TRANSMITTAL

DATE 20 November 2020

20351262-805-TM-Rev0

TO Michel Groleau and Jamie Quesnel
Agnico Eagle Mines Limited

CC

FROM Jen Range and Lasha Young

EMAIL jrange@golder.com

MELIADINE WATERLINE - FAILURE MODES AND EFFECTS ANALYSIS

Michel,

Please find enclosed technical memorandum *Agnico Eagle's Meliadine Mine Waterline Failure Modes and Effects Analysis in Response to Information Requests (CIRNAC-IR-9).* The technical memorandum has been prepared and reviewed by our sub-consultant Golder Associates Inc.

Please contact the undersigned if you require any clarifications.

Sincerely,

GOLDER ASSOCIATES LTD.

Jen Range
Project Manager

Lasha Young
Associate

JR/LY/jr

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GOLDER

TECHNICAL MEMORANDUM

DATE 20 November 2020 **Project No.** 20351262-805-TM-Rev0

TO Agnico Eagle Mines Limited

CC Lasha Young, Jen Range, Mark Musial, and Dr. Feng Li

FROM Dr. Bill Roberds **EMAIL broberds@golder.com**

AGNICO EAGLE'S MELIADINE MINE WATERLINE FAILURE MODES AND EFFECTS ANALYSIS IN REPONSE TO INFORMATION REQUESTS (CIRNAC-IR-9)

1.0 PURPOSE, OBJECTIVES, AND SCOPE

A failure-modes-and-effects-analysis (FMEA) was conducted on Agnico Eagle's Meliadine Mine proposed Waterline (to replace truck transport) on 4 November 2020. It was completed to respond to Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) Information Request (IR) Number 9 (see Appendix A). This FMEA identified all the significant potential "failure modes" (problems) associated with the current waterline plans, and qualitatively assessed their probabilities of occurring and relevant consequences if they were to occur, based on which the various failure modes were prioritized for possible mitigation to reduce those problems (by reducing their probability of occurring and/or their consequences if they were to occur). The scope was limited to potential waterline problems during operations and their impacts on the environment, health & safety, and other social aspects, based solely on available information and expert judgement. The focus of the FMEA was specifically potential accidents and malfunctions, considering design and operational limitations and environmental influences.

2.0 PRELIMINARY PROJECT UNDERSTANDING

Meliadine Mine is being developed as an underground and open pit gold mine located near the western shore of Hudson Bay in the Kivalliq District of Nunavut, about 25 kilometres north of Rankin Inlet (Figure 2).

As shown in Figure 1a, saline water from dewatering the underground mine and surface contact water will be collected and stored in surface ponds. The stored water will be treated in the saline effluent treatment plant (SETP) and then pumped into the Waterline.; From early July through early October (105 days), the treated effluent (3.5% saline at 4^{o}C) will be pumped from the mine site into a 35-km long waterline along the all-weather access road (AWAR) and then along the By-Pass Road to Melvin Bay (see Figure 2), into which the treated effluent will be discharged via submarine diffuser pipe. It is assumed that the waterline will be 80-85% available during the operational period, and will be completely empty when not in use (early October through early July) to prevent freezing.

The normal mine production rate of treated effluent to discharge is 6000 m^3/day. However, much of this treated effluent over the past several years has not been discharged, but stored on-site; it has been estimated that this excess inventory of treated effluent would require discharge of an additional 6000 m^3/day over the next three years for a total of 12,000 m^3/day. The proposed waterline system (pipes, pumps, etc.) has a maximum capacity of 10,000 m^3/day for each of the two pipes, and 20,000 m^3/day combined for the pair of pipes (which is an alternative maximum discharge rate).

Before re-starting operations each summer, the waterline will be inspected and tested, and any detected problems will be fixed. As dictated by topography, emptying at the end of the season will presumably involve: a) draining the water from the waterline high-point to the diffuser and, in the other direction, from the waterline high-point back to the mine site; b) then using a compressed-air-driven one-pass “dumb pig” from the discharge-end (via a “Y”-joint at the transition) 35 km to the mine-site-end to push out any remaining water in the line (e.g., between intermediate high points); and c) collecting and storing the pushed out water at the mine site (e.g., in the same pond it was initially pumped from or in other lined containment ponds that need to be kept empty, e.g., pump out rainfall). Care will be taken to completely empty the waterline, considering that compressed air driving the pig is typically moist, and that the pig does not become stuck somewhere in the waterline. If the pig were to get stuck, the blockage would have to be located and then that 100 m pipe segment would have to be disconnected at the nearest flange to free the pig.

The 35-km waterline route (adjacent to the AWAR from the mine site to Apache Pass and then adjacent to the By-Pass Road to the diffuser) is relatively flat: 60 m elevation at the mine site, rising to a maximum of 100 m elevation at AWAR KP20+000, lowering to a minimum of 0 m elevation at the diffuser (with four intermediate high points between the maximum high point and the diffuser (Figure 2). The AWAR was built 6.5 m wide in 2013 and consists of:

a) about 1m of granular fill placed on top of the generally firm tundra (saturated sandy silt tills, no organic layers, on eskers), without additional fill needed at toe (even through water ponds) where elsewhere sloughing often occurs due to progressive thaw;

b) corrugated steel pipe culverts where ephemeral drainage/ponds occur in the tundra; and

c) three bridges where there are rivers (Char River, Mile 5 crossing, and Meliadine River).

Based on observation and inspection, the seven-year-old AWAR has generally performed well (i.e., permafrost thaw typically of upper 1.5 m has not resulted in any settlement/degradation, although pipe-generated heat and/or saline effluent release could degrade the ice causing more thaw and settlement). The waterline will be placed adjacent to the AWAR and By-Pass Road, and 80 to 90% of it will be covered. The Mine is supplied by heavy trucks on the AWAR, and snow removal by heavy equipment occurs during the winter; similarly, the culverts must be checked for clearance during spring thaw to ensure water is not backing up.

In more detail, the waterline between its source (Meliadine Mine Site) and its terminal (Melvin Bay) consists of the following (Figure 1b):

- a parallel pair of 35-km long 16-inch diameter **HDPE pipes** (with 125 psi internal pressure limit)
  - in 100 m lengths with flanges (which are not covered for +/- 1 m); each pipe contains 3500 m^3 of treated effluent when full over the entire 35 km
  - adjacent to the AWAR/By-Pass Rd, either (see Figure 3):
    - covered by shallow fill (15" over top of pipe, limited by scarce sand/fill resource) to protect pipe and preserve local terrain appearance (for 29km),
    - weighted-down by concrete blocks in wet sections (to prevent pipe float) or uncovered in some rock/stiff soil sections (where excavation by backhoe is difficult) or over culverts or where there are pipe flanges (for 5km); or
    - hung underneath bridges at river crossings (in 3 places)
- air (mechanical for **pressure relief and vacuum breakers**) valve/chambers (to prevent water hammer) at each end of waterline, just after upstream pump/chamber and before downstream diffuser, as well as at 5 intermediate high points (including waterline highpoint) to ensure efficient flow; care must be taken to prevent freezing of vacuum breakers, which would make them temporarily inoperable; no other valves along pipeline
- fiber optic **leak detection system** (LDS) along length of waterline on land (tied to operator monitor) – no power (or gas line) is available along waterline; LDS must be calibrated, but leak detection is difficult during caribou migration (too much interference); supplemented by visual inspection when waterline is operating (by foot or, except near the airstrip, by drone), especially during the first season (when leaks are most likely)
- **pump system** (three pumps with power supply, which is provided by the mine on-site diesel power plant or by backup diesel generators)
  - internal pipe pressure controlled by maximum pump rpm (which is limited) – no pressure monitoring except just downstream from the pump (no power available along the pipeline), only flow metering
  - if leak is detected (by LDS), signal is sent to operator who manually stops pump (all of which takes some time, increasing the amount released in addition to the contents of the pipe at the time)
- **submarine diffuser**
  - diffuser is vertical pipe with 5 vertical ports, 23m deep (well below ice, which is <3m thick); must stabilize to ensure remains vertical (note: previous temporary diffuser used with truck transport toppled, in spite of lateral bracing and ballast); pre-season will check condition of diffuser with diver/ROV
  - transition from waterline to diffuser is currently planned as a horizontal directional drill (HDD) installation if bedrock allows (but possible freezing and draining for winter is question); can't discharge if transition is frozen (unless use temporary by-pass), so will insulate and install redundant heat tracers

- potentially affected **environment/resources, property/infrastructure, and population/traffic**
  - the local population (3000) is concentrated in Rankin Inlet, near the discharge end of the waterline but on the other side of the airstrip; otherwise along the AWAR, there is essentially no population or infrastructure (except the AWAR); however, at Apache Pass and Char River Bridge, there are a few cabins and a 12" diameter HDPE water line (on tundra from lake to town water tank, see Figure 3) for summer use (which has not settled or experienced any problems), and southwest of the airstrip, there are a few cabins
  - major truck traffic and snow removal on AWAR is radio-controlled, and there have not been any known accidents; however, ATVs during summer and small private trucks on AWAR and snowmobiles during winter are not easily controlled
  - the rivers (Char, Mile 5 and Meliadine) crossing the route are fish-bearing, whereas the ephemeral drainage/ponds are not fish-bearing
  - caribou (which are a major traditional source of food for local people) typically migrate through the area within a two-week window (early July), during which only emergency traffic is allowed on AWAR but the pipelines can still be operated

As shown schematically in Figure 4, this waterline system must be designed, permitted, procured, and constructed (including QC and testing) before finally operating (including monitoring, maintenance, and repair). However, as previously noted (see Appendix A), various problems can arise during each of these various phases that result in adverse consequences (e.g., environmental damage). Some of these consequences are of interest to the community and regulators, including typically environmental impacts, health & safety impacts, and other societal impacts (e.g., infrastructure damages/disruption, cultural/recreational damages, etc.). Other types of consequences are of interest primarily to the owner, including their financial impacts (e.g., repair costs, mine production impacts/revenue, etc.) and other corporate impacts (e.g., legal, reputation, etc.).

