Mount Nansen Site

Tailings Facility and Associated Structures

Emergency Response and Preparedness Plan

April 16, 2014

Government of Yukon

Energy, Mines and Resources

Assessment and Abandoned Mines

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Emergency Response and Preparedness Plan – Record Tables

The following tables shall be maintained by the responsible parties

Record of Emergency Response and Preparedness Plan Holders

Name	Position	Organization	Location	Contact Info
Floyd Meersman	Site Manager	DES	Vehicle	Floyd Meersman
Richard Wilkinson	Site Manager	DES	Vehicle	Richard Wilkinson
Sr Project Mgr	Sr Project Mgr	AAM	Office	
Manager	Manager	AAM	Office	
Site Office		AAM	Office	Site Office

Note: *The Operation Maintenance and Surveillance Manual is not currently in these locations, as a final version of this document has not yet been produced.*

Record of Revisions to Emergency Response and Preparedness Plan

Date	Reason	Person Requesting Change	Position	Signature
9-Nov-16	***Personnel and contact info changes***	***Jeff Moore***	***Project Officer***	

Contact Information

AAM Contacts	Position	Office #	Mobile #	Off-Site Residence #
Project Officer	Project Officer	867.456.6157	867.332.1480	867.456.7502
Sr. Proj. Mgr.	Sr. Proj. Mgr.	867.456.6764	867.336.0461	
Manager	Manager	867.667.3208	867.332.4431	
General Office #		867.393.7098		
DES Contacts	**Position**	**Office #**	**Mobile #**	**Off-Site Residence #**
Janet Lowe	Manager	705.848.9191	705.849.3640	
Wade Wiggins	Sr. Proj. Mgr.	705.848.9191 X 236	705.261.1801	
Floyd Meersman	Site Mgr.	867.334.5487	867.334.5487	
Richard Wilkinson	Site Mgr.	867.334.3711	867.334.3711	

1. Introduction

The purpose of the Emergency Response and Preparedness Plan (ERPP) is to provide a plan that includes mechanisms and processes for addressing potential failures of structures and equipment at the Mount Nansen Site. This ERPP describes the internal processes and procedures of a response to a failure or potential failure at the Site. The first respondent will be the site operator's personnel and they shall notify Assessment and Abandoned Mines (AAM) as soon as possible.

2. Site Description

The Mount Nansen Site is a former gold and silver mine that is currently in the care and maintenance stage of the mine's life, and is undergoing closure planning. The Mount Nansen property is located approximately 45 km west of Carmacks and 180 km north of Whitehorse, Yukon and is within the traditional territory of the Little Salmon/ Carmacks First Nation. An all-weather road (i.e. the Mount Nansen Road) connects the site to the North Klondike Highway in Carmacks. The Government of Yukon, Highways and Public Works maintains the Mount Nansen Road up to the property boundary. The site is powered by diesel-fuelled electrical generators and associated infrastructure; these components are maintained by the on-site operator. Telephone communication is available via satellite telephone as well as cellular telephone (CDMA only) assisted by a signal booster located within the site camp facilities. Internet communication is available through a satellite dish antenna within the residence. The site is managed by the Government of Yukon, Energy Mines and Resources, AAM.

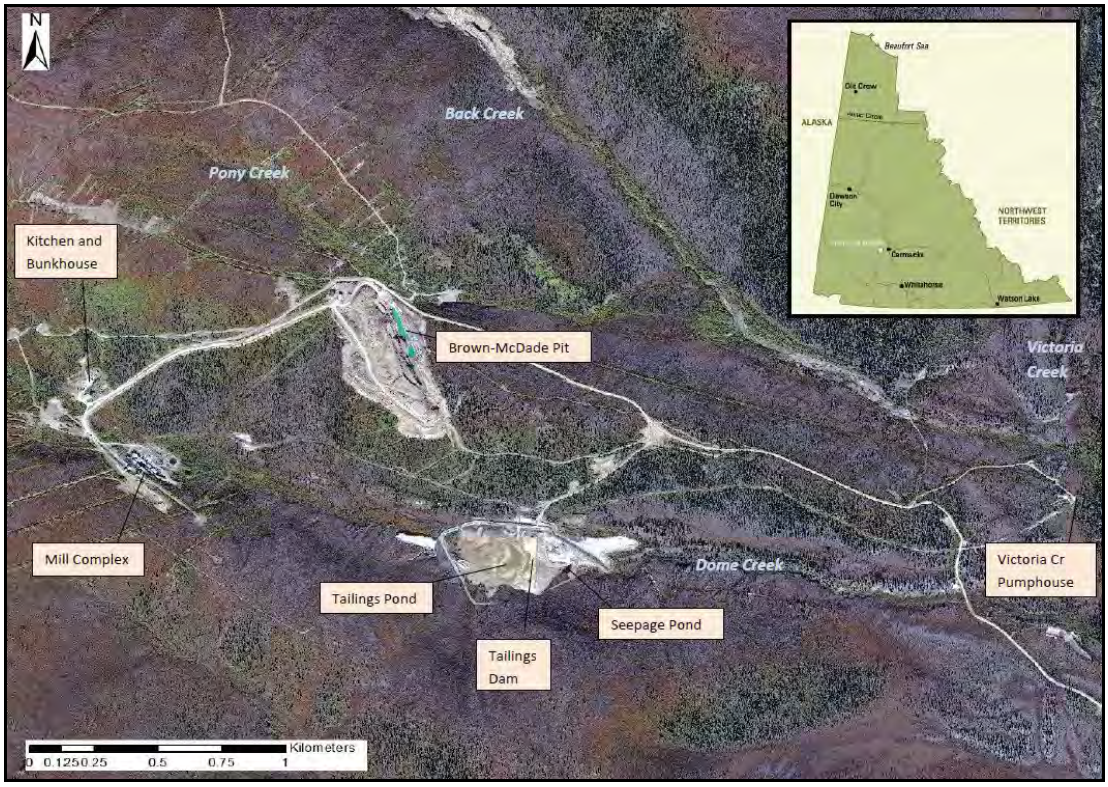

Figure 1 – Mount Nansen Site Layout

There are three structures associated with the Tailings facility at the Mount Nansen Site: the tailings dam, the seepage pond dam, and the diversion channel berm/ditch. All of the structures are of prime importance where failure of any of the structures constitutes an emergency which must be addressed through the procedures and processes within this document.

