Appendix 17.6-B

Ajax Mine: Tailings Dam Failure Modes Assessment and Dam Breach Inundation Evaluation

AJAX PROJECT

Environmental Assessment Certificate Application / Environmental Impact Statement for a Comprehensive Study

Ajax Mine: Tailings Dam Failure Modes Assessment and Dam Breach Inundation Evaluation

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EXECUTIVE SUMMARY

KGHM Ajax Mining Inc. (KAM) proposes to develop the Ajax Project, an open pit copper-gold mine at the historic Afton Mining Camp, British Columbia (BC). The Ajax Project is required to obtain an Environmental Assessment Certificate in accordance with BC's Environmental Assessment Act (BCEAA). This report is prepared to accompany an Application for an Environmental Assessment Certificate by KAM. According to the Application Information Requirements/Environmental Impact Statement Guidelines (AIR/EIS-G), the AIR/EIS-G will identify the likelihood of potential accidents, malfunctions and unplanned events, including a failure of the TSF that could occur in any phase of the Project, and describe how each potential accident, malfunction or unplanned event would be managed or mitigated. The dam breach inundation study accomplished these objectives by carrying out the work in three stages as follows:

- **Stage 1: Screening Level Study:** Collect available information related to the TSF design and staging of the dams and highlight failure scenarios that could lead to a dam breach during pre-production, production and closure. Screen these scenarios to obtain a set of critical scenarios that highlight appropriate "sunny" and "rainy" day failure modes for further failure mode assessment. The Canadian Dam Safety Association (CDA, 2007) provides guidelines that define these terms as:
    - "Sunny-day" failure – A sudden dam failure that occurs during normal operations. It may be caused by internal erosion, piping, earthquakes, mis-operation leading to overtopping, or another event.
    - "Rainy-day" "failure (or flood-induced") – A dam failure resulting from a natural flood of a magnitude that is greater than what the dam can safely pass.
- **Stage 2: Potential Failure Modes Analysis:** Complete a Potential Failure Modes Analysis (PFMA) of the highlighted cases identified in the Screening Level study (Stage 1) to identify potential mechanisms that could lead to a dam breach, generally assess the likelihood of the failure occurring and the effects (consequences) of such failure, and identify potential risk reduction measures that could reduce breach potential. A generalized consequence category was applied to each Potential Failure Mode (PFM) as follows:
    - Category I – PFM with potential for a breach and subsequent inundation with potential for significant impact beyond the property boundary. These mechanisms typically involve water only or tailings and water as the mobile fluid. This is the highest consequence category.

- Category II – PFM with potential for a breach with inundation zone likely to be maintained within the property or results in limited impacts beyond the property boundary.
- Category III – PFMs leading to a structural failure that is unlikely to cause a breach and loss of contents.
- Category IV – PFMs that may be ruled out because the physical possibility does not exist or the PFM is so remote a possibility as to be non-credible or not reasonable to postulate.

- **Stage 3: Dam Breach and Inundation Evaluation:** Complete a dam breach/inundation analyses on the credible cases that could lead to a potential dam breach scenario resulting from the PFMA in Stage 2. Assessment of the breach flows was completed for evaluating the possible inundation and potential consequences of dam failure.

  The results of the PFMA identified Category II failure modes involving potential for breach and partial/complete loss of mobile contents (water and/or liquefied tailings) behind the dam structures. These are the "critical" cases that form the basis for bounding the inundation risks based on the TSF design. Three of these cases are for the North Embankment, involving excessive seepage and one case for the South Embankment involving dam breach. The PFMA indicates that there is no Category I failure modes identified. The TSF design includes several design features that significantly improve embankment stability and protects against downstream slope failures that could lead to a breach and loss of contents:

  1. A mine rock buttress and/or Mine Rock Storage Facility are included on the downstream of the embankment to increase the Factor of Safety (FOS) against a breach several times higher than the minimum design requirement.

  2. Additional freeboard allowance for PMF and wave-run up for all stages of dam development.

  3. 2014 site investigation has not identified continuous clay layers with high plasticity (weak) that could adversely impact global stability. Field investigations identified only localized clay soil units at shallow depth (<5m) and it is planned to remove these materials as part of foundation preparation.

  4. Except for the start-up condition, the design calls for the supernatant pond to be maintained at several hundred meters from the dam crest.

There are three failure modes that could lead to an uncontrolled seepage event; of these Case #1 - North Embankment at the End of Year -1 has the largest potential for high flows. This case has a potential for releasing uncontrolled seepage flows through the North Embankment, and drawing down the start-up water pond. The critical flow path is through the section where the pond has a 12m water head and in contact with the starter embankment over approximately a 115m length at the maximum elevation. Flow through this section will collect at the North Embankment Seepage Collection Pond #2. An estimated average daily flow of 38,000m^3 will discharge during the first week. The discharge rate will gradually reduce, and the estimated total time for the stored 2.4 Mm^3 to completely empty is about 4.5 months, if no interim interventions are made.

Based on the estimated initial discharge rates, the excessive seepage could fill the North Embankment Seepage Collection Pond #2 after about 3 days following the onset of excessive seepage. There are pumps planned for emptying the ponds. Additional emergency pumping will be required to transfer the excessive seepage flows, and prevent the pond from overtopping. Over the filling duration of more than 3 days, it is considered that the mine can adequately deploy additional emergency pumping to draw down the collection pond, and transfer the seepage water elsewhere within the site (i.e. collection ponds, open pit, etc.) to allow work for repair of this impermeable till layer within the embankment to impede flow. Existing pits at site include the Ajax East, West East and West West Pits. The West East Pit occupies an area of approximately 10 ha, measuring about 300 m long by 300 m wide and has a depth of about 60 m to the existing water level (~ 845 masl to 850 masl) (BGC, 2015). The storage volume in this open pit location is expected to provide sufficient temporary storage for managing the estimated seepage volume. If emergency pumping can be deployed and storage is appropriately utilized, excessive seepage flow from the TSF can be contained within the mine property.

Exposure to a risk of a significant release of water occurs just prior to production and shortly thereafter. Once tailings deposition occurs, the slope of the tailings surface will push the pond back from the crest of the dam so that there is significant tailings beach above water developed. Most of the North Embankment will include a massive mine rock buttress placed on the downstream side, constructed as the mine is developed. These conditions cause the potential for a water release to be very remote and beyond current consideration, shortly after production begins (within 1 to 2 years).

There is one failure mode that could lead to a breach and loss of contents; Case #5 – South Embankment at End of Mine Life. At the end of the mine life, tailings deposition will be at full capacity so that these conditions represent the “worst cases” for a tailings breach; assuming that the pond will be managed at a “safe” distance from the dam crest. Clearly careful pond management will be a critical issue with strict operational criteria provided during detailed design. Results for the above dam breach cases showed that the tailings inundation area from a breach will extend over the Ajax property boundary (Case #5) but with no significant impacts downstream. The impacts and inundation results from these cases are summarized as follows:

The estimated areas for Case #5 are contained by topography such that the tailings would not be carried to other catchments through surface runoff. Therefore, downstream surface water environmental impacts are likely to be limited. There is a potential risk to life for those mine personnel present immediately downstream of the embankments where some of the mine infrastructure will be present. Mine infrastructure that includes seepage collection ponds and water management ditches will likely be buried. KAM is planning a thickened tailings strategy using 60% solids content tailings material, based on results from a recent trade off study to identify the Best Available Technology (BAT) for the Ajax Project (Norwest, 2015). Thickened tailings technology has higher solids content to improve physical stability of the tailings deposit and minimizes water requirements within the facility as compared to the unthickened tailings containment.

Based on the estimates for the uncontrolled seepage flows that could occur in the event of a failure of the upstream till blanket, flow discharged from the TSF can be contained within the mine property. This will involve emergency pumping and use of existing storage areas to allow the necessary work for repair of the impermeable till layer within the embankment to impede flow. Surveillance procedures to assist in detecting the onset of excessive seepage, as well as planning and preparedness for deploying emergency pumping and risk management will be evaluated and specified as part of the detailed design, Operation, Maintenance and Surveillance (OMS) manual and Quantitative Risk Assessment (QRA). Pond management will be crucial in limiting the risk of a breach, while design mitigation will include improving stability through shallower slopes and/or revised alignments that allow for a buttress.

1 INTRODUCTION

KGHM Ajax Mining Inc. (KAM) proposes to develop the Ajax Project, an open pit copper-gold mine at the historic Afton Mining Camp, British Columbia (BC). The Ajax Project is required to obtain an Environmental Assessment Certificate in accordance with BC's Environmental Assessment Act (BCEAA). This report is prepared to accompany an Application for an Environmental Assessment Certificate by KAM. According to the Application Information Requirements/Environmental Impact Statement Guidelines (AIR/EIS-G), the AIR/EIS-G will identify the likelihood of potential accidents, malfunctions and unplanned events, including a failure of the TSF that could occur in any phase of the Project, and describe how each potential accident, malfunction or unplanned event would be managed or mitigated. This study is a federal requirement under the *Canadian Environmental Assessment Act* as part of the Accidents and Malfunctions evaluation. Proposed federal studies, such as this report are outlined in an Environmental Impact Statement Guidelines (EIS Guidelines) document; information needed to complete the federal EA process is submitted to the CEA Agency for approval in an Environmental Impact Statement (EIS), which was completed by KAM in a separate document (KAM, July 2015).