In response to CIRNAC-IR-9 (see Appendix A), the primary focus of this FMEA was potential waterline operational problems (i.e., specifically accidents and malfunctions) and consequences of interest to the community and regulators. A secondary focus of this FMEA, which was deferred to a subsequent stage, would be other project development phases (e.g., construction) and/or consequences of interest to the owner (e.g., repair costs, mine production impacts, etc.).

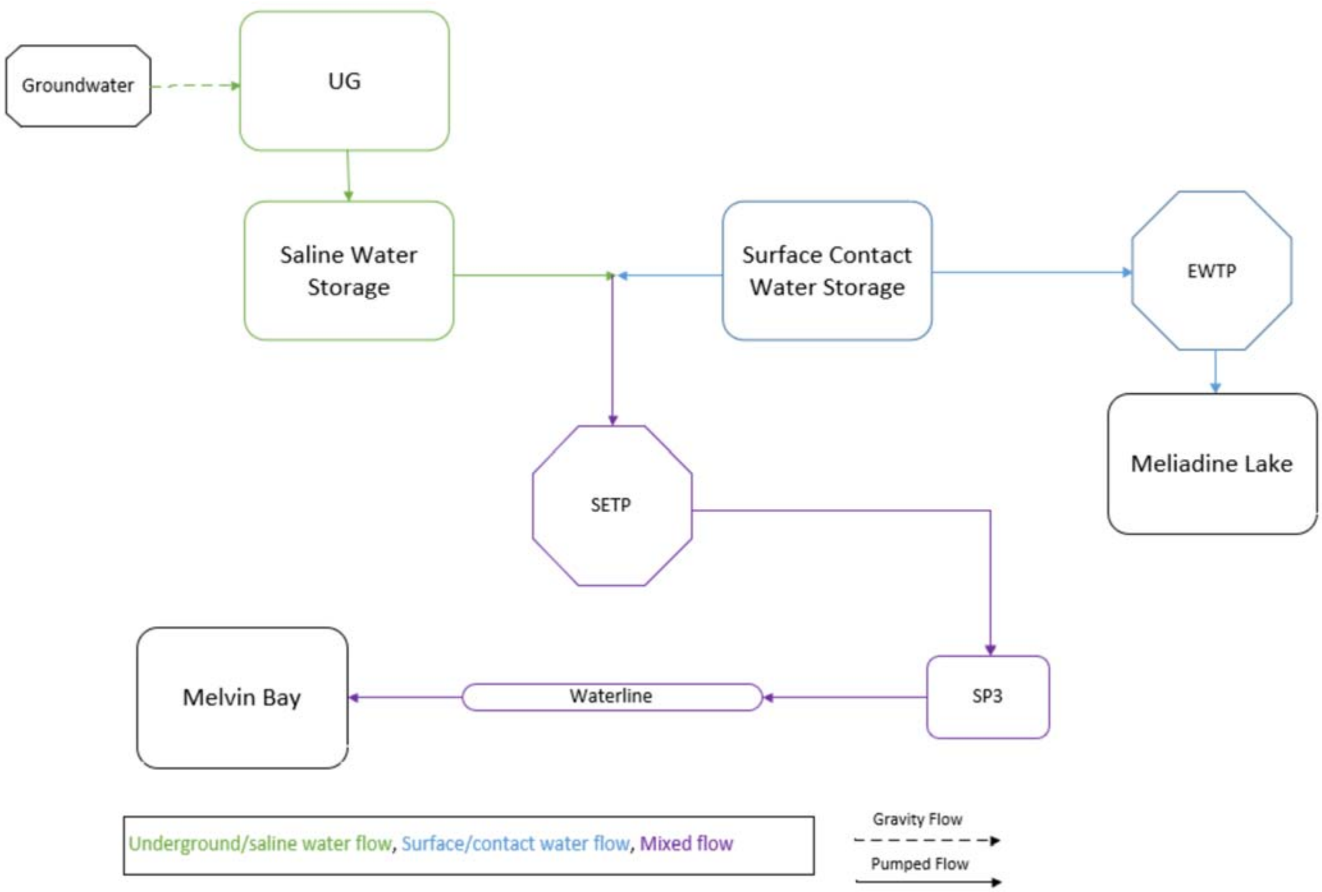
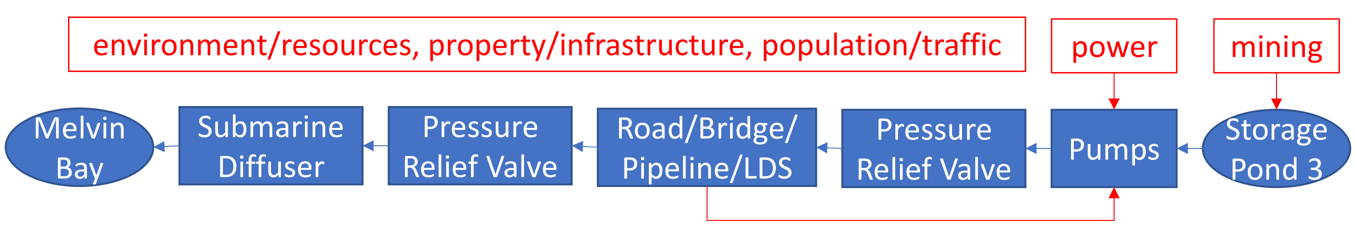


Figure 1a: Mine Water Treatment and Effluent Transport/Discharge System Schematic



Note: see Figure 1a for "waterline" role in mine water treatment and effluent transport/discharge system

Figure 1b: Waterline schematic

Figure 2: Waterline Layout (By-Pass Rd KP0+000 to KP6+000, AWAR KP3+763 to KP29+915, Mine KP29+915to KP32+000)

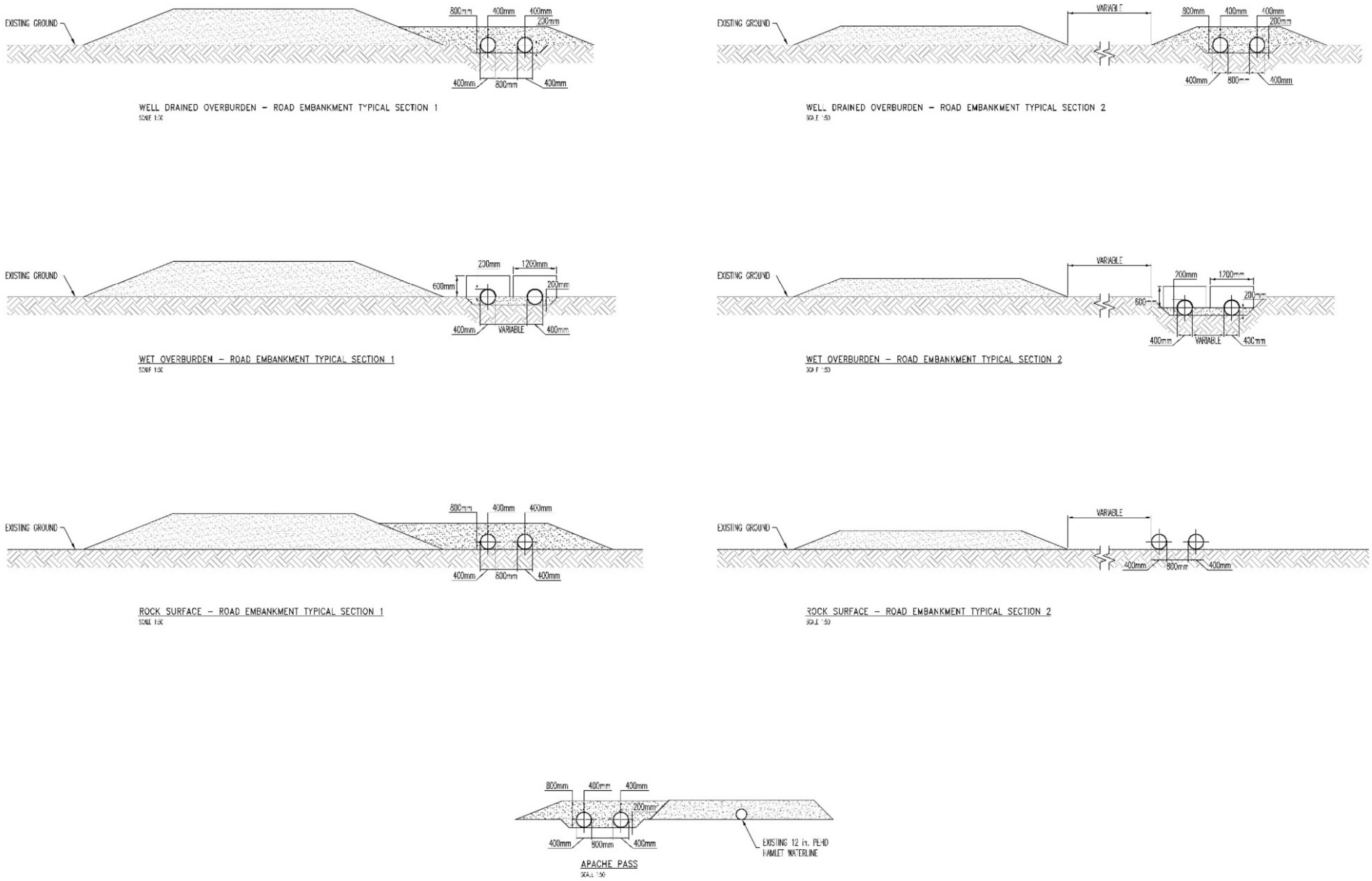


Figure 3: Waterline Covers

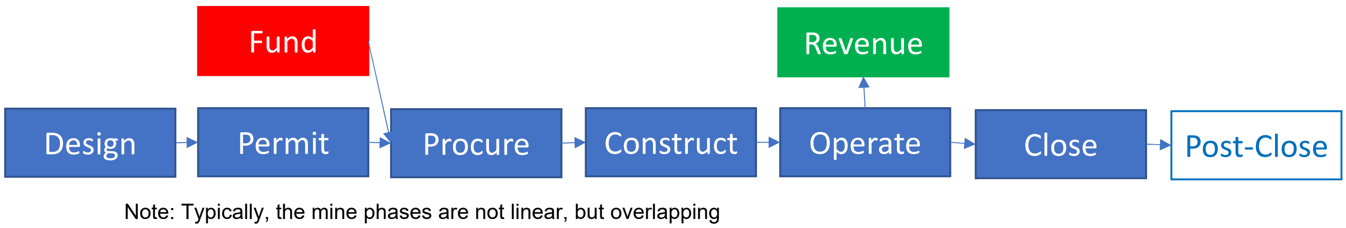


Figure 4: Mine Life Phases

3.0 FMEA APPROACH

This FMEA involved the following steps (see Figure 5):