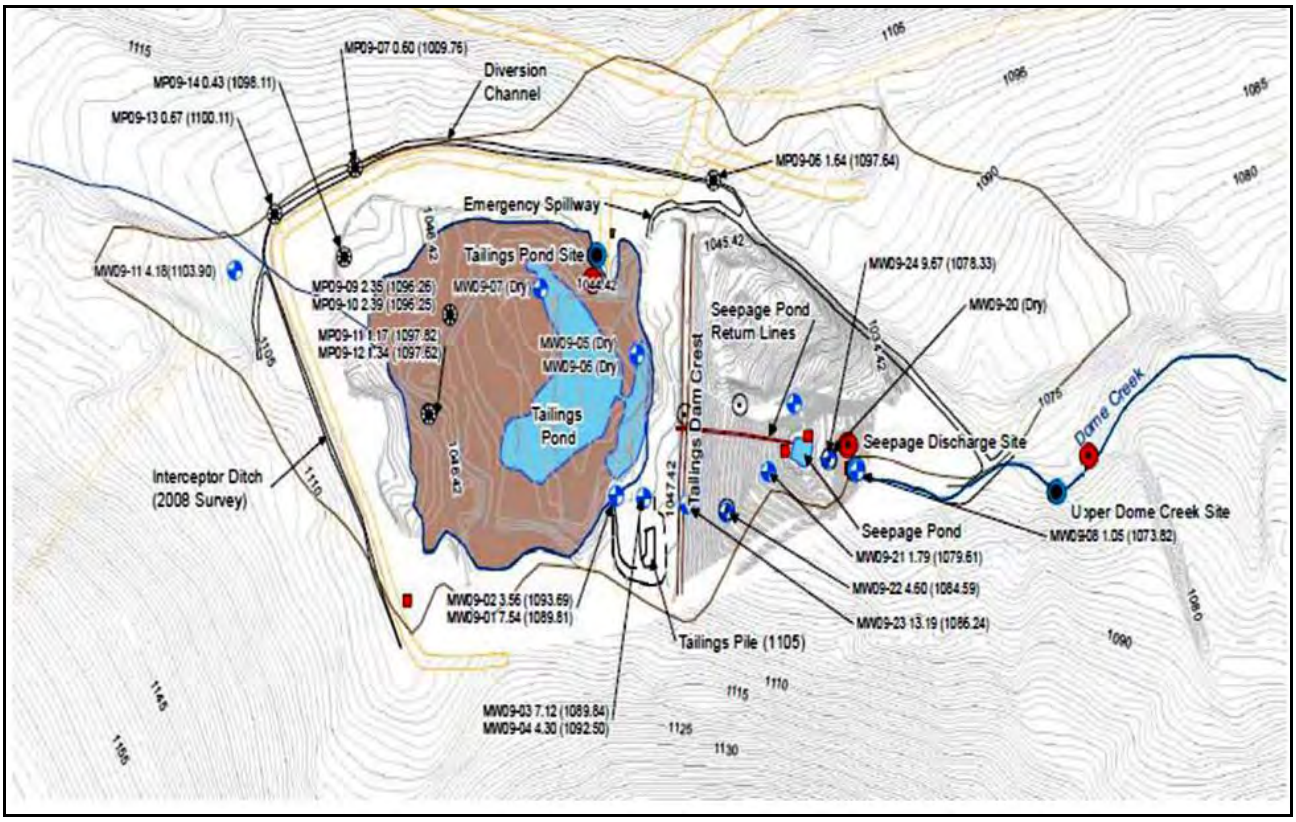

Figure 2 – Tailings Pond Area with Monitoring Wells

The Mount Nansen Site is in a remote location with no local year round residents. Adverse social/public effects of an emergency are limited to placer miners, personnel of nearby geological exploration activities, and seasonal trappers and hunters who are using the Mount Nansen Road which is just outside the site boundary.

The Site is located within the Dome Creek drainage area, which is part of the water shed that leads to the Yukon River; Dome Creek connects to Victoria Creek, which connects to the Nisling River, which connects to the Donjek River, which connects to the White River, which ultimately connects to the Yukon River.

A diversion channel intercepts Dome Creek upstream of the tailings pond and directs the water to release it to the original Dome Creek channel downstream of the seepage pond. All structures were constructed on a permafrost base which is subject to melting.

Seepage through the tailings dam is monitored by a flow meter at the pump in the seepage pond, which is located immediately down gradient of the tailings dam. The flow rate of water from the seepage pond

provides a good indication of the possibility of excess seepage from the tailings dam and thus is a good indicator of failure of the dam subgrade through melting permafrost. Seep water flows through thawed soils easier than through frozen soil; so when the soil thaws out, the volume of the flow will increase.

