pressure Response	Probability of Moderate Consequence	Description
Considerable	1.3E-05	Significant and widespread pore pressure increases in the basal saturated zone or perched saturated zones
Moderate	9.3E-06	Significant but localized pore pressure increases in the basal saturated zone or perched saturated zones
Low/Negligible	7.5E-07	Low to negligible, localized pore pressure increase below response thresholds
Total	**2.3E-05**	Estimated cumulative APF for construction loading-induced failure modes with Moderate consequences.

Note(s):

1. Primary risk drivers estimated for the Major consequence category include scenarios with a considerable and widespread changes to pore pressures as a result of construction loading. The pore pressure response during EL. 6,450 ft lift construction was low/negligible and localized.

3.4.5 MATERIAL DEGRADATION

The potential for embankment instability due to strength and/or stiffness reduction due to material degradation was evaluated for the mechanisms of degradation shown in Table 3.6, including creep occurring along a continuous plane, extension and unloading within the embankment, and acid rock drainage processes. The results presented in Table 3.6 are for the Extreme consequence category. The results of the material degradation event tree for the East-West Embankment are presented on Figure C3.5 in Appendix C3.

The results indicate that the risk of this mechanism of instability for near-term operating conditions was relatively low compared to the other major hazards assessed. There was consensus by the risk assessment team that these processes were potentially important to consider in more detail in future risk assessments with a longer-term lens encompassing future operations and ultimate facility closure. It was also generally agreed that there was limited site-specific knowledge to assess the differences between these mechanisms of strength and stiffness reduction, which may warrant future study.

Table 3.6 Material Degradation Hazard by Mechanism (Extreme Consequence)

Mechanism of Degradation	Probability of Extreme Consequence	Description
Creep	3.3E-08	Creep occurring along a continuous plane causing excess pore pressure development and/or changing confining pressures resulting in strain-induced loss of strength
Extension / Unloading	1.65E-08	Deformation resulting in decreasing confining pressures resulting in strain-induced loss of strength
Acid Rock Drainage	1.65E-08	Continuous acidic drainage and chemical weathering resulting in decreasing strength and/or stiffness properties
Total	**6.6E-08**	Estimated cumulative APF for material degradation-induced failure modes with Extreme consequences.

Note(s):

1. The relative risk profile estimated for the Major and Moderate consequence categories was generally consistent with the results presented for the Extreme consequence category above. The estimated probability of an adverse outcome generally increased with decreasing consequence severity.

3.5 MAIN HAZARDS OF CONCERN IDENTIFIED

The risk assessment results indicate that current normal operating conditions have low risk. The major hazards contributing the normal operating risk profile include construction-loading, material degradation, and relatively small earthquakes and flooding that are expected to be manageable. The estimated probability of an adverse outcome generally increased with decreasing consequence severity.

The main hazards of concern identified by the event tree analyses were extreme earthquakes and floods, which have a very low likelihood of occurring. However, these events also have the potential to result in severe consequences. The guiding risk management objective for the YDTI is to continuously expand understanding of the facility and continuously improve management of the facility to enhance safety to the MR workforce, community, and environment. Mitigation measures were evaluated by the risk assessment team with this risk management objective lens. Mitigation concepts were identified by the participants prior to and during the risk workshops. The evaluation of mitigation options and recommended actions are described in Section 4.

4.0 MITIGATION OPTIONS AND RECOMMENDED ACTIONS

4.1 EVALUATION OF MITIGATION OPTIONS

General mitigation options considered by the risk assessment team included the following types:

- Changes to surveillance and monitoring protocols to detect deviations related to potential failure modes
- Changes to emergency preparedness and response plans
- Developing plans to collect additional data
- Physical mitigation measures (e.g. design refinements) if practicable options are identified that can be implemented

The effectiveness and appropriateness of the potential mitigation options were judged against a variety of factors, including the following:

- Means of risk reduction (e.g. reduces likelihood, consequences, or both)
- Timing
- Effectiveness
- Reliability
- Uncertainty
- Cost (qualitative)
- Potential negative implications (drawbacks)

The following sections outline the consensus recommendations by the risk assessment team for priority actions, medium to long-term actions, and follow up studies for future assessment. Additional details summarizing the evaluation of the recommended actions during the workshop on June 30, 2022 are included in the presentation slides in Appendix D.

4.2 RECOMMENDED ACTIONS

4.2.1 GENERAL

The recommended actions developed by the risk assessment team were focused on mitigating the likelihood and potential consequences of failure related to low-probability, major hazards such as severe earthquakes and flooding. These recommended actions will also further enhance safety of the facility to the MR workforce, community, and environment during normal operating conditions, which already have low risk. The recommendations include actions to enhance stability of the facility, to relocate infrastructure, review and update emergency planning, and to further investigate potential significant areas of uncertainty that could influence dam safety decision making in the future.

The following site-specific mitigation options for the YDTI were discussed and evaluated during the workshops:

- Continued pond inventory management
- On-site Containment Project
- Horseshoe Bend (HsB) Rock Disposal Site (RDS) buttress
- North-South Embankment slope flattening and North RDS

- Truck shop relocation
- Phase site investigation objectives, including:
  - On-going annual site investigation programs within 5-Year plan framework
  - Accelerated investigation of historical leach areas

Additional details related to the evaluation of each of the above mitigation options are summarized in the sections that follow, including a brief description, inferred benefits and drawbacks, effectiveness and practicability, estimated timeframe to implement, and priority for implementation of each mitigation.

4.2.2 CONTINUED POND INVENTORY MANAGEMENT

The previous risk assessment for the YDTI (KP, 2018a) identified that reducing the normal operating pond volume towards a target volume of approximately 15,000 acre-ft would substantially reduce risks associated with facility performance following natural flooding. The Pilot Project began discharging YDTI water off site in September 2019. The annual bathymetric survey and assessment of the YDTI supernatant pond volume completed in June 2022 resulted in an estimated pond volume of approximately 21,500 acre-ft, indicating the pond volume was reduced by approximately 13,000 acre-ft over three years (between Q2 2019 and Q2 2022). The continued reduction in normal operating pond volume is an important, ongoing mitigation. The volume should continue to be reduced towards the target pond volume and maintained there provided there are no adverse impacts to mine operations (e.g. reclaim water quality / clarity issues).

4.2.3 ON-SITE CONTAINMENT PROJECT

The On-site Containment Project was developed based on hypothetical assessment of the potential consequences of a breach of the YDTI. Modelling had previously indicated the most susceptible area for hypothetical breach outflows leaving the mine site involved a relatively low-lying infrastructure corridor located between the Pittsmont Dump and the Continental Pit. The project was designed to enhance containment of hypothetical breach outflows by directing these modelled flows to the Berkeley and Continental Pits. The project involves raising a haul road and haul truck parking area as a deflection berm and adjusting haul road grading towards the YDTI to direct modelled flows towards the pits.

The following benefits of this mitigation were noted by the risk assessment team:

- Reduction in potential Extreme consequences of failure for multiple potential failure modes
- Readily understood by multiple stakeholders
- Passive control (no ongoing maintenance or further action required)
- Facilitates continued mining operations and application of additional mitigation measures

The primary drawbacks of this mitigation were assessed to be a short-term operations inconvenience during construction and the incremental increase in risks related to on-site flooding, particularly in the Continental Pit area. The mitigation was considered to be highly practicable, potentially providing longer-term benefits to mine operations in terms of haul route efficiencies and can be achieved in a period of months (short-term timeframe). It was supported by the team as a high priority to implement.

4.2.4 STAGE 1 HSB RDS BUTTRESS

The Stage 1 HsB RDS buttress involves progressive placement of approximately 20 million tons (Mtons) of excess rockfill generated during mining of the Continental Pit to enhance embankment stability along the maximum section of the embankment. This was an opportunity initially identified during the previous risk assessment (KP, 2018a). The Stage 1 RDS will gradually be raised to EL. 5,900 ft downstream of the central pedestal area of the East-West Embankment. The Stage 1 footprint excludes rockfill placement within the central HsB area where existing site infrastructure is located. A future Stage 2 buttress is also contemplated in the longer-term that will infill this initial exclusion zone to cover the complete footprint of the HsB area. The HsB RDS was designed to enhance stability and improve reclamation potential while also providing economically viable storage for a large volume of rock.

The following benefits are associated with this mitigation opportunity:

- Improved stability with resulting reduction in risk
- Improved instrumentation
- Reduction in potential consequences by relocating the Precipitation Plant and associated personnel
- Improved water management capabilities and access

The primary drawbacks are the costs to relocate infrastructure and implement initial drainage works as well as the potential safety hazards that require management associated with active dumping adjacent to the remaining workers in the HsB area. This mitigation was considered to be a well-established remedial measure, achievable within a few years (short- to medium-term). It is expected to be cost-effective operation with an efficient haul route and adequate rockfill materials available within the implementation timeframe. Placement of rockfill in this RDS was considered to be the highest priority for excess rockfill placement once the foundation drainage system is constructed and rockfill placement for the EL. 6,450 ft lift of the YDTI embankment is complete.

4.2.5 NORTH-SOUTH EMBANKMENT SLOPE FLATTENING AND NORTH RDS

This mitigation involves incorporation of flatter overall slope angles and progressive development of the previously permitted North RDS downstream of the North-South Embankment as rockfill becomes available from mining. The North RDS is planned to be developed to progressively surcharge the historically leach materials in this area and ultimately infill the area downstream of the majority of the North-South Embankment between the embankment and the Rampart Mountain to a similar elevation as the embankment. Initial development of the North RDS will include construction of a new mine haul ramp to the corner of the EL. 6,450 lift of the embankment and additional downstream buttressing along the North-South Embankment with overall slope angles of approximately 3H:1V (30 Mtons of rockfill), as well as placement of material for an initial surcharge up to approximately EL. 6,200 ft (nominally 100 ft-thick) above the historically leached materials in the area (20 Mtons of rockfill). This development will occur progressively over several years along with initial development of the HsB RDS.

The primary benefits associated with this mitigation opportunity are:

- Improved stability with resulting reduction in risk
- Expected improved engineering performance of previously leached materials following surcharge
- Decreased regrading and material placement needs for early closure and/or reclamation

No drawbacks were noted for the North RDS mitigation and it was considered to be an important mitigation to implement in the medium- to long-term. It is also expected to be cost-effective operation with an efficient haul route and rockfill available within the implementation timeframe. Placement of the initial 100 ft-thick layer along the 3H:1V projection from the embankment crest was considered to be the highest priority with on-going placement of additional buttress material thereafter as rockfill becomes available. Generally, the initial development of the North RDS was considered by the risk assessment team to be of secondary priority compared to the Stage 1 HsB RDS; however, both are considered to be important structural mitigations to further enhance stability of the facility.

4.2.6 TRUCK SHOP RELOCATION

The truck shop relocation would involve constructing a new truck maintenance workshop and associated facilities in another area of the mine site further away from the YDTI. The site contemplated is located along a haul road between the Continental Pit and the plant site area near the existing site of an alluvium material stockpile. The primary benefits associated with moving the truck shop are as follows:

- Significant reduction in the potential consequences of failure for multiple failure modes
- Allows for Stage 2 HsB RDS construction
- Reduced safety hazards for personnel access into HsB area
- More convenient for mine operations
- Reduced risk during Stage 1 HsB RDS construction if implemented in the near-term

The primary drawbacks are the large costs to relocate the facilities and a possible downgrade to the existing facilities depending on the replacement costs. There are also requirements for zoning and permitting and the need to relocate the current alluvium stockpile in the area that could influence the implementation timeline. The timeline for implementation was estimated to be approximately two years or more following approval to proceed. The risk assessment team supported this opportunity as a high priority to implement in the short- to medium-term while noting that no single other measure will have a greater positive impact in the short-term on reducing the potential consequences of failure.

4.2.7 PHASED SITE INVESTIGATION OBJECTIVES

Phased investigation of the geotechnical and hydrogeological conditions within the embankment rockfill, tailings, and foundation materials underlying the embankment has been ongoing since 2015, consistent with the guiding risk management objective to continuously expand the understanding of the facility. The site investigation programs are scheduled annually, and investigation priorities are adjusted based on the findings from previous years while considering needs for existing instrumentation replacement. The current investigations are generally following a five-year investigation plan developed by KP in 2021 (KP, 2021). The annual investigations completed since 2015 have greatly enhanced the knowledge and understanding of the YDTI. The instrumentation progressively installed during these programs has resulted in a facility that is well monitored, and the data collected by the monitoring instrumentation continues to indicate the facility is being developed and operated in a manner consistent with designs and operating protocols for the facility. The continued annual investigations following the objectives laid out in the five-year plan in 2021 (KP, 2021) are considered to be important for ongoing risk mitigation.

The investigation programs over the past several have generally focused on the embankment, tailings mass, and foundation conditions with a focus on the maximum East-West Embankment section. There is comparatively limited knowledge about the engineering properties of the historical dump leach materials and their variability within the foundation and downstream of the North-South Embankment. Enhancing the knowledge base related to the expected engineering performance of these historically leached materials was considered by the risk assessment team to be an important mitigation to implement in the short- to medium-term. The primary benefits of further investigation of these materials includes better characterization of the site and improved confidence in the designs and facility performance expectations. The drawbacks include increased costs in the near-term to execute additional investigation programs during the existing five-year investigation plan for the facility. There was consensus the investigations should be done in parallel to the extent practicable without removing resources from the current investigation plans.

4.3 MITIGATIONS FOR FUTURE ASSESSMENT

The following site-specific mitigation options for the YDTI were discussed and deferred for future assessment:

- Review and update TOMS/EPRP (e.g. unusual occurrences indicators and corresponding communications protocols)
- Optimization of haul route and future haul ramp to reduce personnel risk and/or enhance stability in key areas
- Inclusion of interim emergency spillways
- Tailings beach surcharge loading along the North-South Embankment
- Emergency action planning to reduce risk for moderate-sized loading events (e.g. water management action plan for flooded conditions)
- Improved engineering specifications for embankment facing material, including at the interface between the North-South Embankment and Rampart Mountain to reduce risk of internal erosion and piping
- Review possible automation to reduce personnel risk exposure (e.g. tailings spigot discharge automation; haul truck automation
- Review upstream diversion structure options and potential influence on flood water volumes reaching the facility

The relative priority of these assessments and means of potential risk reduction are summarized in Appendix D.

5.0 REFERENCES

Federal Energy Regulatory Commission (FERC, 2017). Engineering Guidelines for the Evaluation of Hydropower Projects. Chapter 14 - Dam Safety Performance Monitoring Program. May 8, 2017.

Global Tailings Review. (GTR, 2020). Global Industry Standard on Tailings Management. Co-convened by the International Council on Mining and Metals, United Nations Environment Programme, and Principles for Responsible Investment.

Knight Piésold Ltd. (KP, 2018a). Yankee Doodle Tailings Impoundment – Dam Breach Risk Assessment, KP Ref. No. VA101-126/12-3 Rev 3, dated March 13, 2018. Vancouver, BC.

Knight Piésold Ltd. (KP, 2021). 5-Year Site Investigation, Instrumentation and Monitoring Plan for Yankee Doodle Tailings Impoundment, KP Ref. No. VA21-02063, dated December 22, 2021. Vancouver, BC.

Independent Review Panel (IRP, 2020). Report of the Independent Review Panel. Periodic Review No. 1 of Yankee Doodle Tailings Impoundment, dated September 12, 2020.

Montana Code Annotated. (MCA, 2019). Title 82: Minerals, Oil, and Gas, Chapter 4: Reclamation, Part 3: Metal Mine Reclamation, Section 376: Tailings Storage Facility – Design Document. Accessed on March 2021.

Montana Department of Natural Resources and Conservation (MNDRC, 2011). Dam Safety Program - Technical Note 7 - Guidelines for Conducting a Simplified Failure Mode Analysis for Montana Dams. December 2011.

Montana Resources, LLP and Knight Piésold Ltd. (MR/KP, 2022). Tailings Operations, Maintenance and Surveillance (TOMS) Manual (Reference No. VA101-126/25-5), Rev 5, dated January 12, 2022.

US Department of the Interior Bureau of Reclamation and US Army Corps of Engineers. (USBR, 2019). Best Practices in Dam and Levee Safety Risk Analysis – Version 4.1, July 2019.

6.0 CERTIFICATION

This report was prepared and reviewed by the undersigned.

MONTANA
2023-07-13
DANIEL DYLAN FONTAINE
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This report was reviewed and accepted by the undersigned. This signature applies only to this joint risk assessment report and only for the purpose under which this report was prepared. Future risk assessment reports are beyond the scope of this report and are therefore excluded from the signatory's acknowledgment.

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APPENDIX A

Additional Reference Information

(Pages A-1 to A-10)

APPENDIX A
ADDITIONAL REFERENCE INFORMATION

1.0 FACILITY DEVLEOPMENT HISTORY

The construction and operational life of the YDTI spans over several owners and six decades from 1962 to present, and the available historical records tend to coincide with certain periods of project development. The Anaconda Company (TAC) was the original owner and operator of the YDTI and began construction of the facility in 1962.

Initial investigations of the facility were conducted, and design and construction recommendations were provided to TAC in the early 1960's by Dames and Moore (Dames and Moore, 1962; Dames and Moore, 1963). These initial investigations were significant because they were completed at the outset of the development of the tailings facility and provide a source of information related to the geological, geotechnical, and hydrogeological conditions at the outset of facility development.

Engineering Management, Inc. (EMI) was engaged by TAC in the early to mid-1970s to provide design and construction criteria guiding the continued development of the YDTI. In parallel, the first formal review board, termed the "Board of Consultants", was formed in 1972 and consisted of Arthur Casagrande, Leo Casagrande, and F.B. Slichter. Dames and Moore performed an additional site investigation program for TAC in 1972, which informed design and construction criteria developed by EMI. However, a report detailing the results of this investigation program is not contained within the currently available project records. The engineering department of TAC with support and guidance provided by EMI, Dames and Moore, the Board of Consultants, developed updated design criteria to guide the continued construction of the YDTI, which was envisaged at the time to reach about EL. 6,350 ft over a 20-year period between approximately 1974 to 1994. Some relevant intercompany correspondence is available documenting the design criteria development during this phase.

TAC was purchased by Atlantic Richfield Company (AR) in 1977. Anaconda Minerals Company began as a TAC operating subsidiary in 1977 and operated the YDTI until 1983. The YDTI was inspected by officials from the United States Army Corps of Engineers (USACE), Mine Safety and Health Administration (MSHA), Montana Department of Natural Resources, and representatives of TAC in May 1978 and a report describing the inspection was issued in 1980 (USACE, 1980). The available intracompany correspondence at the time and external communications with the regulatory officials completing the inspection of the YDTI indicate that the on-going construction of the YDTI following the transfer of ownership continued in general accordance with the design criteria developed by TAC in the early 1970s.

The recommendations arising from the USACE inspection were as follows:

- Initiate immediate action to provide and continually maintain capability to handle projected probable maximum flood (PMF) runoff
- Develop, implement, and periodically test an emergency warning plan to alert downstream interests, inhabitants and mine workers in the event of possible dam failure
- Conduct detailed studies to determine the PMF and modify the project to safely handle the PMF

- Conduct field investigation, laboratory tests, and seismic and engineering studies of the dam embankment and foundation stability, and modify the dam embankment as required to provide for adequate factors of safety under steady state seepage and seismic loading conditions

TAC engaged International Engineering Company, Inc. (IECO) in 1980 to perform studies for the YDTI to address the recommendations arising from the USACE inspection. IECO completed geotechnical and hydrological studies of the impoundment for the facility configuration at the time and for the proposed future enlargement to approximately EL. 6,450 ft. The following tasks were completed by IECO for TAC to form the updated design basis for the facility:

- Estimated the PMF runoff volume and determine what facilities would be required to retain the runoff from the PMF
- Analyzed the effects of a hypothetical breach of the embankment
- Performed site investigations, laboratory testing, and seismicity studies
- Characterized the piezometric conditions prevalent in the embankment
- Characterized material strength properties and analyzed the static and dynamic stability of the embankment up to EL. 6,450 ft
- Developed updated design and construction criteria to guide YDTI development during continued operations up to EL. 6,450 ft
- Developed monitoring plans for on-going operations

MR began operating the YDTI in 1986 and has gradually increased the tailings elevation by about 200 ft since that time. The YDTI was developed since 1986 in general accordance with the design and construction criteria specified by IECO in 1981 and several of the design criteria developed by IECO are still in use today (e.g. minimum crest width and overall downstream slope angle). Certain design basis criteria, such as estimates of the PMF volume and the site-specific seismic hazard assessment that were initially developed by IECO following the USACE inspection in 1980, were updated periodically after MR began operating the YDTI (HLA, 1993; MR, 1999) along with the associated deterministic safety assessments of the impoundment. The first piezometric trigger elevations (action levels) were developed by MR in the late 1990s.

KP's involvement at the YDTI commenced in 2012 and 2013 as part of a failure modes assessment workshop. While elements of risk management are evident in the selected design criteria for the YDTI prior to 2013, KP is unaware of any pre-existing risk analysis documents prepared for the facility prior to the 2013 FMA workshop. KP's responsibilities for the on-going design and development of the YDTI were formalized in 2015, when Mr. Ken Brouwer, P.E. agreed to accept the role of Engineer of Record (EOR) for the YDTI. KP has since been actively involved in the design and development of the YDTI and has worked closely with MR to achieve the fundamental objective of on-going continuous improvement of the safety of the impoundment. Mr. Daniel Fontaine, P.E. of KP, succeeded Mr. Brouwer as the EOR for the YDTI beginning on September 10, 2021.

2.0 REFERENCE COORDINATE SYSTEM AND DATUM

Coordinates and elevations in this report are referenced to the site coordinate system known as the 'Anaconda Mine Grid' established by TAC in 1957. The Anaconda Mine Grid is based on the Anaconda Copper Company (ACC) Datum established in 1915. The MR Site Coordinate System is based on the

Anaconda Mine Grid and utilizes International Feet. All elevations are stated in Anaconda Mine Grid coordinates with respect to the ACC Vertical Datum unless specifically indicated otherwise.

3.0 PREVIOUS RISK ANALYSIS STUDIES

KP completed a report titled "Failure Mode Analysis Information Summary" in early February 2013 (KP, 2013). The purpose of this report was to review the design and operation of the YDTI and to assist in the compilation of relevant information to support the simplified Failure Modes Analysis (FMA) workshop conducted by MR. A summary of the FMA workshop conducted by MR was compiled by KirK Engineering and Natural Resources Inc. in late February 2013 (KirK, 2013). The FMA workshop assessed potential failure modes of the YDTI. Participants in the FMA workshop included representatives from MR, Butte-Silver Bow County government, the MDEQ, the Montana Department of Natural Resources and Conservation (MDNRC), the Montana Bureau of Mines and Geology (MBMG), and the United States Environmental Protection Agency (U.S. EPA).

KP prepared a Dam Breach Risk Assessment (KP, 2018a) for the YDTI in 2018, which was a component of the design document associated with continued use of the YDTI and construction of the YDTI embankments to a crest elevation of 6,450 ft. The study examined potential failure modes and followed a generally qualitative framework to establish risk ratings based on the likelihood of an event occurring (e.g. the return period of an earthquake), probability of a failure occurring coincident with that event (e.g. how likely is it that the earthquake will cause deformation that constitutes a loss of containment), and consequence of an event occurring (e.g. severity of potential damage a loss of containment were to occur). The likelihood of an event occurring was generally defined quantitatively in this previous risk assessment, whereas the probability of coincident failure was generally defined qualitatively and informed by deterministic safety analyses. When a deterministic analysis was not able to be completed to demonstrate adequate performance for a particular event, a conservative assumption of failure probability was used to simplify the risk analysis for dam safety decision making purposes. The consequences of failure due to an event occurring were evaluated based on extent of potential deformation and emergency condition levels as defined in the TOMS Manual (MR/KP, 2019).

4.0 REVIEW OF RECENT IMPORTANT TRENDS

4.1 GENERAL

Risk mitigation opportunities identified in the Dam Breach Risk Assessment (KP, 2018a) developed during preparation of the design document associated with construction of the embankment to EL. 6,450 ft continue to be progressively implemented at the YDTI, and recent trends in this regard are summarized below with excerpts taken from the 2020 and 2021 Annual Inspection Reports (KP, 2021a; KP, 2022a). The risk assessment identified potential failure modes and the factors affecting likelihood and consequences associated with each failure mode. It was recognized that design and operating enhancements could provide further opportunities for risk mitigation, and these enhancements continue to be progressively implemented at the YDTI, taking advantage of the best practicable new technologies and techniques to enhance dam safety. Risk mitigation opportunities incorporated into the design and operating procedures of the YDTI since 2015 include:

- Modifications to the tailings distribution system for improved beach development along all three embankments.
- Stress densification of tailings below the rockfill surcharge to strengthen tailings adjacent to the East-West Embankment, improve seismic performance of the facility, and reduce potential flowability of the underlying tailings mass.
- Water management changes, including substantial reductions to freshwater use from the Silver Lake Water System (SLWS) and development of the Pilot Project to facilitate additional water inventory reductions within the YDTI supernatant pond.
- Continued investigation of the geotechnical and hydrogeological conditions within the embankment rockfill, tailings, and foundation materials underlying the embankment following a phased investigation plan developed by KP.
- Expansion of the piezometric monitoring network and development of surface and subsurface deformation monitoring programs.
- Automation of monitoring systems that are at the leading end of practice.
- Improved data analysis frequency and reporting rigor.
- Updates to the MR Emergency Action Plan (EAP).

The risk assessment also identified opportunities to utilize the observational method during ongoing development of the facility, which was noted to be particularly relevant for the transitional period between implementing the modifications to the tailings distribution system and achieving a new steady-state condition associated with the revised discharge strategy. There was uncertainty identified due to the reliance on modelling predictions related to tailings beach development and water balance modelling, and foreseeable deviations were considered along with the planned observational monitoring related to several factors, including tailings beach development, pore pressure changes within the embankment, and water inventory changes. The trends related to these factors are regularly discussed in the quarterly and annual surveillance reporting, and a status update related to each is provided briefly below.

4.2 TAILINGS BEACH DEVELOPMENT

Tailings were historically discharged into the YDTI at a single location at the southern end of the impoundment near Section 8+00W on the East-West Embankment. Changes to the tailings distribution system were made between 2016 and 2017 with three discharge locations operational as of March 2017. Five additional discharge points were commissioned later in 2017 for a total of eight discharge locations. MR implemented a newly developed tailings operating philosophy and associated surveillance protocols during 2018 to guide and prioritize tailings beach development. Tailings beach development generally progressed in a manner consistent with the design objectives and modelling predictions with the beach transitioning from a deltaic fan shape to a ‘U-shape’. A ninth discharge location was added at the northern end of West Embankment in January 2019 to displace water that was pooling in the northwest corner of the facility and aid in beach development along the West Embankment.

Surveillance of the facility through 2019 indicated that the shortest tailings beach length was typically observed at the northern end of the North-South Embankment and there was a location halfway between the two northernmost discharge points where the beach surface was relatively low due to the longer distance between the discharge points along this section of the embankment. Beach development along the North-South Embankment was recognized as a key risk factor in the risk assessment and related to the potential for piping initiated by natural flooding. The risk assessment identified that improving uniformity of the tailings beach adjacent to the embankments was a potential mitigation measure and thus beach development was monitored closely as part of the surveillance plans for the facility. Beach development continues to be reviewed frequently to inform design and operating enhancements that could provide further opportunities for risk mitigation. Adjustments to the tailings distribution system were recommended in the 2019 Annual Inspection Report and included relocation of discharge location NS-3 closer to NS-2 and extending Line 3 to include a new discharge point, NS-4, located further to the north than the existing location of NS-3. These changes were implemented in August 2020 and are currently operational. Additional tailings distribution system changes are planned following completion of the EL. 6,450 ft lift of the embankment as described in the 2021 Annual Inspection Report (KP, 2022a).

4.3 EMBANKMENT PIEZOMETRIC CONDITIONS

The conceptual hydrogeological model for the YDTI embankments presented in the Site Characterization Report (KP, 2017a) suggests that a basal saturated zone exists within the bottom 50 to 200 ft of embankment rockfill and that isolated perched saturated zones exist within the overlying rockfill. Site investigation programs completed since 2016 (KP, 2018b; KP, 2019a; KP, 2019b; KP, 2020a; KP, 2020b) and piezometric data collected (KP, 2018d; KP, 2019d; KP, 2020d) continue to refine and corroborate this conceptual hydrogeological model. The piezometric monitoring network has been expanded significantly, and piezometric data collection was automated using a remote monitoring system beginning in 2018 to provide near real-time data to MR and KP at approximately 250 monitoring instruments at over 100 sites. All new piezometric monitoring sites are integrated directly with the remote monitoring system during installation.

Piezometric conditions within the East-West Embankment and central tailings mass have reached an approximate equilibrium in response to the changes to the tailings discharge practices initiated in late 2016. Piezometric elevations within the embankment and tailings mass generally decreased from 2017 to 2019, with the rate of decrease slowing during 2019 and piezometric elevations now relatively stable at most sites. Average monthly flow rates observed at the HsB Weir have generally decreased and month-to-month variability reduced since late 2017, other than during the commissioning period for the Pilot Project. Flowrates observed at Seep 10 decreased beginning in the second half of 2017. Flowrates at Seep 10 have been measured automatically since April 2019, and preliminary trends show seasonal variation indicating that flows collected at this location are likely influenced to some extent by meteoric recharge.

Piezometric monitoring sites within the embankment rockfill at the North-South Embankment generally indicate relatively constant piezometric elevations or slightly increasing piezometric elevations since 2018. Fluctuations in piezometric elevations within the North-South Embankment and underlying foundation materials have been attributed to nearby tailings discharge and construction of the downstream step-out of the embankment in 2019 and early 2020.

Piezometric elevations within the foundation of the West Embankment have been relatively constant through 2019 and 2020 following an increasing trend from 2015 to 2019 that was attributed to increasing supernatant pond and tailings elevations resulting from ongoing operations. Piezometric monitoring between the West Embankment and West Ridge continues to indicate that hydrodynamic containment (eastward flow gradient from the West Ridge towards the YDTI) remains present within both critical monitoring areas (the Deep Isolated Fracture System and West Ridge Potentiometric Low). Comparison of West Ridge piezometric data and YDTI pond elevation indicates that the WED is not presently required to maintain hydrodynamic containment; however, it does enhance the security of the hydrodynamic seepage containment system along the West Ridge.

4.4 EMBANKMENT DEFORMATION TRENDS

KP and MR have monitored embankment surface and subsurface deformations since 2020 to characterize deformation conditions and monitor elevated deformations associated with ongoing embankment construction. Additional monitoring techniques were introduced and reporting rigor increased beginning in June 2021 during construction along the Central Pedestal Area of the East-West Embankment and the North-South Embankment. Deformation monitoring relies on both in-situ instrumentation and remote sensing techniques and results have been formally reported in quarterly YDTI instrumentation and monitoring letters and the annual data analysis reports since 2020 (KP, 2021b; KP, 2022b). Key deformation monitoring findings through 2021 included:

- Observed surface deformations within regions of historical rockfill generally continue to occur at constant rates without observation of progressive (accelerating) deformations. Deformation magnitudes are consistent with expectations for end-dumped rockfill and settlement rates are interpreted to vary based on rockfill thickness and time following placement.
- Elevated surface and subsurface deformation rates were observed localized within and around the footprints of newly placed rockfill within the EL. 6,450 ft rockfill surcharge and Central Pedestal Area embankment lifts. The onset of elevated deformation rates corresponds with the advancement of construction and rates begin to slow upon completion of construction in a given area, as expected. Findings do not indicate the development of unexpected deformations within the downstream embankment slope nor evidence of progressive (accelerating) deformations.

4.5 WATER INVENTORY CHANGES

The YDTI supernatant pond provides a source of water to support continuous mill operations and the elevation of the pond surface rises as the volume of tailings in the facility increases. The risk assessment (KP, 2018a) identified that reducing the normal operating pond volume towards a target volume of approximately 15,000 acre-ft would reduce risks associated with facility performance following natural flooding. MR implemented changes to the SLWS use practices in 2016 and 2017 as part of the goal of gradually reducing the operating pond volume and substantially reduced freshwater and make-up water demands for ore processing. MR and KP recognized that changing SLWS practices was an achievable way to influence the water inventory in the YDTI and that other opportunities existed to further reduce water stored within the facility.

The water inventory (estimated during the annual bathymetric survey) increased marginally in 2018 and 2019 despite the changes to SLWS practices. The increases were attributed to the implementation of the revised tailings deposition strategy beginning in 2017 when tailings discharge was concentrated on the northern ends of the West and North-South Embankments to promote development of tailings beaches in these areas. Monitoring data indicated that the focused deposition on the northern ends of the embankments likely caused additional pond water accumulation resulting from the rapidly accumulating surcharge load consolidating the underlying fine tailings on the northern side of the impoundment and the release of interstitial water from the tailings voids on the southern end where tailings discharge occurred less frequently compared to historical practices.

The YDTI is also currently used as part of a pilot project associated with the Butte Mine Flooding Operable Unit (BMFOU) of Superfund. The Pilot Project facilitates the treatment and release of water from the YDTI while introducing flows pumped from Berkeley Pit into the site water management systems. Goals of the Pilot Project include progressively reducing the YDTI supernatant pond volume to approximately 15,000 to 20,000 acre-ft and limiting further rise of the Berkeley Pit water surface elevation.

The Pilot Project began discharging YDTI water off site in September 2019. Updated water balance modelling undertaken in 2020 (KP, 2020e) incorporated a sensitivity analysis related to effluent discharge associated with the Pilot Project. The analysis indicated that the target pond volume of approximately 15,000 acre-ft could be achieved in approximately 2 to 10 years (depending on the net deficit achieved) if the Pilot Project continued. The annual bathymetric survey and assessment of the YDTI supernatant pond volume completed in June 2022 resulted in an estimated pond volume of approximately 21,500 acre-ft, indicating an estimated net volume deficit of approximately 13,000 acre-ft was achieved between Q2 2019 and Q2 2022. The elevation of the supernatant pond has remained approximately the same (with some minor seasonal fluctuations) over this period, despite continuous tailings discharge into the facility, compared with an average rate of rise of approximately 6 ft/year observed previously.