Norwest Corporation (Norwest) has been appointed as the engineering design consultant for the tailings facility at the Ajax project near Kamloops, BC. The mine plan will process ore during approximately 20 years of operation. A basic engineering design of the TSF facility that will store thickened tailings has been completed (Norwest, 2015) and this design forms the basis for this study. The TSF design comprises of four zoned earth-rockfill dams (referred to as the North Embankment, East Embankment, South Embankment, and Southeast Embankment) constructed using the downstream method of construction. During the course of the work, Norwest completed a failure modes assessment and identified opportunities for modifying the design to improve its risk profile and reduce potential consequences accordingly as noted herein.

Potential Failure Modes Analysis (PFMA) is a systematic, proactive method for evaluating a structure or system to identify where and how it might fail (potential failure modes) and generally assess the likelihood of the failure occurring and the effects (consequences) of such failure. The purpose of a dam breach study is to evaluate potential consequences of dam failure in order to classify the dam and to map out potential inundation zones for emergency preparedness measures. The PFMA precedes the dam breach study in order to identify credible failure mechanisms including those that could lead to breach and inundation. The study accomplished its objectives by carrying out the work in three stages as follows:

- **Stage 1: Screening Level Study:** Collect available information related to the TSF design and staging of the dams and highlight failure scenarios that could lead to a dam breach during pre-production, production and closure. Screen these scenarios to obtain a set of critical scenarios that highlight appropriate “sunny” and “rainy” day failure modes for further failure mode assessment. The Canadian Dam Safety Association (CDA, 2007) provides guidelines that define these terms as:

- “Sunny-day” failure – A sudden dam failure that occurs during normal operations. It may be caused by internal erosion, piping, earthquakes, mis-operation leading to overtopping, or another event.
- “Rainy-Day” failure (or “flood-induced”) – A dam failure resulting from a natural flood of a magnitude that is greater than what the dam can safely pass.

- **Stage 2: Potential Failure Modes Analysis:** Complete a Potential Failure Modes Analysis (PFMA) of the highlighted critical cases identified in the Screening Level study (Stage 1) to identify potential mechanisms that could lead to a dam breach, generally assess the likelihood of the failure occurring and the effects (consequences) of such failure, and identify potential risk reduction measures that could reduce breach potential.
- **Stage 3: Dam Breach and Inundation Evaluation:** Complete a dam breach/inundation analyses on the critical failure modes that could lead to a potential dam breach scenario resulting from the PFMA in Stage 2.

Norwest (2015) has recently carried out a tailings technology trade-off study to identify the Best Available Technology (BAT) for the Ajax Project and Thickened Tailings (60% solids slurry) emerged as the most appropriate choice. Thickened tailings technology has higher solids content to improve physical stability of the tailings deposit and minimizes water requirements within the facility as compared to the unthickened tailings containment.

2 TAILINGS STORAGE FACILITY DESCRIPTION

2.1 TSF Design Objectives

The principal design objectives for the TSF are to provide containment for tailings and supernatant water during operations and in the long term (post-closure), and to achieve effective reclamation at mine closure. The TSF design requirements should meet the following criteria:

- Provide permanent, secure and total confinement of all tailings materials within an engineered disposal facility.
- Control seepage through the basin and embankments of the TSF during operations for recycling as process water to the maximum practical extent.
- Application of Best Available Technology (BAT) and Best Available Practices (BAP) for tailings containment.
- No surface water discharge to the environment over the life of the project.

2.2 General

The Project is located in the South-Central Interior of British Columbia, southeast of the junction of the Trans-Canada Highway No. 1 and the Coquihalla Highway (No. 5), within the Thompson Nicola Regional District.

The TSF will be located approximately 1km south of the open pit, east of Lac Le Jeune Road. Drawing C180-KA39-5100-00-011 is general arrangement of the TSF and associated facilities, at End of Mine Life.

Tailings will be deposited and managed in a TSF located south of the open pit. The TSF was designed to permanently store tailings generated during the operation of the mine. The TSF will comprise of four zoned earth-rockfill dams (referred to as the North Embankment, East Embankment, South Embankment, and Southeast Embankment) and will be constructed using the downstream method of construction.

Integral to the embankment design will be the use of mine rock storage facilities downstream of the TSF, which are incorporated in the tailings embankment designs to buttress these structures. The West Mine Rock Storage Facility (WMRSF) will buttress the North Embankment while the South Mine Rock Storage Facility (SMRF) will buttress the East Embankment. The MRSF structures contribute to the overall stability and performance of the TSF.

2.3 TSF Embankment Layouts

The TSF will provide tailings containment using four embankments (See Drawing C180-KA39-5100-00-011):

- North Embankment will be located at the north and western extent of the TSF, where the existing ground elevation is the lowest. The North Embankment is approximately 3,700m long with a foundation footprint of 154ha, and a maximum embankment height of 122m.
- East Embankment is approximately 1,450m long with a foundation footprint of 27ha, and a maximum embankment height of 108m. It is situated across a small valley with steep side slopes on the east side of the TSF basin, just north of Goose Lake. It is estimated that the TSF supernatant pond footprint will reach Goose Lake in Year 2.
- South Embankment is approximately 1,550m long with a foundation footprint of 20ha, and a maximum embankment height of 42m. It is situated at the south end of the TSF basin to constrain the TSF within the KGHM property boundary.
- Southeast Embankment will constrain the TSF within the property boundary at the southern extent. The South Embankment is approximately 550m long with a foundation footprint of 2ha, and a maximum embankment height of 13.5m.

2.4 Planned Embankment Construction Sequence

There are two primary construction phases through life of mine: Pre-Production and Production. Pre-Production is considered the period before mill operations, when there will be no tailings deposited in the TSF (Year -2, -1) and Production (Year 1 to approximately 20) is the period during mill operations. Construction tasks for each of these two phases are as follows:

2.4.1 Pre-Production

TSF starter- North Embankment (Year -2, -1): The starter North Embankment will begin construction approximately 1 to 2 years prior to the operation of the process facility. This embankment will provide capacity for approximately two years of tailings storage and will retain the start-up water pond, which is estimated at approximately 2.4Mm^3 of emergency storage for process water supply to the mill. This start-up water volume estimate is based on a thickened tailings storage facility, which significantly reduces the volume from the previously proposed conventional tailings facility (Norwest 2015).

2.4.2 Production

Embankment raises of TSF Embankments to full height (Year 1 to 20): The thickened tailings will be deposited and managed in a TSF located south of the open pit. Four zoned earth-rockfill dams will be constructed to provide tailings and water storage containment. Tailings will be discharged from the embankments that will result in a supernatant pond toward the southeast corner of the facility. The method of tailings deposition (spigotting from perimeter) is expected to result in beaches with approximately 1 to 2% slopes. Initial tailings deposition into the TSF will be by spigotting from the face of the North Embankment. The East Embankment will not be required to retain tailings and water until Year 3. However, to limit access constraints, construction of the East Embankment will start in Year 1. The South Embankment will be required to retain tailings and water from Year 7 until the end of the mine life. The Southeast Embankment will not be required to be in place until towards end of mine life.

All the embankments will have a crest elevation of 1,056m. Prior to closure of the TSF, the supernatant water will be pumped into the pit to expedite the establishment of a pit lake and eliminate long-term ponded water on the TSF. The tailings will be reclaimed to a terrestrial landscape, as close as practical to pre-mining conditions with a cover system designed to limit infiltration to the TSF. Following reclamation, any runoff and/or flood events will be directed away from the facility to an engineered channel to Humphrey Creek, which is located in the neighboring catchment to the east of the TSF.

A depth area capacity curve that reflects the planned TSF storage volume is shown in Figure 2-1. The volumes and areas are based on topographic information provided by KGHM using 3D MineSight modelling software.

Figure 2-2 shows the TSF filling schedule that shows the cumulative tailings volumes, freeboard for PMF and wave run-up and respective dam crest elevations to contain the water and tailings volumes on an annual basis. The TSF has storage capacity of approximately 321.5Mm^3, which is comprised of 275Mm^3 of tailings (at a dry density of 1.6 tonnes/m^3), 2.4Mm^3 of supernatant water and approximately 4.1Mm^3 allowance for the design flood (Probable Maximum Flood (PMF)) storage.