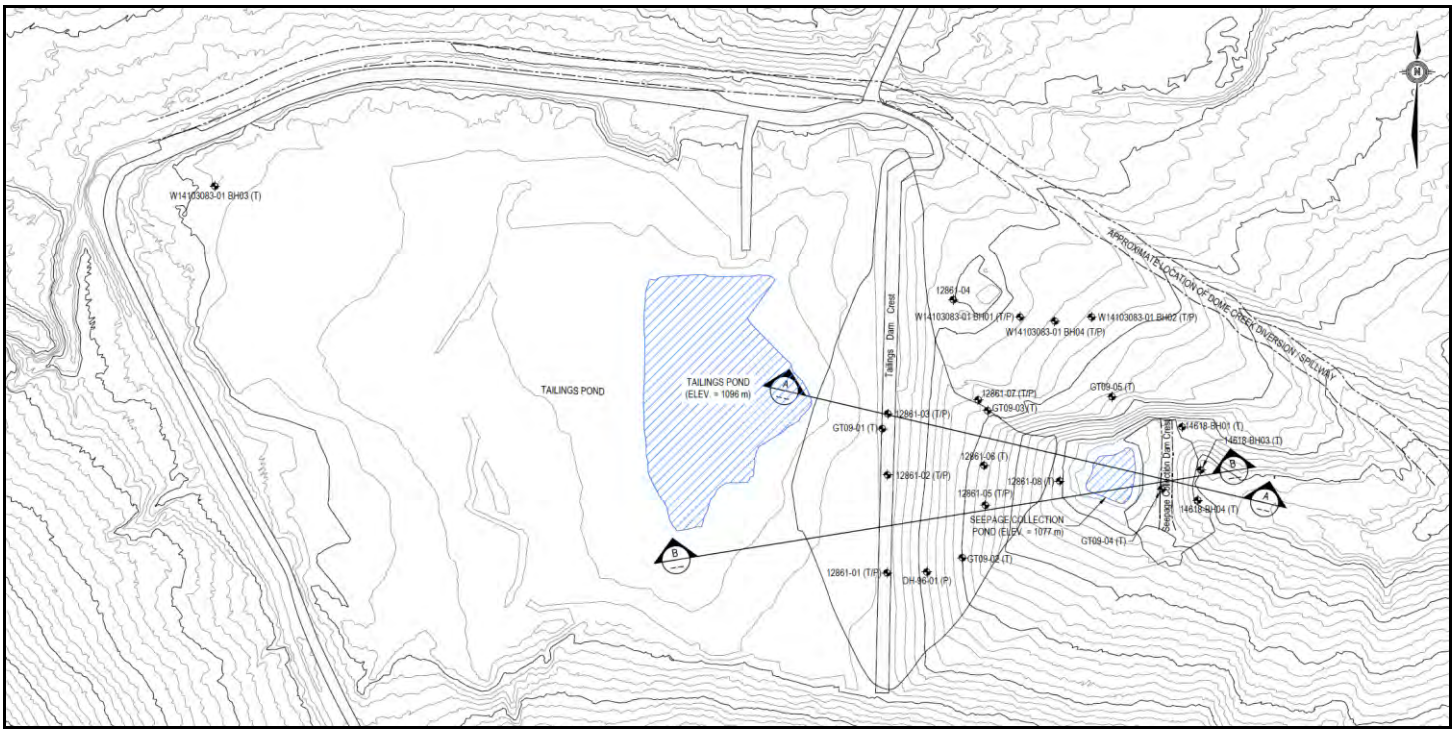

Figure 3 – Tailings Pond Area Instrumentation

The water flow is captured daily and historical database is maintained in order to provide an indication of what flows are normal and what flow value should trigger a response. The level of the water in the ponds are monitored and recorded in order to provide a normal level within the pond. The results are analysed and used to predict changes in conditions.

Excessive precipitation, snowmelt and/ or blockage of the diversion channel could result in overtopping of the diversion channel berm which must be treated as a hazardous condition. The berm is constructed from sand and as such is subject to erosion very quickly. The water level in the pond is maintained by a combination of seepage and evaporation.

The tailings pond contains several hazardous substances such as arsenic and various metals which will be harmful to the natural environment. The large majority of the materials are mill process tailings. Any situation that could result in a release of the substances contained within the tailings facility must be considered as a potential emergency where personnel must follow the procedures outlined in this plan. Environmental damage that could result from a dam failure would almost certainly be caused by the flow of fresh water through the exposed tailings.

Contaminant transport in the event of an incident will travel throughout the downstream watershed. At this time there are no facilities in place to protect the environment from contaminant transport in the

event of a release. A contaminant that is released due to an overtopping or failure event could travel through the entire downstream watershed and would have long term consequences downstream.

Physical risk to people would be limited to the on-site workers due to the site security procedures. Public is permitted along the access road that crosses Dome Creek approximately 1.6 km downstream. It is considered unlikely that the physical effect of a failure would include the crossing at Dome Creek. Site workers are trained in potential hazards and should be aware of the signs of a potential failure and therefore should be able to avoid harm.

3. Identification of a Requirement for Action

Immediately following discovery of a condition (listed below) with the potential to result in a failure of the site facility or hazardous situation, operations staff should immediately verify and assess the level of emergency using predefined criteria to trigger the appropriate response. Below, the three levels of response are defined, with increasing levels of urgency:

- Level 1: Hazardous condition or incident – The hazard or incident does not pose an immediate danger but could develop into one.
- Level 2: Potential emergency – Steps may need to be taken to mitigate hazards to personnel or damage, steps may need to be taken to notify potentially affected parties.
- Level 3: Imminent or actual emergency – Immediate evacuation of downstream areas.

Upon recognition of a situation requiring the activation of the ERPP, site staff should immediately reference to the ERPP and implement the measures directed.

Conditions which may lead to a failure of systems and structures and/or which could constitute an emergency includes, but is not limited to:

- Failure of a major structure such as the diversion channel berm, tailing or seepage dam;
- Failure of major equipment such as electrical generating equipment or pumping equipment;
- Slope failure having the potential to cause dam or berm failure;
- Blockage of the diversion channel which may cause the berm to fail;
- Sudden increase in seep volume occurrences which could lead to dam failure;
- Rapid increase or unexplained cloudy appearance of seepage water;
- Natural disasters such as earthquakes or major storm events (e.g. high precipitation events); and
- Potential environmental contamination such as contaminated water at discharge, contaminated water seeps or tailings entering water courses (e.g. if sampled water suddenly becomes contaminated and does not meet the release threshold).

Incidents that have the potential to cause imminent and unacceptable harm to life, the environment, facilities and / or equipment are to be treated as emergencies. In an emergency situation the first priority is the protection and rescue of people. Particular attention will be given to inspecting, and where necessary, repairing the tailings facility following unusual or extreme events. All unusual events will be reported to supervisory personnel and AAM. In the event that high seepage flows occur down

gradient of the tailings dam, and particularly if water is carrying soil particles from the dam or its foundation, which is an early indication of piping, it will be reported to AAM immediately through the contact list provided at the beginning of this document. AAM will then ensure that the appropriate resources (e.g. geotechnical engineer) are brought to site in order to investigate the situation and provide recommendations for appropriate actions, including actions to prevent further deterioration where feasible. An action follow-up form is provided in Appendix A of this document.

4. Emergency Response and Preparedness Plan

4.1. General

Having an Emergency Response and Preparedness Plan (ERPP) in place enables site personnel to be prepared in the event of an emergency. It also provides one component of a comprehensive facility management system for the tailings facility and associated structures. The goals of the ERPP are to firstly prevent the occurrences of emergencies and secondly to reduce the impact of emergencies. In both cases the goal is to protect human health and safety, and the environment.