4.6 RECENT REFERENCE INFORMATION

Substantial background material was regularly made available by KP to the planned workshop participants. A list of the relevant available reference material, in addition to the historical reference information described above, is as follows:

- Site Investigation Reports and Memos:
  - 2012 Geotechnical Site Investigation Report (KP, 2013)
  - 2013 Geotechnical Site Investigation Report (KP, 2014)
  - 2014 Geotechnical Site Investigation Report (KP, 2015)
  - 2015-2016 Geotechnical Site Investigation Memos (KP, 2017a – Appendix D)
  - 2017 Geotechnical Site Investigation Report (KP, 2018b)
  - 2018 Embankment Geotechnical Site Investigation Report (KP, 2019a)
  - 2018 Horseshoe Bend Geotechnical Site Investigation (KP, 2019b)
  - 2019 Embankment Geotechnical Site Investigation Report (KP, 2020a)
  - 2019 Horseshoe Bend Geotechnical Site Investigation (KP, 2020b)
  - 2020 Embankment Geotechnical Site Investigation Report (KP, 2021c)
- Site Characterization Report (KP, 2017a)
- Stability Assessment Report (KP, 2017b)
- Report on Dynamic Deformation Analyses (KP, 2017c)
- Annual Inspection Reports
  - 2015 Annual Inspection Report (KP, 2016)
  - 2016 Annual Inspection Report (KP, 2017d)
  - 2017 Annual Inspection Report (KP, 2018c)
  - 2018 Annual Inspection Report (KP, 2019c)
  - 2019 Annual Inspection Report (KP, 2020c)
  - 2020 Annual Inspection Report (KP, 2021a)
  - 2021 Annual Inspection Report (KP, 2022a)

- Data Analysis Reports
    - 2017 Data Analysis Report (KP, 2018d)
    - 2018 Data Analysis Report (KP, 2019d)
    - 2019 Data Analysis Report (KP, 2020d)
    - 2020 Data Analysis Report (KP, 2021b)
    - 2021 Data Analysis Report (KP, 2022b)
- Dam Breach Risk Assessment (KP, 2018a)
- Updated Yankee Doodle Tailings Impoundment Water Balance Model with Calibration Period Extended to December 2019 (KP, 2020e)
- TOMS Manual (MR/KP, 2020; MR/KP 2019)
- MR Emergency Action Plan (which includes the latest Dam Breach Inundation Study) (MR, 2021)
- EOR Response to Comments Submitted by Atlantic Richfield Company (KP, 2017e), including an annotated version of the associated AECOM 2017 Report (AECOM, 2017)

5.0 REFERENCES

AECOM, 2017. Final Report – Yankee Doodle Tailings Impoundment – Butte, Montana, dated May 3, 2017.

Dames and Moore, Inc. (1962). Report of Feasibility Study, Proposed Tailings Pond. Salt Lake City, Utah.

Dames and Moore, Inc. (1963). Report of Development of Design and Construction Criteria. Salt Lake City, Utah.

Harding Lawson Associates. (HLA, 1993). Seismic Stability Evaluation. Yankee Doodle Tailings Impoundment. Butte, Montana. HLA Job No. 20860,001.04 (12229-1.0), dated April 9, 1993.

International Engineering Company, Inc. (IECO, 1981). Geotechnical and Hydrologic Studies of Yankee Doodle Tailings Dam. Denver, Colorado.

KirK Engineering and Natural Resources Inc. (KirK, 2013). Yankee Doodle Tailings Dam, Failure Mode Analysis. Submitted to Montana Resources LLP.

Knight Piésold Ltd. (KP, 2013a). Yankee Doodle Tailings Dam, Failure Modes Analysis Information Summary, Rev 0, dated February 1, 2013. Vancouver, BC. Ref. No. VA101-126/7-1.

Knight Piésold Ltd. (KP, 2013b). 2012 Geotechnical Site Investigation Report, Rev 0, dated March 12, 2013. Vancouver, BC. Ref. No. VA101-126/7-2.

Knight Piésold Ltd. (KP, 2014a). 2013 Geotechnical Site Investigation Report, Rev 0, dated November 24, 2014. Vancouver, BC. Ref. No. VA101-126/7-3.

Knight Piésold Ltd. (KP, 2014b). 2014 Geotechnical Site Investigation Report, Rev A, dated December 4, 2014. Vancouver, BC. Ref. No. VA101-126/8-3.

Knight Piésold Ltd. (KP, 2016). 2015 Annual Inspection Report, Rev 0, dated June 8, 2016. Vancouver, BC. Ref. No. VA101-126/13-2.

Knight Piésold Ltd. (KP, 2017a). Site Characterization Report, Rev 2, dated August 11, 2017. Vancouver, BC. Ref. No. VA101-126/14-2.

Knight Piésold Ltd. (KP, 2017b). Stability Assessment Report, Rev 2, dated August 15, 2017. Vancouver, BC. Ref. No. VA101-126/12-2.

Knight Piésold Ltd. (KP, 2017c). Report on Dynamic Deformation Analyses, Rev B, dated December 18, 2017. Denver, CO. Ref. No. VA101-126/17.

Knight Piésold Ltd. (KP, 2017d). 2016 Annual Inspection Report, Rev 1, dated June 29, 2017. Vancouver, BC. Ref. No. VA101-126/15-1.

Knight Piésold Ltd. (KP, 2017e). Response by the Engineer of Record to Comments Submitted by Atlantic Richfield Company, dated September 8, 2017. Vancouver, BC. Ref. No. VA17-01525.

Knight Piésold Ltd. (KP, 2018a). Dam Breach Risk Assessment, Rev 3, dated March 13, 2018. Vancouver, BC. Ref. No. VA101-126/12-3.

Knight Piésold Ltd. (KP, 2018b). 2017 Geotechnical Site Investigation Report, Rev 0, dated May 2, 2018. Vancouver, BC. Ref. No. VA101-126/16-2.

Knight Piésold Ltd. (KP, 2018c). 2017 Annual Inspection Report, Rev 0, dated February 9, 2018. Vancouver, BC. Ref. No. VA101-126/16-3.

Knight Piésold Ltd. (KP, 2018d). 2017 Data Analysis Report, Rev 0, dated July 20, 2018. Vancouver, BC. Ref. No. VA101-126/16-5.

Knight Piésold Ltd. (KP, 2019a). 2018 Embankment Geotechnical Site Investigation Report, Rev 0, dated May 22, 2019. Vancouver, BC. Ref. No. VA101-126/19-1.

Knight Piésold Ltd. (KP, 2019b). 2018 Horseshoe Bend Geotechnical Site Investigation, Rev 0, dated May 27, 2019. Vancouver, BC. Ref. No. VA101-126/20-1.

Knight Piésold Ltd. (KP, 2019c). 2018 Annual Inspection Report, Rev 1, dated January 31, 2019. Vancouver, BC. Ref. No. VA101-126/19-2.

Knight Piésold Ltd. (KP, 2019d). 2018 Data Analysis Report, Rev 0, dated August 15, 2019. Vancouver, BC. Ref. No. VA101-126/19-4.

Knight Piésold Ltd. (KP, 2020a). 2019 Embankment Geotechnical Site Investigation Report, Rev 0, dated July 16, 2020. Vancouver, BC. Ref. No. VA101-126/21-1.

Knight Piésold Ltd. (KP, 2020b). 2019 Horseshoe Bend Geotechnical Site Investigation, Rev 0, dated December 1, 2020. Vancouver, BC. Ref. No. VA101-126/22-1.

Knight Piésold Ltd. (KP, 2020c). 2019 Annual Inspection Report, Rev 0, dated January 31, 2020. Vancouver, BC. Ref. No. VA101-126/21-2.

Knight Piésold Ltd. (KP, 2020d). 2019 Data Analysis Report, Rev 0, dated August 28, 2020. Vancouver, BC. Ref. No. VA101-126/21-3.

Knight Piésold Ltd. (KP, 2020e). Updated Yankee Doodle Tailings Impoundment Water Balance Model with Calibration Period Extended to December 2019 (KP Reference No. VA20-00440 Rev 0), dated May 29, 2020.

Knight Piésold Ltd. (KP, 2021a). 2020 Annual Inspection Report, Rev 0, dated February 11, 2021. Vancouver, BC. Ref. No. VA101-126/23-2.

Knight Piésold Ltd. (KP, 2021b). 2020 Data Analysis Report, Rev 0, dated June 30, 2021. Vancouver, BC. Ref. No. VA101-126/23-5.

Knight Piésold Ltd. (KP, 2021c). 2020 Embankment Geotechnical Site Investigation, Rev 0, dated October 22, 2021. Vancouver, BC. Ref. No. VA101-126/23-4.

Knight Piésold Ltd. (KP, 2022a). 2021 Annual Inspection Report, Rev 0, dated January 11, 2022. Vancouver, BC. Ref. No. VA101-126/25-2.

Knight Piésold Ltd. (KP, 2022b). 2021 Data Analysis Report, Rev 0, dated May 20, 2022. Vancouver, BC. Ref. No. VA101-126/25-6.

Montana Resources, LLP. (MR, 1999). Yankee Doodle Tailings Impoundment Design and Construction, July 1997. Revised March 1999.

Montana Resources, LLP. (MR, 2021). Emergency Action Plan. Yankee Doodle Tailings Impoundment, January 2021.

Montana Resources, LLP and Knight Piésold Ltd. (MR/KP, 2019). Tailings Operations, Maintenance and Surveillance (TOMS) Manual (Reference No. VA101-126/16-1), Rev 3, dated January 7, 2019.

Montana Resources, LLP and Knight Piésold Ltd. (MR/KP, 2020). 2020 Tailings Operations, Maintenance and Surveillance (TOMS) Manual (Reference No. VA101-126/23-1), Rev 4, dated May 13, 2020.

US Army Corps of Engineers. (USACE, 1980). Phase 1 Inspection Report, National Dam Safety Program, Warm Springs Tailings Dams and Yankee Doodle Tailings Dam. Seattle District, US Army Corps of Engineers, February 1980.

APPENDIX B

Potential Failure Modes Analysis

Appendix B1
East-West Embankment PFMA Details

Appendix B2
North-South Embankment PFMA Details

Appendix B3
West Embankment PFMA Details

APPENDIX B1

East-West Embankment PFMA Details

(Pages B1-1 to B1-25)

Knight Piésold CONSULTING

TABLE B1.1

MONTANA RESOURCES, LLC
YANKEE DOODLE TAILINGS IMPOUNDMENT

POTENTIAL FAILURE MODE ANALYSIS
DEVELOPMENT FRAMEWORK AND SCREENING SUMMARY
EAST-WEST EMBANKMENT

CODE	PFM#	Initiating / Loading Event		Location	Potential Failure Mode	Simple Failure Path Progression Description	Preliminary Screening Assessment	Category	Primary Means of Risk Control	Additional Risk Controls to Consider	Potential Data Gaps	Detection and Intervention
		Category	Sub-category									
EW	1	Flood	PMF	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack. (2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment. (3) Embankment facing sufficient to prevent concentrated leakage, but excess drainage into the embankments results in rising pore pressures within the rockfill. (4) Rise in pore pressures within the embankment rockfill is sufficient to decrease effective stress in critical resisting areas near the downstream side of the embankment resulting in slope instability.	Design requirement during all mine phases. Consider in risk assessment workshop.	1	Very low likelihood of this level of severe flooding. Promote and maintain low water inventory and develop long, drained tailings beaches to maximize water storage on beach in the event of flooding.	- Shortening the period of beach inundation. - Additional toe support in HsB area and/or Seep 10 bench, i.e. buttressing. - Spillway in closure. - Pond volume reductions. - Interim overflow channel to control maximum potential water elevation.	Install additional piezometric instrumentation in downstream shell between Seep 10 bench and crest, if practicable.	Can likely detect the intervene by activiating emergency action plans. Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff. Monitoring equipment is available to detect changing piezometric conditions in real-time within critical areas of the embankment.
EW	2	Flood	1/1,000 yr (30-day wet)	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack. (2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches, but flooding not sufficient to reach the upstream side of the embankment. (3 Drainage into the embankments from inundated beaches results in rising pore pressures within the embankment rockfill. (4) Rising pore pressures within embankment are sufficient to decrease effective stress in critical resisting areas near the downstream side of the embankment resulting in slope instability. (5) Potential consequences could range from single or multi-bench failure with no major impacts to operations to a full facility breach, depending on the nature and extent of instability.	Requires consideration in the RA using sensitivity analyses with rising pore water pressure conditions.	1	Promote and maintain low water inventory and develop long, drained tailings beaches to maximize water storage on beach in the event of flooding. Trigger levels on embankment instrumentation and associated emergency response plans.	- Shortening the period of beach inundation. - Additional toe support in HsB area and/or Seep 10 bench, i.e. buttressing. - Spillway in closure. - Pond volume reductions. - Interim overflow channel to control maximum potential water elevation.	Install additional piezometric instrumentation in downstream shell between Seep 10 bench and crest, if practicable.	Rising pond surface would be physically visible by staff. Monitoring equipment is available to detect changing piezometric conditions in real-time within critical areas of the embankment. Changing pore pressure conditions at key instruments is linked with key staff alerts to trigger evaluation of unusual occurrences such as increasing pore pressures.
EW	3	Flood	PMF	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Overtopping	(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack. (2) Flood waters lead to rising pond surface, which exceeds crest elevation of the embankment. (3) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.	Very unlikely and not a risk-driver, not credible unless PMF is substantially underestimated. Consider for completeness, but likely does not require a full event tree build up.	2	Freeboard criteria	- Adjusting freeboard for long-term conditions. - Consider Interim overflow channel to control maximum potential water elevation.	None identified.	Can likely detect the intervene by activiating emergency action plans. Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff and remote sensing tools.
EW	4	Flood	1/1,000 yr (30-day wet)	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Overtopping	(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack. (2) Flood waters lead to rising pond surface, which exceeds crest elevation of the embankment. (3) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.	Not credible; inflow too small relative to freeboard allowance	4	Freeboard criteria	None identified.	None identified.	Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and some evacuations already. Rising pond surface would be physically visible by staff and remote sensing tools.
EW	5	Flood	PMF	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Internal Erosion / Piping	(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack. (2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment. (3) Leakage begins through the embankment facing material, extensive rockfill surcharge, and permeable rockfill resulting flow discharging along the downstream slope or benches of the embankment. (4) (i) Flow discharge results in erosion to downstream slopes and retrogressive slope instability, or (ii) leakage concentrates in an area that is not internally stable resulting in internal erosion, pipe development, and ultimately failure. (5) full breach of the facility occurs.	More credible along the North-South Embankment in areas where the rockfill surcharge is not present. May be more important to evaluate if failure path can occur at lower flood levels, e.g. at what storm return period can flooding reach the embankment, as this would define the event likelihood where there is a step change in the risk profile.	1	Beach development criteria to protect most critical areas of the embankment (i.e. which area of the beach is kept highest)	- Closure spillway will provide some long-term risk control. - Prioritize beach management to push flood inundation preferentially towards West Embankment. - Interim overflow channel to control maximum potential water elevation.	None identified.	Can likely detect the intervene by activiating emergency action plans. Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff and remote sensing tools.
EW	6	Flood	1/1,000 yr (30-day wet)	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Internal Erosion / Piping	(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack. (2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches, but <u>not</u> reaching the upstream facing of the embankment. (3) Drainage gradients from the tailings into the permeable rockfill increase in subsurface interface between the two materials. (4) Embankment facing zone and extensive rockfill surcharge not completely present at depth at the drainage interface or is insufficient to prevent tailings migration into the embankment fill. (5) Tailings results in concentrated tailings migration through a more permeable pathway and tailings are discharged on a bench on the downstream side of the embankment resulting in undesirable seepage and possibly some settlement cracking.	Possible, but low likelihood compared to EW-PMF5. Not a risk-driver unless beaches are mismanaged and a higher probability flood event than this reaches the embankment.	2	Beach development criteria	- Pond volume reductions. - Interim overflow channel to control maximum potential water elevation.	None identified.	Rising pond surface would be physically visible by staff and remote sensing tools. Flooding would trigger more frequent inspections, which would increase likelihood that conditions would be observed and unusual occurrence follow up would be triggered.
EW	7	Earthquake	Median MCE / 1 in 10,000 yr	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Overtopping	(1) Design maximum credible earthquake (Median MCE) occurs along the Continental Fault. (2) The embankment deforms and crest settles due to the seismic loading of the embankment. (3) Tailings upstream of the embankment experience seismic liquefaction causing settlement and allowing the supernatant pond to come southward to the embankment. (4) Embankment crest settles to a final position that is lower than the resulting supernatant pond elevation <u>and</u> the tailings settlement allows the pond to reach the embankment. (5) Overtopping at the lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.	Possibly credible at the East-West Embankment given uncertainty in estimating magnitude of earthquake-induced settlement and material compressibility, uncertainty in spatial variation of material compressibility, YDTI location in a high seismic area, and use of Median MCE as the design basis. Should be considered alongside 'Earthquake-Instability' event trees.	1	Design freeboard.	- Increase design basis earthquake during operations to 84th percentile MCE. - Reduce uncertainty in material compressibility and earthquake-induced settlement magnitudes.	- High tempatures in rockfill and alterations may increase compressibility. - Degree of saturation in tailings.	None identified.
EW	8	Earthquake	84th-percentile MCE / 1 in 100,000 yr	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Overtopping	(1) Design maximum credible earthquake (84th-Percentile MCE) occurs along the Continental Fault. (2) The embankment deforms and crest settles due to the seismic loading of the embankment. (3) Tailings upstream of the embankment experience seismic liquefaction causing settlement and allowing the supernatant pond to come southward to the embankment. (4) Embankment crest settles to a final position that is lower than the resulting supernatant pond elevation <u>and</u> the tailings settlement allows the pond to reach the embnakment. (5) Overtopping at the lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.	As above for EW-PFM7, but with a more unlikely event, exceeding the operational design basis, that may result in higher deformations. Possibly credible due to uncertainties in material compressibility, earthquake-induced settlement magnitudes, and YDTI location in a high seismic area. Should be considered alongside 'Earthquake-Instability' event trees.	1	Very low likelihood of event occuring. Very long well drained beaches and remote location of the supernatant pond. Design freeboard.	None identified.	- Tailings liquefaction potential (surface and below rockfill surcharge). - Contribution of aftershocks to dam response studies.	None identified.

TABLE B1.1

MONTANA RESOURCES, LLC
YANKEE DOODLE TAILINGS IMPOUNDMENT

POTENTIAL FAILURE MODE ANALYSIS
DEVELOPMENT FRAMEWORK AND SCREENING SUMMARY
EAST-WEST EMBANKMENT

CODE	PFM#	Initiating / Loading Event		Location	Potential Failure Mode	Simple Failure Path Progression Description	Preliminary Screening Assessment	Category	Primary Means of Risk Control	Additional Risk Controls to Consider	Potential Data Gaps	Detection and Intervention
		Category	Sub-category									
EW	9	Earthquake	1/1,000 yr return period	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Severe earthquake occurs. (2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment or foundation soils. (3) Increasing pore pressures result in decreasing shear resistance leading to slope instability. (4) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height. (5) Large-scale landsliding and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.	Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to seismic loading.	1	Shear strength of fill materials and predominately drained embankment fill materials.	Additional toe support / buttressing in HsB area and/or Seep 10 bench.	- Tailings liquefaction potential (surface and below rockfill surcharge). - Piezometric instrumentation in downstream shell between Seep 10 bench and crest, if practicable. - Contribution of aftershocks to dam response studies.	None identified.
EW	10	Earthquake	1/1,000 yr return period	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Severe earthquake occurs. (2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment. (3) Increasing pore pressures result in decreasing shear resistance leading to slope instability. (4) Embankment instability occurs through a relatively shallow slip surface impacting the central portion of the embankment. (5) Multi-bench instability and/or slumping deformation occurs in the central pedestal area resulting in damage to the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations. Resulting failure surface does not result in loss of tailings containment within the YDTI.	Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to seismic loading.	1	Shear strength of fill materials and predominately drained embankment fill materials.	Additional toe support / buttressing in HsB area and/or Seep 10 bench.	- Tailings liquefaction potential (surface and below rockfill surcharge). - Contribution of aftershocks to dam response studies.	None identified.
EW	11	Earthquake	1/1,000 yr return period	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Undesirable Embankment Deformation	(1) Severe earthquake occurs. (2) The embankment deforms due to the seismic loading of the embankment. (3) Resulting deformations cause slope adjustments and/or bench settlement through the central pedestal area impacting the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations.	Failure mode possible and could lead to an interruption of operations. Probably not a risk-driver but could create a residual threat that may impact downstream operations (e.g. cracking and deformations altering state of vulnerability).	2	Shear strength of predominantly drained fill materials, relatively modest overall slope angles, and massive nature of the structure.	None identified.	- Contribution of aftershocks to dam response studies.	None identified.
EW	12	Earthquake	1/1,000 yr return period	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Undesirable Embankment Deformation - Transverse Cracking	(1) Severe earthquake occurs. (2) The embankment differentially deforms resulting in vertical cracking at points of intersection of section geometry/embankment limbs without any internal seepage controls (e.g. filters) upstream. (3) Results in potential preferential flow paths that are difficult to assess. (4) (i) either tailings mobilized during seismic loading finds resulting flow paths or (ii) continued operations leads to tailings slurry interacting with unidentified flow paths (5) Loss of tailings occurs.	Difficulty in assessing the failure mode probably warrants more detailed consideration. May be a category 3 item with well reasoned argument; however, this failure path may change state of long-term vulnerability or increase threat of future consequences occurring, i.e. create a residual threat that may not be acceptable for downstream/long-term operations.	1	Massive nature of the structure and extensive drained tailings beaches upstream.	None identified.	- Contribution of aftershocks to dam response studies.	None identified.
EW	13	Construction	6,450 raise	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Construction loading during placement embankment lifts in the central maximum section. (2) Loading results in increased shear stresses with no change in pore pressures within saturated zones; however, increased shear stresses exceed shear resistance. (3) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height. (4) Large-scale landsliding and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.	Failure mode not credible without excess pore pressure development. By default, it should get captured in the construction induced failure event tree along with EW-PFM-14.	4	Shear strength of fill materials and predominately drained embankment fill materials.	None identified.	- Limited historical data showing piezometric response and deformation behavior for similar scale of construction. - Piezometric response for flooding concurrent with construction.	Piezometric and surface/subsurface deformation monitoring programs. Emergency warning systems.
EW	14	Construction	6,450 raise	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Construction loading during placement embankment lifts in the central maximum section. (2) Loading results in increased shear stresses and excess pore pressure development within saturated zones of the embankment fill within critical resisting areas of the embankment exceeding shear resistance. (3) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height. (4) Large-scale landsliding and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.	Requires consideration in the RA using sensitivity analyses that consider either (i) variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to construction loading, or (ii) variation of piezometric pressures within range that could be expected due to construction loading.	1	Shear strength of fill materials, predominately drained embankment fill materials, and controlled loading rate.	None identified.	- Limited historical data showing piezometric response and deformation behavior for similar scale of construction.	Piezometric and surface/subsurface deformation monitoring programs. Emergency warning systems.
EW	15	Construction	6,450 raise	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Construction loading during placement embankment lifts in the central maximum section. (2) Loading results in increased shear stresses exceeding shear resistance. (3) Embankment instability occurs through a relatively shallow slip surface impacting the central portion of the embankment. (4) Multi-bench instability and/or slumping deformation occurs in the central pedestal area resulting in damage to the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations. Resulting failure surface does not result in loss of tailings containment within the YDTI.	Failure mode not credible without excess pore pressure development.	4	Shear strength of fill materials and predominately drained embankment fill materials.	None identified.	- Limited historical data showing piezometric response and deformation behavior for similar scale of construction.	Piezometric and surface/subsurface deformation monitoring programs. Emergency warning systems.
EW	16	Construction	6,450 raise	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Construction loading during placement embankment lifts in the central maximum section. (2) Loading results in increased shear stresses and excess pore pressure development within saturated zones of the embankment fill within critical resisting areas of the embankment exceeding shear resistance. (3) Embankment instability occurs through a relatively shallow slip surface impacting the central portion of the embankment. (4) Multi-bench instability and/or slumping deformation occurs in the central pedestal area resulting in damage to the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations. Resulting failure surface does not result in loss of tailings containment within the YDTI.	Requires consideration in the RA using sensitivity analyses that consider either (i) variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to construction loading, or (ii) variation of piezometric pressures within range that could be expected due to construction loading.	1	Shear strength of fill materials, predominately drained embankment fill materials, and controlled loading rate.	None identified.	- Limited historical data showing piezometric response and deformation behavior for similar scale of construction. - Behavior of 1982 lift top material on Section 0+00.	Piezometric and surface/subsurface deformation monitoring programs. Emergency warning systems.
EW	17	Material_Degradation	Induced strain softening	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Creep occurs within basal saturated zone or a perched saturated zone within the embankment. (2) Deformation causes either (i) excess pore pressure development or (ii) reduced confining pressures resulting in induced strain softening within critical resisting areas of the embankment. (3) Embankment instability occurs either through (i) a deeply seated slip surface impacting the full embankment height or (ii) hypothetical perched saturated condition aligned with the Seep 10 bench. (4) Large-scale landslide and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.	Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to deeply seated creep deformation.	1	Shear strength of fill materials and predominately drained embankment fill materials.	Additional toe support / buttressing in HsB area and/or Seep 10 bench and along other embankment downstream slopes.	- Theoutcome of these various physical processes - Spatial distribution (widespread or local)	Surface and subsurface deformation monitoring programs. Emergency warning systems.

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TABLE B1.1

MONTANA RESOURCES, LLC
YANKEE DOODLE TAILINGS IMPOUNDMENT

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DEVELOPMENT FRAMEWORK AND SCREENING SUMMARY
EAST-WEST EMBANKMENT

CODE	PFM#	Initiating / Loading Event		Location	Potential Failure Mode	Simple Failure Path Progression Description	Preliminary Screening Assessment	Category	Primary Means of Risk Control	Additional Risk Controls to Consider	Potential Data Gaps	Detection and Intervention
		Category	Sub-category									
EW	18	Material_Degradation	Induced strain softening	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Creep occurs locally within basal saturated zone of the embankment in the vicinity of the Seep 10 bench. (2) Deformation causes either (i) excess pore pressure development or (ii) reduced confining pressures resulting in induced strain softening within critical resisting areas of the embankment. (3) Embankment instability occurs locally at the Seep 10 bench. (4) Retrogressive slope instability follows the initial instability causing debris flow within the HsB area impacting mine infrastructure in the area.	Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to deeply seated creep deformation.	1	Shear strength of fill materials and predominately drained embankment fill materials.	Additional toe support / buttressing in HsB area and/or Seep 10 bench and along other embankment downstream slopes.	- The outcome of these various physical processes - Spatial distribution (widespread or local)	Surface and subsurface deformation monitoring programs. Emergency warning systems.
EW	19	Material_Degradation	Acidic drainage	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Continuous acidic drainage within embankment fill material. (2) Chemecial weathering results in decreasing strength properties within critical resisting areas of the embankment. (3) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height. (4) Large-scale landsliding and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.	Part of overall event tree build up for this failure mode.	1	Shear strength of fill materials and predominately drained embankment fill materials.	Additional toe support / buttressing in HsB area and/or Seep 10 bench and along other embankment downstream slopes.	- The outcome of these various physical processes - Spatial distribution (widespread or local)	Limited ability to detect progresive changes to material strength properties due to acidic drainage in critical areas; however, instability would likely manifest in a way similar to other failure modes (i.e. increased subsurface deformation within affected materials).
EW	20	Material_Degradation	Weathering	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Undesirable Embankment Deformation	(1) Exposure of embankment fill materials near surface to atmospheric conditions (air, snow, rain, freeze-thaw, etc.). (2) Physical and chemical weathering results in slope creep, strength reduction, and/or erosion. (3) Resulting deformations cause slope adjustments and/or bench settlement through the central pedestal area impacting the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations, mine haul ramps, etc.	Possible, but probably not a risk-driver. Primarily a maintenance issue and does not require detailed consideration in the RA workshop.	2	Shear strength of fill materials and predominately drained embankment fill materials.	None identified.	None identified.	Periodic inspections and surface deformation monitoring programs should detect any changes. Primarily a maintenance issue.
EW	21	Operational_Upset_Malfunction	Tailings pipeline burst	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Instability (Foundation or Slope)	(1) Tailings pipeline rupture occurs between No. 3 and No. 3 Booster Pump Stations. (2) Tailings slurry discharging from ruptured pipeline erodes downstream slope within the central pedestal area. (3) Erosion of slope progresses through a combination of down-cutting and shallow rotational slip surfaces. (4) Retrogressive slope instability occurs causing debris flow within the HsB area impacting mine infrastructure in the area.	Possible, but probably not a risk-driver. Primarily a maintenance and operations issue and does not require detailed consideration in the RA workshop.	2	Massive nature of the structure and upper more recent fill materials not particularly erodible.	None identified.	None identified.	Primarily a maintenance and operations issue. Detection through tailings pipeline operations monitoring, e.g. pipeline pressures, etc.
EW	22	Geological Hazards	Landslide	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Overtopping	(1) Landslide occurs from Rampart Mountain along the eastern side of the YDTI. (2) Slide reaches the supernatant pond and causes a wave. (3) Wave runs up the tailings beach and overtops the embankment causing erosion and damage on the downstream side of the embankment.	For discussion purposes only. May be difficult to comment on likelihood based on existing knowledge base.	3	No large-scale landslide risk anticipated, only small-scale wedge failures. Orientation of Rampart Mountain relative to East-West Embankment; long tailings beach.	None identified.	- Confirm availabiliity/conclusions of previous geomorphic studies (no large-scale risk, only small-scale wedge failures possible).	None identified.

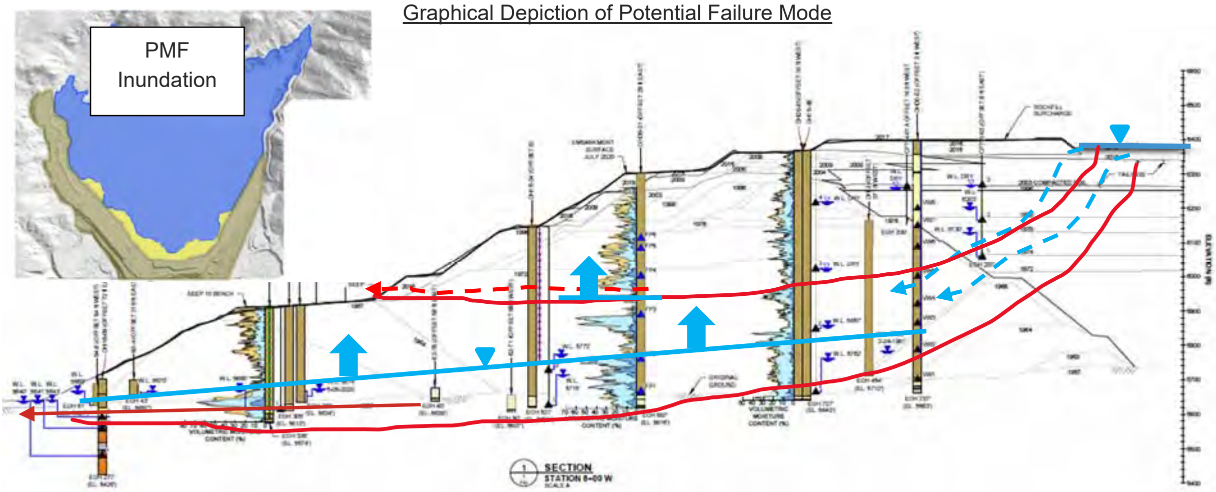
M:\1\01\00126\27\A\Data\Task 510 - Risk Assessment\05 - Potential Failure Modes Analysis\[PFMA Development Summary_r0.xlsx]Table 1 - E-W EMBANKMENT

0	07JUL'23	ISSUED WITH REPORT VA101-00126/27-1	EJA	DDF
REV	DATE	DESCRIPTION	PREP'D	RVW'D

EW-PFM1

Initiating Event: Flood, PMF
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment.
(3) Embankment facing sufficient to prevent concentrated leakage, but excess drainage into the embankments results in rising pore pressures within the rockfill.
(4) Rise in pore pressures within the embankment rockfill is sufficient to decrease effective stress in critical resisting areas near the downstream side of the embankment resulting in slope instability.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Water stored on beach close to embankment crest with higher permeability embankment fill adjacent will result in drainage into the embankment • There is currently a basal saturated zone and some evidence of perched drainage • Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences such as the B.Pit/C.Pit interface) • Known areas of historical leaching activities • Flooded condition could be several months long • Potential for lower material strength within the alluvium foundation unit / saturated rockfill to be considered • Spatial extent of alluvium foundation unit is not currently well defined • Potential concentrated leakage and/or piping may aggravate recharge towards saturated zones of embankment	• Very low likelihood of flood event • Reasonably competent rockfill that drains well • Geometry of rockfill surcharge provides offset to flooded pond position (longer seepage path, stiffer tailings underneath - lower permeability horizontally and vertically) • Relatively modest slope angles • Long well-drained beaches would recharge initially along with drainage into embankment • Variable rockfill dumping orientation and resulting fabric • Well monitored and positive performance observed

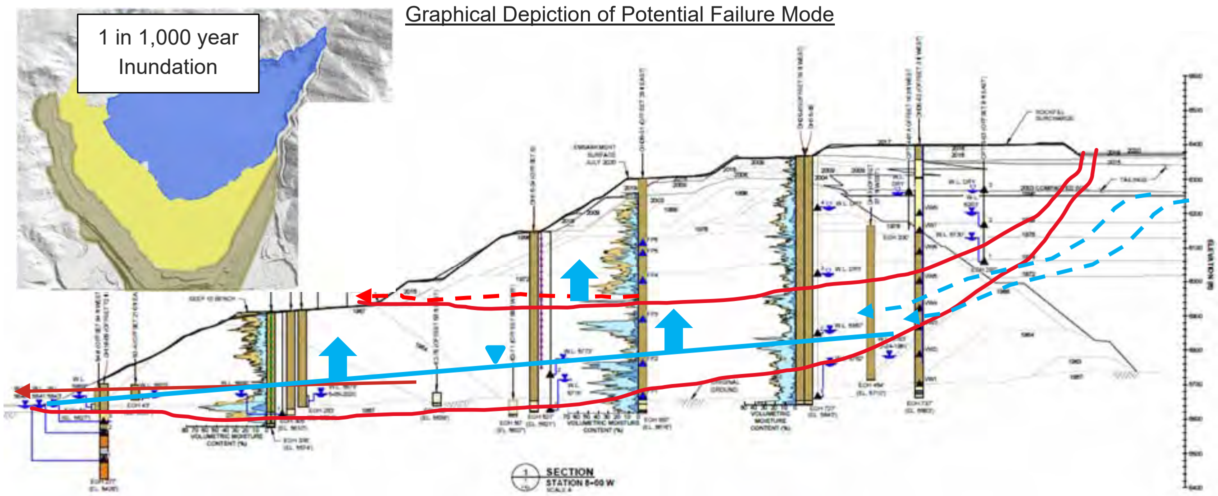
Category: **1**

Overall Screening Decision:
Design consideration during all mine phases. Consider in risk assessment workshop.