- develop an adequate understanding of the "system" of interest (i.e., its components and its processes);
- establish the types of system consequences of interest;
- identify all the various ways the system can fail to perform as intended ("failure modes"), impacting those consequences of interest;
- for each identified failure mode:
  - assess those consequence impacts if that failure mode occurs,
  - assess the probability of that failure mode (as defined by those "conditional" impacts) occurring (e.g., during the duration or per year of a particular development phase), and
  - combine the probability of occurrence and all the conditional consequence impacts into a single metric: expected (probability-weighted-average) value of "severity"; and
- prioritize the failure modes based on their expected value of severity to guide mitigation planning (i.e., identify and evaluate ways to reduce expected value of severity, focusing on the worst failure modes).

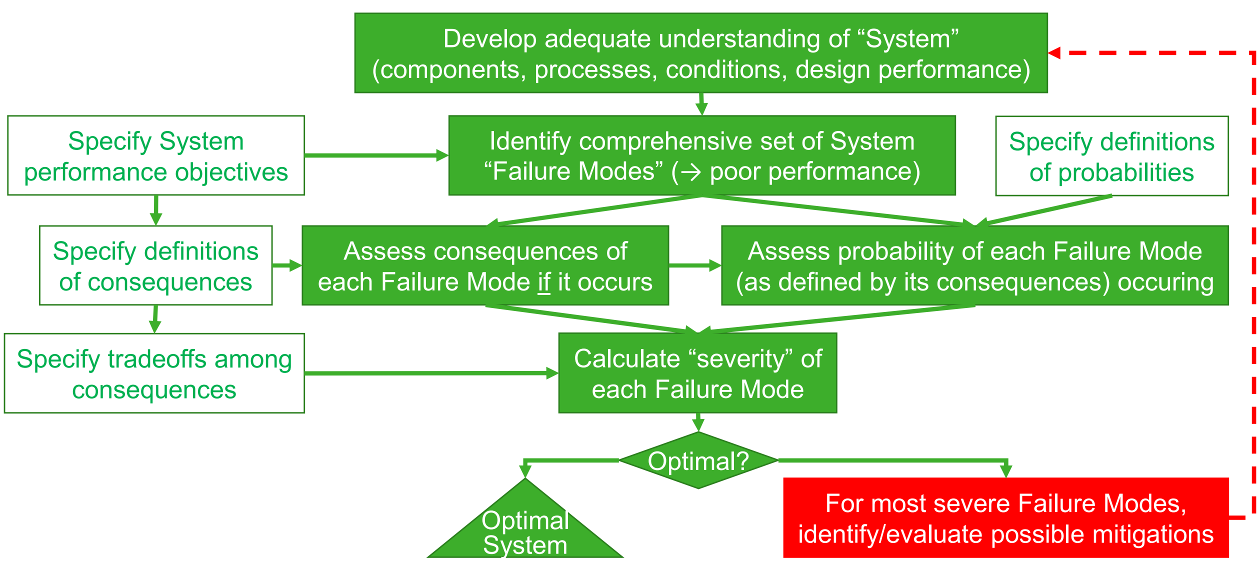


Figure 5. FEMA Process

Golder facilitated this FMEA process with waterline project staff, which included the following three basic tasks:

1) *Pre-workshop* – establishment of the FMEA scope (e.g., waterline operations and definition of relevant types of consequences and their ratings); review and summary of available information provided by Agnico Eagle regarding the project (including system components and performance processes); preliminary identification of potential failure modes (considering all the waterline system components and their role in system performance) based on that.

2) *Workshop* – facilitation of a virtual (via Microsoft Teams) one-day workshop comprised of project staff and subject matter experts (SMEs) to: a) confirm the project description, definition of relevant types of consequences, and preliminary set of failure modes, and to then b) subjectively assess each failure mode's probability of occurrence and its project performance impacts if it does occur, both in terms of predefined definitions and ranges of values, e.g., "high" probability is 50% - 75%, etc.) – as time allowed, identified potential mitigations of relatively highly-rated failure modes for future consideration.

3) *Post-workshop* - analysis of FMEA.

4.0 IDENTIFICATION AND DEFINITION OF CONSEQUENCES OF INTEREST

It is assumed that the consequences of interest to CIRNAC relate to the potentially affected area and population, categorized as follows:

- *Environment* impacts – area/degree/duration of water and land contamination, and damage/loss to habitat/wildlife (considering their importance) (rating of 0=no impact to 100="worst" impact scenario, which has been defined as: large (e.g., 5000 m^3, which would be the maximum amount that would drain out of one pipe (2,500 m^3 from the high point) plus additional pumping for 6 hours (at 400/m^3/hr), and if released on land would result in inundation of 10 acres to an average depth of 10cm or 4 inches) release of treated effluent into river, bay and/or tundra that damages important habitat (e.g., fish-bearing river, marine habitat, and/or caribou-supporting tundra) and wildlife (e.g., fish and/or caribou) for short time (e.g., less than one year), because treated effluent is flushed out of the system relatively quickly by natural high flows of clean water (e.g., river, bay and/or freshets);

- *Health & safety* impacts – additional number of "equivalent" worker and public fatalities (considering severity of injuries and illnesses, in terms of degree/duration, where a fatality is on average 40 "lost" years); including indirect effects of *environmental* impacts (e.g., illness caused by contamination); and

- *Societal* impacts – decrease in collective "quality of life", considering number/degree of people affected (considering disruption/damage/loss of employment, human rights, public services/infrastructure/resources (e.g., water supply), and community/heritage/traditional use/recreational assets); including indirect effects of *environmental* and *health & safety* impacts (rating of 0=no impact to 100="worst" impact scenario, which has been defined as: large (e.g., 1000 people) local population's traditional and recreational uses disrupted, along with cultural impacts of environmental damage, and some employment / local economy disruption for short-time (e.g., less than one year).

All other consequences of interest (especially to the mine owner) have been categorized but not assessed, as follows:

- *Financial* impacts – additional costs (NPV C$) associated with re-design, re-permit, clean-up (spill), repair (waterline/property/infrastructure damage), compensate (disruption), and/or litigate/fine (regulatory), separate from *mine production* (revenue) impacts;
- *Mine production* impacts – delay/decrease in mine production and thus in mine revenue (NPV C$), separate from *financial* (cost) impacts; and
- *Corporate* impacts – additional corporate-wide legal/permitting/reputation issues affecting corporate share price (% share price change); including indirect effects of *environmental*, *health & safety*, *societal*, *financial* and *mine production* impacts.

Collectively, these preliminary consequence categories are relatively comprehensive and non-duplicative, and presumably cover everything of interest to any stakeholder.

Ratings have been defined (in terms of ranges in consequence magnitude) for each of the consequence types, as summarized in Table 1. Note that ratings are not necessarily equivalent for different types of consequences. Tradeoffs have subsequently been defined to translate them into common terms (e.g., to combine all the consequences into a single metric of "severity" for failure mode prioritization).

Table 1: Definition of Consequence Ratings

Consequence	Ratings[a] (order of magnitude)					
	None	Very Low (VL)	Low (L)	Moderate (M)	High (H)	Very High (VH)
Environmental (scenarios, rating 0-100)	no impact {rating=0.0}	0.01%scen. {rating=0.01}	0.1%scen. {rating=0.1}	1%scen. rating=1}	10%scen. {rating=10}	100%scn. {rating=100}
Health & Safety (equivalent fatalities)	0.0	0.01	0.1	1	10	100
Societal (scenarios, rating 0-100)	no impact {rating=0.0}	0.01%scen. {rating=0.01}	0.1%scen. {rating=0.1}	1%scen. rating=1}	10%scen. {rating=10}	100%scn. {rating=100}
Financial (Cost) (cost NPV C$M)	0.0	0.1	1	10	100	1000
Mine Production (Revenue) (revenue NPV C$M)	0.0	0.1	1	10	100	1000
Corporate (% of share value)	0.0	0.01%	0.1%	1%	10%	100%

[a] Ratings of environment and societal impacts, which are scenario based, are expressed numerically relative to a defined "worst" (100%) impact scenario, which is assigned a rating of 100.