This plan describes the responsibilities of key personnel and outlines general procedures to be followed when responding to emergencies in a way that will avoid or reduce risks to human health and safety and the environment. It is expected that the ERPP will continue to be developed throughout closure planning and implementation. The plan will be reviewed and updated annually or when warranted by changes in site conditions. A documented program of updates as well as document control, training and testing will be established to ensure effectiveness during an emergency. The ERPP will be distributed to a closed group in order to ensure that all copies of the plan are accounted for and only designated individuals are keeping the copies up to date.

The distribution list is as follows:

- Site Manager's Office - 1 Copy
- Site Manager's Truck - 2 Copies
- AAM - 2 Copies

4.2. Roles and Responsibilities

All persons on site including site operations personnel, consultants, contractors, and other authorized personnel are required to be aware of site activities for which there is a reasonable cause to believe there is potential for an emergency event to occur.

All personnel from the site operator's team have a responsibility to be fully familiar with the ERPP and to actively participate in emergency response preparation, training and drills. The site operator is also responsible to provide a site briefing to all new authorized personnel completing work at the site. All personnel from the site operator's team have a responsibility to take immediate action as prescribed by procedures contained within this plan to protect themselves, others, the environment and site assets, in that order. All personnel are to be aware that the preservation of their own health is their first priority and to not place themselves in danger.

4.3. Plan Activation

Immediate communication of a potential or actual emergency is essential, in order to get qualified individuals to assess the situation or to assist in response as soon as possible. VHF radios are provided to all site operations personnel and authorized personnel on-site; these are to be used to alert and communicate with others on-site during an emergency. In all situations the site manager must be notified. The site manager shall then notify AAM immediately. AAM will determine if outside assistance is required. Possible examples where outside resources may be required include a spill that cannot be contained or a catastrophic failure that threatens personnel, the public and the environment. The procedure for response and communication in the event of an emergency is presented in Figure 4 below.