EW-PFM2

Initiating Event: Flood, 1/1,000 year (30-day wet)
Location: East-West Embankment – Central Pedestal (e.g. STA 0+00 / 8+00W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches, but flooding not sufficient to reach the upstream side of the embankment.
(3) Drainage into the embankments from inundated beaches results in rising pore pressures within the embankment rockfill.
(4) Rising pore pressures within embankment are sufficient to decrease effective stress in critical resisting areas near the downstream side of the embankment resulting in slope instability.
(5) Potential consequences could range from single or multi-bench failure with no major impacts to operations to a full facility breach, depending on the nature and extent of instability.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Water stored on beach approximately 1,000 ft away from higher permeability embankment fill will result in drainage into the embankment • There is currently a basal saturated zone and some evidence of perched drainage • Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences • Known areas of historical leaching activities • Flooded condition could be a month or so in duration • Potential for lower material strength within the alluvium foundation unit / saturated rockfill to be considered • Potential concentrated leakage and/or piping may aggravate recharge towards saturated zones of embankment.	• Very low likelihood of flood event • Reasonably competent rockfill that drains well. Drainage to perched zones may be less likely than PMF condition • Remaining beach length of 1,000 ft or more • Geometry of rockfill surcharge provides offset to flooded pond position (longer seepage path, stiffer tailings underneath - lower permeability) • Relatively modest slope angles • Long well-drained beaches would recharge initially along with drainage into embankment • Variable rockfill dumping orientation and resulting fabric • Well monitored and positive observed performance • No evidence of significant/prominent sand layering upstream of dam creating preferential flow path towards the embankment

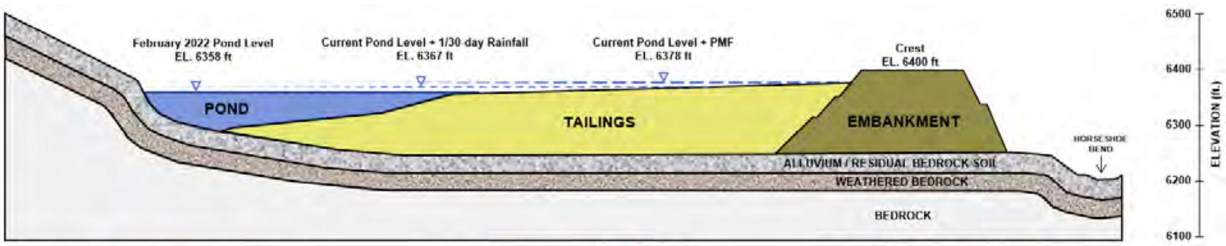
Category: 1

Overall Screening Decision:
Requires consideration in the RA using sensitivity analyses with rising pore water pressure conditions.

EW-PFM3

Initiating Event: Flood, PMF
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Overtopping
<u>Failure Path Description:</u>
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface, which exceeds crest elevation of the embankment.
(3) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.

<u>Graphical Depiction of Potential Failure Mode</u>



Feb. 2022 Pond (Normal Operating Conditions)
Pond Volume ~ 26,600 acre-ft
Pond Elevation ~ EL. 6,358 ft

1 in 1,000 30-day Rainfall Event
Total Pond Volume ~ 33,100 acre-ft
Pond Elevation ~ EL. 6,367 ft

PMF Event
Total Pond Volume ~ 46,600 acre-ft
Pond Elevation ~ EL. 6,378 ft

<u>More Likely (Adverse) Factors</u>	<u>Less Likely (Resisting) Factors</u>
• Becomes more likely as operations progress and EL. 6,450 ft lift is filled. • Mismanagement of water inventory could decrease available freeboard	• Design basis PMF is at the upper end of current engineering practice; design basis uses sum of 24-hr PMP and complete melt of 1/100-yr snowpack, or approximately 20,000 ac-ft. • Starting with large freeboard for PMF conditions; will increase as EL 6450 ft lift is completed. • Rockfill reasonably resistant to erosion in the event of overland flow • Wide crest width including structural crest and rockfill surcharge • Water deficit climate condition in case of mine/labour shutdown • Reducing pond volumes due to operational treatment

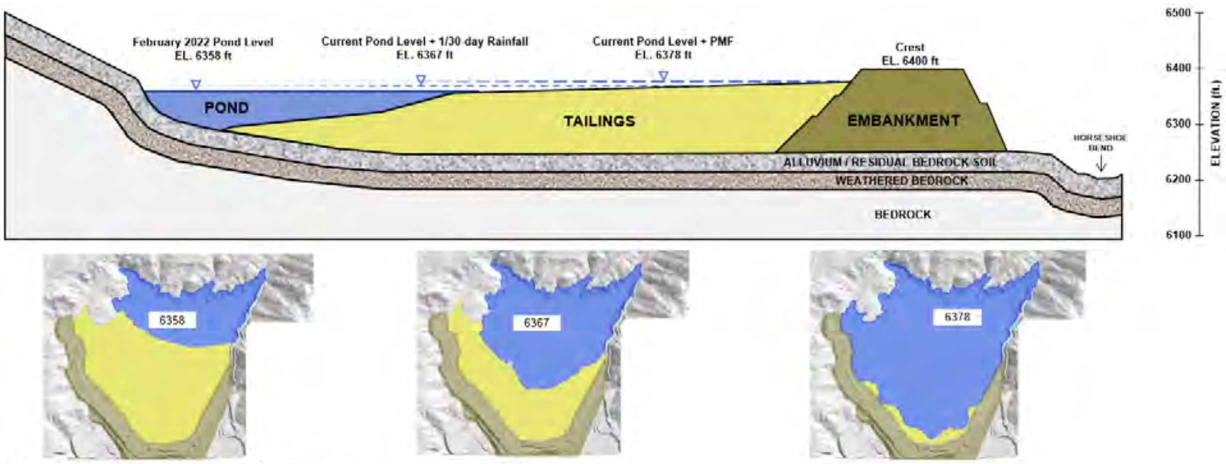
<u>Category:</u> 2

<u>Overall Screening Decision:</u>
Very unlikely and not a risk-driver; not credible unless PMF is substantially underestimated. Considered for completeness, but likely does not require a full event tree build up.

EW-PFM4

Initiating Event: Flood, 1/1,000 year (30-day wet)
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface, which exceeds crest elevation of the embankment.
(3) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.

Graphical Depiction of Potential Failure Mode



Feb. 2022 Pond (Normal Operating Conditions)	1 in 1,000 30-day Rainfall Event	PMF Event
Pond Volume ~ 26,600 acre-ft	Total Pond Volume ~ 33,100 acre-ft	Total Pond Volume ~ 46,600 acre-ft
Pond Elevation ~ EL. 6,358 ft	Pond Elevation ~ EL. 6,367 ft	Pond Elevation ~ EL. 6,378 ft

More Likely (Adverse) Factors

- Becomes more likely as operations progress and EL. 6,450 ft lift is filled.
- If water inventory is mismanaged decreasing available freeboard

Less Likely (Resisting) Factors

- Small inflow volume relative to available freeboard
- Starting with large freeboard for PMF conditions; will increase as EL 6,450 ft lift is completed.
- Rockfill reasonably resistant to erosion in the event of overland flow
- Wide crest width including structural crest and rockfill surcharge
- Water deficit climate condition in case of shutdown
- Reducing pond volumes due to operational treatment

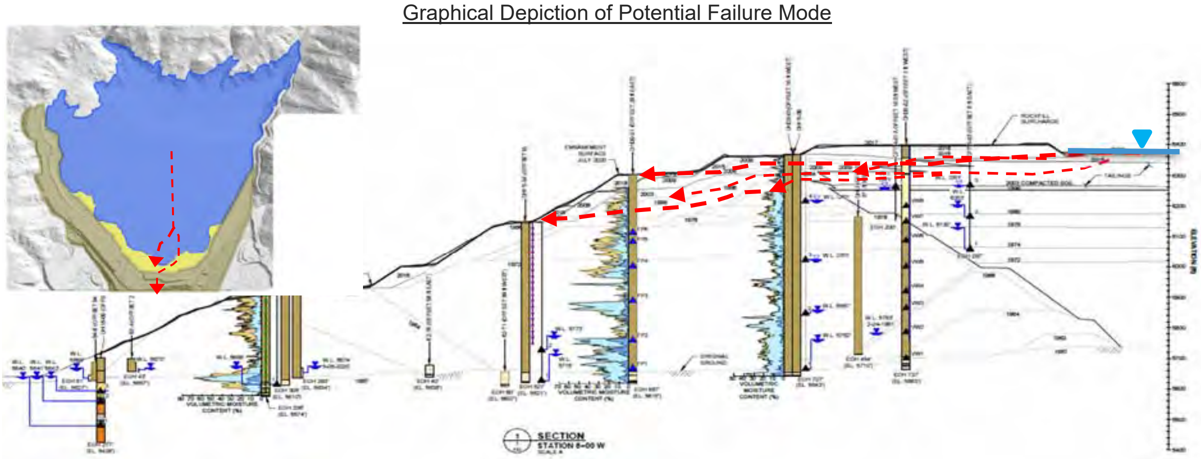
Category: 4

Overall Screening Decision:
Not credible; inflow too small relative to freeboard allowance.

EW-PFM5

Initiating Event: Flood, PMF
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Internal Erosion / Piping
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment.
(3) Leakage begins through the embankment facing material, extensive rockfill surcharge, and permeable rockfill resulting in flow discharging along the downstream slope or benches of the embankment.
(4) (i) Flow discharge results in erosion to downstream slopes and retrogressive slope instability, or (ii) leakage concentrates in an area that is not internally stable resulting in internal erosion, pipe development, and ultimately failure.
(5) Full breach of the facility occurs.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Long exposure period (multiple months) and length along the embankment, with no positive engineering controls • Upper fill is more permeable, particularly along the base of the 50 ft lifts where coarser rockfill has segregated due to construction methodology • Mismanagement of water inventory could decrease available freeboard • 2003 compacted soil layer could act as a conduit or perching layer under flooded conditions	• Low likelihood of flood event • Upper, more recent fill materials not particularly erodible • Closure spillway will provide control in the long-term • Ongoing reduction in pond volume due to operational treatment • Rockfill surcharge extends seepage path length for E-W Embankment and compresses tailings, decreasing permeability, erodibility, and flowability

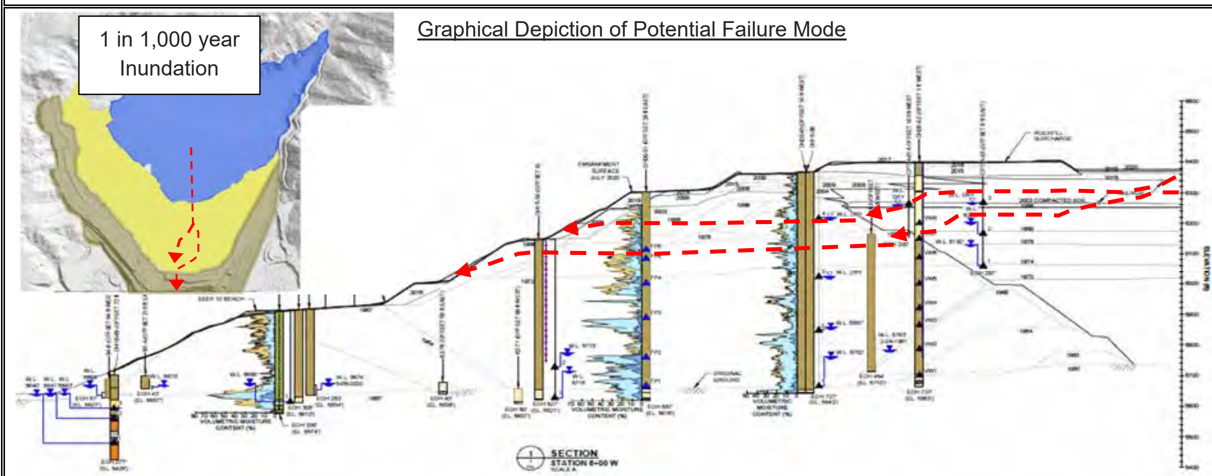
Category: 1

Overall Screening Decision:
More credible along the North-South Embankment in areas where the rockfill surcharge is not present. May be more important to evaluate if failure path can occur at lower flood levels, e.g. at what storm return period can flooding reach the embankment, as this would define the event likelihood where there is a step change in the risk profile.

EW-PFM6

Initiating Event: Flood, 1/1,000 year (30-day wet)
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Internal Erosion / Piping
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches, but not reaching the upstream facing of the embankment.
(3) Drainage gradients from the tailings into the permeable rockfill increase in subsurface interface between the two materials.
(4) Embankment facing zone and extensive rockfill surcharge not completely present at depth at the drainage interface or is insufficient to prevent tailings migration into the embankment fill.
(5) Tailings results in concentrated tailings migration through a more permeable pathway and tailings are discharged onto a bench on the downstream side of the embankment resulting in undesirable seepage and possibly some settlement cracking.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Long exposure period (multiple months), shorter beach length and flow path than normal operating conditions, and no positive engineering controls • Upper fill is more permeable, particularly along the base of the 50 ft lifts where coarser rockfill segregates during dumping • Mismanagement of water inventory could decrease available freeboard • 2003 compacted soil layer could act as a conduit or perching layer under flooded conditions	• Tailings beach remains separating the pond from embankment • Beach elevations are locally higher in this area • Upper, more recent fill materials not particularly erodible • Longer, more tortuous drainage pathway • Long well-drained beaches may control drainage into embankment and gradients at the interface • Closure spillway will provide control in the long-term • Reducing pond volumes due to operational treatment

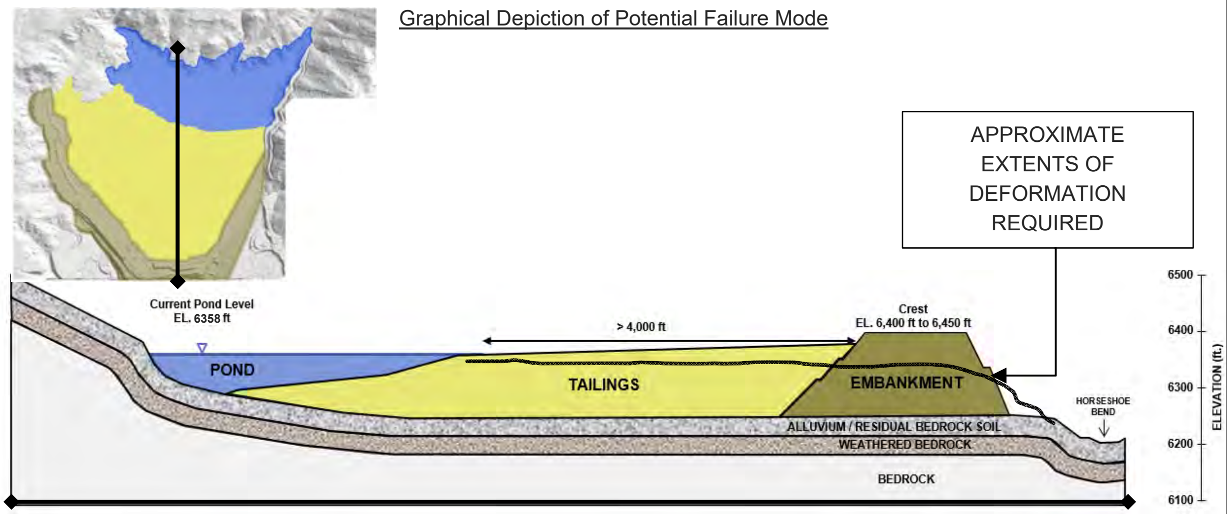
Category: **2**

Overall Screening Decision:
Possible, but low likelihood compared to EW-PMF5. Not a risk-driver unless beaches are mismanaged and a higher probability flood event than this reaches the embankment.

EW-PFM7

Initiating Event: Earthquake, Median MCE / 1 in 10,000 years
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Design maximum credible earthquake (Median MCE) occurs along the Continental Fault.
(2) The embankment deforms, and crest settles due to the seismic loading of the embankment.
(3) Tailings upstream of the embankment experience seismic liquefaction causing settlement and allowing the supernatant pond to come southward to the embankment.
(4) Embankment crest settles to a final position that is lower than the resulting supernatant pond elevation and the tailings settlement allows the pond to reach the embankment.
(5) Overtopping at the lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Material may be more compressible than one thinks due to oxidation/acid weathering processes playing out within the embankment fill, but highly compressible materials may not be broadly present (e.g. leached areas) • High seismic area; significant ground motions possible • Design basis considerations related to Median MCE vs. 84th-percentile MCE warrant further discussion/consideration	• Relatively large freeboard during most of operations • Relatively large settlement required over long distances within the tailings and embankment fill • Tailings less susceptible to oxidation/acid weathering processes • Drained tailings adjacent to embankment less susceptible to liquefaction • Controls readily implemented for conservative settlement estimate e.g. dam raise; low likelihood of earthquake occurring coincidentally with low freeboard due to ongoing continuous dam raises.

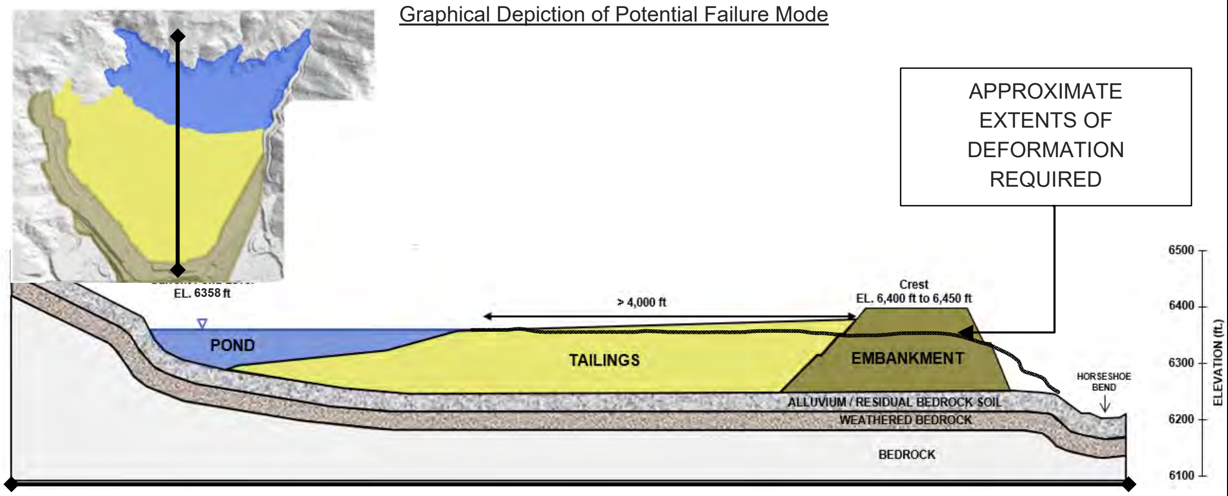
Category: 1

Overall Screening Decision:
Possibly credible at the East-West Embankment given uncertainty in estimating magnitude of earthquake-induced settlement and material compressibility, uncertainty in spatial variation of material compressibility, YDTI location in a high seismic area, and use of Median MCE as the design basis. Should be considered alongside ‘Earthquake-Instability’ event trees.

EW-PFM8

Initiating Event: Earthquake, 84th-percentile MCE / 1 in 100,000 years
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Closure design basis maximum credible earthquake (84th-Percentile MCE) occurs along the Continental Fault during operations.
(2) The embankment deforms and crest settles due to the seismic loading of the embankment.
(3) Tailings upstream of the embankment experience seismic liquefaction causing settlement and allowing the supernatant pond to come southward to the embankment.
(4) Embankment crest settles to a final position that is lower than the resulting supernatant pond elevation and the tailings settlement allows the pond to reach the embankment.
(5) Overtopping at the lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Increased uncertainty in material compressibility due to oxidation/acid weathering processes playing out within the embankment fill; uncertainty in spatial extents of potential highly compressible materials • High seismic area, significant ground motions possible	• Relatively large freeboard during most of operations • Relatively large settlement required over long distances within the tailings and embankment fill • Tailings less susceptible to oxidation/acid weathering processes • Drained tailings adjacent to embankment less susceptible to liquefaction • Controls readily implemented for conservative settlement estimate • 84th-percentile MCE is at the leading edge of current practice

Category: 1

Overall Screening Decision:
As above for EW-PFM7, but with a more unlikely event, exceeding the operational design basis, that may result in higher deformations. Possibly credible due to uncertainties in material compressibility, earthquake-induced settlement magnitudes, and YDTI location in a high seismic area. Should be considered alongside ‘Earthquake-Instability’ event trees.

EW-PFM9

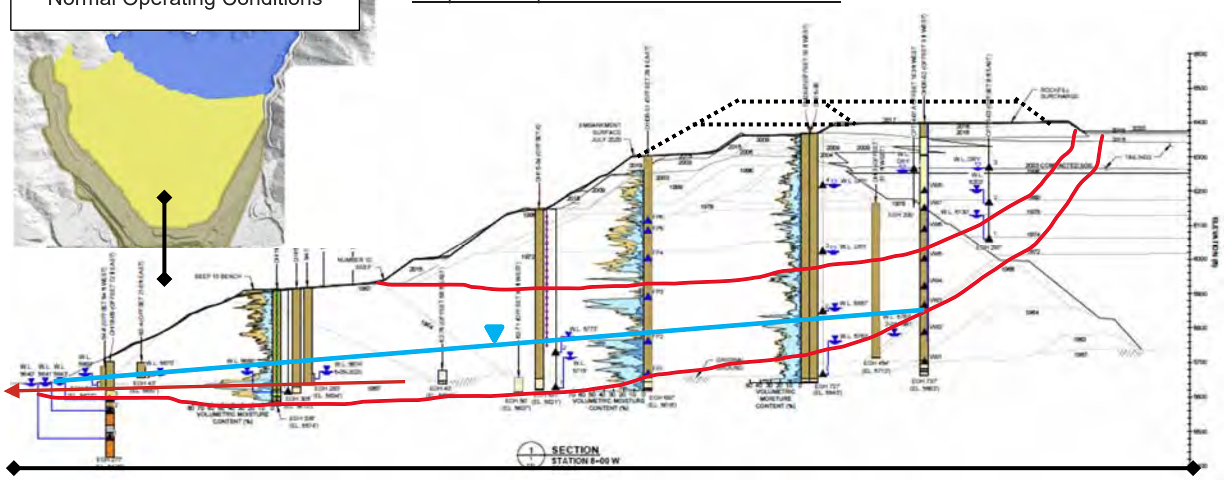
Initiating Event: Earthquake, 1/1,000-year return period, Median MCE / 1 in 10,000-year, 84th-Percentile MCE / 1 in 100,000-year
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)

Failure Path Description:

(1) Severe earthquake occurs.
(2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment or foundation soils.
(3) Increasing pore pressures result in decreasing shear resistance leading to slope instability.
(4) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height.
(5) Large-scale landslide and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.

Normal Operating Conditions

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- There is currently a basal saturated zone and some evidence of perched drainage
- Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences)
- Known areas of historical leaching activities
- Potential for lower material strength within the alluvium foundation unit / saturated rockfill
- High seismic area, significant ground motions possible
- Variability of embankment fill increases uncertainty

Less Likely (Resisting) Factors

- Very low likelihood of earthquake event(s)
- Reasonably competent rockfill that drains well
- Geometry of rockfill surcharge improves tailings response and decreases likelihood of liquefaction
- Relatively modest slope angles
- Long well-drained beaches may limit potential for surficial tailings liquefaction
- Variable rockfill dumping orientation and resulting fabric
- Well monitored and positive performance observed

Category: 1

Overall Screening Decision:

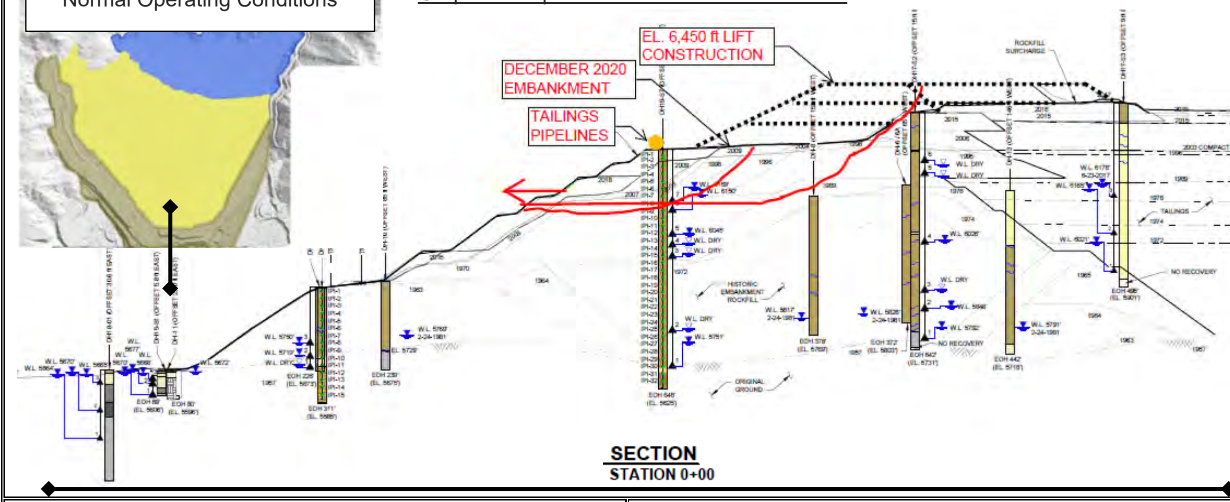
Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to seismic loading.

EW-PFM10

Initiating Event: Earthquake, 1/1,000-year return period, Median MCE / 1 in 10,000 year, 84th-Percentile MCE / 1 in 100,000 year
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Severe earthquake occurs.
(2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment.
(3) Increasing pore pressures result in decreasing shear resistance leading to slope instability.
(4) Embankment instability occurs through a relatively shallow slip surface impacting the central portion of the embankment.
(5) Multi-bench instability and/or slumping deformation occurs in the central pedestal area resulting in damage to the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations. Resulting failure surface does not result in loss of tailings containment within the YDTI.

Normal Operating Conditions

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- There is some evidence of perched drainage
- Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences
- Known areas of historical leaching activities
- Potential for lower material strength within the saturated rockfill to be considered
- High seismic area, significant ground motions possible
- Variability of embankment fill increases uncertainty

Less Likely (Resisting) Factors

- Very low likelihood of earthquake event(s)
- Reasonably competent rockfill that drains well
- Geometry of rockfill surcharge improves tailings response and decreases likelihood of liquefaction
- Relatively modest slope angles
- Long well-drained beaches may limit potential for surficial tailings liquefaction
- Variable rockfill dumping orientation and resulting fabric
- Well monitored and positive performance observed

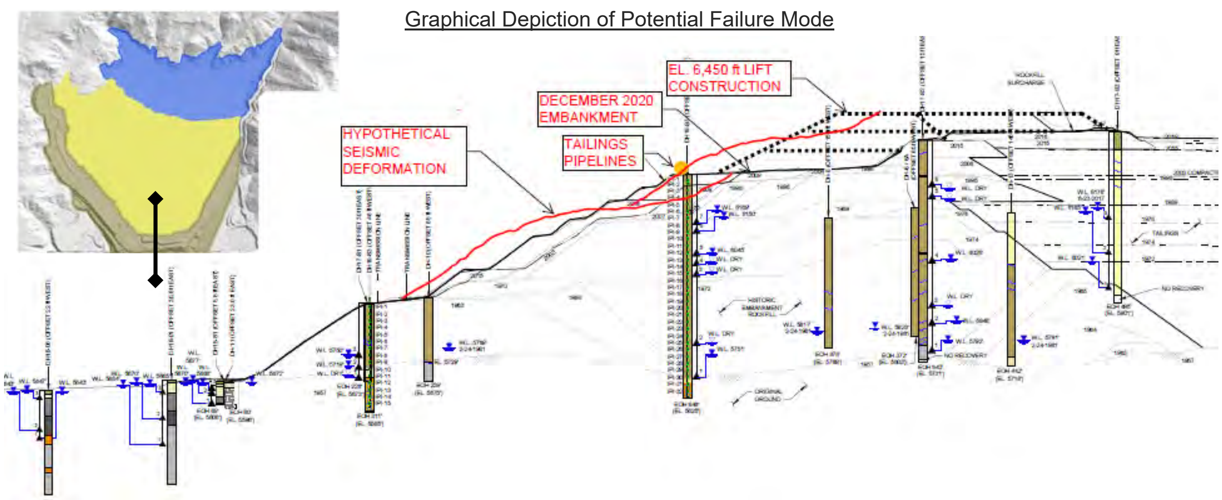
Category: 1

Overall Screening Decision:
Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to seismic loading.

EW-PFM11

Initiating Event: Earthquake, 1/1,000-year return period, Median MCE / 1 in 10,000 year, 84th-Percentile MCE / 1 in 100,000 year
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Undesirable Embankment Deformation
Failure Path Description:
(1) Severe earthquake occurs.
(2) The embankment deforms due to the seismic loading of the embankment.
(3) Resulting deformations cause slope adjustments and/or bench settlement through the central pedestal area impacting the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations and/or No. 3 Booster Station.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences) • High seismic area, significant ground motions possible • Known areas of historical leaching activities • Variability of embankment fill increases uncertainty of deformation magnitudes due to earthquake	• Very low likelihood of earthquake event(s) • Relatively modest slope angles • Variable rockfill dumping orientation and resulting fabric • Well monitored and positive performance observed

Category: 2

Overall Screening Decision:
Failure mode possible and could lead to an interruption of operations. Probably not a risk-driver but could create a residual threat that may impact downstream operations (e.g. cracking and deformations altering state of vulnerability).

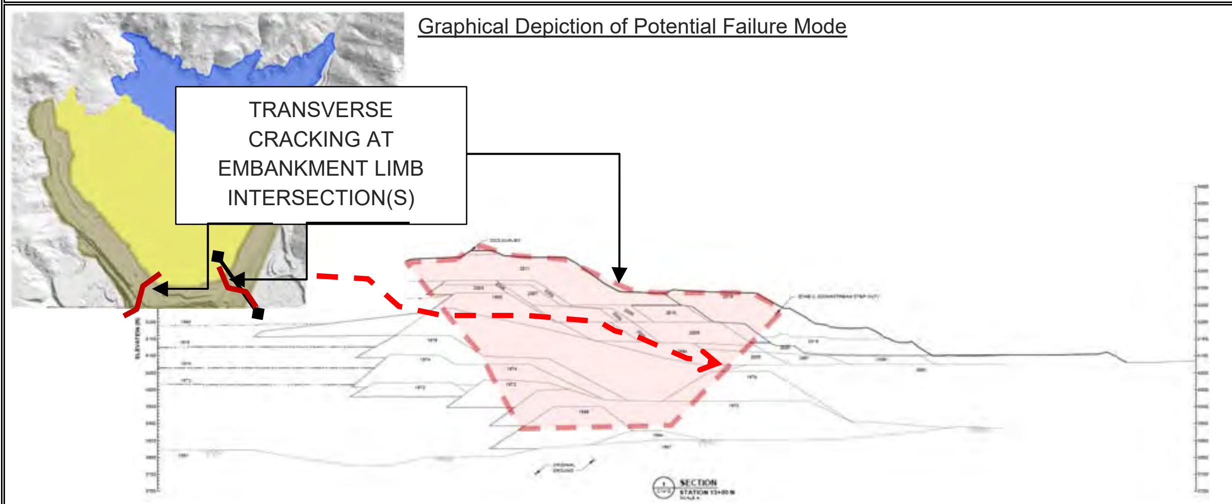
EW-PFM12

Initiating Event: Earthquake, 1/1,000-year return period, Median MCE / 1 in 10,000 year, 84th-Percentile MCE / 1 in 100,000 year
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Transverse Cracking

Failure Path Description:

(1) Severe earthquake occurs.
(2) The embankment differentially deforms resulting in vertical cracking at points of intersection of section geometry/embankment limbs without any internal seepage controls (e.g. filters) upstream.
(3) Results in potential preferential flow paths that are difficult to assess.
(4) (i) either tailings mobilized during seismic loading finds resulting flow paths or (ii) continued operations leads to tailings slurry interacting with unidentified flow paths
(5) Loss of tailings occurs.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- Could develop under moderate earthquakes and go undetected, leading to issues during continued operations and tailings discharge
- Larger lift thicknesses and method of placement (locally heterogenous and with nominal truck compaction) would increase likelihood of local cracking
- Sharp curvature at points of intersection of embankment limbs
- Potential for localized liquefaction at depth finding cracks

Less Likely (Resisting) Factors

- Embankment is relatively wide and difficult to assess whether this would result in a consequential failure
- Relatively wide fill decreases likelihood of full width crack
- Material may not hold a crack
- Long well-drained beaches keep source of water relatively remote from potential area of cracking
- Long well-drained beaches may limit potential for surficial tailings liquefaction and tailings at depth may be resistant to liquefaction and/or non-flowable/reduced fluidity due to higher confining pressures and lower moisture contents

Category: 1

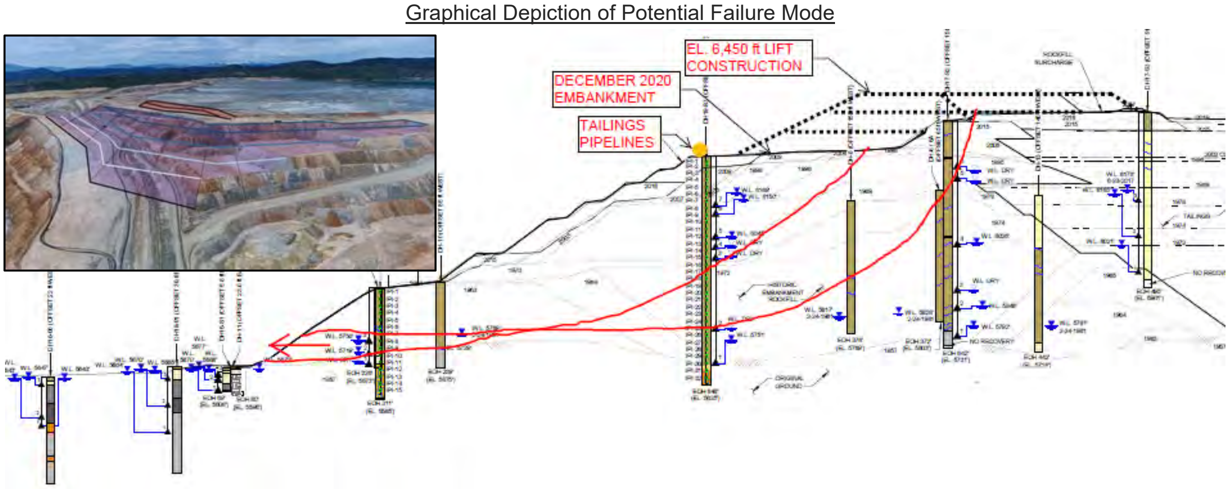
Overall Screening Decision:

Difficulty in assessing the failure mode; probably warrants more detailed consideration. May be a category 3 item with well reasoned argument; however, this failure path may change state of long-term vulnerability or increase threat of future consequences occurring, i.e. create a residual threat that may not be acceptable for downstream/long-term operations.