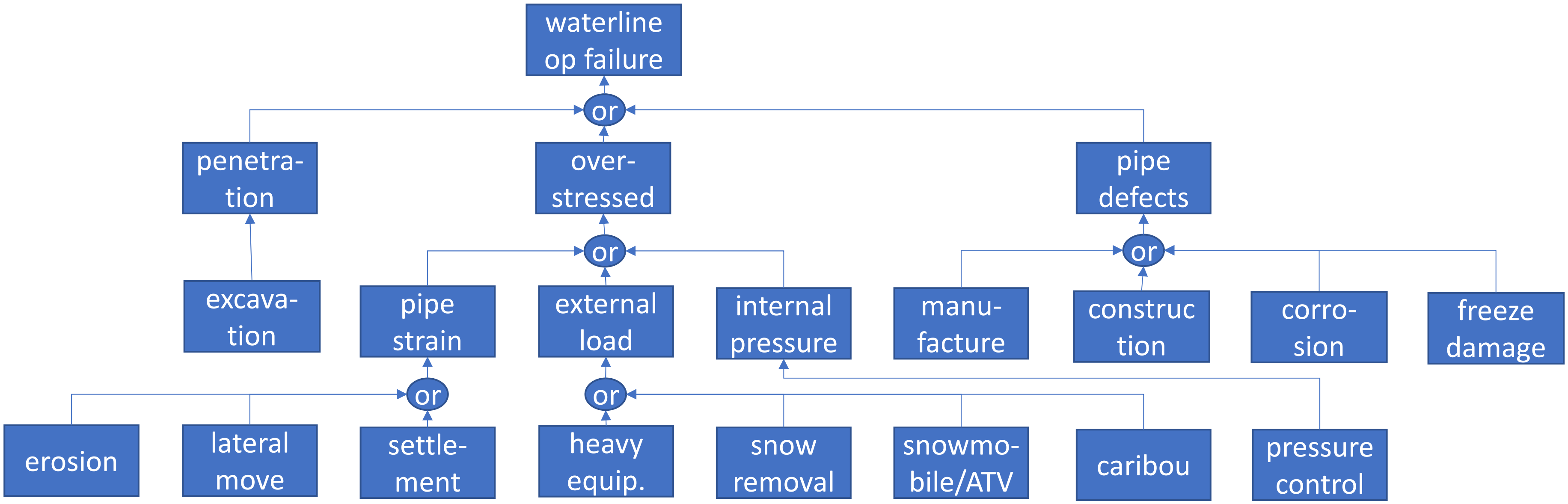
5.0 IDENTIFICATION OF SIGNIFICANT FAILURE MODES

A comprehensive set of significant "failure modes" (i.e., all the different ways in which significant consequences of interest can conceivably occur) must be identified. As previously discussed (Figure 1b), the various waterline components, and their respective failure modes during operations, include primarily:

- waterline (covered, uncovered, and on bridge) failure:
  - the various failure modes for the waterline during operations that will result in an effluent release are depicted in a fault tree (Figure 6); note: other failure events that could affect waterline performance but do not result in effluent release are covered elsewhere; and
  - the potential consequences of an effluent release event generally depend on the location and magnitude of effluent release, where the magnitude depends on the size of waterline failure, the flow rate, pump and valve shutoff times (which in turn is a function of the leak detection system and its connections to the pumps and valves), as well as location of failure and waterline topography and dimensions; these consequences include:
    - waterline damage → casualties and repair (→ environmental damage and casualties) → mine production/employment;
    - environmental damage → compensation, cultural damage and cleanup/rehab (→ casualties) and regulatory/media issues (fines/litigation/mitigation);
    - AWAR damage → traffic/access/disruption/compensation and repair (→ environmental damage and casualties) → mine production/employment;
    - other infrastructure damage → service/employment disruption/compensation and repair (→ environmental damage and casualties) → mine production/employment; and
    - community/cultural damage → disruption/compensation and rehab.
- pumps/power system failure:
  - the various failure modes for the waterline/pump system during operations include separate pump failure and power system failure; and
  - the potential consequences of this failure event include:
    - repair of pump or power system and reduction in discharge, which depending on available effluent storage, could affect mine production in the meantime, and possibly result in worker casualties.
- waterline control system failure:
  - the various failure modes for the waterline control system during operations include:
    - failure of waterline pressure monitoring connected to the pumps (which are rpm controlled) resulting in over pressure of waterline (see elsewhere), or failure to detect leak and thus additional effluent release (see elsewhere);
    - failure of various waterline pressure relief valves / vacuum breakers resulting in overpressure of waterline (see elsewhere), or reduced discharge;

  - failure of waterline fiber optic leak detection system connected via operator to the pumps, which is supplemented by waterline flow meter and pressure monitor, resulting in failure to detect leak and additional effluent release (see elsewhere);
  - “dumb pig” getting stuck in the waterline when emptying the waterline after the summer discharge season; and
- the potential consequences of this failure event not included elsewhere include:
  - repair of waterline control system and reduction in discharge, which depending on available effluent storage, could affect mine production in the meantime, and possibly result in worker casualties.

- submarine diffuser failure:
  - the various failure modes for the submarine diffuser that will result in unacceptable contamination levels in Melvin Bay (non-compliance) or just reduced discharge during operations include:
    - poor mixing, possibly caused by damage (movement) to diffuser, resulting in non-compliance and requiring mitigation/repair;
    - blocked/frozen-plugged transition segment, resulting in reduced discharge and requiring repair; and
    - delay in annual discharge permit renewal, resulting in reduced discharge and possibly mitigation;
  - the potential consequences of this failure event generally depend on the magnitude of contamination; these consequences include:
    - if non-compliant, environmental damage, requiring cleanup and possibly resulting in regulatory/media issues (fines/litigation/mitigation);
    - mitigation/repair of submarine diffuser system and reduction in discharge, which depending on available effluent storage, could affect mine production and possibly result in worker casualties.
    - potential disruption of public services, infrastructure, and employment, as well as possible damage to community/cultural/etc. assets, during mitigation/repair; and
    - potential compensation, additional mine production impacts and/or corporate impacts due to the above.



Note: excludes failure modes that only affect waterline performance without effluent release (which are covered elsewhere)

Figure 6: Fault Tree for Waterline Failure (Effluent Release) during Operations

6.0 DEFINITION OF PROBABILITY OF FAILURE MODE OCCURRENCE

Ratings of probabilities (e.g., of each failure mode, as defined by its set of consequences, occurring) have also been defined, as summarized in Table 2. Note that probability is often a function of the number of trials or exposures, e.g., duration vs. random year. A 20-year design life has been assumed for this FMEA.

Probabilities of an event (over a particular time period), or average frequencies of an event, can be determined from a "fault tree" for that event (e.g., Figure 6) and the probabilities (or frequencies) of each of the causative events. For example:

- if event C will occur if either events A <u>or</u> B occur, then the probability of event C occurring (P[C]) is the sum of the probability of event A occurring (P[A]) and the probability of event B occurring <u>if</u> event A does not occur (P[B|A']) → P[C] = P[A] + P[B] – P[A&B] = P[A] + P[B|A']; and
- if event C will occur only if events A <u>and</u> B occur, then the probability of event C occurring (P[C]) is the product of the probability of event A occurring (P[A]) and the probability of event B occurring <u>if</u> event A does occur (P[B|A]) → P[C] = P[A] x P[B|A].

Table 2: Definition of Probability Ratings

<table>
<tr><th rowspan="3">Probability for operations</th><th colspan="14">Ratings (order of magnitude)</th></tr>
<tr><th colspan="2">None</th><th colspan="2">Very Low (VL)</th><th colspan="2">Low (L)</th><th colspan="2">Moderate (M)</th><th colspan="2">High (H)</th><th colspan="2">Very High (VH)</th><th colspan="2">Given</th></tr>
<tr><td colspan="3">0.0%</td><td colspan="2">0.01%</td><td colspan="2">0.1%</td><td colspan="2">1%</td><td colspan="2">10%</td><td colspan="3">100%</td></tr>
</table>

7.0 FMEA PARAMETER ASSESSMENTS AND MODEL

Each of the identified failure modes were first screened as to whether they were "credible" or not. The parameters characterizing each credible failure mode were approximately assessed based on expert judgement in (and after) the workshop (see Appendix B). These parameters include: a) the "expected" (probability-weighted average) value of the various types of consequences of interest to the regulators <u>if</u> the failure mode occurs (per rating definitions presented in Table 1); and b) the probability of that failure mode (as defined by those consequences) occurring over the project lifetime (20 years) (per per rating definitions presented in Table 2).

- <u>Waterline</u> operational failure modes
  - The approximate consequences of the various waterline operational failure modes resulting in release of treated effluent were assumed to differ primarily depending on where they occurred: a) in the covered sections, where the release would generally be into the tundra; b) in the uncovered sections, where the release would typically be into the ephemeral drainages; or c) on the bridges, where the release would be into the river. It was assessed that a typical release into the river would result in an environmental impact and a societal impact of more than 1% but less than 10% of the defined "worst" scenarios (i.e., "high" ratings), while a typical release into ephemeral drainages would result in a much smaller environmental impact and societal impact (i.e., more than 0.1% but less than 1% of the defined "worst" scenarios, or "moderate" ratings), and a typical release into the tundra would result in an even smaller environmental impact and societal impact (i.e., more than 0.01% but less than 0.1% of the defined "worst" scenarios, or

"low" ratings). It was also assessed that the number and severity of casualties associated with the event, both during and after in repair/cleanup, would collectively be more than 0.01 but less than 0.1 of an "equivalent" fatality (i.e., more than 5 months but less than 4 years of lost time) or "low" health and safety rating, regardless of where the failure occurred.

- The approximate probability of each waterline failure mode (as defined by its consequences) occurring over the 20-year project lifetime was based on each failure mode's assessed order-of-magnitude rates of failure (e.g., per km or per feature, once over project lifetime or per year, per pipe), which were then multiplied by the appropriate number of kms or features, number of years, and number of pipes. These approximate failure probabilities were then translated into pre-defined probability ratings (Table 2).