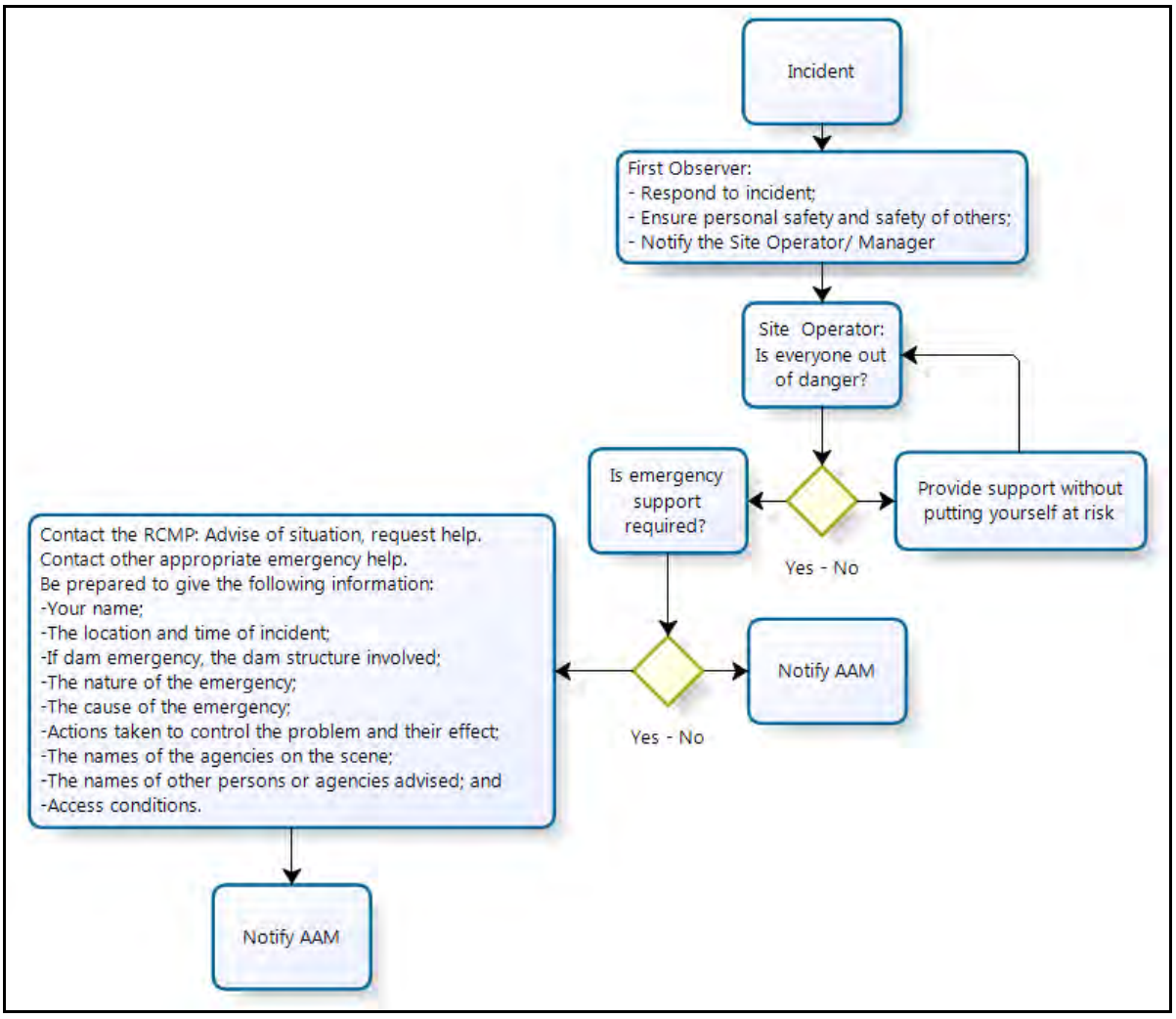

Figure 4 – Incident Response and Communication Flow Chart

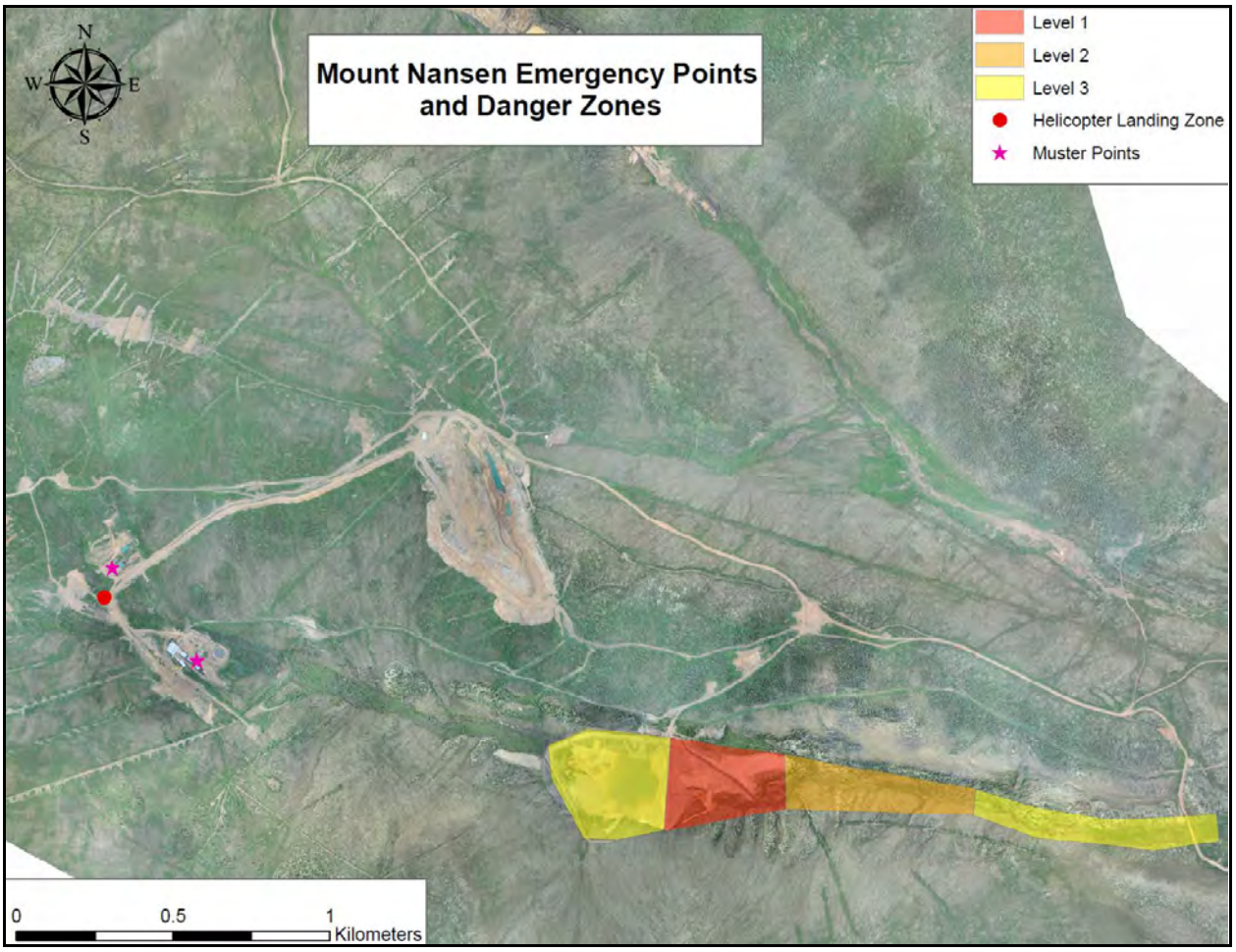

Figure 5 – Mount Nansen Emergency Points and Danger Zones

Figure 5 above identifies the muster points and the helicopter landing zone, as well as the zones that are considered to be dangerous in the case of an emergency; Level 1 being very dangerous, Level 2 being moderately dangerous and Level 3 being marginally dangerous.

4.4. Notification Procedures

Notification is done to alert others of an unusual condition that has occurred or is still occurring and that may require action. It is to be done promptly, but there is typically time to first gather more information on a situation, to analyze possible causes, and to take some initial remedial measures. Notification will occur internally, and externally as deemed necessary by AAM.

Internal notification is given to the site manager according to the chain of command as appropriate. As a general rule, always inform the site manager of any unusual incident that has occurred on site, any anomalous monitoring results, or any potentially hazardous condition. If in doubt about the significance or importance of something you have observed, err on the side of caution and report it to the Manager. The Manager must then pass the information to AAM which will ensure appropriate investigations are being conducted and determine necessary actions.

AAM personnel shall be notified in the event of all incidents on site, particularly events where external notifications to government agencies or downstream-affected persons are necessary. External notification will be communicated by AAM to persons or agencies outside of the Mount Nansen site. Some key persons or agencies that will be notified of an incident include in the order below:

- Emergency Support: In the event of a situation that needs immediate assistance which cannot be provided by AAM the site manager must contact the RCMP who will provide a conduit to acquire help.
- AAM: In the event of any incident, the site manager will notify AAM.
- Appropriate Technical Resources: In the event of potential dam instability, leakage or failure, the appropriate resource (e.g. geotechnical engineer) will be immediately contacted by AAM. Investigative and mitigation actions will then be implemented as recommended.
- Energy, Mines and Resources (EMR) Communication: AAM to contact for public communications.
- Downstream Affected Persons: A dam incident could result in off-site effects, for example a spill, water quality issue, or dam breach. In this case, effort must be made to ensure that all those potentially affected by the situation are notified and given directions to reduce their exposure. Actions must also be taken to prevent the public from unknowingly being affected by the situation (e.g. possibly by restricting access to downstream roads and waterways). AAM will work closely with territorial and appropriate authorities to ensure that notification of downstream-affected persons is timely and comprehensive.
- Other: During and after a significant event, it may be necessary to respond to questions and concerns by the media, general public, special interest groups, and other stakeholders. EMR communication will be responsible for this communication.

Figure 6 below presents the response and communication procedure to follow when a hazardous condition is observed.