EW-PFM13

Initiating Event: Construction, EL. 6,450 ft lift fill placement
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Construction loading during placement of embankment lifts in the central maximum section.
(2) Loading results in increased shear stresses with no change in pore pressures within saturated zones; however, increased shear stresses exceed shear resistance.
(3) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height.
(4) Large-scale landslide and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- There is currently a basal saturated zone and some evidence of perched drainage
- Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences
- Known areas of historical leaching activities
- Potential for lower material strength within the alluvium foundation unit / saturated rockfill to be considered
- Potential for increased piezometric levels due to infiltration from storm events (similar to PFM 1, 2)
- Impractical to monitor all depths within the embankment at all locations does leave some residual uncertainty

Less Likely (Resisting) Factors

- Reasonably competent rockfill that drains well
- Relatively modest slope angles
- Long well-drained beaches would recharge initially along with drainage into embankment
- Variable rockfill dumping orientation and resulting fabric
- Well monitored and positive performance observed; automated alerts with operational TARPs. Good risk controls.
- Surface and subsurface deformation monitoring programs in place
- Factor of safety from previous analyses is approximately 1.9 for drained conditions
- No previous construction induced pore pressure change observed at downstream toe

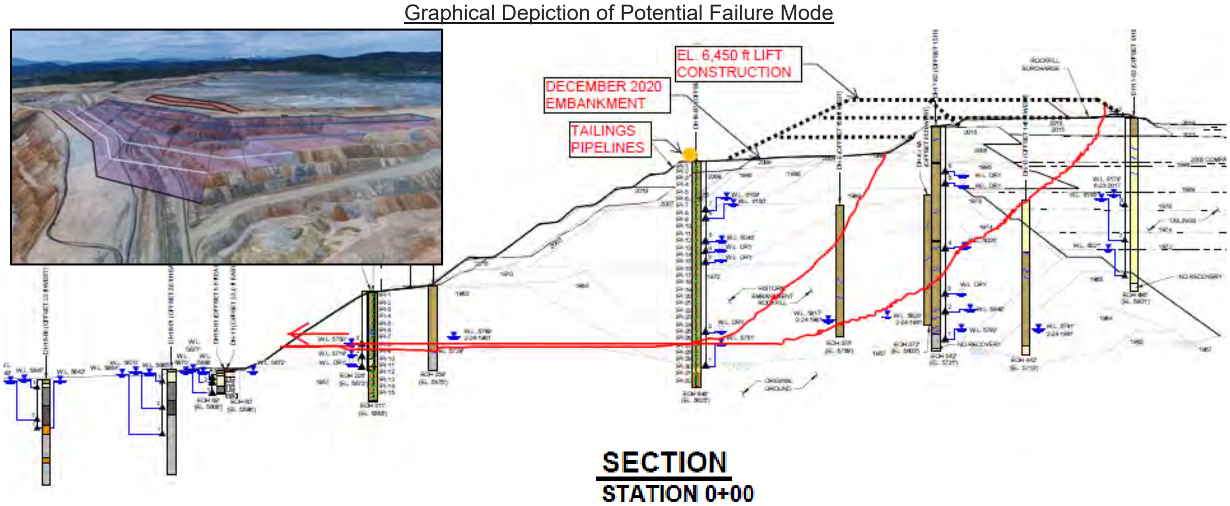
Category: 4

Overall Screening Decision:
Failure mode not credible without excess pore pressure development. By default, it should get captured in the construction induced failure event tree along with EW-PFM14.

EW-PFM14

Initiating Event: Construction, EL. 6,450 ft lift fill placement
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Construction loading during placement of embankment lifts in the central maximum section.
(2) Loading results in increased shear stresses and excess pore pressure development within saturated zones of the embankment fill within critical resisting areas of the embankment exceeding shear resistance.
(3) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height.
(4) Large-scale landslide and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• There is currently a basal saturated zone and some evidence of perched drainage • Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences • Known areas of historical leaching activities • Potential for lower material strength within the alluvium foundation unit / saturated rockfill to be considered • Potential for increased piezometric levels due to infiltration from storm events • Impractical to monitor all depths within the embankment	• Reasonably competent rockfill that drains well • Relatively modest slope angles • Long well-drained beaches would recharge initially along with drainage into embankment • Variable rockfill dumping orientation and resulting fabric • Well monitored and positive performance observed; automated alerts with operational TARPs. Good risk controls. • Surface and subsurface deformation monitoring programs in place • Factor of safety range from previous analyses 1.2-1.9 depending on undrained strength ratio applied • No previous construction induced pore pressure change at downstream toe

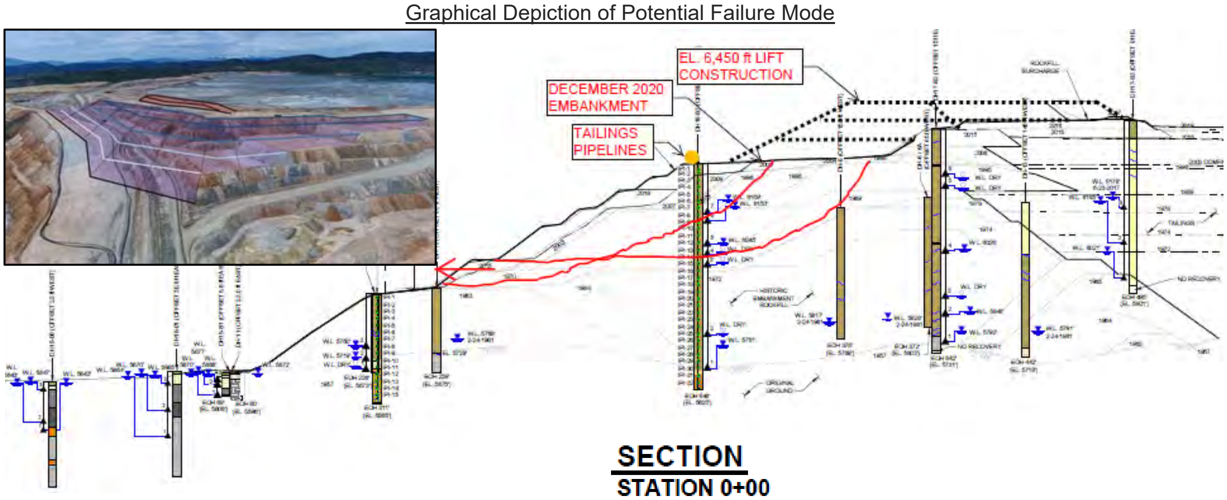
Category: 1

Overall Screening Decision:
Requires consideration in the RA using sensitivity analyses that consider either (i) variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to construction loading, or (ii) variation of piezometric pressures within range that could be expected due to construction loading.

EW-PFM15

Initiating Event: Construction, EL. 6,450 ft lift fill placement
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Construction loading during placement of embankment lifts in the central maximum section.
(2) Loading results in increased shear stresses exceeding shear resistance.
(3) Embankment instability occurs through a relatively shallow slip surface impacting the central portion of the embankment.
(4) Multi-bench instability and/or slumping deformation occurs in the central pedestal area resulting in damage to the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations. Resulting failure surface does not result in loss of tailings containment within the YDTI.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- There is currently some evidence of perched drainage
- Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences
- Known areas of historical leaching activities
- Potential for lower material strength within the saturated rockfill
- Potential for increased piezometric levels due to infiltration from storm events
- Impractical to monitor all depths within the embankment

Less Likely (Resisting) Factors

- Reasonably competent rockfill that drains well
- Relatively modest slope angles
- Long well-drained beaches would recharge initially along with drainage into embankment
- Variable rockfill dumping orientation and resulting fabric
- Well monitored and positive performance observed; automated alerts with operational TARPs. Good risk controls.
- Surface and subsurface deformation monitoring programs in place

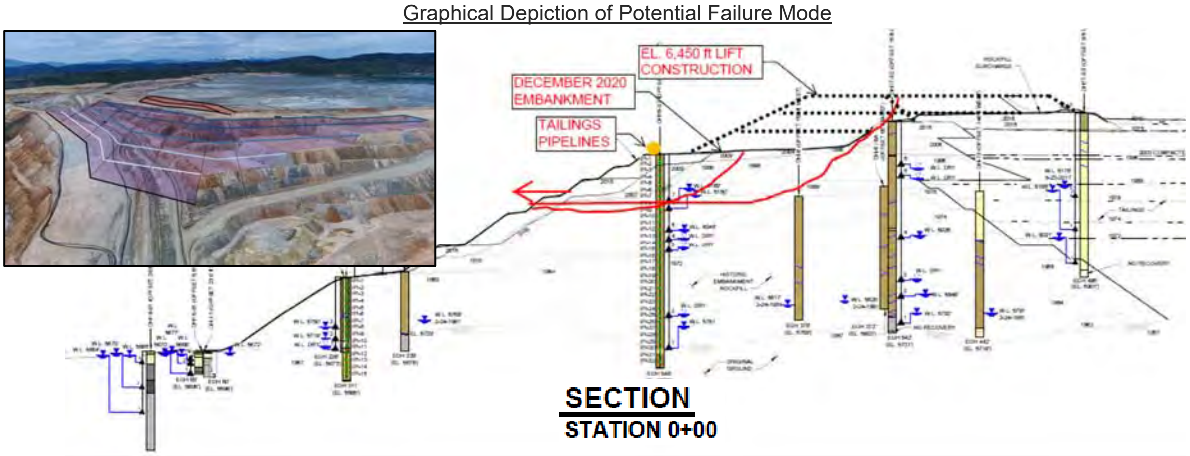
Category: 4

Overall Screening Decision:
Failure mode not credible without excess pore pressure development.

EW-PFM16

Initiating Event: Construction, EL. 6,450 ft lift fill placement
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Construction loading during placement of embankment lifts in the central maximum section.
(2) Loading results in increased shear stresses and excess pore pressure development within saturated zone(s) of the embankment fill within critical resisting areas of the embankment exceeding shear resistance.
(3) Embankment instability occurs through a relatively shallow slip surface impacting the central portion of the embankment.
(4) Multi-bench instability and/or slumping deformation occurs in the central pedestal area resulting in damage to the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations. Resulting failure surface does not result in loss of tailings containment within the YDTI.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Evidence of perched saturation (e.g. in 1982 lift top) • Some evidence of pore pressure decrease/dissipation observed in upper sensors at DH19-S7 • Embankment layering (compacted haul surfaces, finer-grained lift tops, and rockfill material source differences) • Known areas of historical leaching activities • Potential for lower material strength within the / saturated rockfill • Potential for increased piezometric levels due to infiltration from storm events	• Reasonably competent rockfill that drains well; compaction on historical haul ramp where fill toes in • Relatively modest slope angles • Long well-drained beaches would recharge initially along with drainage into embankment • Variable rockfill dumping orientation and resulting fabric • Well monitored and positive performance observed; automated alerts with operational TARPs. Good risk controls. • Surface and subsurface deformation monitoring programs in place • Additional planned comprehensive investigations • Factor of safety range from previous analyses 1.2-1.9 depending on undrained strength ratio applied

Category: 1

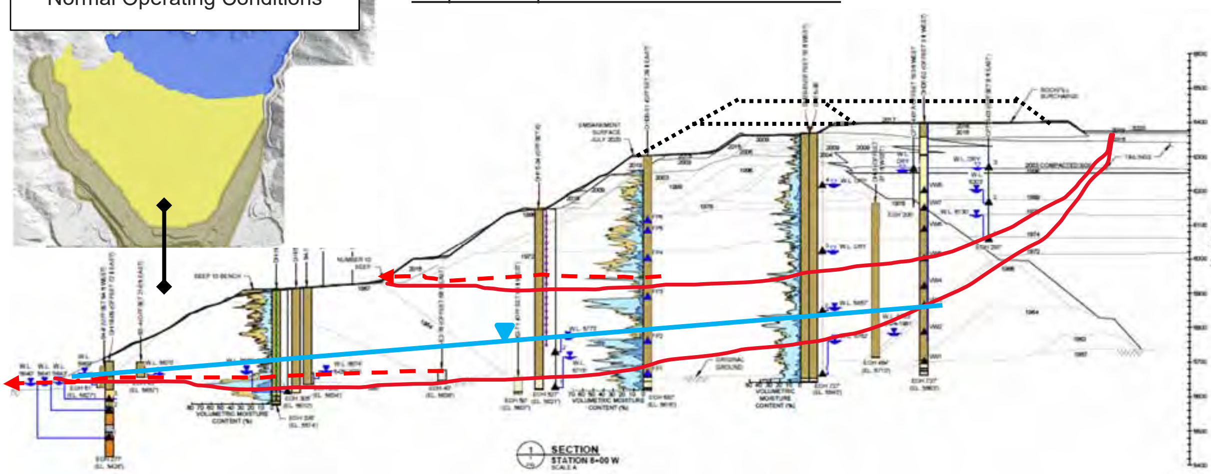
Overall Screening Decision:
Requires consideration in the RA using sensitivity analyses that consider either (i) variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to construction loading, or (ii) variation of piezometric pressures within range that could be expected due to construction loading.

EW-PFM17

Initiating Event: Material degradation, Induced strain softening
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Creep occurs within basal saturated zone or a perched saturated zone within the embankment.
(2) Deformation causes either (i) excess pore pressure development or (ii) reduced confining pressures resulting in induced strain softening within critical resisting areas of the embankment.
(3) Embankment instability occurs either through (i) a deeply seated slip surface impacting the full embankment height or (ii) hypothetical perched saturated condition aligned with the Seep 10 bench.
(4) Large-scale landslide and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.

Normal Operating Conditions

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Do not know the outcome of various material degradation processes and their spatial distribution • There is currently a basal saturated zone and some evidence of perched drainage • Known areas of historical leaching activities • Potential for lower material strength within the alluvium foundation unit / saturated rockfill to be considered • Some evidence of lateral displacement at depth within foundation materials at the Seep 10 bench • Evidence of high temperature zones (to be evaluated further)	• Reasonably competent rockfill that drains well • Relatively modest slope angles • Potential for incremental buttressing which would be beneficial to near-term and long-term performance • Surface and subsurface deformation monitoring programs in place within the critical areas • High confining pressures and age of material may indicate less potential for brittle behavior; weathering to clay increases plastic behavior

Category: 1

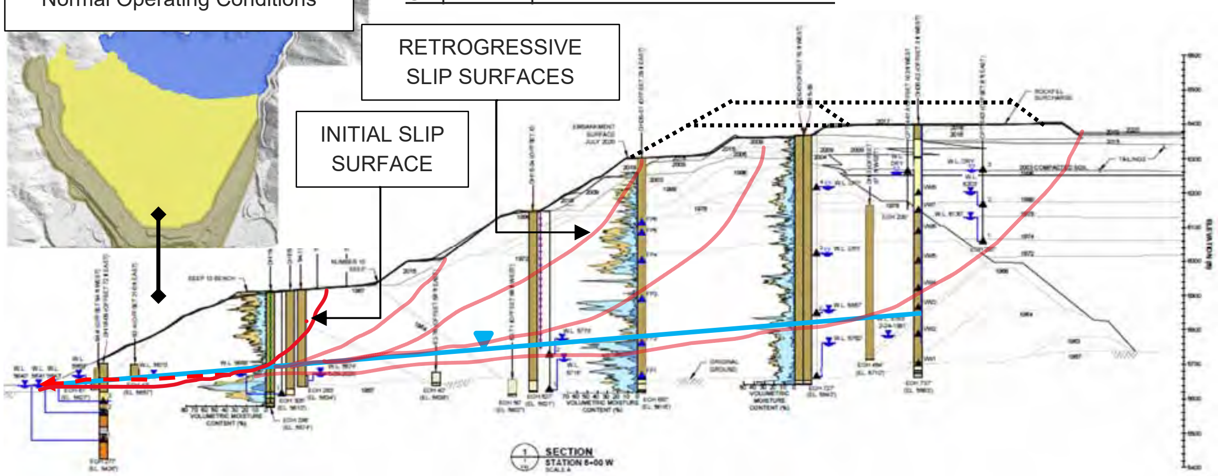
Overall Screening Decision:
Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to deeply seated creep deformation.

EW-PFM18

Initiating Event: Material degradation, induced strain softening
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Creep occurs locally within basal saturated zone of the embankment in the vicinity of the Seep 10 bench.
(2) Deformation causes either (i) excess pore pressure development or (ii) reduced confining pressures resulting in induced strain softening within critical resisting areas of the embankment.
(3) Embankment instability occurs locally at the Seep 10 bench.
(4) Retrogressive slope instability follows the initial instability causing debris flow within the HsB area impacting mine infrastructure in the area.

Normal Operating Conditions

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Do not know the outcome of various material degradation processes and their spatial distribution • There is currently a basal saturated zone and some evidence of perched drainage • Known areas of historical leaching activities • Potential for lower material strength within the alluvium foundation unit / saturated rockfill to be considered • Some evidence of lateral displacement at depth within foundation materials at the Seep 10 bench • Evidence of high temperature zones (to be evaluated further)	• Reasonably competent rockfill that drains well • Relatively modest slope angles • Potential for incremental buttressing which would be beneficial to near-term and long-term performance • Surface and subsurface deformation monitoring programs in place within the critical areas • High confining pressures and age of material may indicate less potential for brittle behavior; weathering to clay increases plastic behavior

Category: 1

Overall Screening Decision:
Requires consideration in the RA using sensitivity analyses that consider variation in undrained strength ratio while recognizing the uncertainty in the piezometric response to deeply seated creep deformation.

EW-PFM19

Initiating Event: Material degradation, acidic drainage
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)

<u>Failure Path Description:</u>

(1) Continuous acidic drainage within embankment fill material.

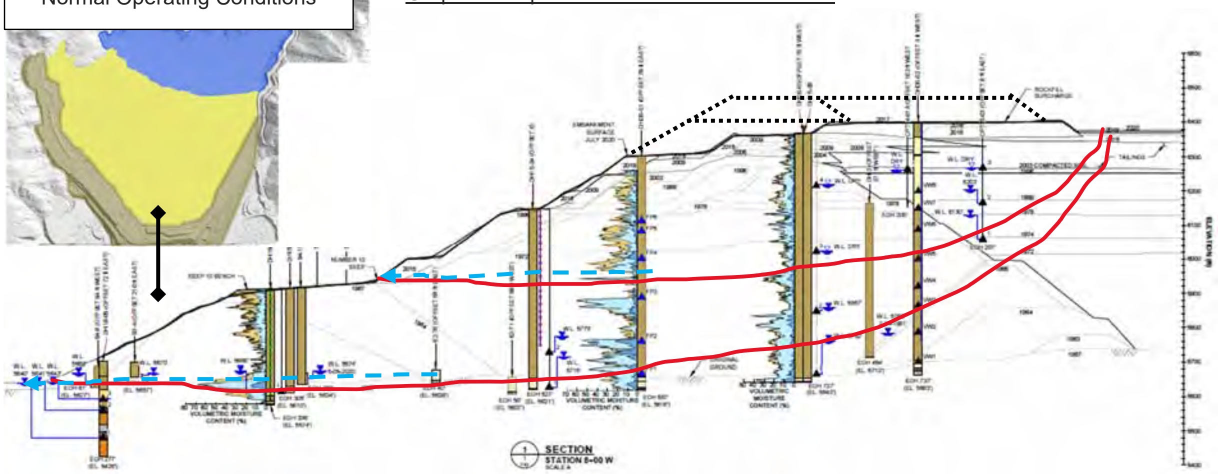
(2) Chemical weathering results in decreasing strength properties within critical resisting areas of the embankment.

(3) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height or aligned with the Seep 10 bench.

(4) Large-scale landslide and/or slumping deformation occurs in the central pedestal area causing debris flow within the HsB area impacting mine infrastructure in the area.

Normal Operating Conditions

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- Do not know the outcome of various material degradation processes and their spatial distribution
- There is currently a basal saturated zone and some evidence of perched drainage
- Known areas of historical leaching activities
- Potential for lower material strength within the alluvium foundation unit / saturated rockfill to be considered
- Some evidence of lateral displacement at depth within foundation materials at the Seep 10 bench
- Evidence of high temperature zones (to be evaluated further)

Less Likely (Resisting) Factors

- Reasonably competent rockfill that drains well
- Relatively modest slope angles
- Potential for incremental buttressing which would be beneficial to near-term and long-term performance
- Surface and subsurface deformation monitoring programs in place within the critical areas
- High confining pressures and age of material may indicate less potential for brittle behavior; weathering to clay increases plastic behavior

<u>Category:</u> 1

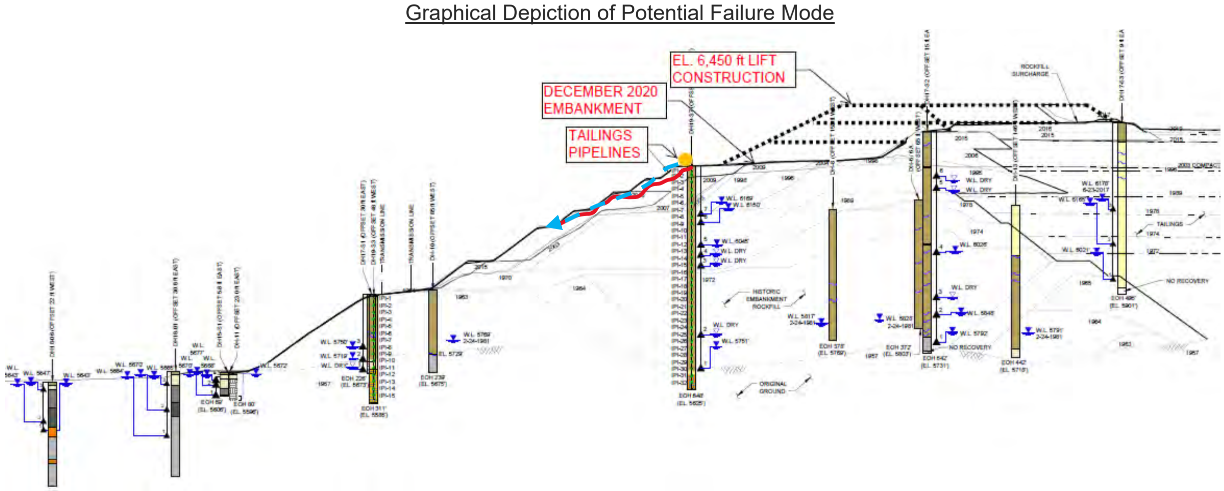
<u>Overall Screening Decision:</u>

Considered as part of overall event tree build up for this failure mode.

EW-PFM20

Initiating Event: Material degradation, weathering
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Undesirable Embankment Deformation
Failure Path Description:
(1) Exposure of embankment fill materials near surface to atmospheric conditions (air, snow, rain, freeze-thaw, etc.).
(2) Physical and chemical weathering results in slope creep, strength reduction, and/or erosion.
(3) Resulting deformations cause slope adjustments and/or bench settlement through the central pedestal area impacting the tailings distribution pipelines between the No. 2 and No. 3 Booster Pump Stations, mine haul ramps, transmission lines on the Seep 10 bench, etc.
(4) Results in an operational shutdown and repair work.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- Do not know the outcome of various material degradation processes and their spatial distribution
- In a climate susceptible to freeze-thaw effects

Less Likely (Resisting) Factors

- Reasonably competent rockfill that drains well
- Relatively modest slope angles
- Potential for incremental buttressing would be beneficial to near-term and long-term performance
- Surface and subsurface deformation monitoring programs in place within the critical areas
- Upper, more recent fill materials not particularly erodible

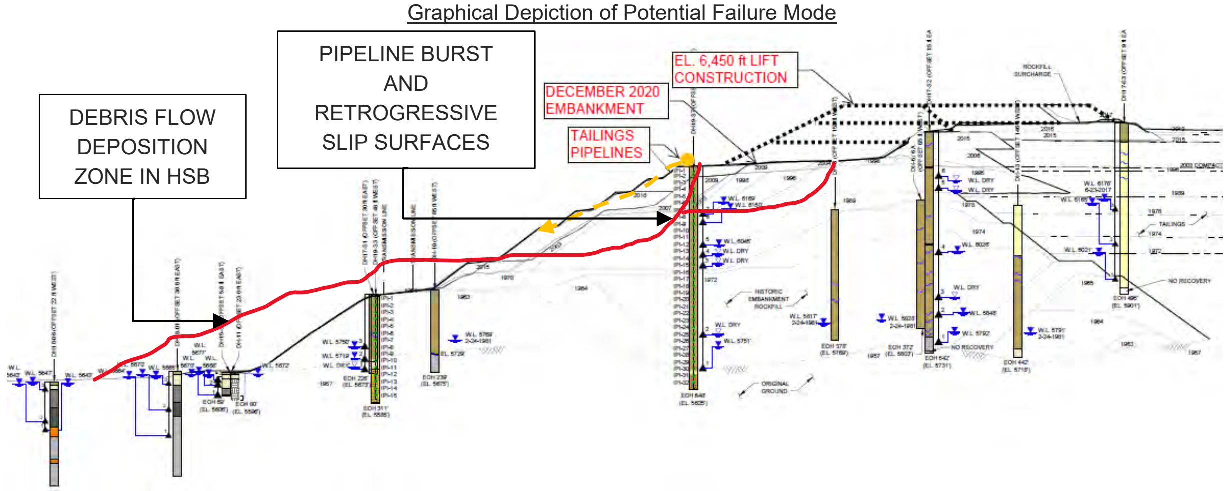
Category: 2

Overall Screening Decision:
Possible, but not a risk-driver. Primarily a maintenance issue and does not require detailed consideration in the RA workshop.

EW-PFM21

Initiating Event: Operational Upset/Malfunction, Tailings pipeline burst
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Tailings pipeline rupture occurs between No. 2 and No. 3 Booster Pump Stations.
(2) Tailings slurry discharging from ruptured pipeline erodes downstream slope within the central pedestal area.
(3) Erosion of slope progresses through a combination of downcutting and shallow rotational slip surfaces.
(4) Retrogressive slope instability occurs causing debris flow within the HsB area impacting mine infrastructure in the area.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during the workshop	• Controls in place to detect pressure changes and shutdown (automated) • Berm along outside edge should prevent most tailings from flowing downslope • Drain back locations available at No. 2 and McQueen Booster pump stations

Category: 2

Overall Screening Decision:
Possible, but not a risk-driver. Primarily a maintenance and operations issue and does not require detailed consideration in the RA workshop.

EW-PFM22

Initiating Event: Geological Hazards, Landslide
Location: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Landslide occurs from Rampart Mountain along the eastern side of the YDTI.
(2) Slide reaches the supernatant pond and causes a wave.
(3) Wave runs up the tailings beach and overtops the embankment causing erosion and damage on the downstream side of the embankment.

Graphical Depiction of Potential Failure Mode

More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Earthquake motion on the Continental Fault would increase possibility of slope movement • Heavy rainfall/snowmelt combinations would increase potential for slope movement	• Localized wedge failures possible, unlikely to see large scale failures • Direction of flood wave may be more oriented towards the west-northwest

Category: 3

Overall Screening Decision:
For discussion purposes only. May be difficult to comment on likelihood based on existing knowledge base.

APPENDIX B2

North-South Embankment PFMA Details

(Pages B2-1 to B2-19)

TABLE B2.1

MONTANA RESOURCES, LLC
YANKEE DOODLE TAILINGS IMPOUNDMENT

POTENTIAL FAILURE MODE ANALYSIS
DEVELOPMENT FRAMEWORK AND SCREENING SUMMARY
NORTH-SOUTH EMBANKMENT

CODE	PFM#	Initiating / Loading Event		Location	Potential Failure Mode	Simple Failure Path Progression Description	Preliminary Screening Assessment	Category	Primary Means of Risk Control	Additional Risk Controls to Consider	Potential Data Gaps	Detection and Intervention
		Category	Sub-category									
NS	1	Flood	PMF	N-S 1: North-South Embankment (e.g. STA. 28+00 N)	Instability (Foundation or Slope)	(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack. (2) Flood inflows to the facility lead to rising pond surface inundating the long, drained tailings beaches. (3) Infiltration into the tailings beach and embankment results in rising phreatic surface within embankment. (4) Rising pore water pressures decrease effective stress in critical resisting areas of the embankment. (5) Results in slope instability.	Requires consideration in workshop – 28+00 N (more adverse geometry) and 43+00 N (tailings beach more likely to inundate before 28+00 N).	1	Very low likelihood of this level of severe flooding. Promote and maintain low water inventory and develop long, drained tailings beaches to maximize water storage on beach in the event of flooding.	- Shortening the period of beach inundation. - Additional toe support and compression of leach materials in North RDS area, i.e. buttressing. - Spillway in closure. - Pond volume reductions. - Interim overflow channel to control maximum potential water elevation.	Historical leach dump material consistency and behavior. Base preparation under leach pads. Additional pore pressure monitoring sensors (planned for future work). InSAR monitor has difficulty picking up downslope creep on N-S due to direction of flight paths / presence of rampart mountain.	Can likely detect the intervene by activiating emergency action plans. Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff. Monitoring equipment is available to detect changing piezometric conditions in real-time within critical areas of the embankment.
NS	2	Flood	PMF	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Internal Erosion / Piping	(1) Flood water hydraulically connects with exising seepage paths that have been observed to daylight on the downstream slope (2) resulting in piping.	Requires consideration in workshop.	1	Beach development and freeboard criteria to protect most critical areas of the embankment (i.e. which area of the beach is kept highest)	- Breakup of flow path at base of lift with some engineering solution. - Enhancement of embankment facing - Closure spillway will provide some long-term risk control. - Prioritize beach management to push flood inundation preferentially towards West Embankment. - Interim overflow channel to control maximum potential water elevation.	None Identified.	Can likely detect the intervene by activiating emergency action plans. Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff and remote sensing tools.
NS	3	Flood	PMF	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Uncontrolled seepage	(1) Flood water hydraulically connects with exising seepage paths that have been observed to daylight on the downstream slope (2) resulting in uncontrolled seepage.	Grouped with NS-PFM2. Event tree could consider potential variations in consequence. The stated consequence is not a risk driver.	2	As above.	None identified.	None Identified.	None identified.
NS	4	Flood	PMF	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Overtopping	(1) Flood occurs causing rise in supernatant pond level. (2) Overtops lowest point on the N-S Embankment. (3) Results in erosion of embankment fill and breach of facility.	Very unlikely and not a risk-driver; not credible unless PMF is substantially underestimated or if freeboard is mismanaged. Considered for completeness, but likely does not require a full event tree build up.	4	Very low likelihood of this level of severe flooding. Freeboard criteria incorporates flood storage for PMF.	- Closure spillway will provide some long-term risk control. - Interim overflow channel to control maximum potential water elevation.	None Identified.	Can likely detect the intervene by activiating emergency action plans. Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff and remote sensing tools.
NS	5	Earthquake	84th-percentile MCE / 1 in 100,000 yr	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Overtopping	(1) Severe earthquake occurs. (2) Response to earthquake results in compression of the buried leach materials on the downstream side of the embankment. (3) Undesirable embankment crest settlement. (4) Results in overtopping of supernatant pond and breach of the facility.	The instability failure mode will be assessed as the primary risk-driver (NS-PFM6) with many of the same considerations. Not Category 1 since freeboard is very large and tailings next to the embankment are well drained.	2	Very low likelihood of event occuring. Very long well drained beaches and remote location of the supernatant pond. Reasonably competent rockfill that drains well. Design freeboard.	- Additional toe support and compression of leach materials in North RDS area, i.e. buttressing.	Compressibility of leached material; potential analogue in Questa project (New Mexico). Seismic response of historical leach material relative to adjacent embankment materials	None identified.
NS	6	Earthquake	84th-percentile MCE / 1 in 100,000 yr	N-S 1: North-South Embankment (e.g. STA. 28+00 N)	Instability (Foundation or Slope)	(1) Severe earthquake occurs. (2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment or foundation soils. (3) Increasing pore pressures result in decreasing shear resistance leading to slope insability. (4) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height.	Requires consideration in workshop.	1	Very low likelihood of event occuring. Very long well drained beaches and remote location of the supernatant pond. Reasonably competent rockfill that drains well. Design freeboard.	- Additional toe support and compression of leach materials in North RDS area, i.e. buttressing.	As above. Three dimensionality of seismic response. Potential for fine grained segragation south of 23+00 N. Continuity of data in pore pressure within 1982 lift top; presence of perched water tables in south part of N-S; continuity of perched water table NE of 0+00	None identified.
NS	7	Material_Degradation	Weathering	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Overtopping	Embankment material degradation/weathering leads to a change in void ratio resulting in unwanted crest settlement which leads to overtopping.	Not credible during operations with on-going mine equipment available to maintain freeboard.	4	Large design freeboard during most of operations.	- Downstream slope flattening and buttressing with North RDS planned and will further limit likelihood.	None identified.	Regular inspection and aerial survey to detect settlement and mine equipment available to maintain freeboard.
NS	8	Material_Degradation	Weathering	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Undesirable Embankment Deformation	Historical leach pad material degradation/weathering processes lead to a change in void ratio resulting in unwanted crest settlement.	Not credible during operations with on-going mine equipment available to maintain freeboard.	4	Large design freeboard during most of operations.	- Downstream slope flattening and buttressing with North RDS planned and will further limit likelihood.	Compressibility of leached material.	Regular inspection and aerial survey to detect settlement and mine equipment available to maintain freeboard.