Figure 2-1

TSF Depth Area Capacity Curve

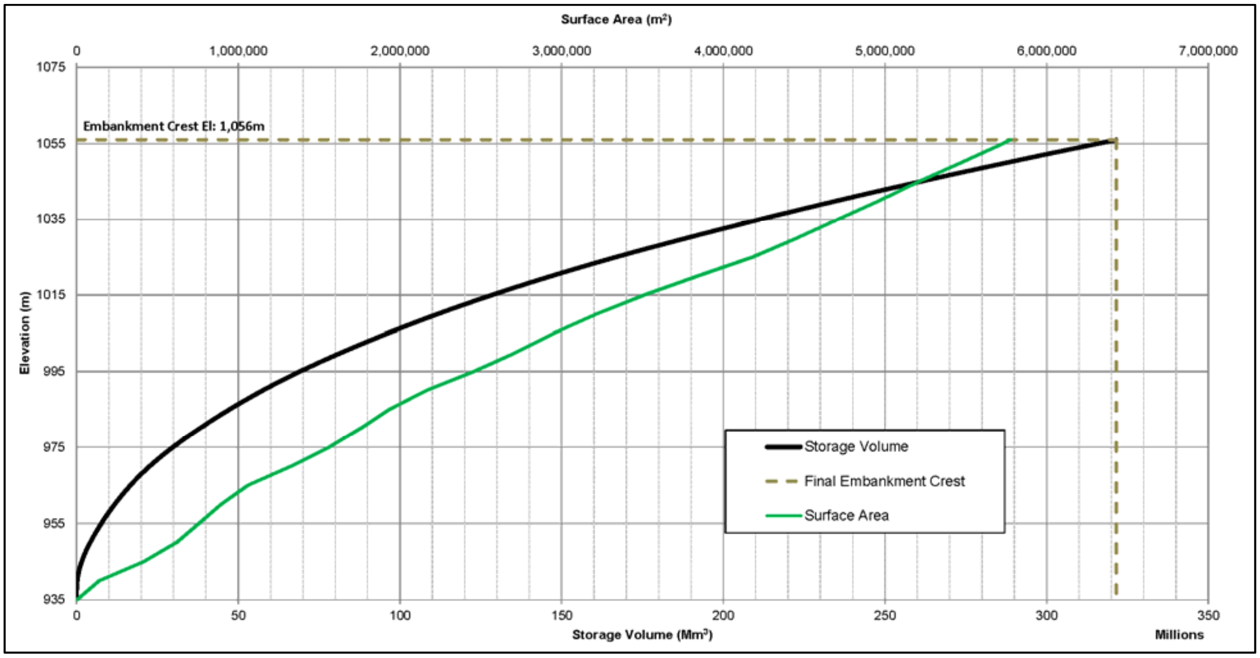
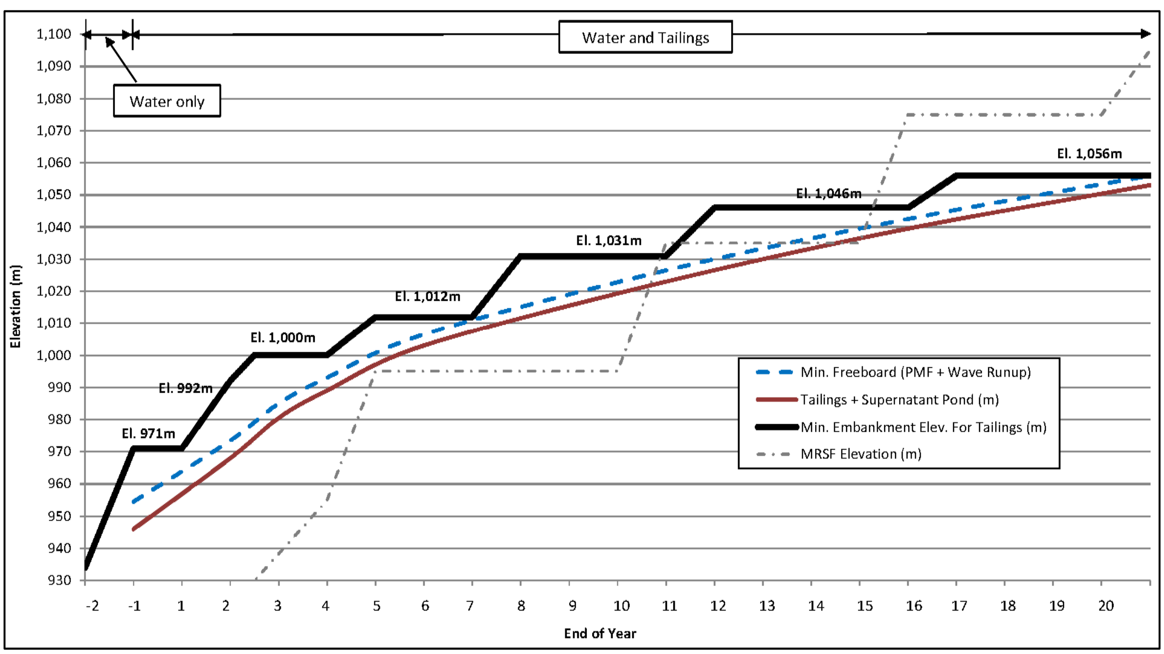


Figure 2-2

TSF Filling Schedule



1).Startup pond volume is estimated at approximately 2.4 Mm³. 2). Minimum crest elevation includes sufficient storage for tailings, pond and allowance for PMF and wave run-up. 3).Tailings volume is assumed to be 65,000 tpd at a mill availability of approximately 92%.

3 SCREENING STUDY

The Ajax tailings facility will be developed over a period of up to approximately 20 years. There are different failure modes and related potential dam breach scenarios that occur at different stages of operation and construction, and in order to evaluate these different time periods a series of scenarios were developed to provide a basis for a screening evaluation. Scenarios considered to be critical are highlighted for further consideration in a Potential Failure Modes Analysis in Section 4. Table 3.1 summarizes the five cases chosen for failure mode evaluation. The Southeast Embankment will not have water or tailings resting against it at end of mine life. Therefore it is not included in the evaluation.

Rationale for defining the critical scenarios at each embankment over the life of the facility is as follows:

3.1 North Embankment:

- Case #1: The North Embankment is required to contain 2.4Mm^3 of water within the facility at start-up (end of Year -1) so that during the period from start-up to shortly after the start of production, the North Embankment will need to function as a water dam. This is the most critical period from a dam breach and risk perspective.
- Case #2: At the end of year 1, the North Embankment will contain tailings and free water within 500m of the dam. The dam configuration includes sufficient downstream construction composed of a mine rock buttress and/or Mine Rock Storage Facility to increase the FOS against a breach several times higher than the minimum design requirement. This downstream buttress is a contingency measure included in the dam design throughout the life of the facility to improve embankment stability against this potential failure mode. However, there may be a risk of uncontrolled seepage from cracking of the impermeable upstream till blanket. Once there are tailings against the upstream embankment face, the risk of blanket failure is low.
- Case #3: The largest tailings volume contained within the facility is at the end of production. The TSF will store approximately 440 million tonnes of tailings with approximately 2.4Mm^3 of supernatant water at the southern end of the facility approximately 1,200m away from the North Embankment. The volume of tailings and water stored in the facility for prior years are less than the final year and therefore the ultimate case is more critical in comparison.

  The North Embankment will be constructed to elevation 1,056m with the WMRSF located downstream approximately 39m higher than the embankment. Although the embankment configuration includes sufficient downstream construction composed of a robust MRSF to increase the FOS against a breach several times higher than the minimum design requirement, there may be a risk of uncontrolled seepage from cracking of the impermeable upstream till blanket.

3.2 East Embankment:

- Case #4: The first stage of construction for the East Embankment will start at the end of year 1 to provide tailings containment for the third year of production. After end of year 3, the SMRSF rapidly expands to provide additional buttressing to the embankment. About 64m of its 108m total height will be completed within the first five years of operation. There will not be any water stored against the upstream face of the embankment and the critical phase is considered to be at the end of production, when the largest tailings volume is contained within the facility. The east embankment will be constructed to elevation 1,056m with a mine rock buttress located downstream above the embankment. The TSF will store approximately 275Mm^3 of tailings with approximately 2.4Mm^3 of supernatant water at the southern end of the facility that is approximately 1,000m away from the east embankment. During prior years, the freeboard is relatively large, and the volume of tailings and water stored in the facility are less than the final year.

3.3 South Embankment:

- Case #5: There is no water impounded against the south dam through the life of the facility. Therefore, the most critical scenario for the Southeast Embankment is at the end of production when the largest tailings volume is contained within the facility. The South Embankment will be constructed to elevation 1,056m. The TSF will store approximately 275Mm^3 of tailings with approximately 2.4Mm^3 of supernatant water at the southern end of the facility approximately 700m away from the south embankment at the end of production.

Table 3-1
Screening Study for Potential Dam Failure Scenarios

End of Year	Crest Elevation (m)	Impounded Contents	TSF Embankments		
			North	East	South
-2		Water Only	Not Critical	Not Built	Not Built
-1	971		**Case #1**		
1	984	Tailings and Water	**Case #2**	Not Critical	
2	992		Not Critical	Not Critical	
5	1,012		Not Critical	Not Critical	
10	1,031		Not Critical	Not Critical	Not Critical
20 (End of Mine Life)	1,056		**Case #3**	**Case #4**	**Case #5**
Closure	1,056		DRY CLOSURE – No impounded water. Consolidated Thickened Tailings deposit		

4 POTENTIAL FAILURE MODES ANALYSIS

Potential Failure Modes Analysis (PFMA) is a systematic, proactive method for evaluating a structure or system to identify where and how it might fail (potential failure modes) and generally assess the likelihood of the failure occurring and the effects (consequences) of such failure.

Norwest has completed a PFMA using the Preliminary TSF Design as a basis. Different failure modes were assessed for each of the five cases from the screening study.

4.1 Methodology

The PFMA presented here was carried out as follows for each of the seven highlighted cases (Table 4-1):

1. Identify and define Potential Failure Modes (PFMs) in terms of the broad type of failure (overtopping, structural failure, and piping), the initiating mechanism and the sequence of events that could subsequently lead to a breach and partial or complete loss of contents.

2. For each PFM, list the factors that were considered to make the failure mode more likely and conceivable (adverse factors) or less likely and remote (positive factors).