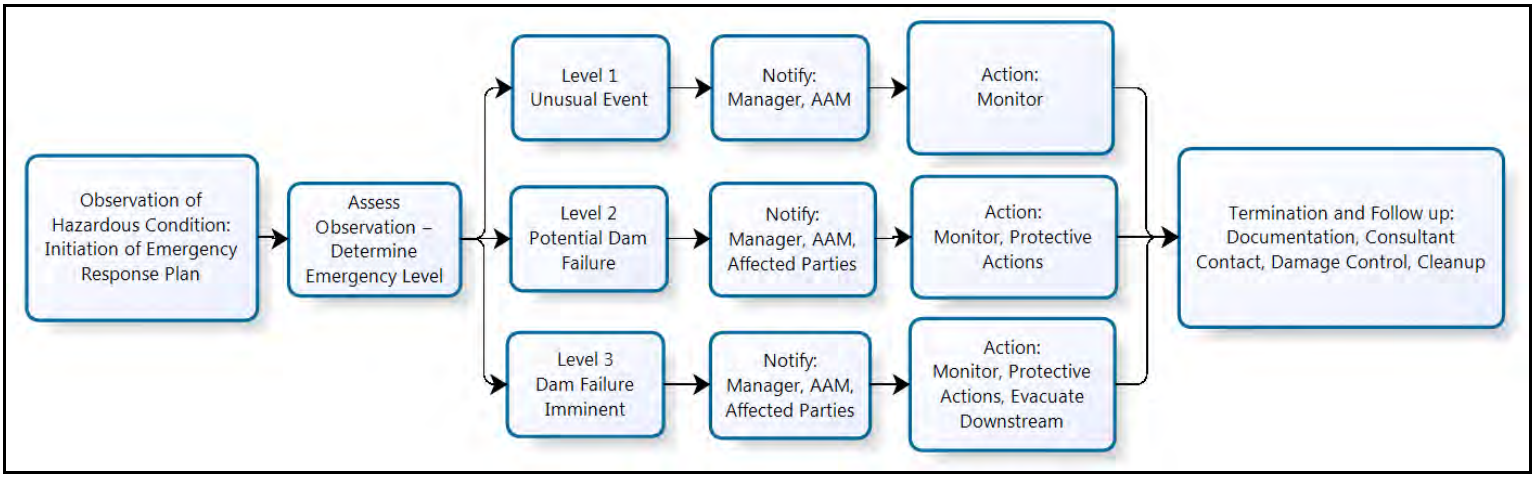

Figure 6 – Observation of Hazardous Condition Response and Communication Flow Chart

4.5. Notification Contacts

Contact details including names of key individuals, their agencies and telephone numbers are provided below:

- AAM:
  - Josée Perron: (867) 456-6775 w, (867) 332-9019 c
  - Patricia Randell: (867) 667-3208 w, (867) 332-4194 c
- DES:
  - Ian Ludgate: (705) 848-9191 w, (705) 849-3640 c
  - Kristian Autio: (705) 848-9191 X 230 w, (705) 849-3641 c
  - Richard Wilkinson and Ed Grennan: radio call on site
- RCMP Carmacks: (867) 863-2677
- Ambulance Services: (867) 863-4444
- Wildfire: (888) 798-3473
- Highways and Public Works: (867) 393-7193
- Spill line: (867) 667-7244
- Emergency Measures Organization: (867) 667-5220
- Yukon Workers' Compensation Health and Safety Board: (867) 667-5450

4.6. Actions to Prevent Structure Failure

The dam breach could be triggered by “piping” (i.e., internal erosion) or overtopping. It is difficult to predict where a dam breach would be initiated and precisely what corrective actions would be required. Nevertheless, to assist the site personnel in dealing with emergency situations threatening the tailings dam, this section describes the resources available to the site and the potential course of actions that could be taken promptly to avert a dam breach. These actions could include: (1) lower tailings pond level; (2) arrest or retard dam internal erosion; and (3) arrest or retard dam external erosion. During site operations there will be continual personnel presence around the tailings facility. If a situation arises that requires immediate attention, AAM has at its disposal the equipment, material, labour and engineering expertise to respond immediately. These resources include personnel on-site and those available through outside contractors and consultants. Review of the Operations, Maintenance and Surveillance Manual may be required for safe water levels and drawdown rates.

The following are potential scenarios as well as temporary mitigations in order to reduce the risk of failure as well as minimizing the potential impact on human health and the environment.

Overtopping of Dam or Berm

- Remove blockage of drainage paths to allow water to flow normally.
- Place sandbags or other water blockage materials to increase freeboard and force more water through spillway or diversion channel.
- Provide erosion protection by placing rock or other materials over eroding areas.
- Divert water away from breach if possible.

Reduction in Freeboard or Loss of Dam Crest Width

- Place additional rip rap or sand bags in damaged areas to prevent further erosion.
- Lower the water level to an elevation below the damaged area.
- Restore freeboard with sandbags of earth and rock fill.
- Continue close inspection of the damaged area.

Slide on the Slope of the Dam Embankment

- Lower the water level at a rate, and to an elevation that is safe given the slide condition. If the outlet is damaged or blocked, pumping, siphoning or a controlled breach may be required.
- Restore lost freeboard by placing sandbags or fill at the top of the slide.
- Stabilize slides on the downstream slope by weighting the toe area with additional rock, soil or gravel.

Erosional Seepage or Leakage (Piping)

- Plug the flow with whatever material is available (hay bales, bentonite, or plastic sheeting).
- Lower the water level until the flow decreases to a non-erosive velocity or it stops.
- Place a blanket filter (sand and gravel) over the exit areas to hold materials in place.
- Continue lowering the water level until the reservoir reaches a safer elevation. The safest elevation of water is when the surface of the water is lower than the seep.

Failure of an Appurtenant Structure such as an Outlet or Spillway

- Implement temporary measures to protect the damaged structure, such as closing an outlet or providing temporary protection for a damaged spillway. This may be achieved by filling the break with gravel, hay bales or using tarps to stop or slow the flow.

Mass Movement of the Dam on its Foundation (Spreading or Mass Sliding Failure)

- Immediately lower the water level until excessive movement stops. This may be achieved by pumping or an emergency release of water using heavy equipment. Ensure that no lives are placed in danger during this process.
- Continue lowering the water level until a safer level is reached.
- Continue operation at a reduced level until repairs are complete.