- Pump system operational failure modes
  - The approximate consequences of the various pump system operational failure modes resulting in repairs and reduced discharge were assessed to have no environmental or societal impacts, and less than 0.01 equivalent fatalities (i.e., less than 5 months of lost time) or "very low" health and safety rating (related to repairs).
  - The approximate probability of each pump system failure mode (as defined by its consequences) occurring over the 20-year project lifetime was assessed to be 100% (and in fact multiple occurrences). These approximate failure probabilities were then translated into pre-defined probability ratings (Table 2).
- Control system operational failure modes
  - The approximate consequences of the various waterline control system operational failure modes (separate from the consequences related to waterline failure modes), except for a stuck pig, generally include repair and reduced (or lost) discharge. For these failure modes, the environmental and societal impacts were assessed to be less than 0.01% of the defined "worst" environmental and societal impact scenarios (i.e., "very low" ratings), except for no environmental impact for leak detection system failure, whereas for a stuck pig, the environmental and societal impacts were assessed to be higher due to perhaps some uncontrolled discharge (i.e., less than 0.1% but more than 0.01% of the defined "worst" environmental and societal impact scenarios or "low" ratings). For each of these waterline control system failure modes, which involve some repair, the number of equivalent casualties was assessed to be less than 0.01 (i.e., 5 months of collective lost time) or "very low" health and safety rating.
  - The approximate probability of each waterline failure mode (as defined by its consequences, separate from contributing to waterline failure which is considered in those failure modes) occurring over the 20-year project lifetime was based on each failure mode's assessed order-of-magnitude rates of failure (e.g., per year, per valve/pipe), which were then multiplied by the appropriate number of years, and number of valves/pipes. These approximate failure probabilities were then translated into pre-defined probability ratings (Table 2).
- Submarine diffuser operational failure modes
  - The approximate consequences of the various submarine diffuser operational failure modes all include reduced (or lost) discharge, which was assessed to have essentially no environmental, casualties or societal impacts (except for permitting delays, which has less than 0.01% of the "worst" societal impact scenario, or "very low" societal rating). Those failure modes that involve repairs/rehab were assessed to

have: a) minimal casualties, less than 0.01 equivalent fatalities (i.e., less than 5 months of lost time) or "very low" health and safety rating, for rehabbing poor mixing or repairing frozen transition, and slightly more casualties for fixing damaged diffuser (i.e., more than 0.01 but less than 0.1 equivalent fatalities, i.e., more than 5 months but less than 4 years of lost time, or "low" rating); and b) at least some societal impact, e.g., repairing a frozen transition was assessed to have less than 0.01% of the "worst" societal impact scenario, or "very low" societal rating. Poor mixing was assessed to result in more than 0.1% but less than 1% of the defined "worst" environmental and societal impact scenarios or "moderate" environmental and societal ratings, whereas the damaged diffuser was assessed to have less environmental and societal impact (i.e., more than 0.01% but less than 0.1% of the defined "worst" environmental and societal impact scenarios equivalent fatalities or "low" environmental and societal ratings.

- The approximate probability of each submarine diffuser failure mode (as defined by its consequences) occurring over the 20-year project lifetime was based on each failure mode's assessed order-of-magnitude rates of failure (e.g., per year), which were then multiplied by the appropriate number of years. These approximate failure probabilities were then translated into pre-defined probability ratings (Table 2).

A model (in Microsoft EXCEL) has been developed to document all the failure modes, their parameter assessments (in terms of ratings for the set of consequences and the probability of that set of consequences occurring, per established definitions), the calculation of their "severity" (combining all the assessments into a single metric, using "tradeoffs" as discussed below), and prioritization of those failure modes based on their severity (summarized in Table 3 and presented in detail in Appendix C). Currently only the environmental, health and safety, and societal consequences have been assessed as they are the consequences of interest to the regulators.

"Tradeoffs" are used to combine various types of consequences into a single combined metric (i.e., severity). This is typically done by applying "weights" to each type of consequence to convert them into approximately equivalent terms, which are then combinable. Reasonable weights have been assessed for each of the consequence types, relative to cost and appropriately considering their units, as summarized in Table 4. These tradeoffs are based on the following: a) an "equivalent" fatality is "valued" at about $10M (which is a widely- accepted industry benchmark); b) the "worst" environmental impact scenario (rating=100) is valued at more than $1M but less than $100M, e.g., $10M; and c) the "worst" societal impact scenario (rating=100) is similarly valued at more than $1M but less than $100M, e.g., $10M.

Definitions of combined consequence ratings and severity ratings are presented in Table 5.

Table 3: FMEA Model Framework

Failure Mode	Notes	Parameter Assessments[a]							Severity[b]	Priority
		Environment	Health&Safety	Social	Cost	Mine Production	Corporate	Probability		

Note: This framework is a simplified version of the complete FMEA model template, which is presented with all failure modes and their parameter assessments for the Agnico Meliadine Mine Waterline in Appendix C.

[a] see Ratings Definitions (Tables 1, 2, and 5)

[b] "Severity" is "expected" (probability-weighted-average) value of combined consequences, in which the various types of consequences are combined (via tradeoffs, Table 4) into a single consequence metric, which is then multiplied by its probability of occurrence.

Table 4: Tradeoffs for Determining Severity

	Environment	Health&Safety	Social	Financial (Cost)	Mine Production (Revenue)	Corporate
Weight	0.1M	10M	0.1M	1	1	1B

Table 5: Definition of Combined Consequences and Severity

	Ratings (order of magnitude)					
	None	Very Low (VL)	Low (L)	Moderate (M)	High (H)	Very High (VH)
Combined Consequence (M)	0.01	0.1	1	10	100	1000
Severity (M)	0.001	0.01	0.1	1	10	100

Table 6. Severity as Combination of Combined Consequence and Probability

Probability	Combined Consequence						
	None	Negligible	Very Low	Low	Moderate	High	Very High
None	None	None	None	None	None	None	None
Very Low	None	Negligible	Negligible	Negligible	Negligible	Very Low	Low
Low	None	Negligible	Negligible	Negligible	Very Low	Low	Moderate
Moderate	None	Negligible	Negligible	Very Low	Low	Moderate	High
High	None	Negligible	Very Low	Low	Moderate	High	Very High
Very High	None	Very Low	Low	Moderate	High	Very High	Extreme
Given	None	Very Low	Low	Moderate	High	Very High	Extreme

8.0 FMEA RESULTS

The results of the FMEA for Meliadine Mine Waterline are summarized below:

- As documented in Appendix C, for each of the 47 identified failure modes, their credibility was first assessed and then, for the 30 credible failure modes, their various consequences and probability (in terms of pre-defined order-of-magnitude ratings) were assessed and input to the FMEA model template, and used to calculate each failure mode's combined consequence (using trade-offs) and severity (also in terms of pre-defined order-of-magnitude ratings). The failure modes were then ranked based on their severity, as summarized in Table 7.
- Of the 30 credible failure modes, none were rated higher than "moderate severity, 11 were rated "moderate" severity, 13 were rated "low" severity, 4 were rated "very low" severity, and 2 were rated "negligible" severity. (Note: this was based on calculated severity levels, which differed slightly from Table 6, which would have rated the top 3 "low" severity rated failure modes as "moderate" severity, the top "very low" severity rated failure mode as "low" severity, and the top rated "negligible" severity rated failure mode as "very low" severity.)

- The four highest ranked failure modes, each with a “moderate” severity rating, due to a “low” combined consequence rating but similar essentially 100% probability, are:
  - snowmobile/ATV/pickup damage to the waterline, at uncovered sections;
  - heavy equipment traffic damage to the waterline, at uncovered sections;
  - internal pressure in the waterline, at uncovered sections; and
  - submarine diffuser damage/movement.

Table 7. Ranking of Failure Modes Based on Severity

Ranking	FM ID	Failure Mode	Severity
1	W8U	Waterline (Uncovered) – Snowmobile/ATV/Pickup Load	Moderate
2	W6U	Waterline (Uncovered) – Heavy Equipment Load	Moderate
3	W5U	Waterline (Uncovered) – Internal Pressure	Moderate
4	D2	Submarine Diffuser – Damage/Movement	Moderate
5	W13C	Waterline (Covered) - Excavation	Moderate
6	W7C	Waterline (Covered) – Snow Removal Equipment Load	Moderate
7	W7U	Waterline (Uncovered) – Snow Removal Equipment Load	Moderate
8	W4U	Waterline (Uncovered) – Freeze Damage Defect	Moderate
9	W10C	Waterline (Covered) - Settlement	Moderate
10	W6C	Waterline (Covered) – Heavy Equipment Load	Moderate
11	W2C	Waterline (Covered) – Construction-Induced Defect	Moderate
12	D1	Submarine Diffuser – Poor Mixing	Low
13	W11B	Waterline (Bridge) – Lateral Shift	Low
14	W10B	Waterline (Bridge) - Settlement	Low
15	C1	Control System – Pressure Control Fail	Low
16	C3	Control System – Leak Detection Fail	Low
17	D3	Submarine Diffuser – Transition Frozen/Blocked	Low
18	P2	Pump System – Pump Fail	Low
19	P1	Pump System – Power Fail	Low
20	C4	Control System – Stuck Pig	Low
21	W2U	Waterline (Uncovered) – Construction-Induced Defect	Low
22	C2	Control System – Vacuum Breaker Fail	Low

Ranking	FM ID	Failure Mode	Severity
23	W12C	Waterline (Covered) - Erosion	Low
24	W11C	Waterline (Covered) – Lateral Shift	Low
25	W2B	Waterline (Bridge) – Construction-Induced Defect	Very Low
26	W12U	Waterline (Uncovered) - Erosion	Very Low
27	W1U	Waterline (Uncovered) – Manufacture Defect	Very Low
28	W1C	Waterline (Covered) – Manufacture Defect	Very Low
29	W1B	Waterline (Bridge) – Manufacture Defect	Negligible
30	D4	Submarine Diffuser – Permitting Delay	Negligible

Notes: See Appendix C for description of each failure mode (referenced by FM ID) and its parameter assessments, and see severity rating definitions in Table 5. The rankings within each rating category are based on calculations of severity.

9.0 CLOSURE

In summary, an FMEA was conducted for operations of Agnico Eagle's Meliadine Mine proposed Waterline to discharge treated effluent from the mine into Melvin Bay in response to CIRNAC-IR-9. A comprehensive set of 47 possible failure modes for this proposed system, specifically focussed on potential accidents and malfunctions, was identified that could have significant environmental, health and safety, and/or societal impacts (which address all regulatory concerns). These failure modes were screened for credibility, and the remaining 30 credible failure modes were evaluated in terms of their "severity", which reflects their probability-weighted average value of combined impacts, which in turn was based on each failure mode's probability of occurring and the environmental, health and safety, and/or societal impacts if that failure mode occurs, considering the relative importance of those different types of impacts. The credibility of each failure mode, and the probability and various types of impacts in terms of pre-defined ratings for each credible failure mode, were assessed by subject matter experts in a facilitated workshop, and subsequently used to calculate severity (also in terms of pre-defined ratings). The failure modes were then ranked based on their severity.