3. Assign PFMs to generalized consequence categories defined as follows:

    a. <u>Category I</u> – PFM with potential for a breach and subsequent inundation with potential for significant impact beyond the property boundary. These mechanisms typically involve water only or tailings and water as the mobile fluid. This is the highest consequence category.

    b. <u>Category II</u> – PFM with potential for a breach and/or uncontrolled release of the tailings and water. Inundation zone presumed to be maintained within the property.

    c. <u>Category III</u> – PFMs leading to a structural failure that will not cause a breach and loss of contents.

    d. <u>Category IV</u> – PFMs that may be ruled out because the physical possibility does not exist or the PFM is so remote a possibility as to be non-credible or not reasonable to postulate.

4. Provide a list of risk reduction measures that mitigate the failure mode by lowering probability of failure and/or reducing or eliminating the consequence altogether. These measures are especially important for managing the risk of a breach event with subsequent downstream inundation potential. As the design advances to the next level of detail, some of these measures may be subsequently adopted.

Table 4-1
Highlighted Dam Breach Cases for Failure Modes Assessment

End of Year	Crest El. (m)	Estimated Tailings and/or Water El. (m)		Impoundment Contents	TSF Embankments			Drawing #
		Tailings	Water		North	East	South	
-1	971		946	Water Only	Case #1			C180-KA39-5110-00-001
1	984	968	954.8	Tailings and Water	Case #2			C180-KA39-5110-00-002
20	1,056	1,053	1043		Case #3	Case #4	Case #5	C180-KA39-5110-00-003, C180-KA39-5120-00-001, C180-KA39-5130-00-001

Note. 1. See Appendix A for Potential Failure Mode (PFM) descriptions and analysis breakdown.

4.2 Potential Failure Modes Assessment Results

Details of the PFMA results are discussed in this section. The PFMs are defined in very general terms as the designs are still at a basic engineering level and details of foundation conditions, construction methods, suitability of fill materials, and tailings deposition plan are still being evaluated.

Key findings for each of the five cases are discussed below by considering each consequence category in turn. A detailed summary of these PFM for these cases, including a description of the PFM, positive and adverse factors, mitigation opportunities and resulting Consequence Category are provided in tabular form as Appendix A.

4.2.1 Consequence Category I

Consequence Category I consider PFMs with potential for a breach and subsequent inundation with potential for significant impact beyond the property boundary. These mechanisms typically involve water only or tailings and water as the mobile fluid. This is the highest consequence category.

The PFMA (Appendix A) indicates that there is no Category I failure modes identified for any of the five cases. The TSF design includes several design features that significantly improve embankment stability and protect against downstream slope failures that could lead to a breach:

- A mine rock buttress and/or MRSF have been included on the downstream slope of the embankment to increase the Factor of Safety (FOS) against a breach to several times higher than the minimum design requirement.
- Additional freeboard allowance for PMF and wave-run up for all stages of dam development.
- The 2014 site investigation has not identified continuous clay layers with high plasticity (weak) that could adversely impact global stability. Field investigations identified only localized clay soil units at shallow depth (<5m) and it is planned to remove these materials as part of foundation preparation.
- Except for the start-up condition, the design calls for the supernatant pond to be maintained at several hundred meters from the dam crest.

4.2.2 Consequence Category II

Consequence Category II considers PFMs with potential for a breach and/or uncontrolled release of the tailings and water. Inundation zone presumed to be maintained within the property.

4.2.2.1 PFM #3 - Case #1: North Embankment at End of Year -1

Potential Failure Mode: Upstream failure of the till blanket that is triggered by a seismic event, rapid drawdown, differential settlement and cracking, poor construction and/or high pore pressures leading to uncontrolled seepage.

Positive Factors:

- Stability analyses completed as part of the preliminary TSF design show that the FOS for this failure mode exceeds design criteria.
- This embankment configuration, which includes the mine rock buttress, results in a very long seepage path that minimizes flow velocities and reduces the potential for internal erosion and piping.
- The rock fill material that provides the structural component of the embankment is not generally susceptible to erosion and piping.

- At the end of year -1, the starter pond will be in contact with the dam over two relatively small areas for a limited time before the start of tailings deposition against the upstream face. The wetted face exposed to the highest water level (12m) is located along the northern upstream section of the starter embankment. The design includes significant freeboard (25m) above this water level to prevent overtopping, safe containment of the PMF and for wave run up.

- Geotextile filter to protect against internal erosion.

Adverse Factors:

- Rapid construction of the till blanket may lead to increased pore pressures and differential settlement.

- Construction of this low permeability till blanket is limited by seasonal construction period and it is expected to have tight construction specifications.

- Potential for settlement and cracking.

Mitigation Opportunities:

- Use geotechnical instruments and construction monitoring to monitor performance, prior to filling of the TSF.

- Develop Quality Assurance/Quality Control of material construction specifications of processed engineered fill.

- Include additional seepage controls: thicker upstream blanket, internal core zone, and/or basin underdrains could be added as a design contingency.

4.2.2.2 PFM #4 - Case #1: North Embankment at End of Year -1

Potential Failure Mode: Excessive and/or preferential seepage flows through foundation that leads to progressive internal erosion or piping.

Positive Factors

- A seepage cut-off is included in the design to minimize seepage losses from the TSF.

- Downstream drains.

Adverse Factors:

- There may be loose granular material in the foundation that could provide a potential seepage pathway that could result in piping failure if not defined and mitigated.

Mitigation Opportunities

- A deeper cut-off wall could be used to minimize seepage.
- Use geotechnical instruments and construction monitoring to monitor performance, prior to filling of the TSF.

4.2.2.3 PMF # 8 - Case #2: North Embankment at End of Year 1

Potential Failure Mode: Excessive and/or preferential seepage flows, inadequately designed filter material or internally unstable soils, seepage through embankment or foundation leading to progressive internal erosion of fill or foundation material starting from the downstream side of the dam.

Positive Factors:

- There is a very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping. The mine rock buttress is over 500m long at places and the sloped tailings beach pushes the supernatant pond over 200m away from the embankments.
- The till blanket on the upstream face will significantly reduce seepage. The filter zones will manage and control internal seepage through the embankment. The majority of seepage will be collected within two downstream seepage collection ponds or report to the open pit.

Adverse Factors:

- There may be loose granular material in the foundation that can provide a potential seepage pathway that could result to piping failure.
- A very large flood or PMF could occur, which would be sufficiently contained within the facility, but a substantial length of beach may be inundated that may result in a pond closer to the embankment.

Mitigation Opportunities

- A deeper cut-off wall could be used to minimize seepage.
- Use geotechnical instruments and construction monitoring to monitor performance, prior to filling of the TSF.
- Underdrain in the upper beach to de-saturate the tailings.

4.2.2.4 PMF # 18 - Case #5: South Embankment at End of Year 20

Potential Failure Mode: Large failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings and water that is contained by topography.

Positive Factors:

- Stability analyses completed as part of the preliminary TSF design show that the FOS for this failure mode exceeds design criteria.
- The potential for structural failure is negligible due to very dense glacial deposits overlying competent bedrock geology beneath the south ultimate embankment.
- Long term baseline data will be collected from geotechnical instruments to monitor performance.

Adverse Factors:

- No rock buttress is incorporated into the design due to property boundary constraints. Any released tailings would be contained within the topography immediately behind the embankment, if a structural failure were to occur.

4.2.3 Consequence Category III

Consequence Category III considers PFMs leading to a structural failure that will not cause a breach and loss of contents.

4.2.3.1 PFM #2 - Case #1: North Embankment at End of Year -1

Potential Failure Mode: Downstream sliding or slumping failure of the mine rock buttress triggered by seismic event, high pore pressures, rapid construction, oversteepened angle-of-repose slopes or weak foundation leading to failure that causes a disruption of access roads, toe drainage and other mine site infrastructure.

Positive Factors:

- The FOS exceeds design criteria and the downstream slopes are relatively shallow (3H:1V).
- Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. Most weak layers were identified at shallow depth (<5m), which will be sub excavated. Continuous weak layers at depth were not identified in the site investigations to date.
- The mine rock buttress will comprise of rock fill material and the toe of the mine rock buttress will be more than 100m from startup water pond.

Adverse Factors:

- Localized clay layers have been identified.
- Increased pore pressures in the foundation may occur due to rapid construction of the mine rock buttress.

4.2.3.2 PFM #7 - Case #2: North Embankment at End of Year 1

Potential Failure Mode: Downstream sliding or slumping failure of the mine rock buttress triggered by seismic event and/or high pore pressures leading to failure that leads to disruption of access roads and toe drainage.

Positive Factors:

- The FOS exceeds design criteria and the downstream slopes are relatively shallow (3H:1V).
- Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock and weak layers that were identified at shallow depth (<5m) will be sub-excavated. Continuous weak layers at depth were not identified in the site investigations to date.

- The mine rock buttress will comprise of well-draining rock fill material and the toe of the mine rock buttress will be a considerable distance away from the start-up water pond.

Adverse Factors:

- Localized clay layers have been identified.

- Increased pore pressures in the foundation may occur due to rapid construction of the mine rock buttress.

Mitigation Opportunities

- Use geotechnical instruments to monitor performance during construction and filling of the TSF.

4.2.3.3 PFM # 11 - Case #3: North Embankment at End of Year 20

Potential Failure Mode: Downstream sliding or slumping failure of the Mine Rock Storage Facility triggered by seismic event, high pore pressures, rapid construction, oversteepened angle-of-repose slopes or weak foundation leading to failure that impacts the downstream North sediment collection ponds and/or Kinder Morgan pipeline.