Excessive Seepage and High Level Saturation of the Embankment

- Lower the water to a safer level.
- Continue frequent monitoring for signs of slides, cracking, or concentrated seepage.
- Continue operations at a reduced level until repairs are complete.

Spillway Back-cutting Threatening Reservoir Evacuation

- Reduce the flow over the spillway by fully opening the main outlet.
- Provide temporary protection at the point of erosion by placing sandbags, rip rap materials, or plastic sheets weighted with sandbags.
- When inflow subsides, lower the reservoir to a safe level.
- Continue operating at a lower water level in order to minimize spillway flow.

Excessive Settlement of the Embankment

- Lower the water level by releasing it through the outlet or by pumping, or siphoning.
- If necessary, restore freeboard, preferably by placing sandbags.
- Lower water to a safer level. The only safe level is when there is no water in the pond.
- Continue operating at a reduced level until repairs can be made.

Attached in Appendix B is a list of dam potential failure modes, including performance parameters, and surveillance activities. In the event of any of the identified failure modes, the performance parameters shall be surveyed using the surveillance methods/ activities identified in the table.

Appendices

Appendix A: Action Follow-up Form

Government of Yukon
Energy, Mines and resources
Assessment and Abandoned Mines
Mount Nansen Site

Name of Respondent: _____

Date of Original Incident: _____

Name of AAM Contact: _____

Date of Action Taken	List All Actions Taken and Completion Dates	Recommended Changes

Signature of Respondent: _____

Date: _____

Appendix B: Potential Failure Modes, Performance Parameters, and Surveillance Activities

Appendix A: Potential Failure Modes, Performance Parameters, and Surveillance Activities

Failure Mode Identification	*Failure Description*	*Performance Parameter*	*Possible Surveillance Methods/Activities*
Overtopping Crest or Impervious Core (Embankment Dam)	• flow over top of core or over top of dam • flow on downstream face of dam • causes erosion of material near exit point on downstream slope • creation of flow gullies and channels on downstream slope • erosion of protective covering • progressive erosion and widening of breach opening • slope instability	• Seepage • Reservoir water level (with respect to core elevation)	• Reservoir water level gauge measurement • Flood/ event visual inspection • Weirs for water flow measurement • Phreatic level measurement with observation wells or piezometers
Piping of Embankment Dam Core into Filter Piping of Embankment Dam materials into Overburden Foundation Piping of Embankment Dam materials into Bedrock Foundation Piping of Overburden Foundation into Dam Piping of Upstream Blanket Piping through Impervious Membrane Piping along Conduits, Outlet Works or Abutment	• internal erosion of dam through downstream filter/shell or through overburden foundation • erosion of foundation material into filter/shell • erosion of shell or foundation material at toe of dam • (backward) erosion leading to loss of support, collapse, slope instability • effect depend on types of earth/rockfill dams • inadequate foundation treatment • poor design or construction practice (may also include leakage from pressure conduits through the dam that leads to piping failure)	• Seepage & turbidity (in seepage water) • Upstream whirlpools • Downstream sand boils • Wet spots and leakage on downstream slopes, groins, abutments or foundation below dam • Piezometer level changes • Sediment deposition in drains and weirs • Sinkholes, depressions	• Phreatic level measurement with observation wells or piezometers • Weirs (downstream) for water flow measurement • Temperature profile measurement • Visual inspection

Failure Mode Identification	*Failure Description*	*Performance Parameter*	*Possible Surveillance Methods/Activities*
Contact			
Seismic Shaking – Liquefaction Seismic - Fault Displacement Beneath Embankment Dam Seismic Shaking – Longitudinal Cracking of Embankment Dam Seismic Shaking - Transverse Cracking of Embankment Dam Seismic Shaking – Settlement of Embankment Dam	• seismic event which causes embankment material and/or foundation to settle • settlement could result in overtopping of dam • liquefaction of one or more embankment zones or foundation overburden • results in excessive settlement leading to overtopping • results in slope instability • seismic movement of fault beneath/adjacent dam • develop shear crack through dam • results in water flow along crack leading to failure • development of longitudinal cracks within dam • development of transverse cracks within dam • results in increased water flow through dam	• Crack development • Upstream and downstream slides • Toe bulges • Horizontal or vertical displacements • Settlement • Sand boils • Seepage increase	• Post seismic visual inspection • Displacement measurements • Artesian pressure/phreatic level measurement • Water flow measurement - downstream weirs
Slope Stability – Embankment Dam	• development of deep seated slope failure resulting in loss of freeboard • can be either upstream or downstream slope	• Settlement of dam crest • Transverse and longitudinal cracking • Toe bulges • Alignment deviations • Closure of downstream drainage ditch	• Artesian pressure/phreatic level measurement • Displacement measurements • Visual inspection
Sliding Stability – Concrete Dam Overturning Stability – Concrete Dam	• sliding along concrete/ bedrock contact or bedrock foundation immediately under contact • high stresses along contact leading to overturning failure	• Increase in leakage at abutment and foundation contacts • Significant increase in discharge from drains within dam or foundation • Leakage from joint or	• Uplift/phreatic level measurement • Displacement measurement • Visual inspection • Water flow measurement • Turbidity

Failure Mode Identification	Failure Description	Performance Parameter	Possible Surveillance Methods/Activities
		crack • Seepage flow or wet areas downstream • Undermining at toe • High uplift pressure • Plugged foundation drainage/ high levels in vertical drains.	• Seepage path investigations • Joint and crack measurement • Horizontal and vertical displacement measurement • Angular displacement measurement • Strain measurement • Stress measurement • Temperature measurement • Soundings • Permeability measurement
Concrete Structural Integrity Concrete Scour	• cracking of concrete during static, hydrologic or seismic event • deterioration of concrete integrity leading to uncontrolled release of headpond water	• Severe structural cracking • Increase in leakage • Deteriorating construction joints • Significant contraction and construction joint movement • Misalignment • Deterioration of deck (log lifter) support beams	• Uplift/phreatic level measurement • Displacement measurement • Visual inspection • Water flow measurement • Turbidity • Chemical analysis • Material deterioration • Seepage path investigations • Joint and crack measurement • Horizontal and vertical displacement measurement • Angular displacement measurement • Strain measurement • Stress measurement • Temperature measurement • Soundings • Permeability measurements
Bedrock Foundation Stability	• failure along a weak plane within foundation bedrock	• Increased foundation leakage • Significant increase in discharge from drains within dam foundation • Differential movement of structure	• Uplift/phreatic level measurement • Displacement measurement • Visual inspection • Water flow measurement • Turbidity • Seepage path