TABLE B2.1

MONTANA RESOURCES, LLC
YANKEE DOODLE TAILINGS IMPOUNDMENT

POTENTIAL FAILURE MODE ANALYSIS
DEVELOPMENT FRAMEWORK AND SCREENING SUMMARY
NORTH-SOUTH EMBANKMENT

CODE	PFM#	Initiating / Loading Event		Location	Potential Failure Mode	Simple Failure Path Progression Description	Preliminary Screening Assessment	Category	Primary Means of Risk Control	Additional Risk Controls to Consider	Potential Data Gaps	Detection and Intervention
		Category	Sub-category									
NS	9	Geological_Hazards	Landslide	N-S 2: North-South Embankment (e.g. STA. 63+00 N)	Impacts to mine operations	Landslide on Rampart Mountain blocks access to the pump-back barge.	Not a dam safety issue, could upset operations. Mine equipment available to clear blockages or could create access from the west side from existing trails within days.	4	Inferred low likelihood of landslides on Rampart Mountain based on existing knowledge base. Multiple points of access to barge area.	None identified.	None identified.	None identified.
NS	10	Geological_Hazards	Landslide	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Overtopping	Landslide on Rampart Mountain causes wave in the decant pond that erodes the crest causing breach.	For discussion purposes only. May be difficult to comment on likelihood based on existing knowledge base.	3	Inferred low likelihood of landslides on Rampart Mountain based on existing knowledge base.	None identified.	Uncertainty regarding potential for landslide along Rampart Mountain could warrant future study.	None identified.
NS	11	Geological_Hazards	Wind	N-S 1: North-South Embankment (e.g. STA. 28+00 N)	Instability (Foundation or Slope)	High, sustained winds generate dust so severe that operations personnel cannot observe deposition or crest condition.	Adequate controls in place. Unlikely to impact dam safety except perhaps in combination.	4	Climate monitoring provides prediction of upcoming dusting events and dust management plans are in place including proactive management measures.	None identified.	None Identified.	Climate monitoring and forecast predictions. Dust management measures and emeregency response plans well developed.
NS	12	Geological_Hazards	Fire	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Instability (Foundation or Slope)	Fire in immediate vicinity results in site evacuation with no eyes on the deposition or pumps.	Mill shutdown would occur in the event of site evacuation, which negates any concerns related monitoring continued operations.	4	Emergency management plans in place. Automated remote monitoring systems are powered by batteries and cummunicate using radio signals and cellular telemetry.	None identified.	None Identified.	None identified.
NS	13	Geological_Hazards	Drought	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Undesirable Embankment Deformation	Severe, sustained drought results in unavailabilty of water to suppress dust on dam roads and beach area.	Unlikely to be a dam safety issue.	4	Water rights on fresh water supply and adequate contingency.	None identified.	None Identified.	None identified.
NS	14	Geological_Hazards	Berkeley Pit wall failure	N-S 1: North-South Embankment (e.g. STA. 28+00 N)	Instability (Foundation or Slope)	A pit wall failure will greatly reduce the storage capacity of that pit. If the YDTI fails there is now reduced containment onsite.	Not within terms of reference for YDTI risk assessment. Warrants discussion related to reliability of mitigation measures (i.e. if chosen mitigation measure relies on containment and if containment capacity decreases, the chosen mitigation measure is not reliable such that more practicable mitigation measures should be considered).	4	Not within terms of reference for this risk assessment.	None identified.	None Identified.	None identified.
NS	15	Operational_Upset_Malfunction	Inoperable reclaim barge	N-S 2: North-South Embankment (e.g. STA. 43+00 N)	Impact to Mine Operations	Pump failure on barge during rain storm compounded with landslide on Rampart Mountain preventing access to the pump.	Not a dam safety issue, could upset operations. Mine equipment available to clear blockages or could create access from the west side from existing trails within days.	4	Not a dam safety issue.	None identified.	Uncertainty regarding landslide along Rampart Mountain	Would be visible during regular site inspections. Mine equipment available to clear blockages or create access from west side from existing trails within days.
NS	16	Operational_Upset_Malfunction	Tailings pipeline burst	N-S 1: North-South Embankment (e.g. STA. 28+00 N)	Instability (Foundation or Slope)	TDL rupture could result in slurry flow eroding road and embankment, and contributing to the saturation of materials causing slope failure.	Possible, but probably not a risk-driver. Primarily a maintenance and operations issue and does not require detailed consideration in the RA workshop.	2	Massive nature of the structure and upper more recent fill materials not particularly erodible.	None identified.	None Identified.	Primarily a maintenance and operations issue. Detection through tailings pipeline operations monitoring, e.g. pipeline pressures, etc.
NS	17	Operational_Upset_Malfunction	Power loss	N-S 1: North-South Embankment (e.g. STA. 28+00 N)	Instability (Foundation or Slope)	Power loss to pumps would result in rising pond elevation that if left unchecked could result in uncontrolled seepage and/or an embankment failure.	Possible, but probably not a risk-driver. Primarily a maintenance and operations issue and does not require detailed consideration in the RA workshop.	2	Large design freeboard during most of operations. Climatic conditions in deficit.	None identified.	None Identified.	Rising pond levels would be identified through multiple monitoring mechanisms and emergency response could be initiated as requried.

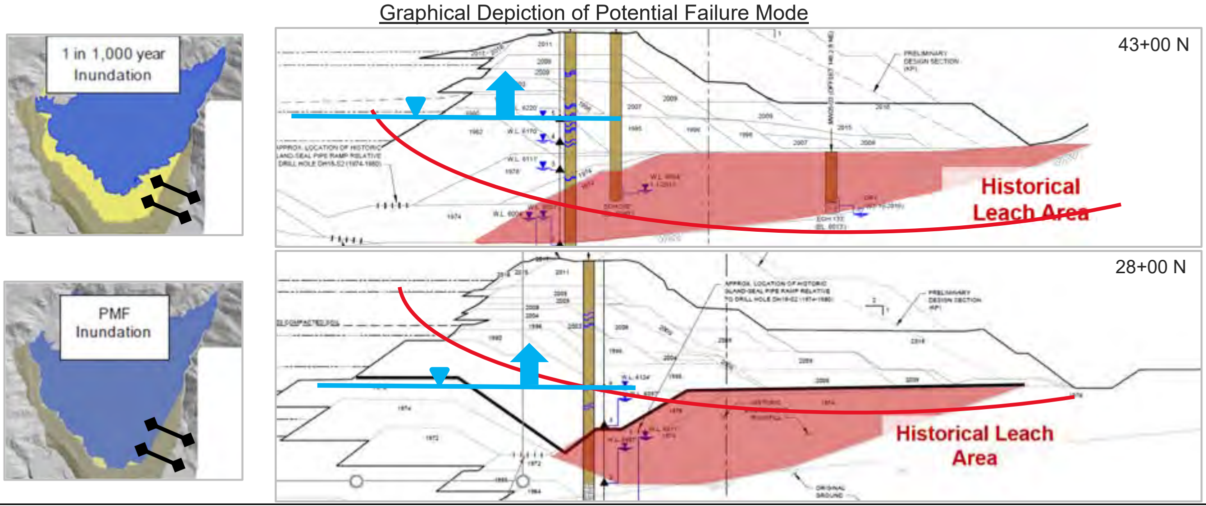
M:\1\01\00126\27\A\Data\Task 510 - Risk Assessment\05 - Potential Failure Modes Analysis\[PFMA Development Summary_r0.xlsx]Table 2 - N-S EMBANKMENT

0	07JUL'23	ISSUED WITH REPORT VA101-00126/27-1	EJA	DDF
REV	DATE	DESCRIPTION	PREP'D	RVW'D

NS-PFM1

Initiating Event: Flood, 1/1000 yr (30-day wet) or PMF
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack
(2) Flood inflows to the facility lead to rising pond surface inundating the long, drained tailings beaches
(3) Infiltration into the tailings beach and embankment results in rising phreatic surface within embankment.
(4) Rising pore water pressures decrease effective stress in critical resisting areas of the embankment.
(5) Results in slope instability.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- Construction over historical leach pads
- Potential for accumulation of seepage water within historical leach area
- Limited information related to historical leach area materials
- Relatively high pre-existing shear stress
- Construction induced pore pressures observed in foundation older alluvium, limited construction pore pressure response in basal rockfill zone

Less Likely (Resisting) Factors

- Drainage pathways follow historical drainage pathways, which centralize flow towards the YDTI and East-West Embankment
- Favorable orientation of natural ground under the N-S Embankment that generally slopes into the TSF
- Very low likelihood of flood event
- Reasonably competent rockfill that drains well
- Flatter overall slope angles to 3H:1V planned following EL. 6,450 ft lift construction, and could be advanced sooner if monitoring indicated the need (no permit constraint)
- Very wide crest width along N-S Embankment
- Downward gradients, likely perched water with unsaturated zones in between

Category: 1

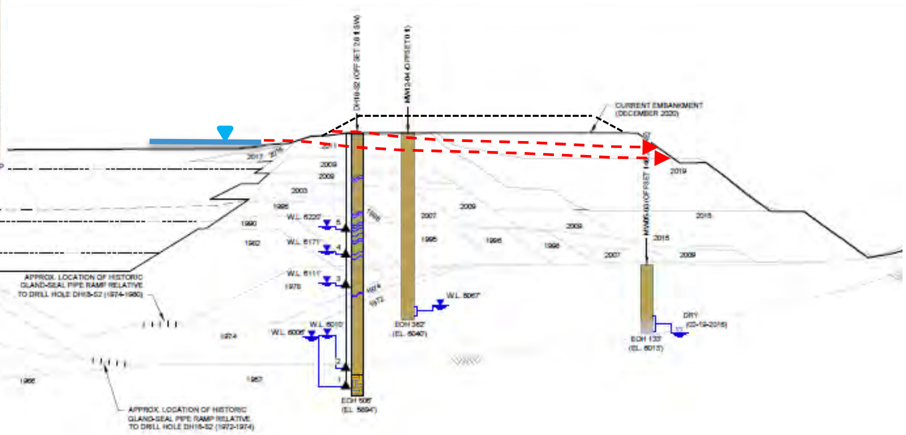
Overall Screening Decision:
Requires consideration in workshop – 28+00 N (more adverse geometry) and 43+00 N (more likely to inundate before 28+00 N).

NS-PFM2

Initiating Event: Flood, 1/1,000 yr (30-day wet) or PMF
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Internal Erosion / Piping
Failure Path Description:
(1) Flood water hydraulically connects with existing seepage paths that have been observed to daylight on the downstream slope.
(2) Results in piping.

Graphical Depiction of Potential Failure Mode

Photo 2. Seepage incident on North-South Embankment reported in 2016 KP EOR report.



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Concentrated seepage through lift base has been observed in the past due to tailings slurry pooling and preferential drainage of flow paths through coarse materials at the bottom of end-dumped rockfill lifts. • Higher likelihood of pond reaching embankment compared with the East-West Embankment • Flood water retention could last up to several months and occur along the whole embankment length, and no positive engineering controls are present • Mismanagement of water inventory could decrease available freeboard	• Low likelihood of flood event • Relatively wide width of embankment section due to downstream step-out which interrupts previously continuous flow path • Upstream alluvium facing has been effective in the past • Significant beach development improvements, added deposition points to raise beaches in most susceptible area • On-going tailings distribution system adjustments possible to respond to observed beach development • Reducing pond volumes due to operational treatment

Category: 1

Overall Screening Decision:
Requires consideration in workshop.

NS-PFM3

Initiating Event: Flood, 1/1,000 yr (30-day wet) or PMF
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Uncontrolled Seepage
Failure Path Description:
(1) Flood water hydraulically connects with existing seepage paths that have been observed to daylight on the downstream slope.
(2) Results in uncontrolled seepage.

Graphical Depiction of Potential Failure Mode

Photo 2. Seepage incident on North-South Embankment reported in 2016 KP EOR report.

More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Concentrated seepage through lift base has been observed in the past due to tailings slurry pooling • Higher likelihood of pond reaching embankment compared with the East-West Embankment • Flood water retention could last up to several months and occur along the whole embankment length, and no positive engineering controls as present • Mismanagement of water inventory could decrease available freeboard	• Low likelihood of flood event • Relatively wide width of embankment section due to downstream step-out which interrupts previously continuous flow path • Upstream alluvium facing has been effective in the past • Significant beach development improvements since previously observed; added deposition points to raise beaches in most susceptible area • On-going tailings distribution system adjustments possible to respond to observed beach development • Reducing pond volumes due to operational treatment

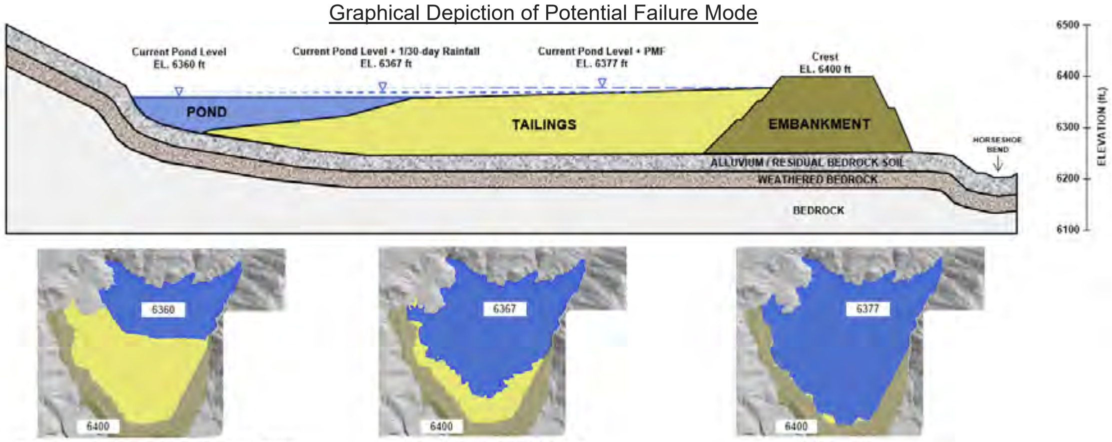
Category: 2

Overall Screening Decision:
Grouped with NS-PFM2. Event tree could consider potential variations in consequence. The stated consequence is not a risk driver.

NS-PFM4

Initiating Event: Flood, 1/1,000 yr (30-day wet) or PMF
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Flood occurs causing rise in pond.
(2) Overtops lowest point on the N-S Embankment.
(3) Results in erosion of embankment fill and breach of facility.

Graphical Depiction of Potential Failure Mode



Current Pond (Normal Operating Conditions)
Pond Volume ~ 32,100 acre-ft
Pond Elevation ~ 6360 ft

1 in 1,000 30-day Rainfall Event
Total Pond Volume ~ 38,500 acre-ft
Pond Elevation ~ 6367 ft

PMF Event
Total Pond Volume ~ 52,100 acre-ft
Pond Elevation ~ 6377 ft

More Likely (Adverse) Factors

- Becomes more likely as operations progress and EL. 6,450 ft lift is filled.
- Mismanagement of water inventory could decrease available freeboard

Less Likely (Resisting) Factors

- Design basis PMF is at the upper end of current engineering practice; design basis uses sum of 24-hr PMP and complete melt of 1/100-yr snowpack, or approximately 20,000 ac-ft.
- Starting with large freeboard for PMF conditions; will increase as EL. 6,450 ft lift is completed.
- Rockfill reasonably resistant to erosion in the event of overland flow
- Wide crest width
- Water deficit climate condition in case of shutdown
- Reducing pond volumes due to operational treatment

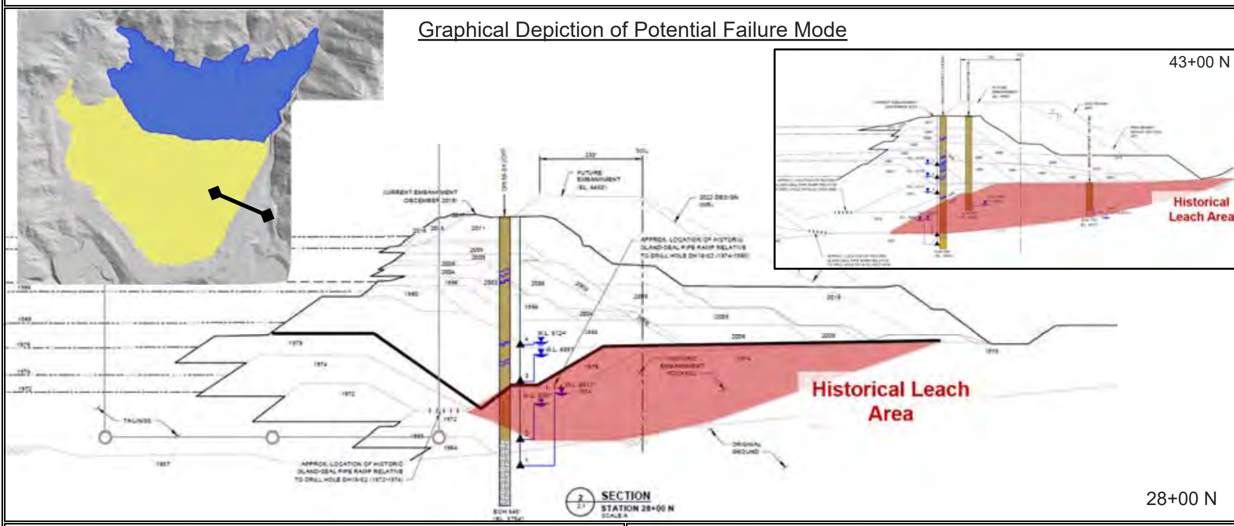
Category: 4

Overall Screening Decision:
Very unlikely and not a risk-driver; not credible unless PMF is substantially underestimated or if freeboard is mismanaged. Considered for completeness, but likely does not require a full event tree build up.

NS-PFM5

Initiating Event: Earthquake, 1/1,000 yr return period, Median MCE / 1 in 10,000 yr, or 84th-percentile MCE / 1 in 100,000 yr
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Severe earthquake occurs.
(2) Response to earthquake results in compression of the buried leach materials on the downstream side of the embankment.
(3) Undesirable embankment crest settlement.
(4) Results in overtopping of supernatant pond and breach of the facility.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- Historical leach material could be meta-stable, did not settle/consolidate during leaching, is potentially collapsible if meta-stable. High level of uncertainty and potential data gaps related to material response.
- High seismic area, significant ground motions possible
- Complex three-dimensional geometry and interactions between historical leach material and embankment materials

Less Likely (Resisting) Factors

- Relatively high freeboard during most of operations
- Relatively large settlement required over long distances within the tailings and embankment fill to bring pond near enough for breach to occur

Category: 2

Overall Screening Decision:
The instability failure mode will be assessed as the primary risk-driver with many of the same considerations. Not Category 1 since freeboard is very large and tailings next to the embankment are well drained.

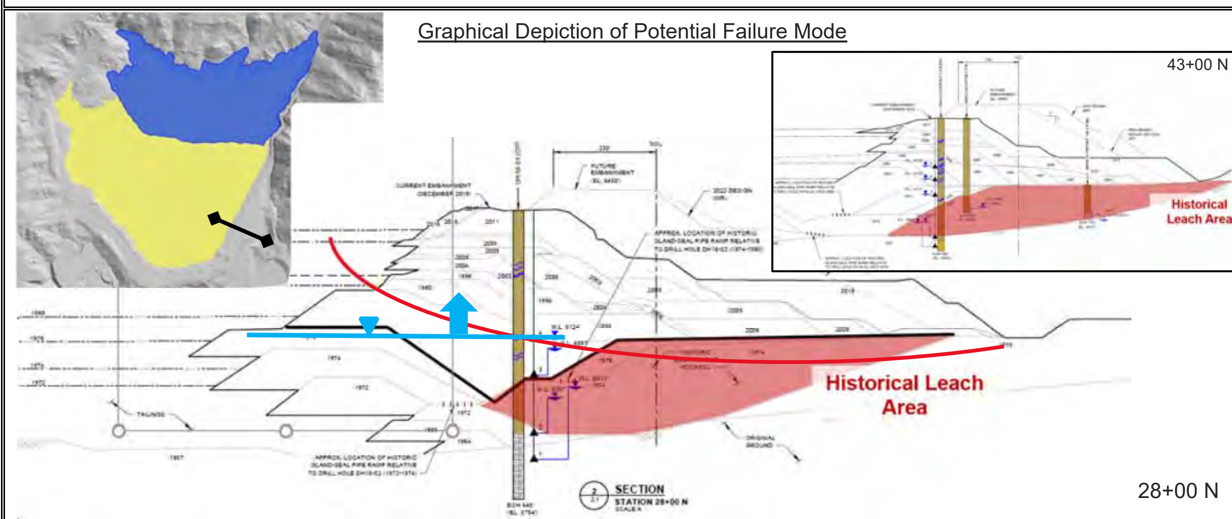
NS-PFM6

Initiating Event: Earthquake, 1/1,000 yr return period, Median MCE / 1 in 10,000 yr, or 84th-percentile MCE / 1 in 100,000 yr
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Instability (Foundation or Slope)

Failure Path Description:

(1) Severe earthquake occurs.
(2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment or foundation soils.
(3) Increasing pore pressures result in decreasing shear resistance leading to slope instability.
(4) Embankment instability occurs through a deeply seated slip surface impacting the full embankment height.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- Historical leach material could be meta-stable, did not settle/consolidate during leaching, is potentially collapsible if meta-stable. High level of uncertainty and potential data gaps related to material response.
- High seismic area, significant ground motions possible
- Complex three-dimensional geometry and interactions between historical leach material and embankment materials

Less Likely (Resisting) Factors

- Reasonably competent rockfill that drains well
- Flatter overall slope angles to 3H:1V planned following EL. 6,450 ft lift construction, and could be advanced sooner if monitoring indicated the need (no permit constraint)
- Very wide crest width along N-S Embankment
- Downward gradients, likely perched water with unsaturated zones in between

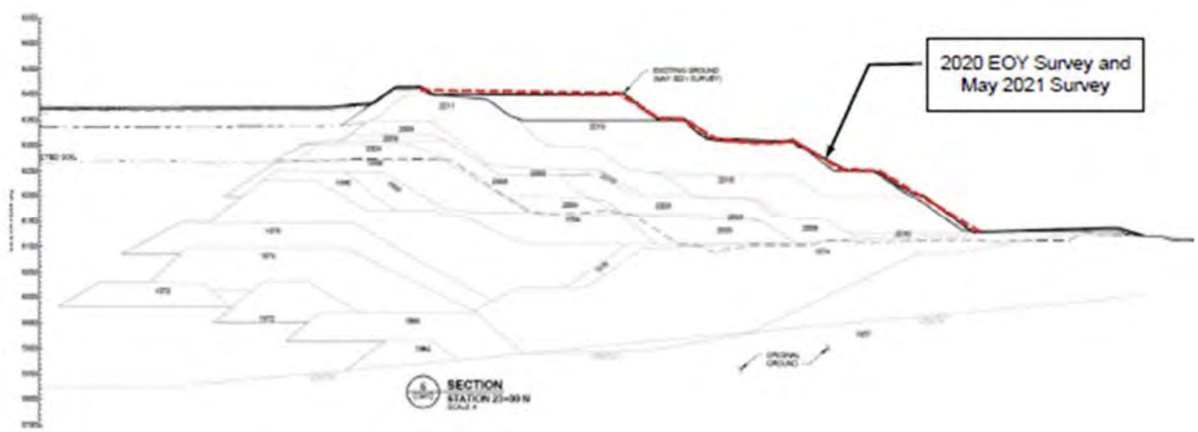
Category: 1

Overall Screening Decision:
Requires consideration in workshop.

NS-PFM7

Initiating Event: Material Degradation, Particle crushing, Acidic drainage, Weathering, Induced strain softening
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Embankment material degrades/weathers.
(2) Leads to a change in void ratio.
(3) Results in unwanted crest settlement or deformation.
(4) Leads to overtopping.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• On-going vertical settlement is observed at relatively constant rates, additional fill placement can occur as needed to maintain freeboard • Relatively high existing freeboard

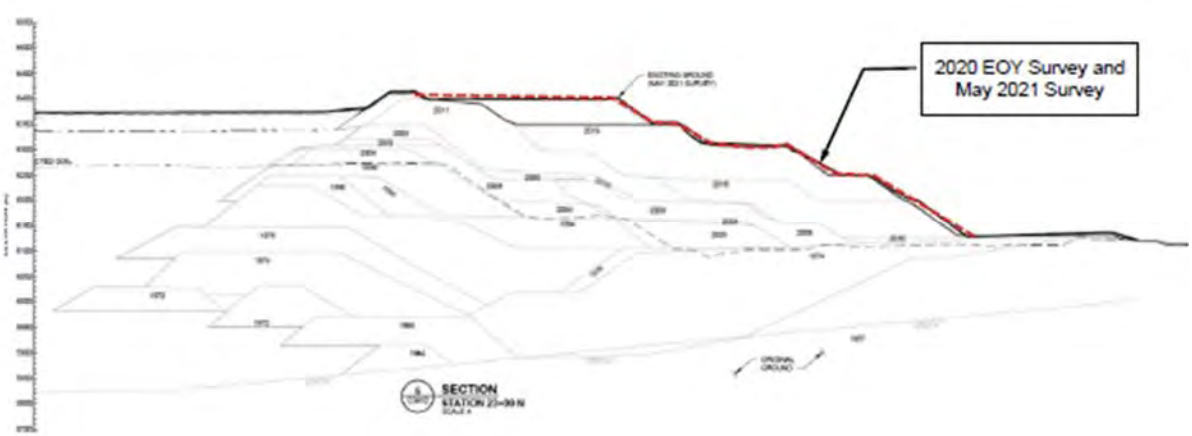
Category: 4

Overall Screening Decision:
Not credible during operations with on-going mine equipment available to maintain freeboard.

NS-PFM8

Initiating Event: Material Degradation, Particle crushing, Acidic drainage, Weathering, Induced strain softening
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Undesirable Embankment Deformation
Failure Path Description:
(1) Historical leach pad material degrades/weathers.
(2) Leads to a change in void ratio.
(3) Results in unwanted crest settlement or deformation.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• None noted during workshop

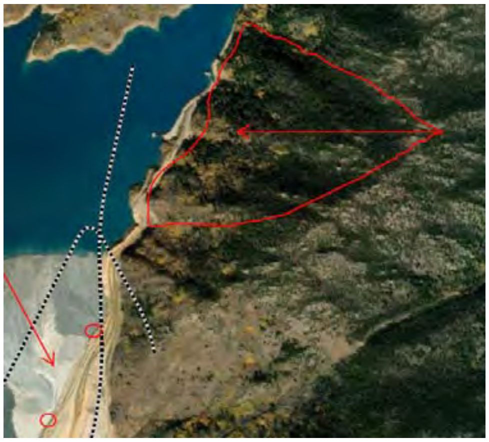
Category: 4

Overall Screening Decision:
Not credible during operations with on-going mine equipment available to maintain freeboard.

NS-PFM9

Initiating Event: Geological Hazards, Landslide
Location: North-South Embankment, e.g. Section. 63+00 N
Potential Failure Mode Type: Impacts to mine operations
Failure Path Description:
(1) Landslide on Rampart Mountain.
(2) Blocks access to the pump-back barge.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Earthquake motion on the Continental Fault would increase possibility of slope movement • Heavy rainfall/snowmelt combinations would increase potential for slope movement	• Localized wedge failures possible, unlikely to see large scale failures • Direction of flood wave may be more oriented towards the west-northwest

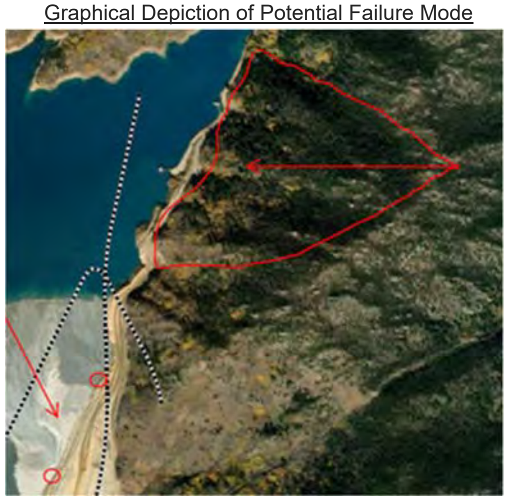
Category: 4

Overall Screening Decision:
Not a dam safety issue, could upset operations. Mine equipment available to clear blockages or could create access from the west side from existing trails within days.

NS-PFM10

Initiating Event: Geological Hazards, Landslide
Location: North-South Embankment, e.g. Section. 63+00 N
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Landslide on Rampart Mountain.
(2) Causes wave in the decant pond.
(3) Erodes the crest causing breach.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Earthquake motion on the Continental Fault would increase possibility of slope movement • Heavy rainfall/snowmelt combinations would increase potential for slope movement	• Localized wedge failures possible, unlikely to see large scale failures • Direction of flood wave may be more oriented towards the west-northwest

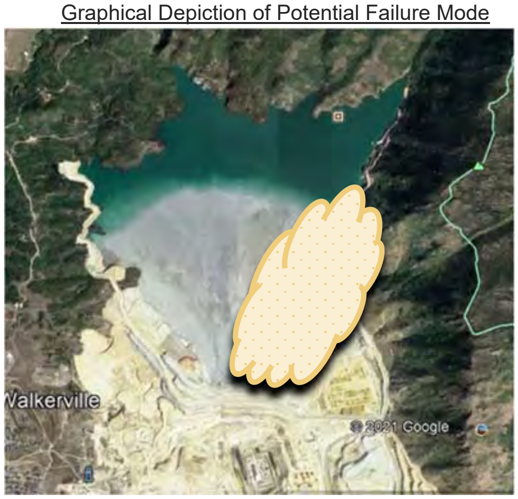
Category: 3

Overall Screening Decision:
For discussion purposes only. May be difficult to comment on likelihood based on existing knowledge base.

NS-PFM11

Initiating Event: Geological Hazards, Wind
Location: North-South Embankment, N-S 1 (e.g. Section. 18+00 N) and/or N-S 4 (e.g. Section. 63+00 N)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) High, sustained winds generate severe dust.
(2) Operations personnel cannot observe deposition or crest condition.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• Climate monitoring provides prediction of upcoming dusting events • Dust management plans in place including proactive management measures and emergency response plans for dust management.

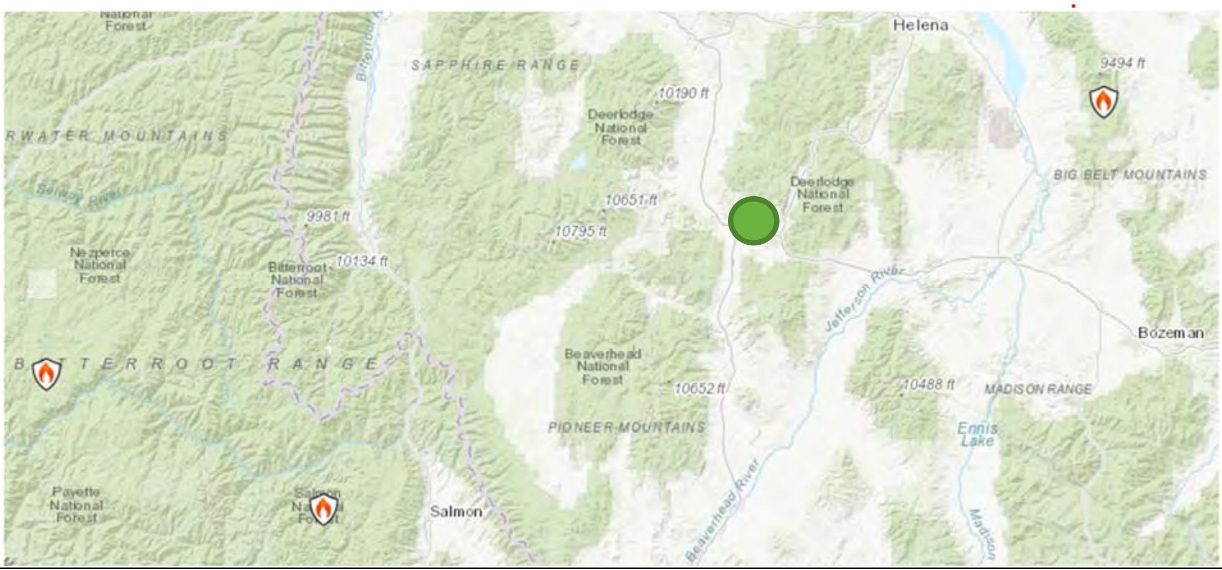
Category: 4

Overall Screening Decision:
Adequate controls in place. Unlikely to impact dam safety except perhaps in combination.

NS-PFM12

Initiating Event: Geological Hazards, Fire
Location: North-South Embankment, N-S 1 (e.g. Section. 18+00 N) and/or N-S 4 (e.g. Section. 63+00 N)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Fire in immediate vicinity to YDTI.
(2) Results in site evacuation.
(3) No eyes on the deposition or pumps; could impact power supply.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• Mill shutdown in event of site evacuation.

Category: 4

Overall Screening Decision:
Mill shutdown would occur in the event of site evacuation, which negates any concerns related monitoring continued operations. Automated remote monitoring systems are powered by batteries and communicate using radio signals and cellular telemetry.

NS-PFM13

Initiating Event: Geological Hazards, Drought
Location: North-South Embankment, N-S 1 (e.g. Section. 18+00 N) and/or N-S 4 (e.g. Section. 63+00 N)
Potential Failure Mode Type: Undesirable Embankment Deformation
Failure Path Description:
(1) Severe, sustained drought.
(2) Results in scarcity of water to suppress dust on dam roads and beach area.
(3) No eyes on the deposition or pumps.

Graphical Depiction of Potential Failure Mode

More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• Water rights on fresh water supply; adequate contingency water supply. • Drought would cause accelerated reduction of supernatant pond volume.

Category: 4

Overall Screening Decision:
Unlikely to be a dam safety issue.

NS-PFM14

Initiating Event: Geological Hazards, Berkeley Pit Wall Failure
Location: Berkeley Pit
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) A pit wall fails.
(2) Greatly reduces the storage capacity in the pit.
(3) Results in reduced containment onsite.