Conclusions from the FMEA include:

- There are numerous potential failure modes for operations of this proposed waterline system related to potential accidents and malfunctions. It is believed that all these significant potential failure modes have been identified and adequately evaluated with respect to regulatory concerns (i.e., environmental, health and safety, and societal impacts).
- Several failure modes dominate (have highest severity), including:
  - snowmobile/ATV/pickup damage to the waterline, at uncovered sections,
  - heavy equipment traffic damage to the waterline, at uncovered sections,
  - internal pressure in the waterline, at uncovered sections, and
  - submarine diffuser damage/movement.
- The rest of the failure modes are much less severe.

Recommendations include:

- The severity of the various failure modes should be reviewed regarding acceptability.
- For failure modes with unacceptably high or potentially cost-effectively reduced severity, potential mitigations should be identified and evaluated. This evaluation should include incorporation of any other relevant failure mode impacts (e.g., of interest to the mine owner, such as cost, revenue, and corporate impacts, not just to the regulator), the anticipated reduction in failure mode probability and/or impacts if the mitigation is implemented, and the impacts (e.g., cost) of implementing the mitigation, regardless of its effectiveness.

Limitations of this FMEA include:

- Other failure modes, which were not identified, are conceivable.
- The evaluation of the identified failure modes was based on order-of-magnitude subjective assessments by a group of experts (consensus expert opinion) of those failure mode parameters (probability and environmental, health and safety, and societal impacts), based on current limited and imperfect information. These assessments could change based on new additional information, as well as a result of more refined assessments.
- Trade-offs amongst the different types of impacts were assumed, consistent with the definition of impacts, and used to calculate combined impacts and severity. These trade-offs could change, e.g., due to variation in values among different stakeholders.

Please contact the undersigned with any questions or concerns.

GOLDER ASSOCIATES INC.

Dr. Bill Roberds
Principal, Decision and Risk Analysis Program Leader

Distribution: Agnico Eagle
- Jamie Quesnel
- Michel Groleau

Attachments: Appendix A: Information Request CIRNAC-IR-9
Appendix B: 04Nov2020 Workshop Agenda
Appendix C: FMEA Model

https://golderassociates.sharepoint.com/sites/132380/project files/5 technical work/01_information_requests/03_ir commitments/2320_fmea/fmea/20351262-805-tm-mel waterline fmea in response to technical comments-rev0.docx

10.0 REFERENCES

Agnico Eagle (Agnico Eagle Mines Limited). 2020. Waterline FEIS Addendum – Meliadine Mine. Information Request Responses (and supporting appendices). Submitted to Nunavut Impact Review Board. October 13, 2020.

APPENDIX A

Information Request: CIRNAC-IR-9

AGNICO EAGLE

Waterline FEIS Addendum
IR Responses
October 13, 2020

Interested Party:	CIRNAC	Rec No.:	CIRNAC-IR-9
Re:	Waterline Failure Modes and Effects Assessment		

Recommendation Made by Interested Party:
CIRNAC requests that AEM identify potential failure modes in the system and their causes and effects for the proposed amendment.

Agnico Eagle's Response to Recommendation:
At this time Agnico Eagle has not completed a failure modes analysis of the system; however, below is an assessment of the potential outcome of an accident or malfunction.

Table CIRNAC-IR-9 provides a list of potential accidents and malfunctions and identified mitigation measures related to the waterline. Given the level of engineering completed to date, the likelihood and potential outcome should be interpreted qualitatively.

Table CIRNAC-IR-9: Summary of Accidents and Malfunctions

Accident or Malfunction	Mitigation	Consequence	Likelihood
Failure of the covered/buried portions of the waterline	Buried/covered Regular internal inspections Leak detection system, such as a pressure drop sensor Designed for corrosion protection and freeze/thaw consistent with northern environments. Spill Contingency Plan	Dependent on the location and the size of the leak or spill from the waterline the consequence can be limited and localized with no to limited detectable impacts. A reasonable worst case scenario is localized measurable impacts to fish and fish habitat if the spill or leak was to occur over a river or localized measurable impacts to soils, terrain and vegetation on land. A reasonable worse case scenario would be a measurable reversible impact on valued components.	The likelihood of small leaks with limited to no detectable effect could occur at some point during the mine life. The chance of a large leak going undetected and causing harm to fish or wildlife is low.
Failure of exposed waterline	Regular internal inspections. Leak detection system, such as a pressure drop sensor Designed for corrosion protection and freeze/thaw consistent with northern environments. Emergency response plan		
Spills during construction from construction equipment	Trained drivers Speed restrictions Regular maintenance Emergency response plans Spill Response Plan	These spills are expected to have limited impacts on the environment due to the detection time and ability to contain the spill.	The likelihood of small spills with limited to no detectable effect could occur at some point during the mine life.
Sabotage of the waterline	80% to 90% of the line is buried/covered Regular internal inspections Leak detection system, such as a pressure drop sensor Emergency response plan	Dependent on the location of the sabotage the consequence can be limited and localized with no to limited detectable impacts to localized measurable impacts to fish and fish habitat (including localized loss of fish)	Sabotage to the waterline could occur during the mine life.

Accident or Malfunction	Mitigation	Consequence	Likelihood
		and wildlife, vegetation, soils terrain and permafrost. A reasonable worse case scenario would be a measurable reversible impact on valued components.	
Sloughing below the waterline	Regular internal inspections HDPE can tolerate a certain amount of movement without failing	Measurable change in terrain, soils and permafrost.	Low chance of occurring due to project design.
Water freezing in the waterline, compromising performance and/or leading to failure	No discharge foreseen during freezing conditions Winterization of the waterline Regular inspection and maintenance.	Reasonable worse case scenario is the waterline is damaged and requires repair and/or portions of it may require removal and replacement. This could result in additional construction effort and additional sensory disturbance to wildlife while this additional work occurs.	This is unlikely to occur due to Agnico Eagle's experience with other lines on the mine site and experience clearing lines.
Cover and slope failure	Sufficient cover depth Use of gravel and sand to construct covers Designed for travel overtop Appropriate sloping 2.5H:1V for stability (e.g., the outside slope of the pipe covering will be same as the road)	Localized cover failure could make it more difficult for wildlife to cross the waterline. There is a potential for a small localized effect to a few individual animals.	This is unlikely to occur due to the planned slopes and planned construction material and regular inspections.
Seepage from the underground portion of the marine discharge pipe	Marine water quality monitoring Ice free discharge only	Localized minor impacts to marine habitat due to the flushing capacity of Melvin Bay and an ice free only discharge.	This may occur during the Project life. Monitoring water quality during the discharge season will occur.

Some additional information of the failure modes are presented here with their mitigation measure:

Over pressure in the system: there are two relief valves that protects both pipeline from over pressure, they are to be installed at each end of the line one draining in the pump box, the other draining at the diffuser (see Appendix IR-1 and Appendix IR-3 of this response package).

Bad operation: Again, both relief valve will protect the pipeline. The control system also will have integrated security logic that will prevent operating the system outside its designed mode.

Equipment malfunction: System is equipped with leak detection that will be triggered by any leak. All three pumps are also equipped with an emergency stop.

Major pipeline failure: System is equipped with leak detection that will be triggered by any leak. All three pumps are also equipped with an emergency stop. Once pumps are stopped, leak volume will be limited to the volume contained between up and down hill high point from the failure point.

The pressure class of a polyethylene pipe includes an allowance for surge pressures. The allowance for recurring surge pressures (regular valve and pump operation) is 50% of the pressure class. For occasional surge pressures (unanticipated system failures), the allowance is 100% the pressure class.

APPENDIX B

04 November 2020 Workshop Agenda and Participants

Agnico Eagle's Meliadine Mine Waterline FMEA Workshop Agenda 04Nov2020

(times are in EST and are flexible)

09:30 – 10:15 **Introduction**
- welcome, workshop logistics, HSSE, participants
- workshop purpose/objectives/scope
- FMEA approach (process, consequence definitions/ratings/tradeoffs, probability definitions/ratings, "severity" definition/ratings, model)

10:15 – 10:45 **System Description**
- phases
- components/processes/controls
- relevant setting/conditions

10:45 – 11:45 **Failure Mode Identification/Screening**

11:45 – 12:30 Lunch

12:30 - 16:10 **Significant Failure Mode Consequences and Probability Ratings Assessments**
Note: will start this session before lunch break if ahead of schedule, and mitigations for high severity failure modes will be addressed if time is available

16:10 - 16:30 **Closure**
- summary
- action items
- Q&A/comments
- adjourn

Workshop Participants

Michel Groleau (Agnico – Permitting & Regulatory Affairs Superintendent)

Jamie Quesnel (Agnico – Director, Permitting & Regulatory Affairs)

Matt Gilman (Agnico - Water Management General Supervisor)

Bruno Laverdure (Agnico – E&I Superintendent)

Jean-Claude Blais (Agnico – General Superintendent)

Daniel Seguin (Agnico – Project Manager-Meliadine)

Mark Long (Agnico – Construction Superintendent)

Bruno Roy (Agnico - Engineering Lead)

Lasha Young (Golder – Environmental SME)

Mark Musial (Golder – Geotechnical SME)

Dr. Feng Li (Golder – Assistant Risk Facilitator

Dr. Bill Roberds (Golder – Risk Facilitator)