Failure Mode Identification	*Failure Description*	*Performance Parameter*	*Possible Surveillance Methods/Activities*
		• Seepage flow or wet areas downstream • Undermining at toe • High uplift pressure	investigations • Joint and crack measurements • Horizontal and vertical displacement measurement • angular displacement measurement • strain measurement • stress measurement • temperature measurement • soundings • permeability measurement
Bedrock Abutment Stability	• loss of abutment support for dam, likely along weak planes within rock • may be either concrete or embankment dams	• Increase in foundation leakage • Significant increase in discharge from drains within dam foundation • Differential movement of structure • Seepage flow or wet areas downstream • Undermining at toe • High uplift pressure • Inadequate design • Poor foundation • Deterioration of concrete/bedrock contact	• uplift/phreatic level measurement • displacement measurement • visual inspection • water flow measurements • turbidity • seepage path investigations • joint and crack measurement • horizontal and vertical displacement measurement • angular displacement measurement • strain measurement • stress measurement • temperature measurement • soundings • permeability measurement
Bedrock Foundation Integrity Bedrock Scour	• bedrock foundation deterioration • ravelling of material • increased flow from foundation bedrock • undermining of foundations	• cracking • increase in leakage • deteriorating bedrock conditions • significant contraction and construction joint movement • inadequate design • poor construction practice	• uplift/phreatic level measurement • displacement measurement • visual inspection • sampling and laboratory testing • water flow measurement • turbidity • chemical analysis • material deterioration • seepage path

Failure Mode Identification		Failure Description	Performance Parameter	Possible Surveillance Methods/Activities
				investigations • joint and crack measurement • horizontal and vertical displacement measurement • angular displacement measurement • strain measurement • stress measurement • temperature measurement • soundings • permeability measurement
Unlined Tunnels	Bursting	• failure of tunnel to carry water effectively	• seepage from ground and new streams developing • turbid seepage • leakage from tunnel into rock	• visual inspections with tunnel watered up • monitoring of seepage, pressures and movement
	Rockfall	• partial tunnel blockage	• rocks/gravel through valves or turbines • rock traps filled • unexplained flow reduction	• visual inspections • audible noise
	Collapse	• tunnel blockage - full, partial	• decreased discharge • rock trap filled • turbid discharge	• visual inspection • monitoring precursor activities, e.g. rockfalls
Lined Tunnels (Steel and Concrete)	Bursting	• displacement of tunnel plug • tension failure of concrete and/or steel liner	• seepage from ground and new streams developing • turbid seepage observed • liner or plug bursting under pressure	• visual inspections with tunnel watered up • monitor tunnel discharge
	Collapse by crushing	• tunnel blockage: full, partial	• decreased discharge • rock trap filled • turbid discharge	• visual inspections for potential defects or changes • monitor tunnel discharge •
	Collapse by negative pressure or reverse loading on liner	• tunnel blockage - full, partial	• buckling of steel liner • spalled concrete • exposed rebar	• visual inspection • monitor tunnel discharge
	Rock displacement	• pulled apart in tension, steel plate buckling in compression	• seepage from ground and new streams developing	• visual inspection for potential defects or changes

	Failure Mode Identification	Failure Description	Performance Parameter	Possible Surveillance Methods/Activities
		• tunnel blockage		• survey • extensometers
Steel Penstock	Bursting	• pinhole leaks up to penstock failure	• leaks at corrosion holes • sudden longitudinal opening of pipe (unzipping action) • higher pressure due to unusual water hammer	• visual inspections • operational review for compliance with design
	Collapse by negative pressure	• penstock blockage: full, partial • pipe sags -structural shape no longer adequate to span between supports	• buckling of steel liner: areas caved in or dented • loss of steel section due to corrosion • lower pressure due to unusual water hammer • air inlet valve or intake air shaft blockage	• visual inspections • operational review for compliance with design
	Support collapse or movement	• penstock blockage: full, partial • pipe sags: structural shape no longer adequate to span between supports	• buckling of liner: thin, curved steel plate carrying large water load will not tolerate displacements	• visual inspection of foundations, saddles and trestles • monitor penstock settlement and displacement of anchor blocks
	Penstock bending between supports	• weakened structure susceptible to partial or full failure during load rejection or seismic loads, etc	• buckling at top, tension at bottom • coating failure along stress lines • leakage	• visual inspections • monitor penstock settlement and displacement
	Expansion/ contraction	• wear on sealing surfaces damaging coatings and erosion of steel • potential erosion of penstock support structure • increased stress on penstock	• increasing leakage from around expansion joint • plate buckling due to non operation of expansion joint or support slide	• visual inspections • instrumentation
	Vibration/ resonance	• potential for partial or full penstock collapse	• fatigue failure • coating failure along stress lines • noticeable vibration • anchor block erosion	• visual inspection

	Failure Mode Identification	*Failure Description*	*Performance Parameter*	*Possible Surveillance Methods/Activities*
Wood Stave Penstock	Collapse by crushing of buried penstocks	• penstock blockage - full, partial	• seepage from ground and new streams developing • turbid seepage • collapsed wet ground	• visual inspections
	Collapse by negative pressure in conduit	• partial or full penstock failure	• section of conduit damaged • leakage and resulting winter ice accumulation • loss of stave cross section due to rotting, splitting of staves • poor design and materials	• visual inspections • operational review for compliance with design
	Bursting	• partial or full penstock failure	• section of conduit damaged • leakage and resulting winter ice accumulation • band failure • loss of water tightness due to rotting, splitting of staves	• visual inspections • operational review for compliance with design
	Support collapse or foundation movement	• partial or full penstock failure	• section of conduit damaged • increased leakage and resulting winter ice accumulation • settlement • land slides	• visual inspections of foundations, saddles and trestles • monitor penstock settlement and displacement of anchor blocks