Graphical Depiction of Potential Failure Mode

More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• None noted during workshop

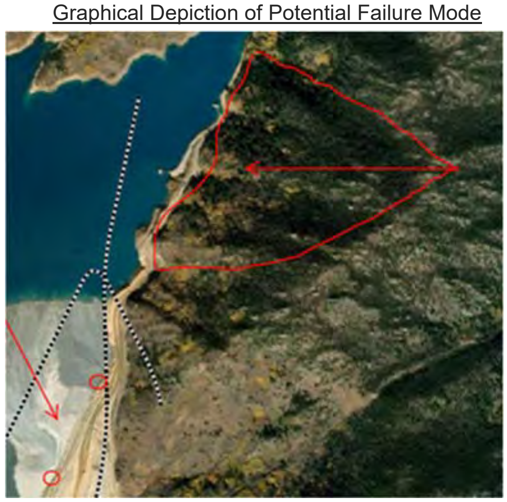
Category: 4

Overall Screening Decision:
Not within terms of reference for YDTI risk assessment. Warrants discussion related to reliability of mitigation measures (i.e. if chosen mitigation measure relies on containment and if containment capacity decreases, the chosen mitigation measure is not reliable such that more practicable mitigation measures should be considered).

NS-PFM15

Initiating Event: Geological Hazards, Landslide
Location: North-South Embankment, e.g. Section. 28+00 N and/or Section. 43+00 N
Potential Failure Mode Type: Impact to Mine Operations
Failure Path Description:
(1) Pump failure on barge during rainstorm compounded with landslide on Rampart Mountain.
(2) Prevents access to the pumps.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Earthquake motion on the Continental Fault would increase possibility of slope movement • Heavy rainfall/snowmelt combinations would increase potential for slope movement	• Localized wedge failures possible, unlikely to see large scale failures • Direction of flood wave may be more oriented towards the west-northwest

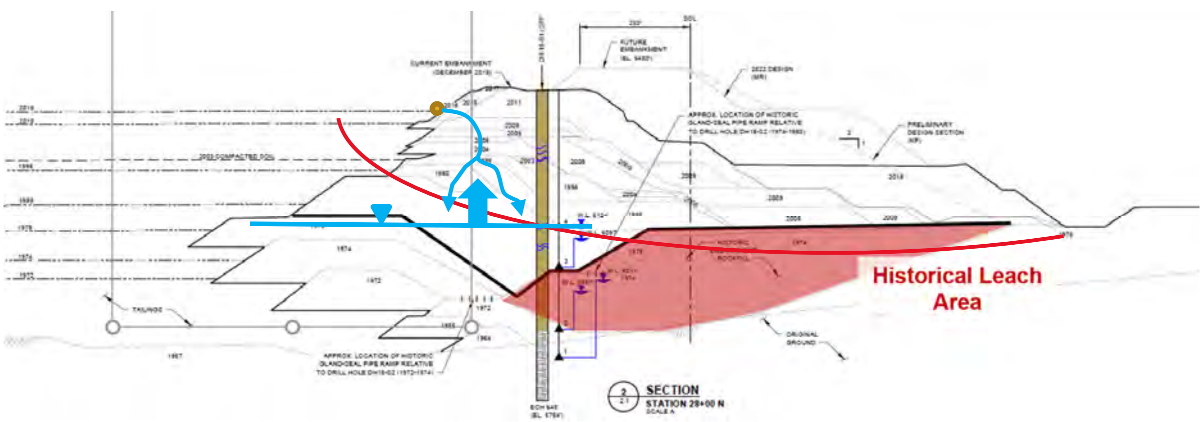
Category: 4

Overall Screening Decision:
Not a dam safety issue, could upset operations. Mine equipment available to clear blockages or could create access from the west side from existing trails within days.

NS-PFM16

Initiating Event: Operational-Upset Conditions-Malfunctions, Tailing Pipeline Burst
Location: North-South Embankment, N-S 1 (e.g. Section. 18+00 N) and/or N-S 4 (e.g. Section. 63+00 N)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Tailing delivery pipeline rupture.
(2) Results in slurry flow eroding road and embankment.
(3) Contributes to the saturation of embankment materials.
(4) Causes slope failure.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• None noted during workshop

Category: 2

Overall Screening Decision:
Possible, but probably not a risk-driver. Primarily a maintenance and operations issue and does not require detailed consideration in the workshop.

NS-PFM17

Initiating Event: Operational-Upset Conditions-Malfunctions, Power Loss
Location: North-South Embankment, N-S 1 (e.g. Section. 18+00 N) and/or N-S 4 (e.g. Section. 63+00 N)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Power loss to pumps.
(2) Results in rising pond elevation.
(3) If left unchecked could result in uncontrolled seepage and embankment failure.

Graphical Depiction of Potential Failure Mode

More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• None noted during workshop	• None noted during workshop

Category: 2

Overall Screening Decision:
Possible, but probably not a risk-driver. Primarily a maintenance and operations issue and does not require detailed consideration in the workshop.

APPENDIX B3

West Embankment PFMA Details

(Pages B3-1 to B3-11)

Knight Piésold CONSULTING

TABLE B3.1

MONTANA RESOURCES, LLC
YANKEE DOODLE TAILINGS IMPOUNDMENT

POTENTIAL FAILURE MODE ANALYSIS
DEVELOPMENT FRAMEWORK AND SCREENING SUMMARY
WEST EMBANKMENT

CODE	PFM#	Initiating / Loading Event		Location	Potential Failure Mode	Simple Failure Path Progression Description	Preliminary Screening Assessment	Category	Primary Means of Risk Control	Additional Risk Controls to Consider	Potential Data Gaps	Detection and Intervention
		Category	Sub-category									
W	1	Flood	PMF	W: West Embankment (e.g. STA. 108+00W)	Instability (Foundation or Slope)	(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack. (2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment. (3) Seepage overwhelms capacity of the West Embankment Drain (WED). (4) Rise in pore pressures within the embankment rockfill is sufficient to decrease effective stress in critical resisting areas near the downstream side of the embankment resulting in slope instability.	Consider and perform limit equilibrium stability analyses considering a range of water levels, but may not warrant consideration in the workshop. Sufficient capacity in the WED.	2	Design capacity of the WED.	None identified.	None identified.	Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff. Monitoring equipment is available to detect changing piezometric conditions in near real-time within critical areas of the embankment. Changing pore pressure conditions at key instruments is linked with key staff alerts.
W	2	Flood	PMF	W: West Embankment (e.g. STA. 108+00W)	Uncontrolled seepage	(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack. (2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment. (3) Seepage overwhelms capacity of the West Embankment Drain (WED). (4) Rise in pore pressures within the embankment rockfill and foundation materials increases to above Potentiometric Low (PL) or Deep Isolated Facture System (DIFS) in the West Ridge. (5) Elevated pore pressures within the PL or DIFS are sustained for sufficient period of time, such that uncontrolled seepage from the YDTI occurs towards/beyond the West Ridge.	Sufficient risk controls are in place. Judged to be highly unlikely due to the capacity of the WED, and installed/uninstalled mitigation measures are included in the design to address a reasonable range of possible outcomes.	2	Design capacity of the WED.	None identified.	None identified.	Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff. Monitoring equipment is available to detect changing piezometric conditions in near real-time within critical environmental containment areas (e.g. the PL and DIFS).
W	3	Flood	PMF	W: West Embankment (e.g. STA. 108+00W)	Internal Erosion / Piping	(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack. (2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment. (3) Leakage begins through the embankment facing material and permeable rockfill to the WED. (4) Seepage at the interface between the WED and overlying materials causes suffusion with finer soil particles washed into the highly porous drainage zone. (5) WED becomes plugged by fines, preventing drainage towards the Extraction Pond, and rendering the WED ineffective.	Sufficient risk controls are in place. Judged to be highly unlikely due to the capacity of the WED, and installed/uninstalled mitigation measures are included in the design to address a reasonable range of possible outcomes.	2	Filter relationships between WED and surrounding materials.	None identified.	None identified.	Monitoring equipment is available to detect changing piezometric conditions in select areas of the WED.
W	4	Flood	PMF	W: West Embankment (e.g. STA. 108+00W)	Overtopping	(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack. (2) Flood waters lead to rising pond surface, which exceeds crest elevation of the embankment. (3) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.	Very unlikely and not a risk-driver, not credible unless PMF is substantially underestimated. Consider for completeness, but likely does not require a full event tree build up.	2	Freeboard criteria	None identified.	None identified.	Climate monitoring to detect large snowpack. Extreme rainfall event of this magnitude would result in regional scale flooding and evacuations already. Rising pond surface would be physically visible by staff.
W	5	Earthquake	Median MCE / 1 in 10,000 yr	W: West Embankment (e.g. STA. 108+00W)	Overtopping	(1) Severe earthquake occurs. (2) The embankment deforms and crest settles due to the seismic loading of the embankment. (3) Tailings upstream of the embankment experience seismic liquefaction causing settlement and allowing the supernatant pond to come westward to the embankment. (4) Embankment crest settles to a final position that is lower than the resulting supernatant pond elevation and the tailings settlement allows the pond to reach the embankment. (5) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.	Very unlikely and not a risk-driver, possibly not credible at the West Embankment given the required sequence of events, height and width of the embankment in this area, foundation conditions, and long tailings beach.	4	Height and width of the embankment in this area, foundation conditions, and long tailings beach.	None identified.	None identified.	None Identified.
W	6	Earthquake	Median MCE / 1 in 10,000 yr	W: West Embankment (e.g. STA. 108+00W)	Instability (Foundation or Slope)	(1) Severe earthquake occurs. (2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment or foundation materials. (3) Increasing pore pressures result in decreasing shear resistance leading to slope instability. (4) Embankment instability occurs. (5) Slumping deformation occurs in one or more areas where the embanking is not completely buttressed by the West Ridge.	Very unlikely and not a risk-driver, possibly not credible at the West Embankment given the required sequence of events, height and width of the embankment in this area, foundation conditions, and long tailings beach.	4	Height and width of the embankment in this area, foundation conditions, and long tailings beach.	None identified.	None identified.	None Identified.
W	7	Earthquake	Median MCE / 1 in 10,000 yr	W: West Embankment (e.g. STA. 108+00W)	Instability (Foundation or Slope)	(1) Severe earthquake occurs. (2) Seismic loading results in tailings liquefaction adjacent to the embankment. (3) Embankment instability occurs on the upstream side of the embankment where the WED is constructed in fill. (4) Slumping deformation occurs and renders a critical section of the WED ineffective.	Unlikely and probably not a risk driver. May require consideration in select locations and further study at an appropriate time in the next several years.	3	Very low likelihood of event occuring. Long, relatively well drained beaches. Most of the WED was constructed along natural ground and unlikely to be affected significantly by potential liquefaction.	None identified.	May warrant consideration in future site investigation program planning in the next five year plan.	None Identified.
W	8	Material_Degradation	Acidic drainage	W: West Embankment (e.g. STA. 108+00W)	Undesirable Embankment Deformation	(1) Continuous acidic drainage within WED. (2) Chemecial weathering results in decreasing porosity within the highly porous zone of the WED due to material breakdown and/or precipitate build up. (3) WED becomes plugged, preventing drainage towards the Extraction Pond, and rendering the WED ineffective.	Some evidence of chemical weathering or precipitate development is currently observed at the WED outlet. No current concerns about capacity and mitigation measures were included in the design to manage a range of outcomes; however, the chemical weathering processes warrant further consideration and study.	3	Design capacity of the WED.	None identified.	None identified.	None Identified.
W	9	Construction	6,450 raise	W: West Embankment (e.g. STA. 108+00W)	Undesirable Embankment Deformation	(1) Construction loading during placement embankment lifts on the West Embankment. (2) On-going settlement within the embankment rockfill materials and WED leads to a decrease in porosity within the WED. (3) WED porosity decreases over time becoming less effective at conveying seepage to the Extraction Pond and leading to increased pore pressures within the embankment.	Settlement induced decreases in porosity are unlikely to affect the capacity of the WED sufficiently alone to cause problems. Worth consideration in combination and during future raises as confining pressures increase and other processes (e.g. chemical weathering) play out.	4	Design capacity of the WED. EL. 6,450 ft embankment lift already constructed and WED operating as designed.	None identified.	None identified.	None Identified.
W	10	Geological Hazards	Landslide	E-W 1: East-West Embankment - Central Pedestal (e.g. STA. 0+00 / 8+00 W)	Overtopping	(1) Landslide occurs from Rampart Mountain along the eastern side of the YDTI. (2) Slide reaches the supernatant pond and causes a wave. (3) Wave runs up the tailings beach and overtops the embankment causing erosion and damage on the downstream side of the embankment.	May warrant consideration due to orientation of Rampart Mountain. May be difficult to comment on likelihood based on existing knowledge base. Most susceptible embankment based on the orientation of Rampart Mountain.	3	Inferred low likelihood of landslides on Rampart Mountain based on existing knowledge base.	None Identified.	May warrant performance of a geologic hazard study (landslide and avalanche), beginning with a desktop level assessment, to investigate for any potential issues requiring consideration in the near term.	None Identified.

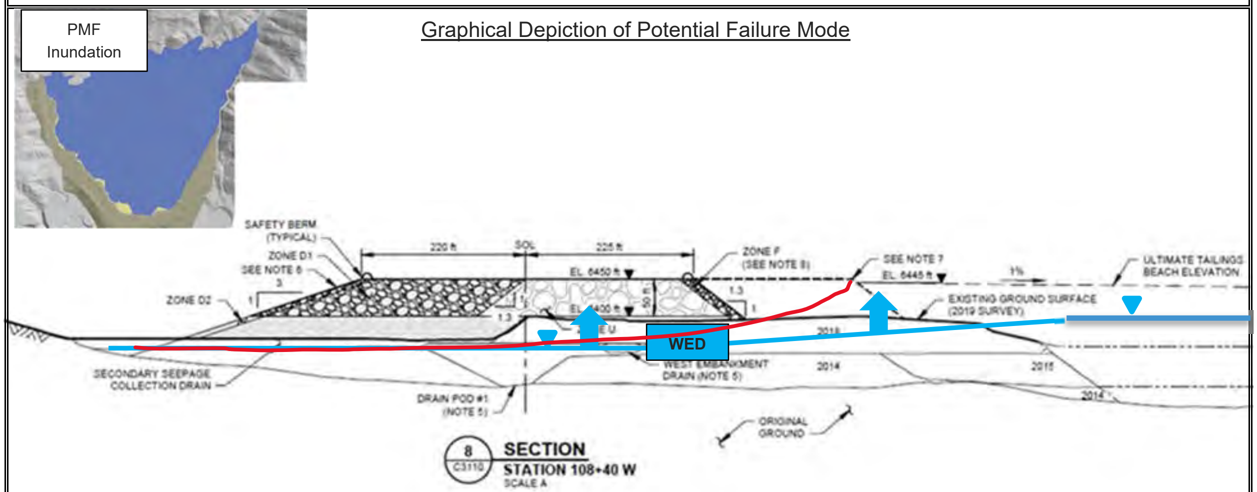
M:\1\01\00126\27\A\Data\Task 510 - Risk Assessment\05 - Potential Failure Modes Analysis\[PFMA Development Summary_r0.xlsx]Table 3 - W EMBANKMENT

0	07JUL'23	ISSUED WITH REPORT VA101-00126/27-1	EJA	DDF
REV	DATE	DESCRIPTION	PREP'D	RVW'D

W-PFM1

Initiating Event: Flood, PMF
Location: West Embankment (e.g. Section 108+00W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment.
(3) Seepage overwhelms capacity of the West Embankment Drain (WED).
(4) Rise in pore pressures within the embankment rockfill is sufficient to decrease effective stress in critical resisting areas near the downstream side of the embankment resulting in slope instability.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Uncertainty in drain capacity	• Adequate design basis drain capacity to manage flooded condition • Ability to install additional pumps to drains to increase capacity, if required • Good quality control during recent construction • Substantial instrumentation to monitoring performance, routinely monitored • Performance to date in line with design expectations • Gravity flow system • Relatively shallow downstream slopes angles (3H:1V); Zone D1 constructed with compacted 5 ft lifts • West Ridge buttresses downstream toe • Relatively wide embankment crest and lower height compared to other embankment sections

Category: 2

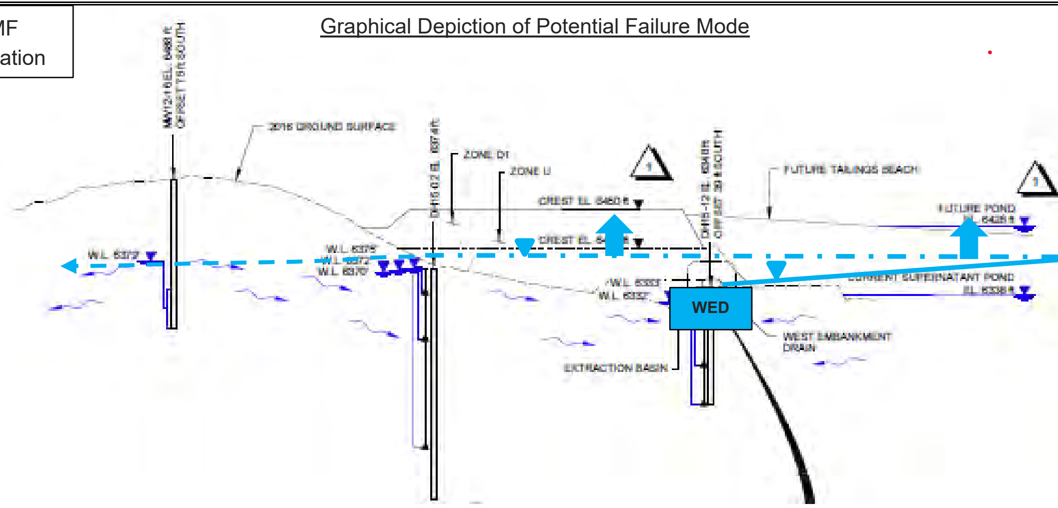
Overall Screening Decision:
Consider and perform limit equilibrium stability analyses considering a range of water levels but may not warrant consideration in the workshop. Sufficient capacity in the WED.

W-PFM2

Initiating Event: Flood, PMF
Location: West Embankment (e.g. Section 95+00W)
Potential Failure Mode Type: Undesirable Seepage
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainfall and snowpack.
(2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment.
(3) Seepage overwhelms capacity of the West Embankment Drain (WED).
(4) Rise in pore pressures within the embankment rockfill and foundation materials increases to above Potentiometric Low (PL) or Deep Isolated Facture System (DIFS) in the West Ridge.
(5) Elevated pore pressures within the PL or DIFS are sustained for sufficient period of time, such that uncontrolled seepage from the YDTI occurs towards/beyond the West Ridge.

PMF Inundation

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors

- Complex geology and local fracturing that may not be completely understood
- Possibility of future decreases in water levels if drier than average climatic conditions were to persist over the long-term

Less Likely (Resisting) Factors

- Extensive studies, including drilling investigations, pore pressure monitoring, pumping tests completed to understand bulk response of the systems
- Ability to install additional pumps to drains to increase capacity, if required
- Adequate design basis drain capacity to manage flooded condition
- Good quality control during recent construction
- Substantial instrumentation to monitoring performance, routinely monitored
- Drain performance to date in line with design expectations
- Gravity flow system
- Increasing water levels over the past five years resulting from wetter than average climatic conditions

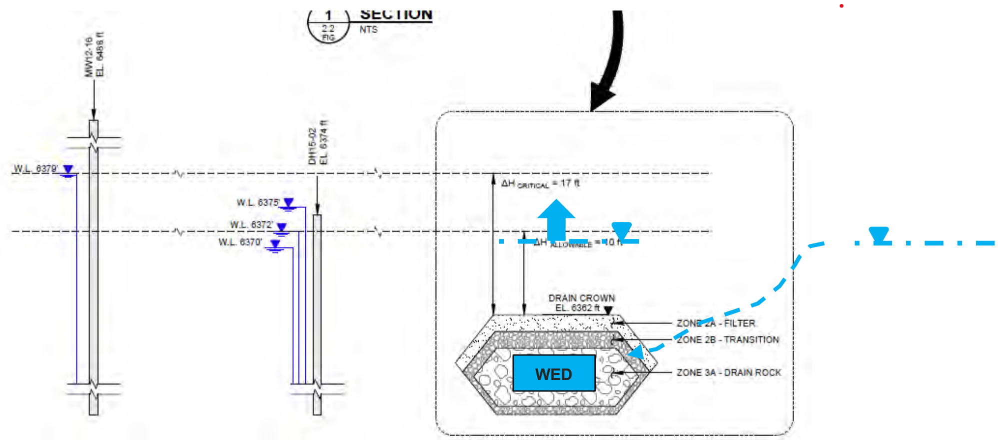
Category: 2

Overall Screening Decision:
Sufficient risk controls are in place. Judged to be highly unlikely due to the capacity of the WED, and mitigation measures are included in the design to address a reasonable range of possible outcomes.

W-PFM3

Initiating Event: Flood, PMF
Location: West Embankment (e.g. Section. 108+00W)
Potential Failure Mode Type: Internal Erosion / Piping
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack.
(2) Flood waters lead to rising pond surface inundating the long, drained tailings beaches and flooding the upstream facing of the embankment.
(3) Leakage begins through the embankment facing material and permeable rockfill to the WED.
(4) Seepage at the interface between the WED and overlying materials causes suffusion with finer soil particles washed into the highly porous drainage zone.
(5) WED becomes plugged by fines, preventing drainage towards the Extraction Pond, and rendering the WED less effective or ineffective.

Graphical Depiction of Potential Failure Mode



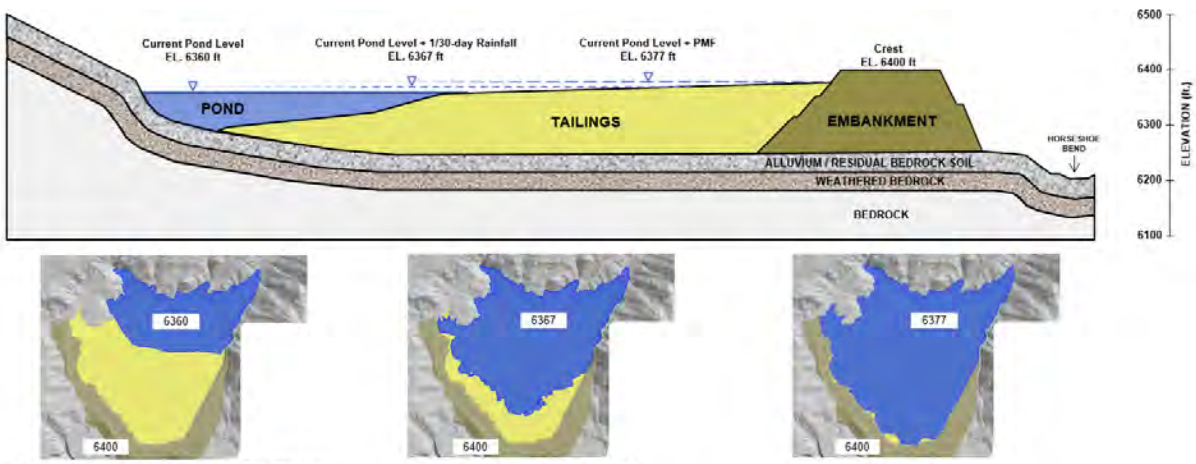
More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Potential for construction defects due to relatively long length of the drain • Potential for degradation of filters over the long-term	• Filters included in the design to prevent migration of fines • Relatively recent construction, good quality control • Extra pumping available during operations to manage flows in the event of drain plugging prevent gravity flow • Emergency spillway to manage maximum pond level in flooded condition in the long-term following closure • Serviceability can be dealt with under closure conditions due to perpetual care at the site • Drain not expected to be required for hydrodynamic containment in perpetuity at current design elevation • Consequence of primary concern is uncontrolled seepage, not embankment instability

Category: 2
Overall Screening Decision:
Sufficient risk controls are in place. Judged to be highly unlikely due to the capacity of the WED and installed/uninstalled mitigation measures are included in the design to address a reasonable range of possible outcomes.

W-PFM4

Initiating Event: Flood, PMF
Location: West Embankment (e.g. Section. 108+00W)
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Severe natural flooding occurs resulting from some combination of extreme rainful and snowpack.
(2) Flood waters lead to rising pond surface, which exceeds crest elevation of the embankment.
(3) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.

Graphical Depiction of Potential Failure Mode



Current Pond (Normal Operating Conditions)
Pond Volume ~ 32,100 acre-ft
Pond Elevation ~ 6360 ft

1 in 1,000 30-day Rainfall Event
Total Pond Volume ~ 38,500 acre-ft
Pond Elevation ~ 6367 ft

PMF Event
Total Pond Volume ~ 52,100 acre-ft
Pond Elevation ~ 6377 ft

More Likely (Adverse) Factors

- Becomes more likely as operations progress and EL. 6,450 ft lift is filled.
- Mismanagement of water inventory would decrease available freeboard

Less Likely (Resisting) Factors

- Small inflow volume relative to available freeboard
- Starting with large freeboard for PMF conditions; current embankment crest elevation EL. 6,450 ft.
- Rockfill reasonably resistant to erosion in the event of overland flow
- Wide crest width; embankment buttressed by the West Ridge along its entire length
- Water deficit climate condition in case of shutdown
- Reducing pond volumes due to operational treatment
- Emergency spillway planned to manage PMF in the long-term following closure

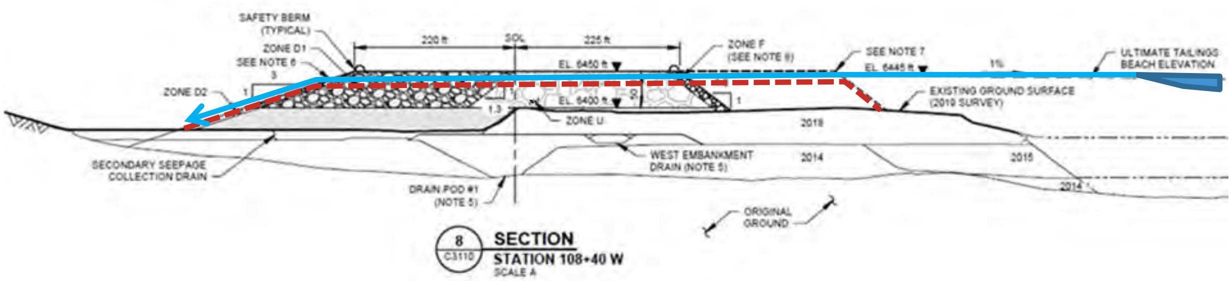
Category: 2

Overall Screening Decision:
Very unlikely and not a risk-driver, not credible unless PMF is substantially underestimated. Consider for completeness, but likely does not require a full event tree build up. Might be considered further when ALARP is applied.

W-PFM5

Initiating Event: Earthquake, Median MCE / 1 in 10,000 year or 84th-Percentile MCE / 1 in 100,000 year
Location: West Embankment (e.g. Section 108+00W)
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Severe earthquake occurs.
(2) The embankment deforms and crest settles due to the seismic loading of the embankment.
(3) Tailings upstream of the embankment experience seismic liquefaction causing settlement and allowing the supernatant pond to come westward to the embankment.
(4) Embankment crest settles to a final position that is lower than the resulting supernatant pond elevation and the tailings settlement allows the pond to reach the embankment.
(5) Overtopping at lowest point results in erosion and downcutting through the embankment ultimately leading to a full breach of the facility.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• High seismic area, significant ground motions possible	• Relatively large freeboard during most of operations • Relatively large settlement required over long distances within the tailings and embankment fill • Controls readily implemented during operations if settlement occurs • Foundation materials primarily bedrock • Embankment height relatively small compared to other embankment sections and seismic deformation and crest settlement expected to be correspondingly low • Good quality control during recent construction

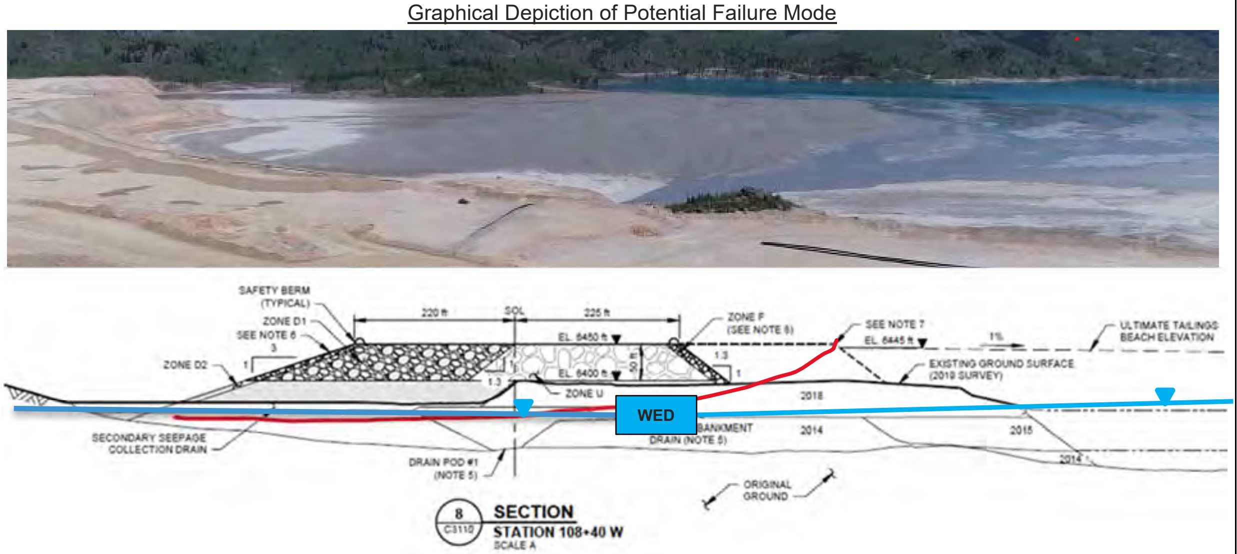
Category: 4

Overall Screening Decision:
Very unlikely and not a risk-driver, possibly not credible at the West Embankment given the required sequence of events, height and width of the embankment in this area, foundation conditions, and long tailings beach.

W-PFM6

Initiating Event: Earthquake, Median MCE / 1 in 10,000 year or 84th-Percentile MCE / 1 in 100,000 year
Location: West Embankment (e.g. Section. 108+00W)
Potential Failure Mode Type: Instability (Foundation or Slope)
Failure Path Description:
(1) Severe earthquake occurs.
(2) Seismic loading results in excess pore pressure development within critical resisting areas of the embankment or foundation materials.
(3) Increasing pore pressures result in decreasing shear resistance leading to slope instability.
(4) Embankment instability occurs.
(5) Slumping deformation occurs in one or more areas where the embankment is not completely buttressed by the West Ridge.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• High seismic area, significant ground motions possible	• Relatively large freeboard during most of operations • Large crest width at current elevation • Foundation materials primarily bedrock • Embankment relatively low (modest height) compared to other embankment sections • Good quality control during recent construction • Piezometric conditions maintained drained by WED • Downstream slopes angles 3H:1V and buttress by the West Ridge along entire length

Category: 4

Overall Screening Decision:
Very unlikely and not a risk-driver, possibly not credible at the West Embankment given the required sequence of events, height and width of the embankment in this area, foundation conditions, and long tailings beach.

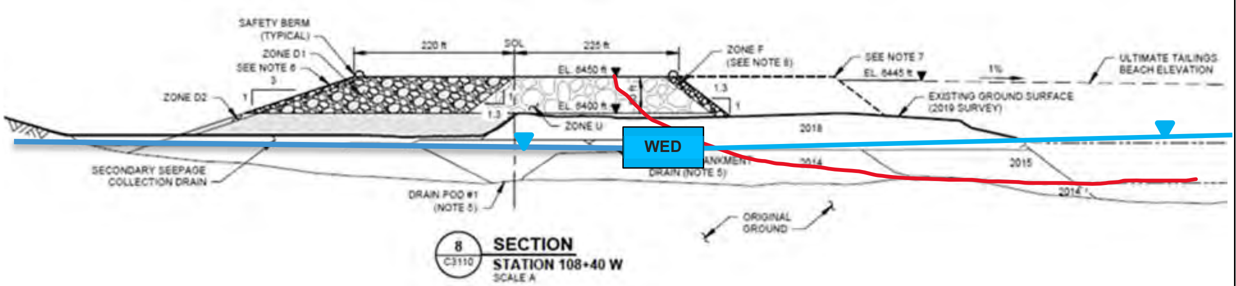
W-PFM7

Initiating Event: Earthquake, Median MCE / 1 in 10,000 year or 84th-Percentile MCE / 1 in 100,000 year
Location: West Embankment (e.g. Section. 108+00W)
Potential Failure Mode Type: Instability (Foundation or Slope)

Failure Path Description:

(1) Severe earthquake occurs.
(2) Seismic loading results in tailings liquefaction adjacent to the embankment.
(3) Embankment instability occurs on the upstream side of the embankment where the WED is constructed in fill.
(4) Slumping deformation occurs and renders a critical section of the WED ineffective.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• One or more locations may include small sections where fill was placed over thin accumulations of tailings • High seismic area with significant ground motions possible	• Majority of the drain is built along natural ground with some sections in fill over natural ground • Increasing tailings deposit and fill placement limits the potential for deformation gradually over time • Compression of these tailings and availability of drainage (upwards and into the WED) would lessen potential for deformation within the materials

Category: 3

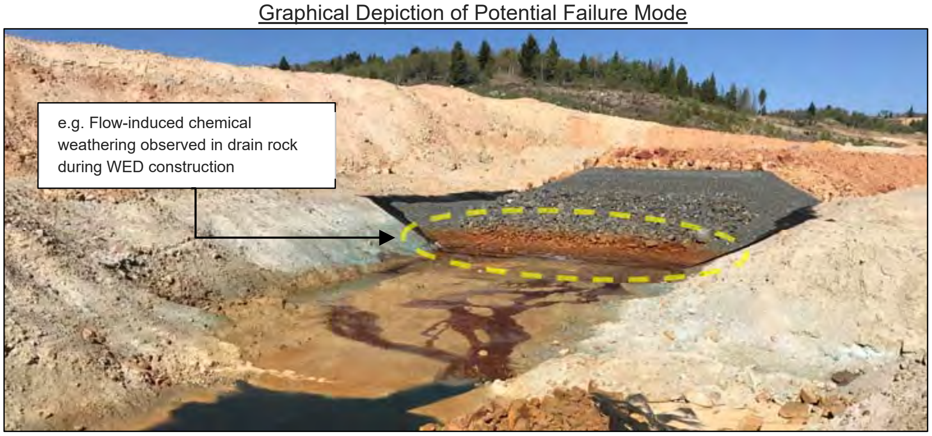
Overall Screening Decision:

Unlikely and probably not a risk driver. May require updated consideration in select locations and further study at an appropriate time in the next several years.