APPENDIX C

FMEA Assessments and Model

Table C-1 Rating Definitions and Consequence Weights

	Ratings (Expected Values)							
Consequences	**None**	**Very Low**	**Low**	**Moderate**	**High**	**Very High**	**Given**	**Weight**
Environment (rating 0 to 100)	0	0.004	0.04	0.4	4	40		1.0E+05
Health&Safety (eq fatalities)	0	0.004	0.04	0.4	4	40		1.0E+07
Societal (rating 0 to 100)	0	0.004	0.04	0.4	4	40		1.0E+05
Financial (cost NPV C$M)	0	0.04	0.4	4	40	400		1.0E+06
Mine Prod (rev NPV C$M)	0	0.04	0.4	4	40	400		1.0E+06
Corporate (% share value)	0%	0.004%	0.04%	0.4%	4%	40%		1.0E+07
Probability	0%	0.004%	0.04%	0.4%	4%	40%	100%	
	Negligible	**Very Low**	**Low**	**Moderate**	**High**	**Very High**	**Extreme**	
Lower bound for Combined Conseq	1.0E+03	1.0E+04	1.0E+05	1.0E+06	1.0E+07	1.00E+08	1.00E+09	
Lower bound for Severity	1.0E+02	1.0E+03	1.0E+04	1.0E+05	1.0E+06	1.00E+07	1.00E+08	

Project: Agnico Meliadine Waterline FMEA - CIRNAC-IR-9 (accident/malfunction failure modes only)

Workshop Date: 11/04/2020

Workshop Sponsor: Michel Groleau & Jamie Quesnel (Agnico Eagle)
Engineer: Lasha Young & Mark Musial (Golder)
Workshop Facilitator: Dr. Bill Roberds and Dr. Feng Li (Golder)

Risk Identification									Risk Classification (pre-mitigation, with current controls)											
										Consequence Rating										
Component[1]	Sub-Component	Triggering Event or Prerequisite (individually or in combination)	Potential Failure Mode (PFM)	Failure Mode ID	Failure Mode is Credible (Yes/No)?	Notes on Site Conditions / Applicability	Notes on Probability Rating (over 20-year design life)	Notes on Consequence Rating	Current Controls (including confidence in their effectiveness)	Environ-ment	Health& Safety	Societal	Financial (cost)	Mine Prod (revenue)	Corporate	Combined Conseq	Likelihood of these Conse-quences due to PFM with Current Controls	Initial Severity (combined Conseq x Probability)	Ranking	
Waterline (Operational Failure leading to Effluent Release)	Covered (29km)	Manufacture defect	Pipe Defect	W1C	Yes	a large number (680) of 100m-long pipe sections; potential for defects.	10-4/km per pipe (most likely in first year of ops): 10-4 x 29 x 2 = 5.8x10-3	effluent release on tundra	QA/QC, initial inspection/pressure testing, visual examination of the surface condition of the pipes	Low	Low	Low				Low	Moderate	Very Low	28	W1C
	Uncovered (culvert or rock, 5km)			W1U	Yes		same: 10-4 x 5 x 2 = 10-3	effluent release in ephemeral drainages		Moderate	Low	Moderate				Low	Moderate	Very Low	27	W1U
	On Bridge (3)			W1B	Yes		10-4/bridge per pipe (most likely in first year of ops): 10-4 x 3 x 2 = 6x10-4	effluent release in river		High	Low	High				Moderate	Low	Negligible	29	W1B
	Covered (29km)	Construction (installation)-induced defect		W2C	Yes	likely (e.g., due to sharp gravels) in the fill soils	5x10-3/km per pipe (most likely in first year of ops): 5x10-3 x 29 x 2 = 0.29	effluent release on tundra	Construction inspection, visual examination of pipes after installation, initial pressure testing	Low	Low	Low				Low	Very High	Moderate	11	W2C
	Uncovered (culvert or rock, 5km)			W2U	Yes	less but still likely when moving the pipes to the construction site	1x10-3/km per pipe (most likely in first year of ops): 10-3 x 5 x 2 = 10-2	effluent release in ephemeral drainages		Moderate	Low	Moderate				Low	High	Low	21	W2U
	On Bridge (3)			W2B	Yes		1x10-3/bridge per pipe (most likely in first year of ops): 10-3 x 3 x 2 = 6x10-3	effluent release in river		High	Low	High				Moderate	Moderate	Very Low	25	W2B
	Covered (29km)	Corrosion-induced defect		W3	No	HDPE pipes carrying saline water only - no corrosion			Design							None		None	82	W3
	Uncovered (culvert or rock, 5km)															None		None	81	0
	On Bridge (3)															None		None	80	0
	Covered (29km)	Freeze-damage defect		W4C	No	imperfect emptying			Design, winter emptying/pigging, pre-season inspection/testing							None		None	79	W4C
	Uncovered (culvert or rock, 5km)			W4U	Yes	imperfect emptying, or infiltration into line after flushing if in standing water, and then freeze	1x10-3/km per year per pipe: 10-3 x 5 x 20 x 2 = 0.20	effluent release in ephemeral drainages		Moderate	Low	Moderate				Low	Very High	Moderate	8	W4U
	On Bridge (3)			W4B	No	imperfect emptying										None		None	78	W4B
	Covered (29km)	Over-pressure (pressure control	Overstressed pipe - internal	W5C	No	not highest stress area										None		None	77	W5C

Project: Agnico Meliadine Waterline FMEA - CIRNAC-IR-9 (accident/malfunction failure modes only)

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Risk Identification									Risk Classification (pre-mitigation, with current controls)											
										Consequence Rating										
Component[1]	Sub-Component	Triggering Event or Prerequisite (individually or in combination)	Potential Failure Mode (PFM)	Failure Mode ID	Failure Mode is Credible (Yes/No)?	Notes on Site Conditions / Applicability	Notes on Probability Rating (over 20-year design life)	Notes on Consequence Rating	Current Controls (including confidence in their effectiveness)	Environ-ment	Health& Safety	Societal	Financial (cost)	Mine Prod (revenue)	Corporate	Combined Conseq	Likelihood of these Conse-quences due to PFM with Current Controls	Initial Severity (combined Conseq x Probability)	Ranking	
	Uncovered (culvert or rock, 5km)	failure)	pressure	W5U	Yes	the highest stress occurs immediately downstream of pump	1x10-1 per year per pump/pipe: 10-1 x 20 x 2 = 4.0	effluent release in ephemeral drainages	Pressure control system, monitoring	Moderate	Low	Moderate				Low	Given	Moderate	3	W5U
	On Bridge (3)			W5B	No	not highest stress area										None		None	76	W5B
	Covered (29km)	Heavy equipment load on pipe	Overstressed pipe - external load	W6C	Yes	waterline adjacent to road, but so far no truck slip-off incident observed in the summer; exploration in tundra, heavy equipment crossings in the winter, but the cover soils are frozen in the winter	1x10-3/km per year per pipe: 10-3 x 5 x 20 x 2 = 0.20	effluent release on tundra	Design (pipe and cover), traffic control/monitoring, pre-season inspection/testing	Low	Low	Low				Low	Very High	Moderate	10	W6C
	Uncovered (culvert or rock, 5km)			W6U	Yes	no cover to protect	1x10-2/km per year per pipe: 10-2 x 5 x 20 x 2 = 2.0	effluent release in ephemeral drainages	same + signage	Moderate	Low	Moderate				Low	Given	Moderate	2	W6U
	On Bridge (3)			W6B	No	not accessible										None		None	75	W6B
	Covered (29km)	Snow removal equipment load on pipe		W7C	Yes	unlikely snow removal equipment on the pipe, but snow may be pushed and loaded onto the pipe; pipe is protected by frozen soil cover.	1x10-3/km per year per pipe: 10-3 x 29 x 20 x 2 = 1.2	effluent release on tundra	Design (pipe and cover), traffic control/monitoring, pre-season inspection/testing	Low	Low	Low				Low	Given	Moderate	6	W7C
	Uncovered (culvert or rock, 5km)			W7U	Yes	potential when cleaning out culverts	1x10-3/km per year per pipe: 10-3 x 5 x 20 x 2 = 0.20	effluent release in ephemeral drainages	same + signage	Moderate	Low	Moderate				Low	Very High	Moderate	7	W7U
	On Bridge (3)			W7B	No	not accessible										None		None	74	W7B
	Covered (29km)	Snowmobile/ATV/pickup load on pipe		W8C	No	protected by the soil cover; traffic control difficult			Design (pipe and cover), pre-season inspection/testing, monitoring							None		None	73	W8C
	Uncovered (culvert or rock, 5km)			W8U	Yes	exposed; potentially scarred or even punched through	10-2/km per year per pipe: 10-2 x 5 x 20 x 2 = 2.0	effluent release in ephemeral drainages	same + signage	Moderate	Low	Moderate				Low	Given	Moderate	1	W8U
	On Bridge (3)			W8B	No	not accessible										None		None	72	W8B
	Covered	Caribou load on pipe		W9C	No	low load and cover.			Design (pipe and cover), pre-season inspection/testing, monitoring							None		None	71	W9C
	Uncovered			W9U	No	low load but potential damage by caribou hoofs										None		None	70	W9U
	On Bridge			W9B	No	not accessible										None		None	69	W9B

Project: Agnico Meliadine Waterline FMEA - CIRNAC-IR-9 (accident/malfunction failure modes only)