Positive Factors:

- The FOS for the end of mine life configuration exceeds design criteria and the downstream slopes are relatively shallow (3H:1V).

- Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. Most weak layers were identified at shallow depth (<5m), which will be sub excavated. Continuous weak layers at depth were not identified in the site investigations to date.

- The mine rock buttress will comprise of well-draining rock fill material.

Adverse Factors:

- Localized clay layers have been identified.

- Rapid construction of mine rock buttress that may lead to increased pore pressures in the foundation.

4.2.4 Consequence Category IV

Consequence Category IV considers PFMs that may be ruled out because the physical possibility does not exist or the PFM is so remote a possibility as to be non-credible or not reasonable to postulate.

4.2.4.1 PFM #5, PFM #9, PFM #13, PFM # 17, PFM #19 - Overtopping PFM for all Four Embankments

Case #1 to #6 have a Category IV assignment for the overtopping PFMs, and this mechanism is not considered for further inundation evaluation. The tailings facility has capacity for the Probable Maximum Flood (PMF) event which is the highest theoretical inflow so that this "rainy day" scenario is very unlikely to lead to a failure due to overtopping.

4.2.4.2 PFM # 1 - Case #1: North Embankment at End of Year -1

Potential Failure Mode: Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of water into Peterson Creek and off site.

Positive Factors:

- The FOS for the Year -1 starter embankment configuration is several times higher than design criteria.
- There will be over 25m of freeboard above the pond water.
- 2014 site investigation has not identified continuous clay layers with high plasticity (weak) that could adversely impact global stability. Field investigations identified only localized clay soil units at shallow depth (<5m) and it is planned to remove these materials as part of foundation preparation.
- Mine rock buttress on downstream side is >500m at places.
- Short period of time that water is against upstream face prior to tailings deposition.

Adverse Factors:

- There will be approximately 12m (north side) and 3m (west side) of water head against the North starter embankment.

The mine rock buttress was included as part of the starter dam configuration. This buttress has a base width up to 400m, which is approximately 2/3 the height of the starter embankment, and a downstream slope of 3:1. Due to the very large buttress that is built adjacent to the engineered fill embankment, very high safety factors are obtained for the breached condition under static and seismic conditions. This means that a breach or a large catastrophic failure that leads to deep seated foundation failure and subsequent breach and a release of water into Peterson Creek and off site is considered very unlikely based on the assumed conditions. For this reason, this PFM may be ruled out for Stage 3 evaluation.

4.2.4.3 PFM #6 - Case #2: North Embankment at End of Year 1

Potential Failure Mode: Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings and water into Peterson Creek and off site.

Positive Factors:

- The FOS for the End of Year 1 configuration is several times higher than design criteria.
- There will be over 22m of freeboard above the supernatant pond water, which is expected to be over 200m away from the embankment.
- 2014 site investigation has not identified continuous clay layers with high plasticity (weak) that could adversely impact global stability. Field investigations identified only localized clay soil units at shallow depth (<5m) and it is planned to remove these materials as part of foundation preparation.
- Mine rock buttress on downstream side is >500m at places.

Adverse Factors:

- Localized clay layers have been identified that require further definition.

With the high Factor of Safety for the Year 1 embankment configuration a large catastrophic failure that leads to deep seated foundation failure and subsequent breach and a release of water into Peterson Creek and off site is considered remote. For this reason, this PFM may be ruled out for Stage 3 evaluation.

4.2.4.4 PFM # 10 - Case #3: North Embankment at End of Year 20

Potential Failure Mode: Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings and water into Peterson Creek and off site.

Positive Factors:

- The FOS of the embankments at the end of production is several times higher than design criteria.
- There will be over 13m of freeboard above the supernatant pond, which will be over 1,200m away from the embankment.
- 2014 site investigation has not identified continuous clay layers with high plasticity (weak) that could adversely impact global stability. Field investigations identified only localized clay soil units at shallow depth (<5m) and it is planned to remove these materials as part of foundation preparation.
- Mine rock buttress on downstream side is >500m at places.

Adverse Factors:

- Localized clay layers have been identified that require further definition.
- Rapid construction of mine rock buttress that may lead to increased pore pressures in the foundation.

Stability analyses were completed in a separate study (Norwest, August 2015) to demonstrate adequate stability of the dams for static and pseudo-static conditions. With the high FOS for the embankments at the end of production, a large catastrophic failure that leads to deep seated foundation failure and subsequent breach and a release of water into Peterson Creek and off site is considered remote. Due to the large WMRSF downstream of the embankment (that is approximately 39m higher than the dam itself), the large consolidated tailings beach adjacent to the upstream embankment (that is approximately

1,200m wide) that pushes the supernatant pond from the dam crest, this PFM may be ruled out for Stage 3 evaluation.

4.2.4.5 PFM # 12 - Case #3: North Embankment at End of Year 20

Potential Failure Mode: Piping due to excessive and/or preferential seepage flows, inadequately designed filter material or internally unstable soils, seepage through embankment or foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation.

Positive Factors:

- The mine rock buttress is over 500m long at places and the tailings beach length will be over 1,200m, which results in a very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping.
- The till blanket on the upstream face of the embankment will significantly reduce seepage. The filter zones will manage and control internal seepage through the embankment.

Adverse Factors:

- Localized clay layers have been identified that require further definition.
- Rapid construction of mine rock buttress that may lead to increased pore pressures in the foundation.

With these factors and the height of tailings deposited through the mine life, piping through embankment or foundation that leads to progressive internal erosion of fill or foundation starting from the downstream side of the dam or foundation was considered remote and may be ruled out for Stage 3 evaluation.

4.2.4.6 PFM # 14 - Case #4: East Embankment at End of Year 20

Potential Failure Mode: Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings and water into Peterson Creek and off site.

Positive Factors:

- The FOS at the end of construction is several times higher than design criteria. There will be over 13m of pond water freeboard, and the pond will be about 1,000m away from the embankment.
- Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. Continuous weak layers at depth were not identified in the site investigations to date.
- With the high FOS for end of production, a large catastrophic failure that leads to deep seated foundation failure and subsequent breach and a release of water into Peterson Creek and off site is considered remote and this PFM may be ruled out for Stage 3 evaluation.

4.2.4.7 PFM # 16 - Case #4: East Embankment at End of Year 20

Potential Failure Mode: Piping due to excessive and/or preferential seepage flows, inadequately designed filter material or internally unstable soils, seepage through embankment or foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation.

Positive Factors:

- The mine rock buttress is over 500m long at places and there is a very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping.
- At the End of Mine Life, the beach length will be over 1,000m. The till blanket on the upstream face of will significantly reduce seepage.
- The filter zones will manage and control internal seepage through the embankment.

Adverse Factors:

- There may be loose granular material in the foundation that can provide a potential seepage pathway that could lead to piping failure.

With these factors and the height of tailings deposited through the mine life, piping through embankment or foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation site is considered remote and this PFM may be ruled out for Stage 3 evaluation.

4.2.4.8 Closure Case for all Four Embankments

KAM plans to implement a dry closure strategy that will minimize infiltration and divert surface drainage over an engineered spillway to natural drainages (i.e. Humphrey Creek). The terrestrial landscape closure and reclamation cover will reduce embankment stability risks during the post-closure period as no water is impounded. PFM will likely result in a structural failure that is unlikely to cause a breach and loss of contents. For this reason, the PFM at closure were not considered for further inundation evaluation.

5 DAM BREACH INUNDATION EVALUATION

The Potential Failure Modes Analysis (PMFA) has identified four cases involving potential for breach and partial/complete loss of mobile contents (water and/or liquefied tailings) behind the dam structures, as summarized in Table 5-1. These are the “critical” cases that form the basis for bounding the inundation risks based on the preliminary design. There are no Category I PFMs identified and 4 PFMs are assigned as Category II as shown in Table 5-1. Category II means that there is potential for a breach and loss of TSF contents which should not result in any significant impact beyond the property boundary.

Table 5-1
Highlighted Cases for Dam Breach Study

End of Year	Crest El. (m)	Estimated Tailings and/or Water El. (m)	Mobile Contents	Potential Failure Mode[1]	Consequence Category	North	South	Drawing #
-1	971	946	Water Only	Till blanket failure leading to excessive seepage **(PFM #3)**	II	Case #1		C180-KA39-5110-00-001
				Piping/seepage through foundation **(PFM #4)**	II			
1	984	968	Water and Tailings	Till blanket cracking leading to excessive seepage **(PFM #8)**	II	Case #2		C180-KA39-5110-00-002
20	1,056	1,053	Tailings Only	Structural (Foundation) Failure **(PFM #18)**	II		Case #5	C180-KA39-5130-00-001

Note. 1. See Appendix A for Potential Failure Mode (PFM) descriptions and analysis breakdown.

The four cases summarized in Table 5-1 were taken forward for additional evaluation of breach flows and potential for inundation. The recently issued CDA Technical Bulletin titled “Application of Dam Safety Guidelines to Mining Dams” does not prescribe procedures for conducting dam breach analyses, but is rather limited to identifying “some specific issues that should be considered during the design and safety evaluation of mining dams” (CDA, 2014). Accordingly, the choice of which methodology is selected for tailings dam breach analyses, including the simplifying assumptions made about the mode of failure and its defining characteristics is largely reliant on the judgment and experience of the engineer.