W-PFM8

Initiating Event: Material Degradation, Acidic Drainage
Location: West Embankment, West Embankment Drain (WED)
Potential Failure Mode Type: Undesirable Embankment Deformation
Failure Path Description:
(1) Continuous acidic drainage within WED.
(2) Chemical weathering results in decreasing porosity within the highly porous zone of the WED due to material breakdown and/or precipitate build up.
(3) WED becomes plugged, preventing drainage towards the Extraction Pond, and rendering the WED ineffective.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Long-term conditions and reliability requires on-going consideration and evaluation • Some discoloration and precipitate potentially being observed at the drain outlet at the Extraction Pond	• Basalt rockfill source from off site; relatively resistant to chemical degradation and breakdown • May be inconsequential during operations

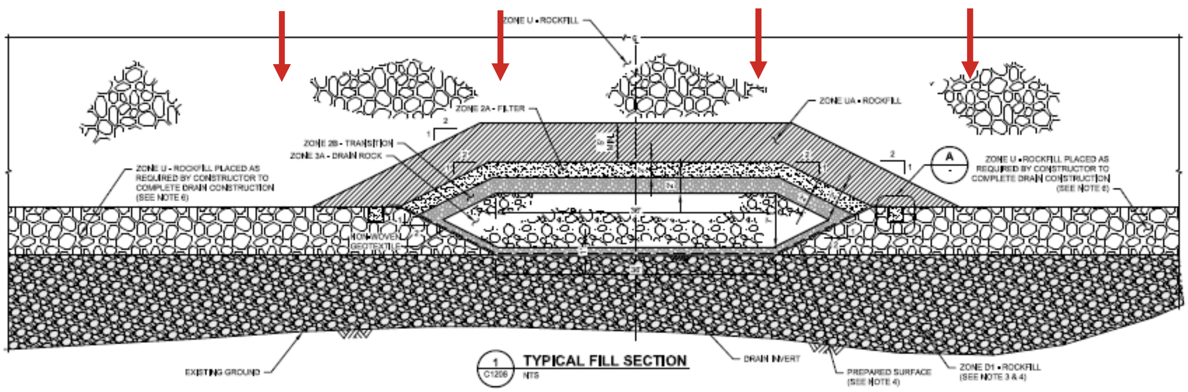
Category: 3

Overall Screening Decision:
Some evidence of chemical weathering or precipitate development is currently observed at the WED outlet. No current concerns about capacity and mitigation measures were included in the design to manage a range of outcomes; however, the chemical weathering processes warrant further consideration and study for long-term conditions.

W-PFM9

Initiating Event: Construction, El. 6,450 ft Raise
Location: West Embankment, West Embankment Drain (WED)
Potential Failure Mode Type: Undesirable Embankment Deformation
Failure Path Description:
(1) Construction loading during placement embankment lifts on the West Embankment.
(2) On-going settlement within the embankment rockfill materials and WED leads to a decrease in porosity within the WED.
(3) WED porosity decreases over time becoming less effective at conveying seepage to the Extraction Pond and leading to increased pore pressures within the embankment.

Graphical Depiction of Potential Failure Mode



More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• May warrant consideration for future design phases	• Inconsistent with design and likely not credible currently • EL. 6,450 ft lift complete; drain functioning fine

Category: 4

Overall Screening Decision:
Settlement induced decreases in porosity are unlikely to affect the capacity of the WED sufficiently alone to cause problems. Worth consideration in combination and during future raises as confining pressures increase and other processes (e.g. chemical weathering) play out.

W-PFM10

Initiating Event: Geological Hazards, Landslide
Location: West Embankment (e.g. Section 108+00W)
Potential Failure Mode Type: Overtopping
Failure Path Description:
(1) Landslide occurs from Rampart Mountain along the eastern side of the YDTI.
(2) Slide reaches the supernatant pond and causes a wave.
(3) Wave runs up the tailings beach and overtops the embankment causing erosion and damage on the downstream side of the embankment.

Graphical Depiction of Potential Failure Mode

More Likely (Adverse) Factors	Less Likely (Resisting) Factors
• Earthquake motion on the Continental Fault would increase possibility of slope movement • Heavy rainfall/snowmelt combinations would increase potential for slope movement	• Localized wedge failures possible, unlikely to see large scale failures • Direction of flood wave may be more oriented towards the west-northwest

Category: 3

Overall Screening Decision:
May warrant further consideration due to orientation of Rampart Mountain. May be difficult to comment on likelihood based on existing knowledge base. May warrant performance of a geologic hazard study (landslide and avalanche), beginning with a desktop level assessment, to investigate for any potential issues requiring consideration in the near term.

APPENDIX C

Event Tree Analyses

Appendix C1
Generalized Event Tree Example

Appendix C2
Probability Guidelines and Consequence Criteria

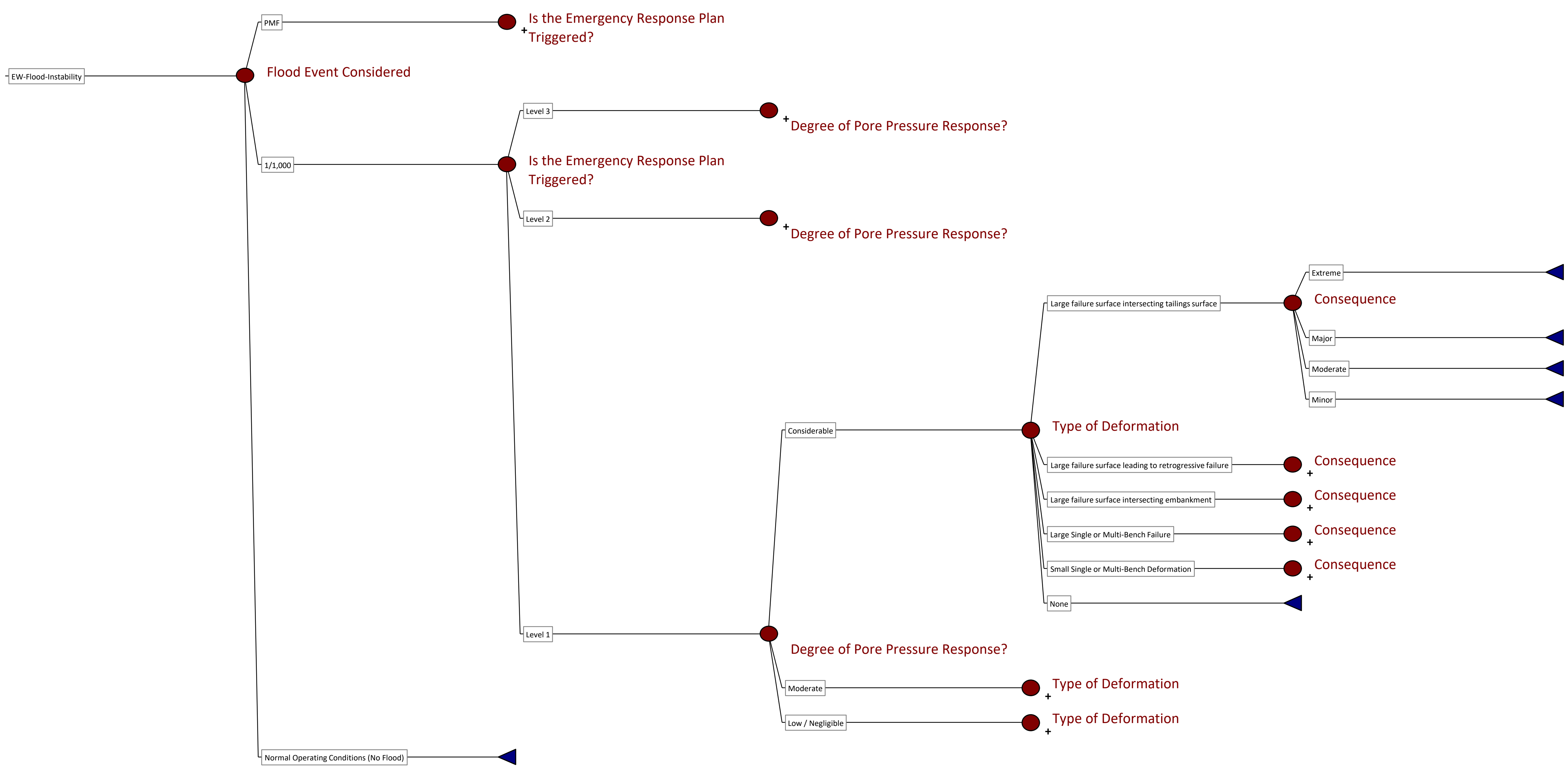
Appendix C3
Summary of Results

APPENDIX C1

Generalized Event Tree Examples

(Figures C1.1 to C1.5)

EVENT TREE BEING EVALUATED	FAILURE PATHWAYS AND BRANCH PROBABILITY ASSIGNMENT	ANNUAL PROBABILITY OF FAILURE



NOTES:

1. DUPLICATE BRANCHES ARE COLLAPSED FOR EASE OF PRESENTATION.

REV	DATE	DESCRIPTION	PREP'D	RVW'D
0	07JUL'23	ISSUED WITH REPORT	EJA	DDF

MONTANA RESOURCES, LLC

YANKEE DOODLE TAILINGS IMPOUNDMENT

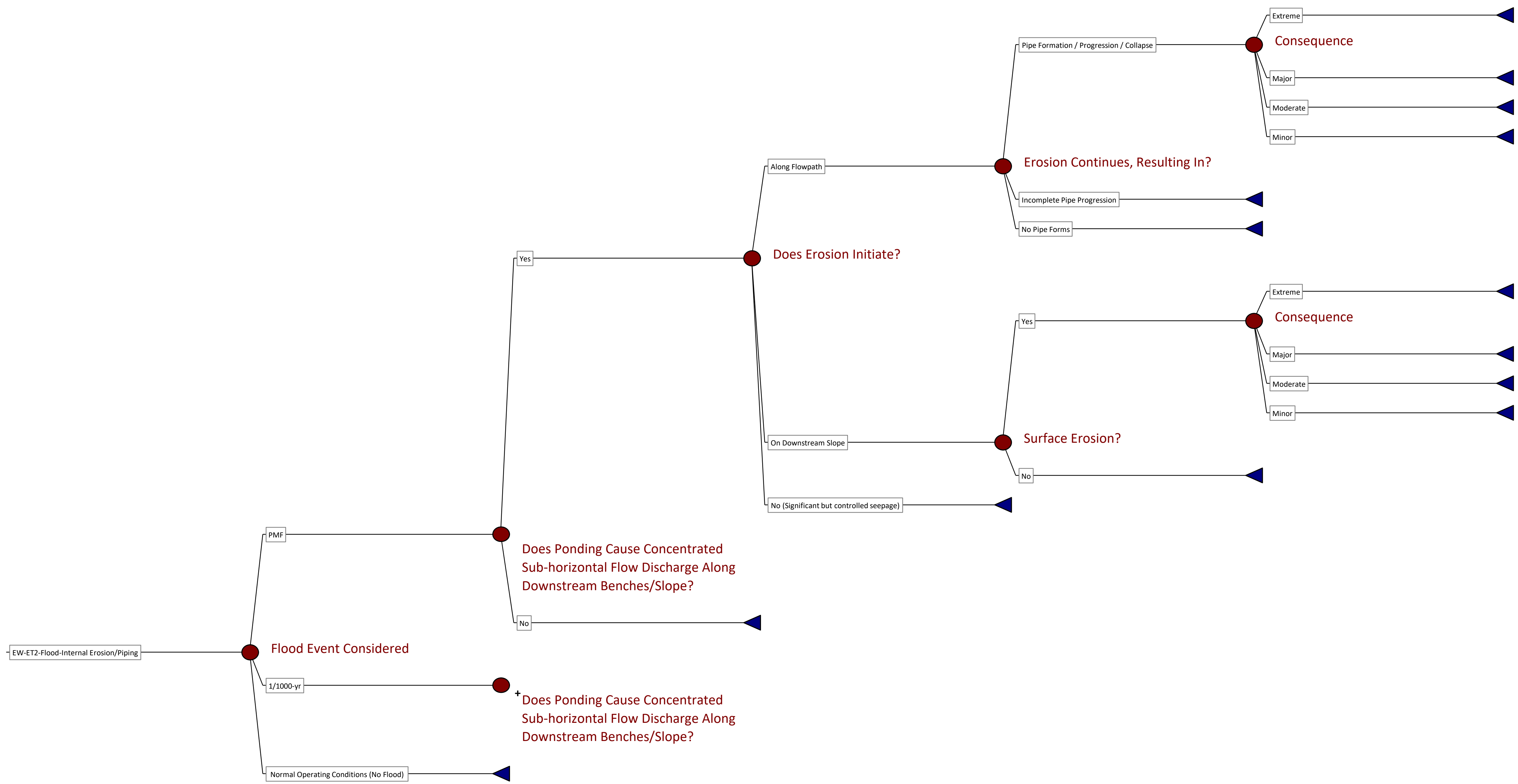
2022 RISK ASSESSMENT REPORT
EVENT TREE 1 (ET1)
FLOOD-INDUCED INSTABILITY

Knight Piésold CONSULTING

P/A NO. VA/101-00126/27 | REF. NO. 1

FIGURE C1.1 | REV 0

EVENT TREE BEING EVALUATED	FAILURE PATHWAYS AND BRANCH PROBABILITY ASSIGNMENT	ANNUAL PROBABILITY OF FAILURE



NOTES:

1. DUPLICATE BRANCHES ARE COLLAPSED FOR EASE OF PRESENTATION.

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2022 RISK ASSESSMENT REPORT
EVENT TREE 1 (ET2)
FLOOD-INDUCED PIPING

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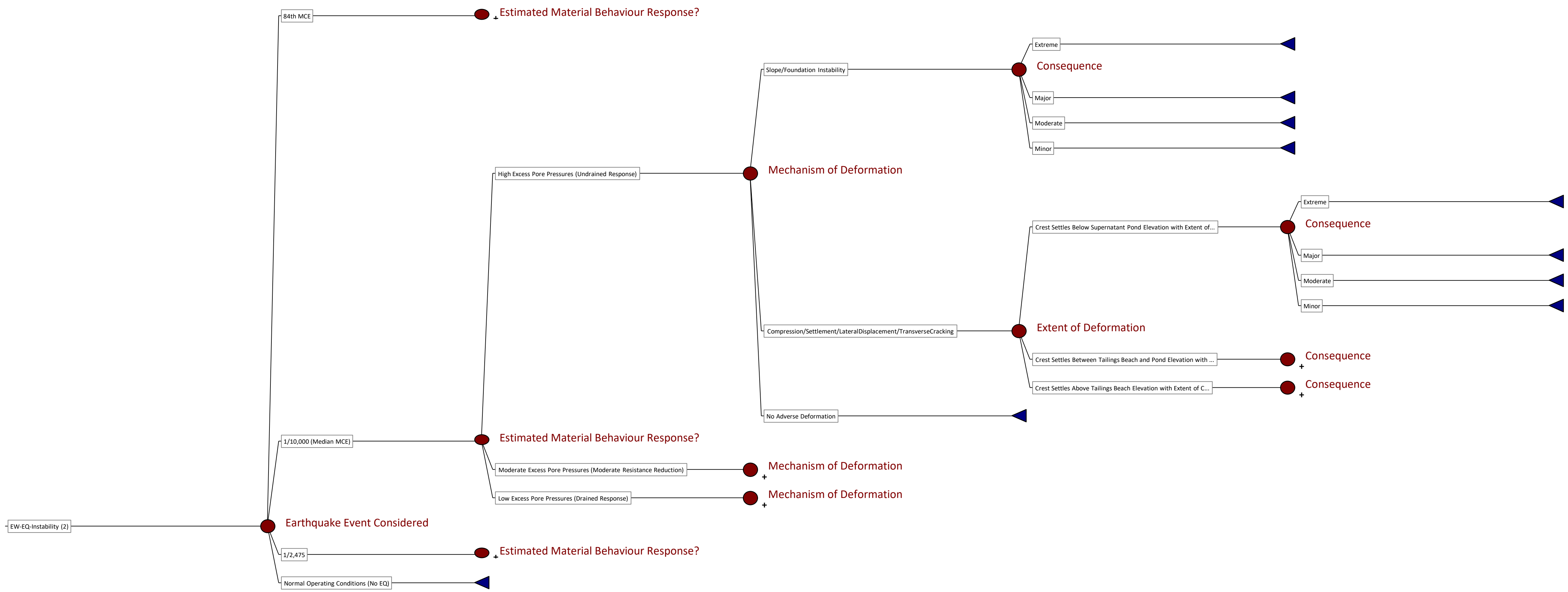
FIGURE C1.2 | REV 0

EVENT TREE BEING EVALUATED	FAILURE PATHWAYS AND BRANCH PROBABILITY ASSIGNMENT	ANNUAL PROBABILITY OF FAILURE



NOTES:

1. DUPLICATE BRANCHES ARE COLLAPSED FOR EASE OF PRESENTATION.

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2022 RISK ASSESSMENT REPORT
EVENT TREE 3 (ET3)
EARTHQUAKE-INDUCED DEFORMATION

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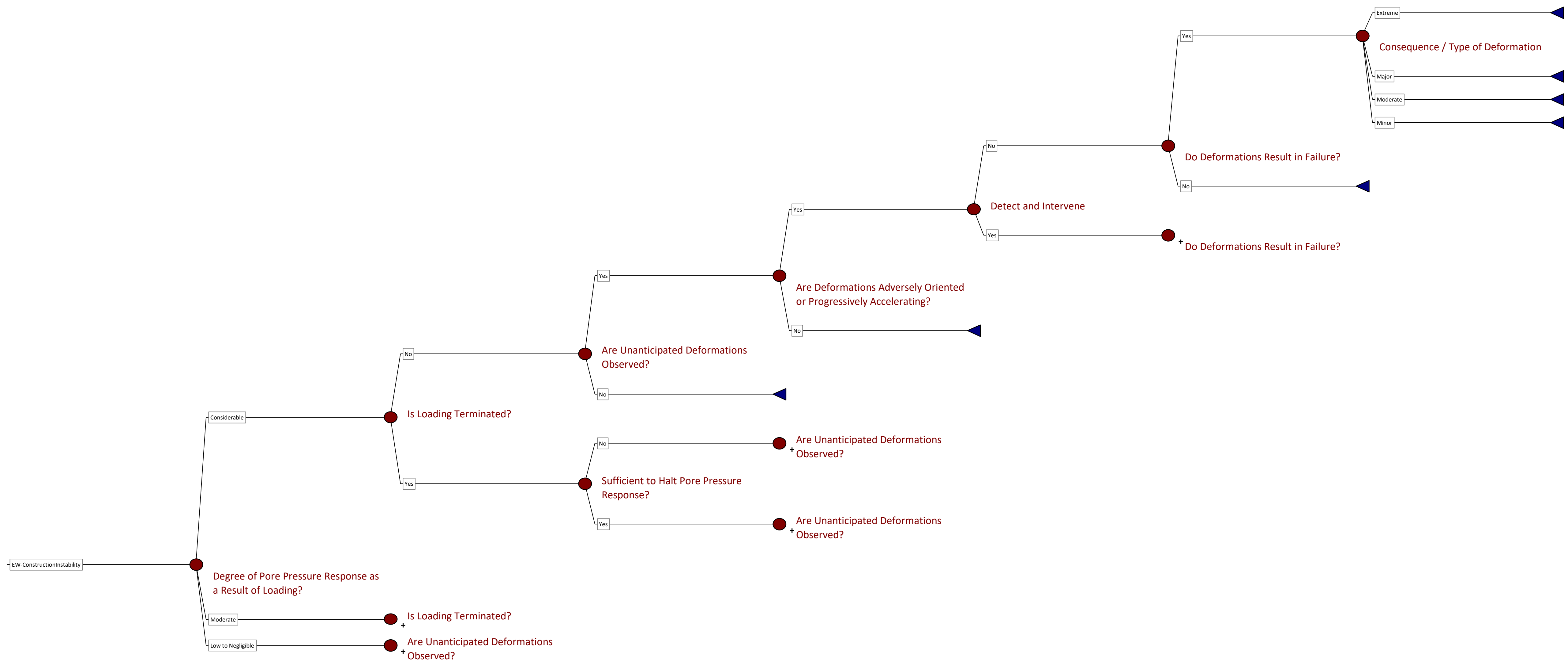
P/A NO. VA/101-00126/27

REF. NO. 1

FIGURE C1.3

REV 0

EVENT TREE BEING EVALUATED	FAILURE PATHWAYS AND BRANCH PROBABILITY ASSIGNMENT	ANNUAL PROBABILITY OF FAILURE



NOTES:

1. DUPLICATE BRANCHES ARE COLLAPSED FOR EASE OF PRESENTATION.

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REV	DATE	DESCRIPTION	PREP'D	RVW'D

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YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE 4 (ET4)
CONSTRUCTION LOADING-INDUCED INSTABILITY

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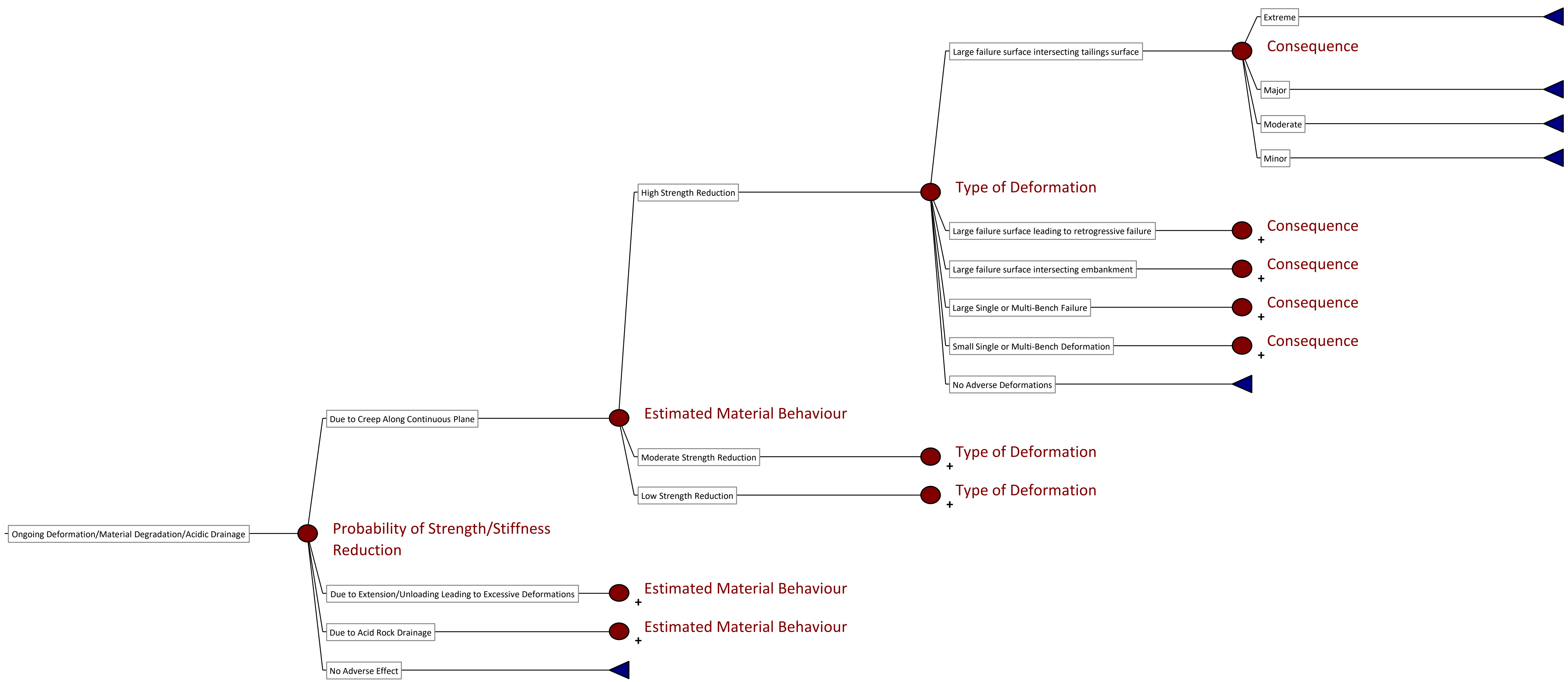
P/A NO. VA/101-00126/27 | REF. NO. 1

FIGURE C1.4 | REV 0

EVENT TREE BEING EVALUATED	FAILURE PATHWAYS AND BRANCH PROBABILITY ASSIGNMENT	ANNUAL PROBABILITY OF FAILURE



NOTES:

1. DUPLICATE BRANCHES ARE COLLAPSED FOR EASE OF PRESENTATION.

REV	DATE	DESCRIPTION	PREP'D	RVW'D
0	07JUL'23	ISSUED WITH REPORT	EJA	DDF

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YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE 5 (ET5)
MATERIAL STRENGTH DEGRADATION INSTABILITY

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P/A NO. VA101-00126/27 | REF. NO. 1

FIGURE C1.5 | REV 0

APPENDIX C2

Probability Guidelines and Consequence Criteria

(Pages C2-1 to C2-4)

APPENDIX C2
PROBABILITY GUIDELINES AND CONSEQUENCE CRITERIA

1.0 GENERAL

A quantitative risk analysis (QRA) process was used to evaluate the credible failure modes that were highlighted by the potential failure failure modes analysis. The QRA process is a risk categorization system that can be used to assign likelihood and consequence categories to potential failure modes based on existing data and available consequence estimates. QRA uses a risk matrix approach to assess individual potential failure modes as well as the total risk for a project, which can be used to prioritize dam safety activities and determine if higher level studies would be beneficial for specific potential failure modes (USBR, 2019).

Risk is represented in a general sense by the product of the likelihood of an adverse outcome occurring and the consequences of that outcome:

Risk = Likelihood x Consequence

Risk combines the probability and severity of an adverse event. To identify risk, three questions must be addressed:

1. What can happen?
2. How likely is it that it will happen?
3. If it does happen, what are the consequences?

In general terms, risk is higher when the likelihood and consequence of failure is higher, and risk is lower when the likelihood and consequence is lower. However, risk prediction is complex and uncertain, and dam failures often result from a complex series of adverse conditions, flaws, or errors in combination rather than a simple design or construction flaw (Hartford and Baecher, 2004).

Event tree analysis is a commonly used QRA tool to identify, characterize, and estimate risk associated with dam safety. The event trees developed for this project generally followed the logic outlined in USBR (2019). Each event tree begins typically begins with an initiating event (or hazard) and graphs the sequences of subsequent hypothetical events that ultimately could lead to failure. Branches of the tree must be mutually exclusive (only one outcome can occur). Probabilities across branches can be summed and branches must be collectively exhaustive (i.e. the sum of probabilities across all branches must equal one). The probability of an outcome of a pathway (at an end node) depends on all events along the pathway to the left with cumulative probability represented by the product of the branch probabilities along the pathway. The cumulative probability calculated for each pathway represents the Annualized Probability of Failure (APF) for that individual potential failure mode.

2.0 PROBABILITY GUIDELINES

One component of the event tree analysis is the estimation of the probability of each branch or event. There were generally two approaches used to assign a numerical value to the likelihood of events depending on the circumstances of the event and the available information. The first approach was to evaluate an explicit estimation of the Annual Exceedance Probability (AEP), which is common practice when estimating design floods and seismic hazard for a facility. The second approach was to refer to the subjective probability guidelines adopted for the risk analysis as shown in Table C2.1, which were created by combining the order of magnitude probability scheme from Barneich et al. (1996) with intermediate verbal mapping descriptors between 10% and 100% likelihood levels. These subjective probability guidelines were used by the risk assessment team where explicit estimation of AEP was not practicable.

Table C2.1 Subjective Probability Guidelines (after Barneich et al., 1996)

<table>
<tr><th colspan="4">Subjective Probability Guidelines</th></tr>
<tr><th colspan="2">Description of Condition or Event</th><th>%</th><th>Order of Magnitude</th></tr>
<tr><td colspan="2">Occurrence is virtually impossible</td><td>0.001</td><td>10^{-5}</td></tr>
<tr><td colspan="2">The condition or event has not been observed, and no plausible scenario could be identified, even after considerable effort.</td><td>0.01</td><td>10^{-4}</td></tr>
<tr><td colspan="2">The occurrence of the condition or event is not observed in the available database. It is difficult to think about any plausible failure scenario; however, a single scenario could be identified after considerable effort.</td><td>0.1</td><td>10^{-3}</td></tr>
<tr><td colspan="2">The occurrence of the condition or event is not observed, or is observed in one isolated instance, in the available database; several potential failure scenarios can be identified.</td><td>1</td><td>10^{-2}</td></tr>
<tr><td rowspan="5">Occurrence of the condition or event are observed in the available database.</td><td>Unlikely</td><td>10</td><td rowspan="5">10^{-1}</td></tr>
<tr><td>More unlikely than likely</td><td>25</td></tr>
<tr><td>Possible</td><td>50</td></tr>
<tr><td>More likely than not</td><td>75</td></tr>
<tr><td>Likely</td><td>90</td></tr>
<tr><td colspan="2">Occurrence is virtually certain</td><td>99.999</td><td>1</td></tr>
</table>

3.0 CONSEQUENCE CRITERIA

Four categories describing the potential consequences of failure were defined for the risk analysis as shown in Table C2.2 and range from Minor/Low to Catastrophic/Extreme. These categories expand on previously used consequence definitions (KP, 2018a). Qualitative descriptions are included in the table below to elaborate on the severity of the potential damage if failure were to occur, including a description of the potential impact to mine operations and any associated life safety risks.

Table C2.2 Subjective Consequence Criteria

Subjective Consequence Criteria		
Category	**Impact to Mine Operations**	**Life Safety Risks**
Catastrophic/Extreme	Potential to render key site facilities inoperable and cause off-site damages	On-site worker and off-site public safety risks
Major	Potential impact on precipitate plant, maintenance workshop, and Booster Pump Houses	Potential impacts to permanent on-site workers
Moderate	Potential impact on operability of pipelines, mine haul ramps, and #3 Booster Pump House	Potential impacts to transient on-site workers
Minor/Low	No facilities impacted; resulting failure investigations may impact operations or have no impact to daily operations	Minimal to no on-site worker safety risk

The Low/Minor consequence category is generally consistent with a Level 1 unusual occurrence, as defined in the Tailings Operations Maintenance and Surveillance (TOMS) Manual (MR/KP, 2022). This level of consequence would not lead to uncontrolled release of impounded materials and would be acceptable if the level of deformation is expected for the loading condition under consideration. A low/minor consequence is considered to be a deformation that is aesthetic, easily repairable, and has no direct impact on mine operations. An example of a consequence with a minor severity is a ravelling or erosion of a local bench slope, localized failure of an angle of repose bench, or localized cracking on the embankment crest or slopes. Typically, this sort of deformation would require increased daily surveillance to monitor displacement until the problem is understood and minor repairs are completed.

A Moderate consequence is defined as a relatively large deformation impacting mine operations or erosion impacting the crest width, or crest cracking that is progressively increasing provided there is no uncontrolled release of impounded materials. The moderate consequence category is consistent with a Level 2 unusual occurrence in the TOMS Manual. These are conditions that represent a potential emergency, if sustained or allowed to progress, but an emergency situation is not imminent. A field investigation to identify the cause of the deformation would typically be required, and corrective repairs would be performed to return the facility to operating condition.

The Major and Catastrophic/Extreme consequence categories are all consistent with potential Level 3 emergency conditions in the TOMS Manual, defined as an actual or imminent failure of containment. A consequence severity threshold adopted for this analysis defines the mine site boundary as one spatial limitation to the consequence definitions. A Major consequence is defined as a failure impacting only the mine site and without uncontrolled release of the supernatant pond or flowable tailings. An example of a major consequence would be a large embankment slip surface with the potential to impact permanent on-site workers, such as those present at the Precipitation Plant, truck maintenance workshop (Berkeley Garage), and the various tailings and water management pump houses positioned on or adjacent to the embankment.

The Catastrophic/Extreme consequence category is reserved for failures that could result in a dam breach causing fluidized outflows (tailings or water driven) that have the potential to render key on-site facilities inoperable and cause off-site damages. Permanent on-site workers would be at considerable risk in such failure scenarios and off-site public safety risks would be possible depending on assumptions related to a variety of factors, such as the assumed location of the failure and assumed rate of breach development. Where uncertainty is large, a conservative assumption that failure consequences are potentially catastrophic can be made to simplify the risk analysis for dam safety decision making purposes.

4.0 REFERENCES

Barneich, J., D. Majors, Y. Moriwaki, R. Kulkarni, and R. Davidson (Barneich et al., 1996). “Application of Reliability Analysis in the Environmental Impact Report (EIR) and Design of a Major Dam Project,” Geotechnical Special Publication, Vol. 2, No. 58, pp. 1367-1382. American Society of Civil Engineers, New York, New York, 1996.