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Risk Identification									Risk Classification (pre-mitigation, with current controls)											
										Consequence Rating										
Component[1]	Sub-Component	Triggering Event or Prerequisite (individually or in combination)	Potential Failure Mode (PFM)	Failure Mode ID	Failure Mode is Credible (Yes/No)?	Notes on Site Conditions / Applicability	Notes on Probability Rating (over 20-year design life)	Notes on Consequence Rating	Current Controls (including confidence in their effectiveness)	Environ-ment	Health& Safety	Societal	Financial (cost)	Mine Prod (revenue)	Corporate	Combined Conseq	Likelihood of these Conse-quences due to PFM with Current Controls	Initial Severity (combined Conseq x Probability)	Ranking	
	Covered (29km)	Settlement (differential)	Overstressed pipe - movement/strain	W10C	Yes	good past road performance & till-like subsurface soils & few organics (except at limited pond locations), so low likelihood; but potential due to climate change and increased prob. of extreme weather	10-4/km per year per pipe: 10-4 x 29 x 20 x 2 = 0.12	effluent release on tundra	Design (pipe and cover), pre-season inspection/testing, monitoring	Low	Low	Low				Low	Very High	Moderate	9	W10C
	Uncovered (culvert or rock, 5km)			W10U	No	uncovered has no issue; but transitions between uncovered and covered is more susceptible, which is included in the "covered" case above										None		None	68	W10U
	On Bridge (3)			W10B	Yes	transitions are susceptible	5x10-4/bridge per year per pipe: 5x10-4 x 3 x 20 x 2 = 0.06	effluent release in river	Design (pipe and hanger), pre-season inspection/testing, monitoring	High	Low	High				Moderate	High	Low	14	W10B
	Covered (29km)	Lateral shift (slope failure)		W11C	Yes	no slopes and good past road performance, but increase due to climate change	10-5/km per year per pipe: 10-5 x 29 x 20 x 2 = 0.012	effluent release on tundra	Design (pipe and cover), pre-season inspection/testing, monitoring	Low	Low	Low				Low	High	Low	24	W11C
	Uncovered (culvert or rock, 5km)			W11U	No	"floating" pipes do not move with ground										None		None	67	W11U
	On Bridge (3)			W11B	Yes	transitions are susceptible	10-4/bridge per year per pipe: 10-4 x 3 x 20 x 2 = 0.012	effluent release in river	Design (pipe and hanger), pre-season inspection/testing, monitoring	High	Low	High				Moderate	High	Low	13	W11B
	Covered (29km)	Erosion		W12C	Yes	Increase due to climate change, increased gullying and sedimentation, but competent foundation	10-5/km per year per pipe: 10-5 x 29 x 20 x 2 = 0.012	effluent release on tundra	Design (pipe and cover), pre-season inspection/testing, monitoring	Low	Low	Low				Low	High	Low	23	W12C
	Uncovered (culvert or rock, 5km)			W12U	Yes	Erosion around culvert, good past performance	10-5/km per year per pipe: 10-5 x 5 x 20 x 2 = 2.0x10-3	effluent release in ephemeral drainages	Design (pipe and culvert), pre-season inspection/testing, monitoring	Moderate	Low	Moderate				Low	Moderate	Very Low	26	W12U
	On Bridge (3)			W12B	No	unless bridge failure, and the design life of the waterline is only 20 years.										None		None	66	W12B
	Covered (29km)	Excavation (unintentional)	Pipe penetration	W13C	Yes	Apache Pass KP5.7-6.3km uncontrolled	10% per year collectively (both pipes in short segment): 0.1 x 20 = 2.0	effluent release on tundra	Signage, permit, pre-season inspection/testing, monitoring	Low	Low	Low				Low	Given	Moderate	5	W13C
	Uncovered (culvert or rock, 5km)			W13U	No	not susceptible to unintentional excavation										None		None	65	W13U

Project: Agnico Meliadine Waterline FMEA - CIRNAC-IR-9 (accident/malfunction failure modes only)

Workshop Date: 11/04/2020

Workshop Sponsor: Michel Groleau & Jamie Quesnel (Agnico Eagle)
Engineer: Lasha Young & Mark Musial (Golder)
Workshop Facilitator: Dr. Bill Roberds and Dr. Feng Li (Golder)

Risk Identification									**Risk Classification (pre-mitigation, with current controls)**											
										Consequence Rating										
Component[1]	**Sub-Component**	**Triggering Event or Prerequisite (individually or in combination)**	**Potential Failure Mode (PFM)**	**Failure Mode ID**	**Failure Mode is Credible (Yes/No)?**	**Notes on Site Conditions / Applicability**	**Notes on Probability Rating (over 20-year design life)**	**Notes on Consequence Rating**	**Current Controls (including confidence in their effectiveness)**	**Environ-ment**	**Health& Safety**	**Societal**	**Financial (cost)**	**Mine Prod (revenue)**	**Corporate**	**Combined Conseq**	**Likelihood of these Conse-quences due to PFM with Current Controls**	**Initial Severity (combined Conseq x Probability)**	**Ranking**	
	On Bridge (3)			W13B	No	not susceptible to unintentional excavation										None		None	64	W13B
																None		None	63	0
Sub-marine diffuser (operational failure)	Diffuser	Poor mixing	Unacceptable contamination levels in Melvin Bay	D1	Yes	Melvin Bay has large tidal flux/mixing, which helps reduce the probability of poor mixing	4%/year: 4% x 20 = 80%	non-compliance, rehab/mitigation, several weeks of discharge lost per incident	Design, construction inspection, initial testing, monitoring	Moderate	Very Low	Moderate				Low	Very High	Low	12	D1
	Diffuser	Movement of diffuser	Discharge season shortened, poor performance / possibly non-compliance	D2	Yes	need good mixing, permanent diffuser bigger	30%/year: 30% x 20 = 6.0	repair, rehab/mitigation, 1 to 2 weeks of discharge lost per incident	design, pre-season inspection (diver or ROV), visual inspection during operation	Low	Low	Low				Low	Given	Moderate	4	D2
	Transition	Blocked/plugged by frozen	Inoperable for part of discharge season	D3	Yes	from surface pipeline to diffuser at 23m deep; installed by HDD, with heat-tracers but no to drain upper section	5%/year: 5% x 20 = 1.0	1 to 2 weeks of discharge lost per incident	insulate, redundant heat traces, warm water/glycol, temporary bypass	None	Very Low	Very Low				Very Low	Given	Low	17	D3
	Permitting	Stakeholder objections	HTO discharge permit renewal, non-operable / discharge delay	D4	Yes	stakeholder opposition	10%/year: 10% x 20 = 2.0	several weeks of discharge lost per incident	Regulatory/stakeholder outreach	None	None	Very Low				None	Given	Negligible	30	D4
Pump system (operational failure)	Power	Power failure	Temporarily inoperable	P1	Yes	no redundancy in power feed, diesel power plant for the mine site only	100% chance of current average of 2 hrs/month power outage	collectively one day of discharge lost per year	Design, QA/QC, construction inspection, initial testing, monitoring, maintenance	None	Very Low	None				Very Low	Given	Low	19	P1
	Pump	Pump failure	Temporarily inoperable	P2	Yes	one redundant pump, only considering 80-85% availability of two pumps	100% chance of already incorporated reduced availability	days of discharge lost already included in availability	Design, QA/QC, construction inspection, initial testing, monitoring, maintenance, redundancy	None	Very Low	None				Very Low	Given	Low	18	P2

Project: Agnico Meliadine Waterline FMEA - CIRNAC-IR-9 (accident/malfunction failure modes only)

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Risk Identification									Risk Classification (pre-mitigation, with current controls)											
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Component[1]	Sub-Component	Triggering Event or Prerequisite (individually or in combination)	Potential Failure Mode (PFM)	Failure Mode ID	Failure Mode is Credible (Yes/No)?	Notes on Site Conditions / Applicability	Notes on Probability Rating (over 20-year design life)	Notes on Consequence Rating	Current Controls (including confidence in their effectiveness)	Environ-ment	Health& Safety	Societal	Financial (cost)	Mine Prod (revenue)	Corporate	Combined Conseq	Likelihood of these Conse-quences due to PFM with Current Controls	Initial Severity (combined Conseq x Probability)	Ranking	
Waterline **control system** (operational failure, separate from contributing to waterline operational failure)	Pressure Control System	Pressure control system (pressure relief valve) failure/freeze	Temporarily inoperable (waterline failure elsewhere)	C1	Yes	maximum rpm (to be found out) controls the maximum pressure; water hammer if pressure relief valve freezes, e.g., at the end of summer season; only manual valves, no power along pipeline	pressure relief valve freezes/fails 50% chance per year per line, shutting down system (pipe break considered elsewhere): 50% x 20 x 2 = 20.0	several days of discharge lost per incident	Design (re water hammer), QA/QC, construction inspection, initial testing, procedures for start/restart, monitoring, maintenance	Very Low	Very Low	Very Low				Very Low	Given	Low	15	C1
		Air release valve (i.e. vacuum breakers) fails/freezes	Flow reduction	C2	Yes	mechanical valves (subject to freezing) at 5 high points in line (total of 10 valves for 2 lines)	10-3 per year per valve: 10-3 x 10 x 20 =0.20	reduced discharge for several days per incident	Design, maintenance, inspection	Very Low	Very Low	Very Low				Very Low	Very High	Low	22	C2
	Leak Detection System	Leak detection system failure	Temporary waterline shutdown for false positive (impact on waterline failure, e.g., additional release, due to false negative considered elsewhere)	C3	Yes	continuous very sensitive system that senses leak or break, but needs calibration over time (may take at least 4 to 5 months), which might be difficult during caribou migration season; potential false poistive results in waterline shutdown to check (i.e.,lost discharge), whereas false negative results in undetected (and thus larger) spill (which is considered in waterline failure).	100% chance each year of false positives (false negative considered in waterline failure)	collectilvey several days of discharge lost per year	Design, QA/QC, construction inspection, initial testing, monitoring (by field crew or camera or drone), maintenance	None	Very Low	Very Low				Very Low	Given	Low	16	C3
	Waterline Emtying System	Stuck pig (emptying for winter)	Contained effluent release	C4	Yes	Dumb pig stuck, needs to be found and removed; requiring some waterline drainage (with containment).	25%/year per pipe	small effluent release to selected less important environment (tundra)	Design, procedures, smart pig (to locate)?, spill containment? Pigging expert?	Low	Very Low	Low				Very Low	Very High	Low	20	C4

1- Where multiple similar components exist, the component listed was assumed to represent the worst-case segment or location. Other similar components, unless specifically listed, are assumed to have equal or lesser risk.