5.1 Excessive Seepage - Case #1 and Case #2

Case #1 and Case #2 include three Category II PFMs that could result in seepage losses from the TSF but can be managed and maintained within the property. These failure modes are described in detail in Section 4.2.2 and are summarized as follows:

- PFM #4 and #8 piping failures due to excessive and/or preferential seepage flows through foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation.
- PFM #3 considers the till blanket failure resulting in excessive seepage through the embankment.

The piping failure through the foundation is considered less likely failure mechanism than the potential failure of the till blanket due to:

- the low in-situ permeability of the foundation material,
- the low permeability seepage cut-off that will tie into the foundation to minimize infiltration through the in-situ soils, and
- the rock drains that will convey any seepage flow from the downstream toe to seepage collection ponds, and relieve any hydrostatic pressures within the embankment and downstream mine rock buttress.

For this reason, the till blanket failure (PFM #3 for Case#1) is the dominant mechanism (worst case) compared to the other two PFMs and therefore assessed further.

5.1.1 Case #1 Methodology

During Case #1, the start-up pond is retained by the North Embankment, with no tailings upstream. A failure of the till blanket would lead to excessive seepage through the embankment. Norwest has estimated seepage flow rates that could potentially occur. In the estimates, it is conservatively assumed that the till blanket along the entire length of the starter embankment that is in contact with the pond fails almost simultaneously. The seepage analysis was completed for Section A and Section B shown on Drawing No. C180-KA39-5110-00-001. Through Section A, the pond has a 12m water head that is in contact with the starter embankment over an approximate 115m width at the maximum elevation. Through Section B, the pond has a 3m water head that is in contact with the starter embankment over an approximate 270m width at the maximum elevation.

As identified in the PFMA (Appendix A), the length of the rock buttress, which is over 500m at the critical failure section assessed, is such that the excessive seepage is very unlikely to lead to piping failure that washes away the embankment and releases flow through an open channel or enlarged pipe. Rather, it is assumed that a relatively large, uncontrolled seepage flux through the face of the mine rock embankment in contact with the pond will occur.

To estimate the excessive seepage conditions, Norwest has utilized a SEEP/W model for the seepage flow rates, followed by a Hydraulic Engineering Center- Hydrologic Modeling System (HEC-HMS) model to estimate the rate at which the 2.4Mm^3 empties from the pond.

5.1.1.1 SEEP/W Seepage Flow Rate Estimates

A seepage analysis was run to estimate the seepage flow rates from the starter pond in the event of a failure of the till blanket. The finite element software SEEP/W 2012 (Version 8.14) was used for the seepage analysis. The analysis was based on steady state conditions.

The seepage boundaries were defined as follows:

- Constant total head boundary which was based on the pond level elevation at the upstream slope and upstream toe.
- Zero pressure boundary at downstream toe.
- Seepage boundary along downstream slope face.

The parameters used for hydraulic conductivity are listed in Table 5-2.

Table 5-2
Model Hydraulic Conductivity Parameters

Material	Hydraulic Conductivity, Ksat (m/s)	Kv/Kh
Mine Rock	0.01	1
Undifferentiated Foundation	1.0E-07	0.1

A hydraulic conductivity (Ksat) of 0.01m/s was selected as the base case parameter. To test sensitivity, Ksat values of 0.0005m/s and 0.015m/s were also used.

Initial analysis showed due to the low water head and volume for Section B, the flow rate through that section is much lower than through Section A. Therefore, only Section A analysis results are presented here. The analyses were done for the following pond elevations; EL946m, 944m, 942m and 938m, which correspond to the 12m, 10m, 8m and 4m water head, respectively.

5.1.1.2 HEC-HMS Starter Pond Drawdown Estimates

The HEC-HMS software package includes a routine procedure that can be used to estimate the outflow curve based on the relationship between storage and discharge. The purpose of this calculation is to estimate water quantities released from the starter pond through the time it takes to empty it, so that potential impacts and measures for dealing with the released flow can be evaluated.

The HEC-HMS model was created using the Elevation-Storage-Discharge option, which utilizes both a storage-discharge curve, and an elevation-storage relationship. The storage-discharge relationship used is as estimated by the SEEP/W analysis, and presented on Table 5-3, and the elevation-storage relationship is as shown on Figure 2-1. The HEC-HMS model was run for the assumptions that the excessive seepage starts when the pond has been filled to the targeted 2.4Mm^3, and that the entire 2.4Mm^3 is discharged.

5.1.2 Case #1 Uncontrolled Seepage Flow Results

Table 5-3 summarizes the results of the SEEP/W seepage flow estimates for the range of water elevations within the TSF. The results are presented for the base case with Ksat=0.01m/s, as well as high and low Ksat values of 0.015m/s and 0.005m/s that were used to check sensitivity. Measures to manage the seepage flow are discussed further under Section 5.1.3.

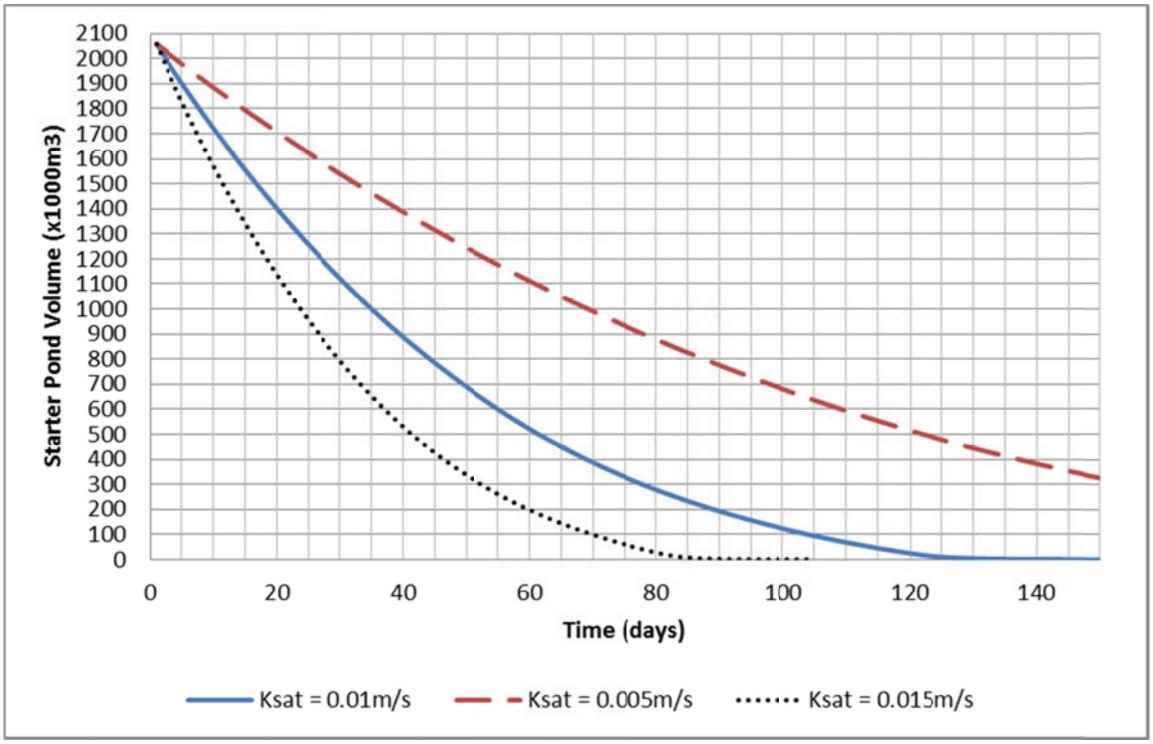
Table 5-3
SEEP/W Uncontrolled Seepage Flow Estimates

Section	Mine Rock Permeability (m/s)	Pond Level (m)	Pond Depth (m)	Unit Flux (m^3/s/m)	Length of Dam in Contact with Pond (m)	Total Flux (m^3/day)
Section A (see Drawing No. C180-KA39-5110-00-001)	0.005	946	12	2E-03	115	19,900
		944	10	2E-03	96	13,500
		942	8	1E-03	77	8,500
		938	4	6E-04	38	2,000
	0.01	946	12	4E-03	115	39,700
		944	10	3E-03	96	27,000
		942	8	3E-03	77	16,900
		938	4	1E-03	38	3,900
	0.015	946	12	6E-03	115	59,500
		944	10	5E-03	96	40,400
		942	8	4E-03	77	25,300
		938	4	2E-03	38	5,800

Figure 5-1 shows the drawdown of the starter pond volume with time, as a result of seepage discharge through Section A. Assuming a Ksat of 0.01m/s, an estimated average daily flow of 38,000m^3 will discharge during the first week. The discharge rate will gradually reduce, and the estimated total time for the stored 2.4Mm^3 to completely empty is about 4.5months.

From the sensitivity assessment, if the mine rock permeability (Ksat) is as low as 0.005m/s, initial daily discharge would be approximately 20,000m^3, and the drawdown period will be considerably longer, at about 16 months. If the mine rock permeability (Ksat) is as high as 0.015m/s, initial daily discharge would be approximately 60,000m^3, and the drawdown about 3 months.

Figure 5-1
Estimated TSF Starter Pond Drawdown



5.1.3 Case #1 Impacts and Mitigation

Seepage discharged through the embankment will collect in the collection ponds located at the toe of the final WMRSF footprint, with flows through Section A discharging to North Embankment Collection Pond #2 and flows through Section B discharging to North Embankment Collection Pond #1.