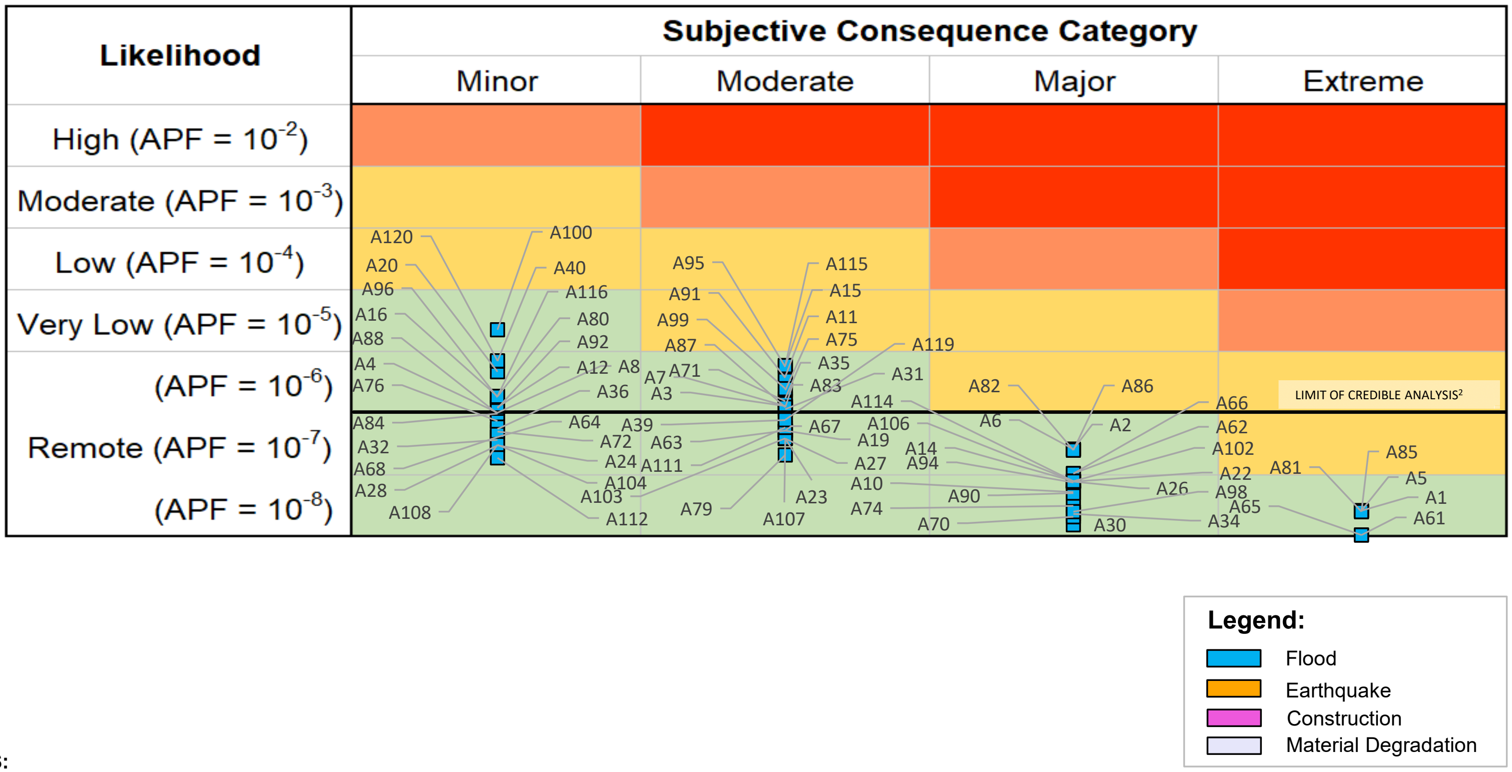
Knight Piésold Ltd. (KP, 2018a). Dam Breach Risk Assessment, Rev 3, dated March 13, 2018. Vancouver, BC. Ref. No. VA101-126/12-3.

Montana Resources, LLP and Knight Piésold Ltd. (MR/KP, 2022). Tailings Operations, Maintenance and Surveillance (TOMS) Manual (Reference No. VA101-126/25-5), Rev 5, dated January 12, 2022.

APPENDIX C3

Summary of Results

(Figures C3.1 to C3.8)



NOTES:

1. BRANCHES WITH AN ANNUALIZED PROBABILITY OF FAILURE (APF) LESS THAN 10^{-8} ARE NOT SHOWN.
2. LIMIT OF CREDIBLE ANALYSIS SHOWN ON THE 10^-6 LINE.

REV	DATE	DESCRIPTION	PREP'D	RVW'D
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YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE ANALYSIS RESULTS
EAST-WEST EMBANKMENT
FLOOD-INDUCED INSTABILITY

Knight Piésold CONSULTING

P/A NO.	REF. NO.	
VA101-126/27	1	
FIGURE C3.1		REV 0

Likelihood	Subjective Consequence Category			
	Minor	Moderate	Major	Extreme
High (APF = 10^{-2})				
Moderate (APF = 10^{-3})				
Low (APF = 10^{-4})				
Very Low (APF = 10^{-5})	F4, F8			
(APF = 10^{-6})				LIMIT OF CREDIBLE ANALYSIS[2]
Remote (APF = 10^{-7})		F3, F7	F2, F6	
(APF = 10^{-8})	F12, F16			F1, F5

Legend:

- Flood
- Earthquake
- Construction
- Material Degradation

NOTES:

1. BRANCHES WITH AN ANNUALIZED PROBABILITY OF FAILURE (APF) LESS THAN 10^{-8} ARE NOT SHOWN.
2. LIMIT OF CREDIBLE ANALYSIS SHOWN ON THE 10^-6 LINE.

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YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE ANALYSIS RESULTS
EAST-WEST EMBANKMENT
FLOOD-INDUCED PIPING/INTERNAL EROSION

Knight Piésold CONSULTING

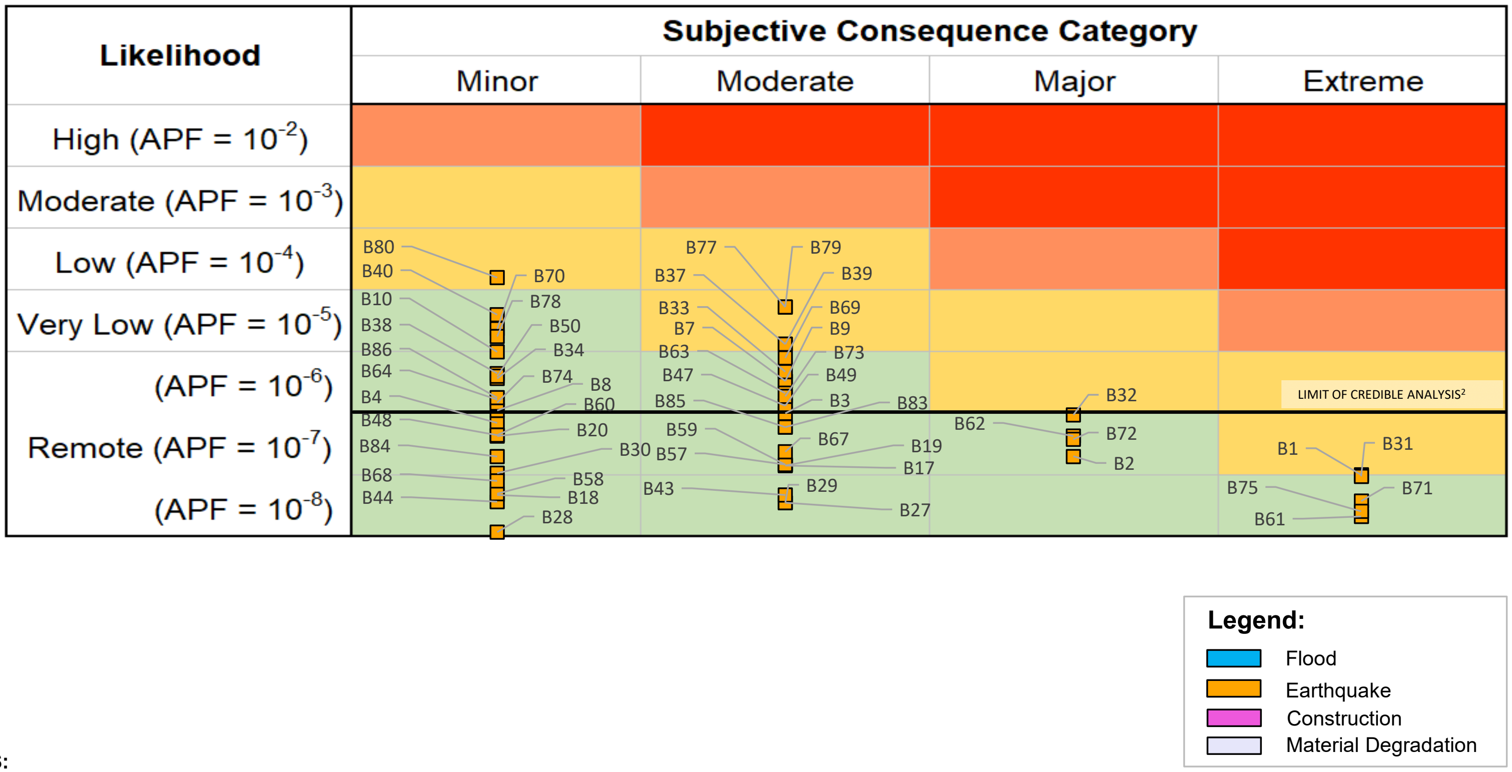
P/A NO. VA101-126/27

REF. NO. 1

FIGURE C3.2

REV 0

REV	DATE	DESCRIPTION	PREP'D	RVW'D
0	07JUL'23	ISSUED WITH REPORT	EJA	DDF



NOTES:

1. BRANCHES WITH AN ANNUALIZED PROBABILITY OF FAILURE (APF) LESS THAN 10^{-8} ARE NOT SHOWN.
2. LIMIT OF CREDIBLE ANALYSIS SHOWN ON THE 10^-6 LINE.

REV	DATE	DESCRIPTION	PREP'D	RVW'D
0	07JUL'23	ISSUED WITH REPORT	EJA	DDF

MONTANA RESOURCES, LLC

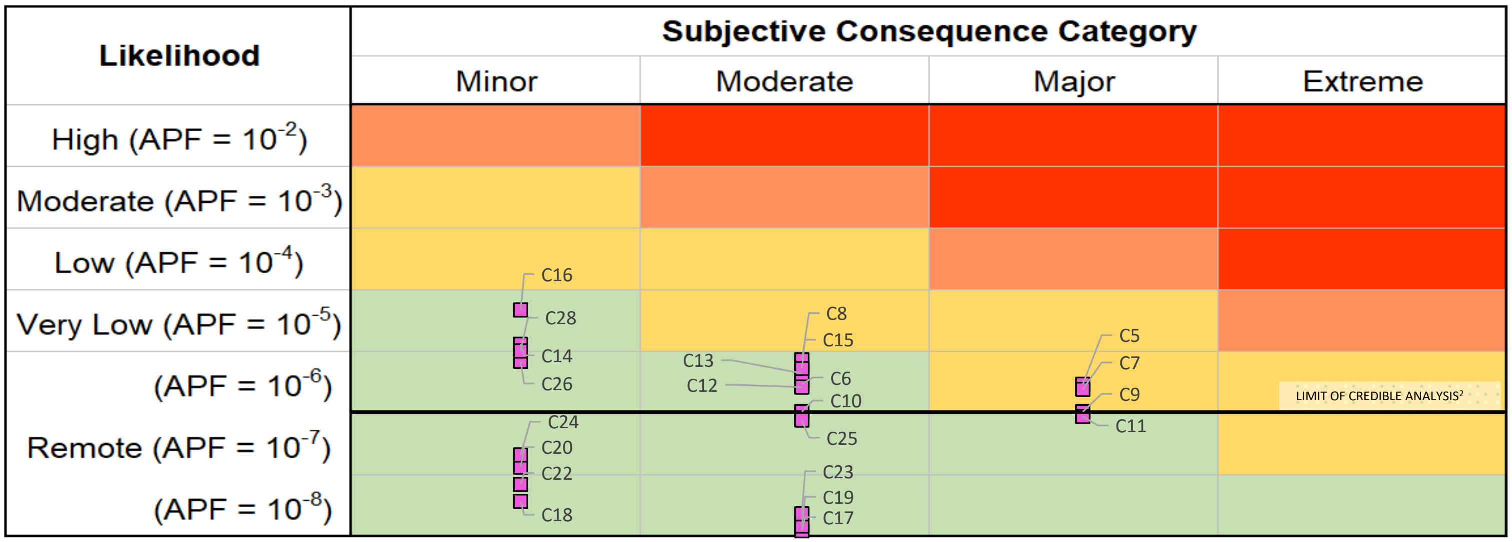
YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE ANALYSIS RESULTS
EAST-WEST EMBANKMENT
EARTHQUAKE-INDUCED DEFORMATION

Knight Piésold CONSULTING

P/A NO. VA101-126/27 | REF. NO. 1

FIGURE C3.3 | REV 0



Legend:

- Flood
- Earthquake
- Construction
- Material Degradation

NOTES:

1. BRANCHES WITH AN ANNUALIZED PROBABILITY OF FAILURE (APF) LESS THAN 10^{-8} ARE NOT SHOWN.
2. LIMIT OF CREDIBLE ANALYSIS SHOWN ON THE 10^-6 LINE.

REV	DATE	DESCRIPTION	PREP'D	RVW'D
0	07JUL'23	ISSUED WITH REPORT	EJA	DDF

MONTANA RESOURCES, LLC

YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE ANALYSIS RESULTS
EAST-WEST EMBANKMENT
CONSTRUCTION LOADING-INDUCED INSTABILITY

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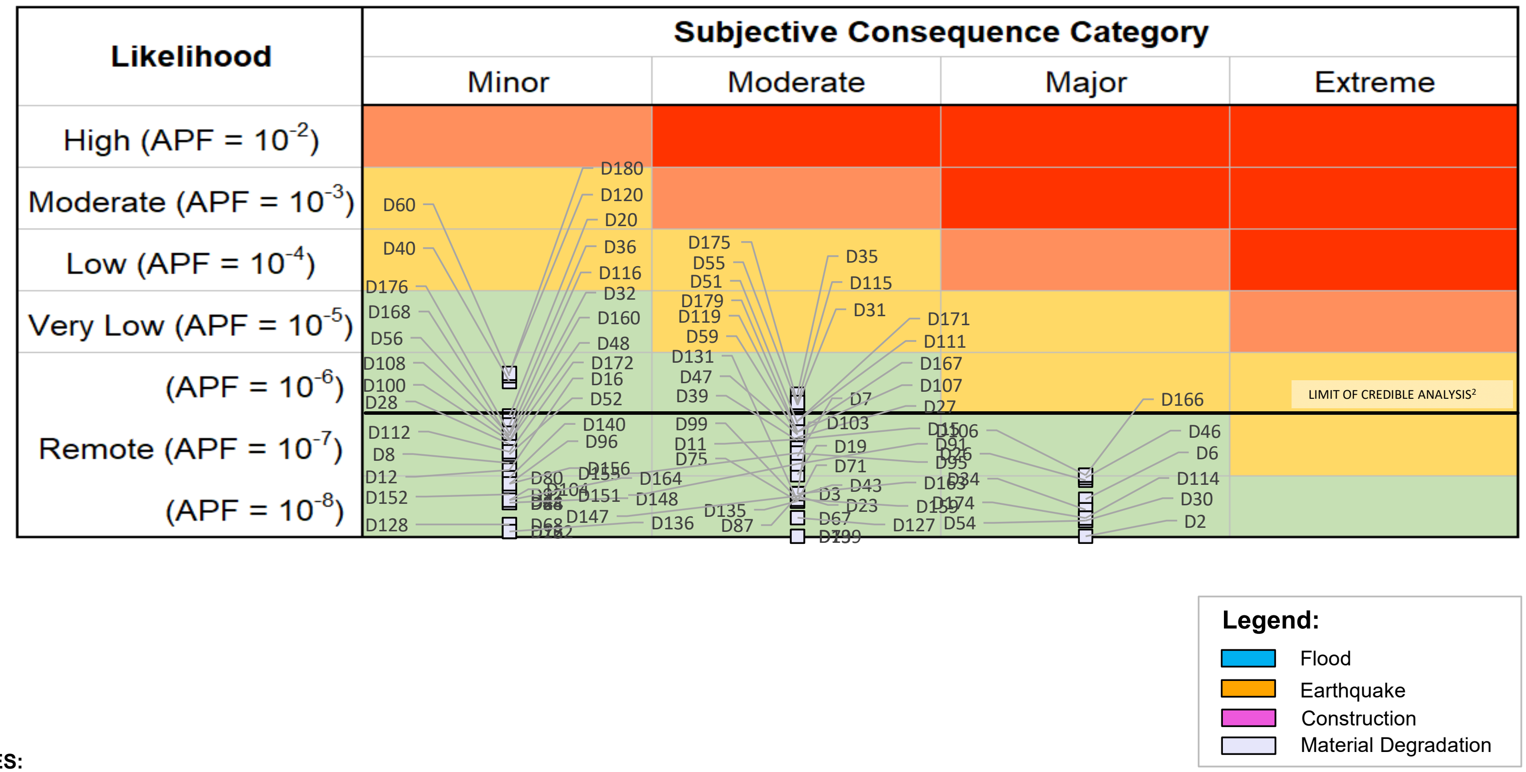
P/A NO. VA101-126/27

REF. NO. 1

FIGURE C3.4

REV 0



NOTES:

1. BRANCHES WITH AN ANNUALIZED PROBABILITY OF FAILURE (APF) LESS THAN 10^{-8} ARE NOT SHOWN.
2. LIMIT OF CREDIBLE ANALYSIS SHOWN ON THE 10^-6 LINE.

0	07JUL'23	ISSUED WITH REPORT	EJA	DDF
REV	DATE	DESCRIPTION	PREP'D	RVW'D

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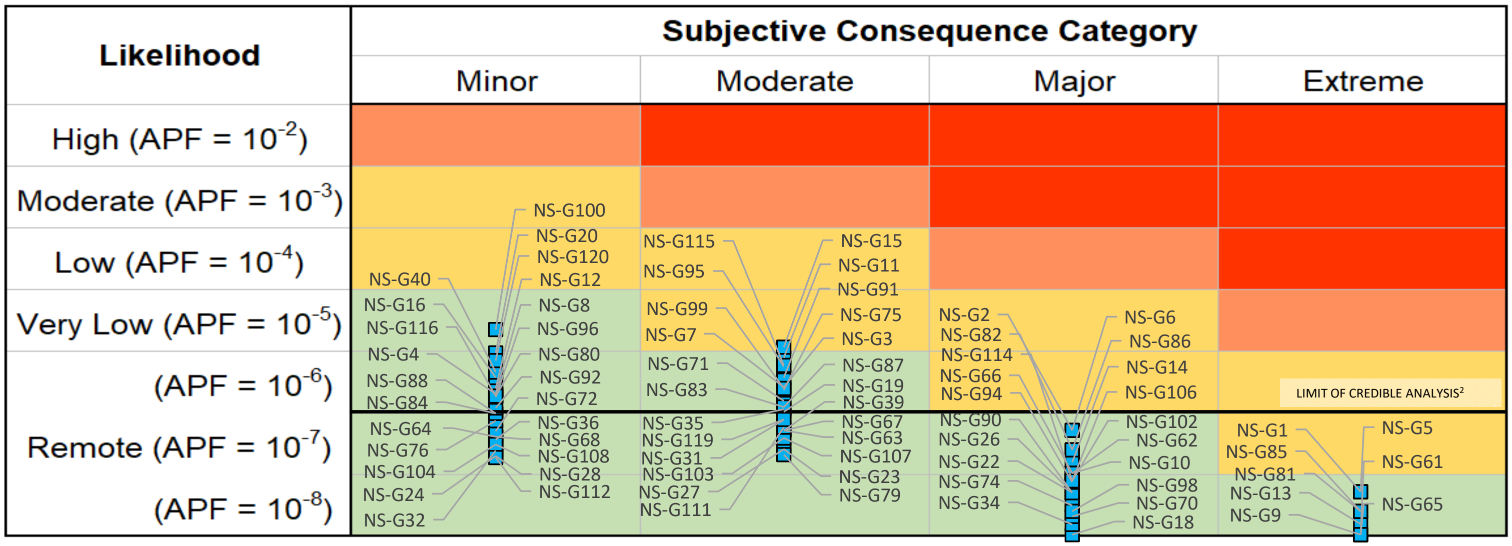
YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE ANALYSIS RESULTS
EAST-WEST EMBANKMENT
MATERIAL DEGRADATION INSTABILITY

Knight Piésold CONSULTING

P/A NO.	REF. NO.
VA101-126/27	1

FIGURE C3.5 REV 0



Legend:

- Flood
- Earthquake
- Construction
- Material Degradation

NOTES:

1. BRANCHES WITH AN ANNUALIZED PROBABILITY OF FAILURE (APF) LESS THAN 10^{-8} ARE NOT SHOWN.
2. LIMIT OF CREDIBLE ANALYSIS SHOWN ON THE 10^-6 LINE.

REV	DATE	DESCRIPTION	PREP'D	RVW'D
0	07JUL'23	ISSUED WITH REPORT	EJA	DDF

MONTANA RESOURCES, LLC

YANKEE DOODLE TAILINGS IMPOUNDMENT

2022 RISK ASSESSMENT REPORT
EVENT TREE ANALYSIS RESULTS
NORTH-SOUTH EMBANKMENT
FLOOD-INDUCED INSTABILITY

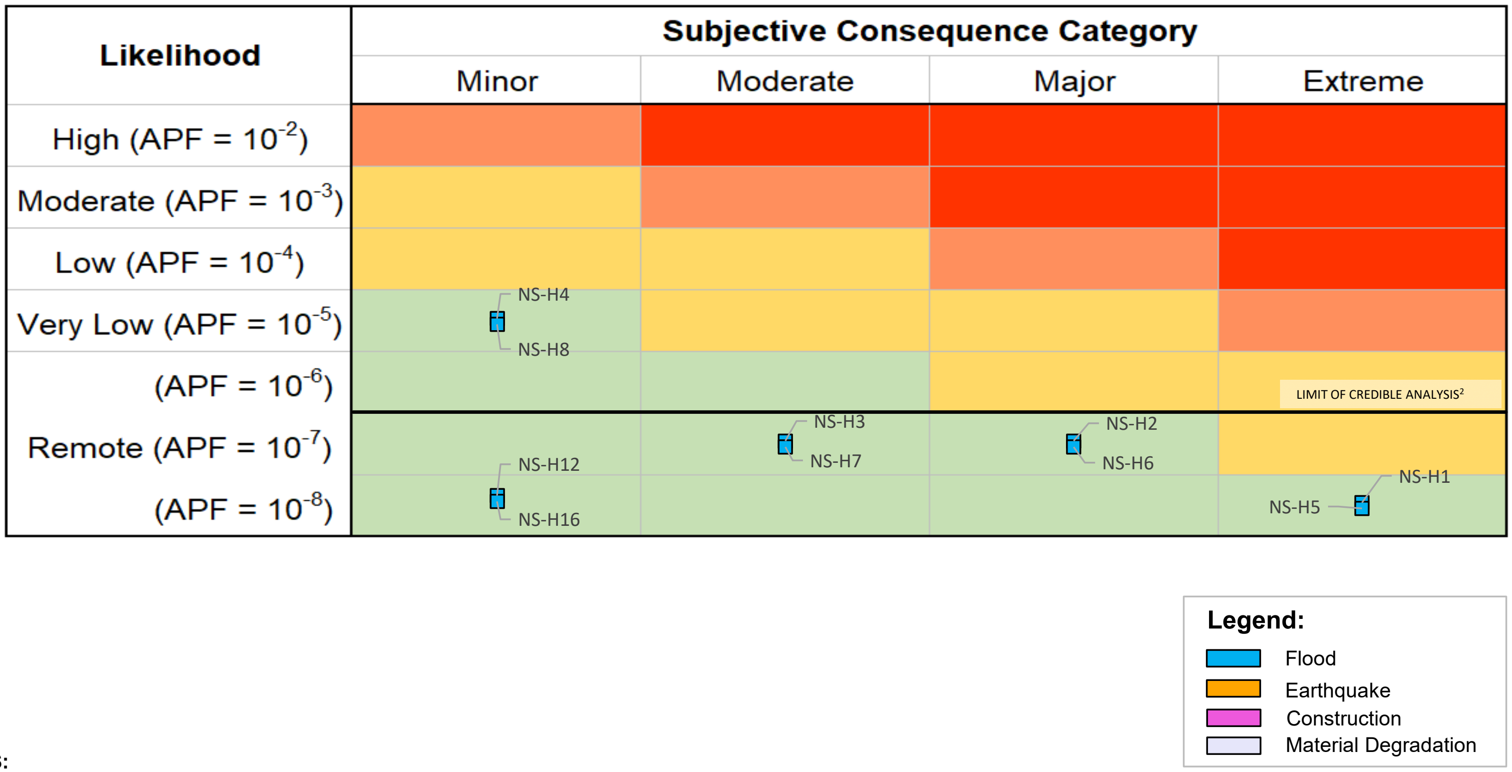
Knight Piésold CONSULTING

P/A NO. VA101-126/27

REF. NO. 1

FIGURE C3.6

REV 0



NOTES:

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2022 RISK ASSESSMENT REPORT
EVENT TREE ANALYSIS RESULTS
NORTH-SOUTH EMBANKMENT
FLOOD-INDUCED PIPING/INTERNAL EROSION

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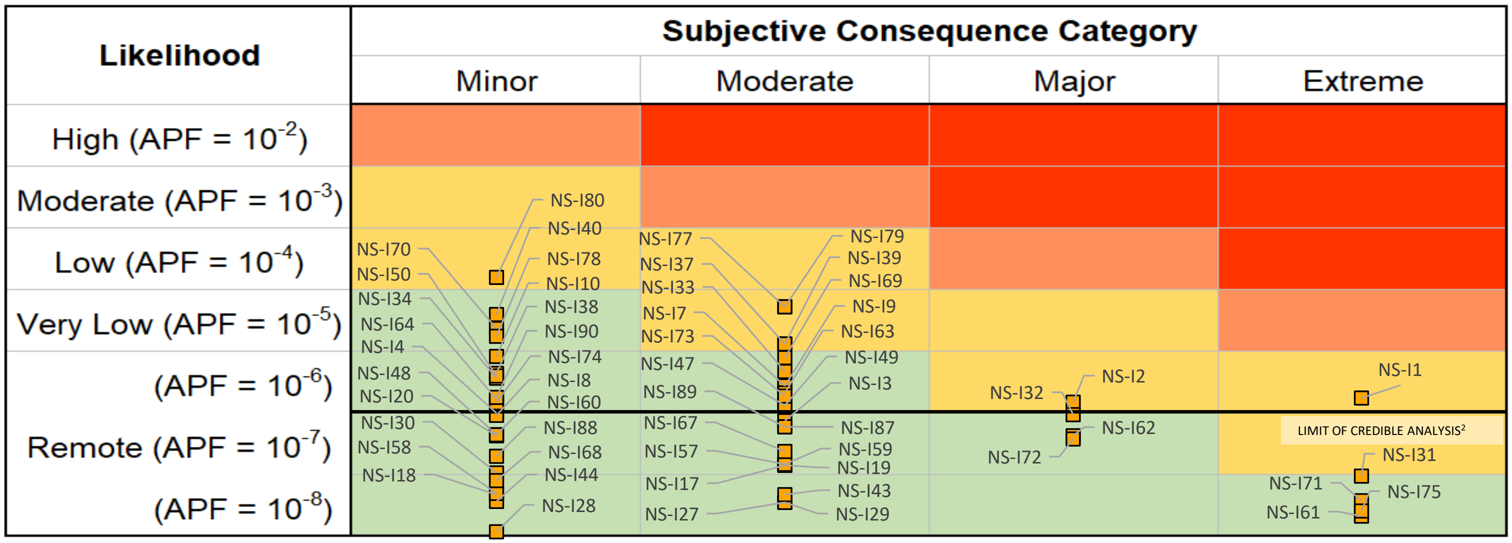
FIGURE C3.7

REV 0



Legend:
- Flood
- Earthquake
- Construction
- Material Degradation

NOTES:

1. BRANCHES WITH AN ANNUALIZED PROBABILITY OF FAILURE (APF) LESS THAN 10^{-8} ARE NOT SHOWN.
2. LIMIT OF CREDIBLE ANALYSIS SHOWN ON THE 10^-6 LINE.

REV	DATE	DESCRIPTION	PREP'D	RVW'D
0	07JUL'23	ISSUED WITH REPORT	EJA	DDF

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YANKEE DOODLE TAILINGS IMPOUNDMENT

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NORTH-SOUTH EMBANKMENT
EARTHQUAKE-INDUCED DEFORMATION

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FIGURE C3.8 | REV 0

APPENDIX D

Mitigations Summary

(Pages D-1 to D-13)

Yankee Doodle Tailings Impoundment

2022 Risk Assessment – Mitigations Summary

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Adding value. Delivering results.

Outline

1 Previously Implemented Measures
2 Additional Mitigation Opportunities

Previously Implemented Measures

Risk Mitigation

Implemented Measures (since 2015)

- Modifications to the tailings distribution system for improved beach development along all three embankments.
- Stress densification of tailings below the rockfill surcharge to strengthen tailings adjacent to the East-West Embankment, improve seismic performance of the facility, and reduce potential flowability of the underlying tailings mass.
- Water management changes, including substantial reductions to freshwater use from the Silver Lake Water System (SLWS) and development of the Pilot Project to facilitate additional water inventory reductions within the YDTI supernatant pond.
- Improved understanding of current conditions through continued investigation of the geotechnical and hydrogeological conditions within the embankment rockfill, tailings, and foundation materials underlying the embankment following a phased investigation plan developed by KP.
- Expansion of the piezometric monitoring network and development of surface and subsurface deformation monitoring programs.
- Automation of monitoring systems and alert functions.
- Improved data analysis frequency and reporting rigor.
- Updates to the MR Emergency Action Plan (EAP).
- Commenced buttress construction in the Horseshoe Bend area and movement of facilities in the area.
- Ongoing planning to move power lines downstream of the East-West Embankment.

Additional Mitigation Opportunities

Risk Mitigation Opportunities

Current Business and Mine Plan

Structural Controls:	Priority:
On-site Containment Project	*High Priority*
HsB RDS buttress	*High Priority*
Truck shop relocation	*High Priority*
North-South Embankment slope flattening and North RDS	*Secondary Priority to HsB RDS*
Continued pond inventory management	*Important and On-going*

Non-Structural Controls:	
Review and update TOMS/EPRP (e.g. unusual occurrences indicators and corresponding communications protocols)	*Continuous Improvement*
On-going annual site investigation programs within 5-Year plan framework	*Important and On-going*
Accelerated investigation of historical leach areas	*Medium to High Priority*

Risk Mitigation Opportunities

Mitigation Evaluation

Mitigation Measure	Timeframe to Implement	Benefits (e.g. decreased likelihood, reduced consequences)	Drawbacks	Effectiveness / Appropriateness / Practicability	Comments / Priority
On-site Containment Project	Short-term	• Clear reduction in potential consequences of failure for multiple failure modes • Readily understood by multiple stakeholders • Passive control (no further action required) • Facilitates continued mining operations and application of additional mitigation measures	• Short-term operations inconvenience • Introduces incremental increase to risks in Continental Pit area	• Will not increase coordination/communications with agencies (e.g. EPA) • Effective consequence mitigation • Highly practicable and can be achieved in months • Very minor incremental increase in on-site flooding	• High priority • In progress (estimated completion within the year)

Risk Mitigation Opportunities

Mitigation Evaluation

Mitigation Measure	Timeframe to Implement	Benefits (e.g. decreased likelihood, reduced consequences)	Drawbacks	Effectiveness / Appropriateness / Practicability	Comments / Priority
Stage 1 HsB RDS Buttress	Short to Medium-term	• Improved stability with resulting reduction in risk • Improved instrumentation • Reduces consequence by relocating Precipitation Plant staff • Improved water management capabilities • Improved access	• Active dumping adjacent to HsB workers poses potential safety hazard	• Well-established remedial measure • Achievable within a few years • High likelihood of rapid permitting • Efficient haul route • Cost-effective • Rockfill available within implementation timeframe • Improving surface reclamation potential	• Foundation layer construction in progress • Highest priority for surplus rockfill • Estimated completion within next few years

Risk Mitigation Opportunities

Mitigation Evaluation

Mitigation Measure	Timeframe to Implement	Benefits (e.g. decreased likelihood, reduced consequences)	Drawbacks	Effectiveness / Appropriateness / Practicability	Comments / Priority
Truck Shop Relocation	Short- to Medium-term	• Significant consequence reductions • Allows for Stage 2 HsB RDS • Reduced safety hazard for personnel access • More convenient for mine operations • Reduced risk during Stage 1 HsB RDS construction	• Large costs to relocate (approximately $50M) • Likely downgrade to existing facilities • Zoning and construction permits	• Requires relocation of Alluvium Stockpile • Very effective potential consequence mitigation	• Estimated completion time is ~2 years following approval to proceed • High priority • No single measure will have greater positive impacts on potential consequences

Risk Mitigation Opportunities

Mitigation Evaluation

Mitigation Measure	Timeframe to Implement	Benefits (e.g. decreased likelihood, reduced consequences)	Drawbacks	Effectiveness / Appropriateness / Practicability	Comments / Priority
North-South Embankment slope flattening and North RDS buttressing	Medium to Long-term	• Improved stability with resulting risk reduction • Decreases regrading and material placement needs for early closure and/or reclamation	• None identified	• Initial placement of 100 ft at 3:1 slope is highest priority • On-going placement of additional buttress as surplus rockfill available	• Secondary priority to Stage 1 HsB RDS • Relative priority of North RDS and Stage 2 HsB RDS remains to be determined • Increased understanding of historical leached area materials may influence relative priority

Risk Mitigation Opportunities

Mitigation Evaluation

Mitigation Measure	Timeframe to Implement	Benefits (e.g. decreased likelihood, reduced consequences)	Drawbacks	Effectiveness / Appropriateness / Practicability	Comments / Priority
Investigation of Historical Leached Area	Short to Medium Term	• Improved understanding of historical leached material • Better site characterization • Improved confidence in designs and facility performance expectations	• Increased costs in near term to execute additional parallel program during 5-year plan	• Objectives of current investigation plans are important objectives • New investigations should be executed in parallel	• Should be executed during the next 5 years • Commence with surface seismic investigations and cone penetration testing in 2022, if possible. • Do not remove resources from current investigation plans

Risk Mitigation Opportunities

Considered Mitigations (Pending Future Assessment)

Mitigation Measure / Description	Means of Risk Reduction (e.g. decreased likelihood, reduced consequences)	Assessment Priority
Optimize haul route and future haul ramp to reduce personnel risk and/or enhance stability in key areas	Both	1 (Further assess as soon as practicable)
Inclusion of interim emergency spillways	Likelihood	2 (Assess as a secondary priority)
Tailings beach surcharge loading along N-S Embankment	Likelihood	2 (Assess as a secondary priority)
Revisit Emergency Action Plan to reduce risk for moderate-sized loading events (e.g. water management action plan under flooded conditions)	Consequence	1 (Further assess as soon as practicable)
Improved engineering specifications for Zone F at the N-S Embankment / Rampart Mountain to reduce the risk of piping	Likelihood	3 (Engineering design consideration)
Review possible automation to reduce personnel risk exposure (e.g. Tailings spigot discharge automation, haul truck automation)	Both	4 (Record and consider further in the future)
Review potential upstream diversion structure options and their relative influence on PMF volume	Both	4 (Record and consider further in the future)


THANK
YOU
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