North Embankment Collection Pond #2 will be designed for a storage volume of approximately 130,000m^3. There are pumps planned for emptying the ponds and the evaluation assumes that they will be largely empty at the onset of an "uncontrolled discharge". Therefore, based on the estimated initial discharge rates, the excessive seepage could fill the pond after about 3 days following the onset of excessive seepage. Pumping with the pumps planned as part of the pond infrastructure will delay the filling. However, additional emergency pumping will be required to transfer the excessive seepage flows, and prevent the pond from overtopping.

Over the filling duration of more than 3 days, the mine can deploy additional emergency pumping to draw down the collection pond.

The seepage water collected at the North Embankment Collection Pond #2 can be transferred elsewhere within the site, where the volume can be managed until repairs are made. For example, at Year -1, the existing open pit will be located approximately 600m northeast of the collection pond (see Drawing No. C180-KA39-5110-00-001). The existing open pit has volume in excess of 2.4Mm^3, and therefore could contain all the flow pumped from the collection ponds under emergency conditions.

Operational surveillance procedures will be in place to assist in detecting the onset of excessive seepage, as well as planning and preparedness for deploying emergency pumping. Based on the seepage flow estimates, it is recommended that the emergency pumping should have capacity in excess of the initial flow rates into the pond, 40,000m^3/d (0.5m^3/s).

If emergency pumping can be deployed and storage such as the open pit utilized, excessive seepage flow from the TSF can be contained within the mine property.

This PFM is based on the assumption that the till blanket fails simultaneously across the entire length of embankment that is in contact with the pond. If a failure were to occur, it is deemed very unlikely that the entire till blanket loses function simultaneously.

The pumping requirements for the range of estimated seepage flows shown on Table 5.3 (average = 950m^3/hr, taking into account the sensitivity considered) is expected to be feasible through an emergency pumping system.

5.2 Tailings Runout - Cases #5

5.2.1 Case #5 Methodology

Case #5 applies to the end of tailings deposition when the TSF is at full capacity. The dam is a small structure compared to the North and East Embankments. The South Embankment will be constructed at the end of year 10 to provide tailings control to manage the supernatant pond at the TSF and contain the tailings deposit within the mine boundary limits. The potential for structural failure is unlikely due to the large consolidated tailings mass upstream that provides structural support and also due to the foundation being relatively compact to very dense However, the dam is not buttressed with mine rock and was therefore considered for the dam breach evaluation. A dam breach of the South Embankment would release tailings only, as the supernatant pond is located a safe distance away from the dam crest. The maximum inundation extent downstream of the embankments was estimated to be the same tailings elevation stored within the TSF, as the topography will contain any tailings and water that are released in the event of a dam breach.

5.2.2 Case #5 Inundation Results

Drawing No. C180-KA39-5130-00-002 shows the estimated maximum inundation extents in the case of a breach of the South Embankment. It is assumed that the tailings will liquefy and flow as a fluid with very low strength. Immediately south of the embankment, the terrain steepens uphill; therefore the runout distance will be limited. Inundation could extend as far as 300m from the toe of the South Embankment.

5.2.3 Case #5 Impacts and Mitigation

The inundation area from a breach of the South Embankment will extend over the Ajax southern property boundary. The estimated area is contained by topography such that the tailings would not be carried to other catchments through surface runoff. Therefore, downstream surface water environmental impacts are likely to be limited.

There is a potential risk to life for those mine personnel present immediately downstream of the embankments where the South Embankment Collection Pond and associated infrastructure will be present. The seepage collection ponds and water management ditches will likely be buried.

6 CONCLUSIONS

The Potential Failure Modes Analysis (PMFA) has identified four failure modes that have potential for breach and partial/complete loss of mobile contents (water and/or liquefied tailings) behind the dam structures. Three of the four failure modes identified could cause excessive seepage and one structural (foundation) failure mode was identified that could cause a breach with inundation potential.

The PFM for Case #1 resulting in excessive seepage through the North Embankment is worse than the other two critical North Embankment cases identified, which are for seepage and piping through the foundation. Therefore the worst case was assessed further.

Thus there are two conditions that are considered for dam breach inundation evaluations:

- <u>Case #1 - North Embankment at the End of Year -1</u>: This case has a potential for releasing uncontrolled seepage flows through the North Embankment, and drawing down the starter pond. The critical flow path is through the section where the pond has a 12m water head and is in contact with the starter embankment over an approximate 115m length at the maximum elevation. Flow through this section will collect at the North Embankment Seepage Collection Pond #2. An estimated average daily flow of 38,000m^3 will discharge during the first week. The discharge rate will gradually reduce, and the estimated total time for the stored 2.4Mm^3 to completely empty is about 4.5 months, if no interim interventions are made.

  Based on the estimated initial discharge rates, the excessive seepage could fill the North Embankment Seepage Collection Pond #2 after about 3 days following the onset of excessive seepage, if there was no concurrent pumping from the collection pond. The duration to fill the collection pond is considered reasonably adequate for the mine to deploy additional emergency pumping to draw down the collection pond and transfer the seepage water elsewhere within the site, such as to the open pit. Existing pits at site include the Ajax East, West East and West West Pits. The West East Pit occupies an area of approximately 10 ha, measuring about 300 m long by 300 m wide and has a depth of about 60 m to the existing water level (~ 845 masl to 850 masl) (BGC, 2015). The storage volume in this open pit location is expected to provide sufficient temporary storage for managing the estimated seepage volume. If emergency pumping can be deployed and storage such as the open pit utilized, excessive seepage flow from the TSF can be contained within the mine property.

  Exposure to a risk of a significant release of water occurs just prior to production and shortly thereafter. Once tailings deposition occurs, the slope of the tailings surface will push the pond back from the crest of the dam so that there is significant tailings beach above water developed. Most of the North Embankment will include a massive mine rock buttress placed on the downstream side, constructed as the mine is developed. These conditions cause the potential for a water release to be very remote and beyond current consideration, shortly after production begins (within 1 to 2 years).

Case #5, –South Embankment at End of Year 20: At the end of the mine life, tailings deposition will be at full capacity so that these conditions represent the "worst cases" for a tailings breach; assuming that the pond will be managed at a "safe" distance from the dam crest. Clearly, careful pond management will be a critical issue with strict operational criteria provided during detailed design. Results for the above dam breach cases showed that the tailings inundation area from a breach will extend over the Ajax property boundary (Case #5) but with no significant impacts downstream.

The impacts and inundation results from these cases are summarized as follows:

- The estimated inundation area for Case #5 is contained by topography such that the tailings would not be carried to other catchments through surface runoff. Therefore, downstream surface water environmental impacts are likely to be limited. There is a potential risk to life for those mine personnel present immediately downstream of the embankments where some of the mine infrastructure will be present. Mine infrastructure that includes seepage collection ponds and water management ditches will likely be buried.

7 CLOSURE

This report has been prepared for KGHM Ajax Mining Inc. to provide a dam breach assessment for the proposed tailings storage facility at the Ajax Project, located near Kamloops, British Columbia. As mutual protection to KGHM Ajax Mining Inc., the public, and Norwest Corporation, this report and its figures are submitted for exclusive use by KGHM Ajax Mining Inc. We specifically disclaim any responsibility for losses or damages incurred though the use of our work for a purpose other than described in the report. Our report and recommendations should not be reproduced in whole or in part without our express written permission.

August 26, 2015

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Appendix A
Potential Failure Modes Assessment

Table A.1

Potential Failure Modes Assessment Case #1 – North Embankment – End of Year -1 (Start-up)

Potential Failure Mode #	Potential Failure Mode	Positive Factors	Adverse Factors	Mitigation Opportunity	Consequence Category (I and IV)
PFM # 1	Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of water into Peterson Creek and off site.	• Factor of Safety is several time higher than design criteria. • 25m of pond water freeboard • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified.	• Localized clay layer was identified but not fully defined. • Approximately 14m (north side) and 4m (west side) of water North embankment. • PMF or large flood volume during construction that exceeds minimum freeboard.	•Use geotechnical instruments to monitor performance, prior to filling of the TSF. • Use internal cofferdam(s) to minimize water against the starter embankment. • Sub excavate weak layers identified at shallow depth (<5m).	Category IV
PFM # 2	Downstream sliding or slumping failure of the mine rock buttress triggered by seismic event and/or high pore pressures leading to disruption of access roads and toe drainage.	• Factor of Safety exceeds design criteria. • Downstream slopes are relatively shallow (3H:1V). • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified. • Mine rock buttress comprised of well-draining rock fill material. • The toe of the Mine Rock Buttress is >100m from startup water pond.	• Localized clay layer was identified but not fully defined. • Rapid construction of mine rock buttress that may lead to increased pore pressures in the foundation.	•Use geotechnical instruments to monitor performance, prior to filling of the TSF. • Sub excavate weak layers identified at shallow depth (<5m).	Category III

PFM # 3	Upstream failure of the till blanket that is triggered by a seismic event, rapid drawdown, poor construction and/or high pore pressures leading to uncontrolled seepage.	• Factor of Safety exceeds design criteria. • Very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping. • Rock fill material is not susceptible to erosion and piping. • Spatial and limited time of contact over a relatively small area. Startup pond has limited contact with the upstream face of the starter embankment.	•Limited by seasonal construction period. • Borrow areas are not well defined. • Rapid construction of till blanket that may lead to increased pore pressures and differential settlement.	•Use geotechnical instruments and construction monitoring to monitor performance, prior to filling of the TSF. • QA/QC of material construction specifications of processed engineered fill. • Use additional seepage control, thicker upstream blanket, and internal core zone as a design contingency.	Category II
PFM # 4	Piping due to excessive and/or preferential seepage flows through foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation.	• Very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping. • Till blanket on upstream face of dam, any seepage through fills is limited to liner defects until deposition of tailings, which will line the TSF and will significantly reduce seepage. • Seepage cutoff used to minimize seepage losses from basin. • Filter zones will manage and control internal seepage through the embankment. • Majority of seepage will be collected within two downstream seepage collection ponds or report to the open pit.	• Loose granular material in the foundation.	• Use deeper cutoff wall to minimize seepage. • Use geotechnical instruments and construction monitoring to monitor performance during construction, prior to filling the TSF.	Category II
PFM # 5	Overtopping due to major precipitation event, and/or inadequate water balance, inadequate freeboard that leads to a rise in impoundment water level which eventually overtops and erodes confining embankments.	•Freeboard = 25m, which significantly exceeds minimum requirements to accommodate PMF and wave run-up above water elevation.	• None.	• Water management and maintenance of freeboard availability.	Category IV

Table A.2

Potential Failure Modes Assessment Case #2 – North Embankment – End of Year 1

Potential Failure Mode #	Potential Failure Mode	Positive Factors	Adverse Factors	Mitigation Opportunity	Consequence Category (I and IV)
PFM # 6	Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings and water into Peterson Creek and off site.	• Factor of Safety is several time higher than design criteria. •22m of pond water freeboard • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified.	• Localized clay layer was identified but not fully defined.	•Use geotechnical instruments to monitor performance. • Sub excavate weak layers identified at shallow depth (<5m).	Category IV
PFM # 7	Downstream sliding or slumping failure of the Mine Rock Buttress triggered by seismic event and/or high pore pressures to disruption of access roads and toe drainage.	• Factor of Safety exceeds design criteria. • Downstream slopes are relatively shallow (3H:1V). • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified. • Mine rock buttress comprised of well-draining rock fill material. • The toe of the Mine rock buttress is	• Localized clay layer was identified but not fully defined. • Rapid construction of mine rock buttress that may lead to increased pore pressures in the foundation.	•Use geotechnical instruments to monitor performance. • Sub excavate weak layers identified at shallow depth (<5m).	Category III

		>100m from startup water pond.			
PFM # 8	Piping due to excessive and/or preferential seepage flows through foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation.	• Very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping. There is a >200m beach length. • Till blanket and tailings on upstream face of dam and significantly reduces seepage. • Filter zones will manage and control internal seepage through the embankment. • Majority of seepage will be collected within two downstream seepage collection ponds or report to the open pit.	• Loose granular material in the foundation. • Very large flood or PMF leading to loss of tailings beach length.	• Use deeper cutoff wall to minimize seepage. • Use geotechnical instruments and construction monitoring to monitor performance during construction.	Category II
PFM # 9	Overtopping due to major precipitation event, and/or inadequate water balance, inadequate freeboard that leads to a rise in impoundment water level which eventually overtops and erodes confining embankments.	•Freeboard = 22m, which significantly exceeds minimum requirements to accommodate PMF and wave run-up above water elevation. •Sloped tailings beaches push supernatant pond over >400m away from north embankment.	• Water management and maintenance of freeboard availability.	• None.	Category IV

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Table A.3

Potential Failure Modes Assessment Case #3 – North Embankment – End of Year 20 (Ultimate)

Potential Failure Mode #	Potential Failure Mode	Positive Factors	Adverse Factors	Mitigation Opportunity	Consequence Category (I and IV)
PFM # 10	Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings and water into Peterson Creek and off site.	• Factor of Safety is several time higher than design criteria. •13m of pond water freeboard • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified.	• Localized clay layer was identified but not fully defined.	•Use geotechnical instruments to monitor performance. • Sub excavate weak layers identified at shallow depth (<5m).	Category IV
PFM # 11	Downstream sliding or slumping failure of the Mine Rock Storage Facility triggered by seismic event and/or high pore pressures leading to failure that impacts the downstream North sediment collection ponds and/or Kinder Morgan pipeline	• Factor of Safety exceeds design criteria. • Downstream slopes are relatively shallow (3H:1V). • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified. • Mine Rock Storage Facility	• Localized clay layer was identified but not fully defined. • Rapid construction of Mine Rock Storage Facility may lead to increased pore pressures in the foundation.	• Use geotechnical instruments to monitor performance. •Sub excavate weak layers identified at shallow depth (<5m). •Monitor rate of construction.	Category III

		comprised of well-draining rock fill material.			
PFM # 12	Piping due to excessive and/or preferential seepage flows through foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation.	• Very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping. There is a >1000m beach length. • Till blanket and tailings on upstream face of dam and significantly reduces seepage. • Filter zones will manage and control internal seepage through the embankment. • Majority of seepage will be collected within two downstream seepage collection ponds or report to the open pit.	• Loose granular material in the foundation.	• Use deeper cutoff wall to minimize seepage. • Use geotechnical instruments and construction monitoring to monitor performance during construction, prior to filling the TSF.	Category IV
PFM # 13	Overtopping due to major precipitation event, and/or inadequate water balance, inadequate freeboard that leads to a rise in impoundment water level which eventually overtops and erodes confining embankments.	•Freeboard = 13m, which significantly exceeds minimum requirements to accommodate PMF and wave run-up above water elevation. •Sloped tailings beaches push supernatant pond over >1000m away from north embankment.	• None.	• Water management and maintenance of freeboard availability.	Category IV

Table A.4

Potential Failure Modes Assessment Case #4 – East Embankment – End of Year 20 (Ultimate)

Potential Failure Mode #	Potential Failure Mode	Positive Factors	Adverse Factors	Mitigation Opportunity	Consequence Category (I and IV)
PFM # 14	Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings and water into Peterson Creek and off site.	• Factor of Safety is several time higher than design criteria. •13m of pond water freeboard • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified.	• Localized clay layer was identified but not fully defined.	•Use geotechnical instruments to monitor performance, prior to filling of the TSF. • Sub excavate weak layers identified at shallow depth (<5m).	Category IV
PFM # 15	Downstream sliding or slumping failure of the South Mine Rock Storage Facility triggered by seismic event and/or high pore pressures leading to failure that impacts the downstream plant site and infrastructure in close proximity.	• Factor of Safety meets design criteria. • Downstream slopes are relatively shallow (2.5H:1V). • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified.	• Rapid construction of Mine Rock Storage Facility may lead to increased pore pressures in the foundation.	• Use geotechnical instruments to monitor performance, prior to filling of the TSF. •Sub excavate weak layers identified at shallow depth (<5m). •Monitor rate of construction.	Category III

		• Mine Rock Storage Facility comprised of well-draining rock fill material.			
PFM # 16	Piping due to excessive and/or preferential seepage flows through foundation that leads to progressive internal erosion of fill or foundation material starting from the downstream side of the dam or foundation.	• Very long seepage path that minimizes flow velocities that reduces internal erosion and potential for piping. There is a >700m beach length. • Till blanket and tailings on upstream face of dam and significantly reduces seepage. • Filter zones will manage and control internal seepage through the embankment. • Majority of seepage will be collected within two downstream seepage collection ponds or report to the open pit.	• Loose granular material in the foundation.	• Use deeper cutoff wall to minimize seepage. • Use geotechnical instruments and construction monitoring to monitor performance during construction, prior to filling the TSF.	Category IV
PFM # 17	Overtopping due to major precipitation event, and/or inadequate water balance, inadequate freeboard that leads to a rise in impoundment water level which eventually overtops and erodes confining embankments.	•Freeboard = 13m, which significantly exceeds minimum requirements to accommodate PMF and wave run-up above water elevation. •Sloped tailings beaches push supernatant pond over >700m away from east embankment.	• None.	• Water management and maintenance of freeboard availability.	Category IV

Table A.5

Potential Failure Modes Assessment Case #5 – South Embankment – End of Year 20 (Ultimate)

Potential Failure Mode #	Potential Failure Mode	Positive Factors	Adverse Factors	Mitigation Opportunity	Consequence Category (I and IV)
PFM # 18	Large catastrophic failure triggered by a seismic event and/or high pore pressures leading to deep seated foundation failure and subsequent breach and a release of tailings downstream.	• Factor of Safety is several times higher than design criteria. •13m of pond water freeboard • Foundation geology consists mostly of compact to very dense glacial deposits overlying competent bedrock. • Most weak layers were identified at shallow depth (<5m), which will be sub excavated out. • Continuous weak layers at depth were not identified.	• Shallow weak unit identified beneath foundation approximately 5m deep.	• Add rock buttress or reduce overall downstream slopes to improve stability. • Provide performance monitoring program to monitor to confirm that no movements within the foundation.	Category II
PFM # 19	Overtopping due to major precipitation event, and/or inadequate water balance, inadequate freeboard that leads to a rise in impoundment water level which eventually overtops and erodes confining embankments.	•Freeboard = 13m, which significantly exceeds minimum requirements to accommodate PMF and wave run-up above water elevation. •Sloped tailings beaches push supernatant pond over >700m away from south embankment.	• None.	• Water management and maintenance of freeboard availability.	Category IV