

FMEA Worksheet - Gunnar Mine Tailings Cover System Design - July 2015

| Failure Mode ID | Failure Mode Description | Effects and Pathways | Likelihood | Consequences | | | | | | | | | | | Level of Confidence | Highest Risk Rating | Mitigation / Comments | |
|-----------------|---|---|------------|----------------------|------------------------|-----------------------------|-------------------|--------------------------------|-------------------------|----|------|------|------|----|---------------------|---------------------|---|--|
| | | | | Environmental Impact | Special Considerations | Legal and Other Obligations | Consequence Costs | Community / Media / Reputation | Human Health and Safety | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 1a | Poor execution of construction QA/QC program and/or inexperienced personnel supervising construction; | Thickness of till cover layer not built to specification leading to gamma radiation levels on the reclaimed surface exceeding SSRO. | L | L | L | Mo | Mo | Mo | Mo | Mo | Mo | Mo | Mo | Mi | L | H | Mo | Assumed by group that 5 ha requires repair. Likelihood is low because cover design is not complex and confidence in contractors is high. Mitigation methods are to have a rigorous QA/QC program. |
| 1b | | Material with substantial fines content used for top lift of till cover layer resulting in gully erosion >8" deep. | L | L | L | Mi | L | Mi | L | Ma | Mo-H | Ma | Mo-H | Mi | L | H | Mo-H | Assumed by group that significant repair required--placement of armouring layer to reduce erosion. Likelihood still low because cover design is not complex and confidence in contractors is high. Mitigation methods are to have a rigorous QA/QC program. |
| 1c | | Waste rock used as fill in areas not specified in design leading to loadings of COPC in Langley Bay in exceedance of SSROs. | NL | Ma | Mo | Mi | L | Mo | L | Ma | Mo | Ma | Mo | Mi | L | H | Mo | Likelihood of waste rock used in inappropriate places may be low or moderate but the likelihood of this leading to exceedance of SSROs in Langley Bay is extremely low. Mitigation methods are to have a rigorous QA/QC program. |
| 1d | | cover system thinner than designed resulting in SSRO exceedance in Langley Bay | NL | Ma | Mo | Mi | L | Mo | L | Ma | Mo | Ma | Mo | Mi | L | H | Mo | Mitigation of impacts to Langley Bay not reliant on net percolation reduction therefore a thinner cover system will be highly unlikely to impact Langley Bay. Mitigation methods are to have a rigorous QA/QC program. |
| 2a | Insufficient volume of till material available to complete cover system construction | Modification to the design required due to lack of suitable materials leading to construction delays and/or higher capex costs. | M | L | L | L | L | L | Ma | H | Mo | Mo-H | L | L | M | H | Optimize use of coarse-textured material by using finer-textured till material in lower layer of growth medium layer. Additional surveying, and material sampling to confirm till materials meet specs. | |
| 2b | | Modification to the design required due to lack of sufficient volumes of fill materials meeting design specs (or due to needs from other site aspects), leading to construction delays and/or higher capex costs. | H | L | Mo | L | Mo | L | Mo | Ma | H | Mo | Mo-H | L | Mo | M | H | Optimize use of coarse-textured material by using finer-textured till material in lower layer of growth medium layer. Additional surveying, and material sampling to confirm till materials meet specs. Continuous communication throughout design process to ensure the designs align for the other site aspects. Could add additional waste rock to tailings final landforms to reduce cover material requirements for other site aspects. |

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| 3 | Insufficient volume of coarse-textured material available to construct access roads | Waste rock used to construct access roads and CNSC requires removal of roads resulting in higher capex costs. | E | Mi | Mo-H | L | Mo | L | Mo | Mo | H | Mi | Mo-H | Mi | Mo-H | H | H | Early discussion with regulator regarding expectations over road construction and removal. Appropriate budgeting to include road removal. Careful alignment of roads and consider using clean material in sensitive areas. Optimize borrow material development to minimize road construction. |
| 4a | Excessive rill/gully formation due to higher than expected runoff | Formation of gullies >8" deep leading to gamma radiation levels in exceedance of SSRO. | L | L | L | Mi | L | Mo | Mo | Mi | L | Mi | L | Mi | L | M | Mo | Likelihood is low due to thickness of cover materials--which are sufficiently thick to withstand some erosion events without compromising performance. |
| 4b | | Loss of material due to erosion from cover resulting in erosion of cover system material leading to exceedance of SSROs in Langley Bay. | L | Mo | Mo | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | Mo | Likelihood is low due to thickness of cover materials--which are sufficiently thick to withstand some erosion events without compromising performance. |
| 4c | | Loss of material due to erosion from cover resulting in erosion of cover system material leading to unacceptable TSS levels in Langley Bay. | M | Mo | Mo-H | Mi | Mo | Mi | Mo | Mi | Mo | Mi | Mo | L | L | M | Mo-H | Likelihood is moderate as some erosion is expected over assessment period (500 years) and a major erosional event would have some likelihood (1-10% chance) of generating a short term plume in Langley Bay. Mitigation methods are monitoring and maintenance of surface water management. |
| 5a | Storm event greater than design storm post-reclamation | Higher than expected flow rates in channels resulting in erosion of cover system material leading to unacceptable TSS levels in Langley Bay. | M | Mo | Mo-H | Mi | Mo | Mi | Mo | Mi | Mo | Mi | Mo | L | L | M | Mo-H | Likelihood is moderate as some erosion is expected over assessment period (500 years) and a major erosional event would have some likelihood (1-10% chance) of generating a short term plume in Langley Bay. Mitigation methods are monitoring and maintenance of surface water management. |
| 5b | | Higher flow rates in channels resulting in erosion of cover system profile to the point where tailings are exposed leading to gamma radiation levels higher than SSRO. | M | L | L | Mi | Mo | Mo | Mo-H | Mi | Mo | Mi | Mo | Mi | Mo | M | Mo-H | Likelihood is moderate as some erosion is expected over assessment period (500 years) and a major erosional event would have some likelihood (1-10% chance) of generating a short term plume in Langley Bay. Mitigation methods are monitoring and maintenance of surface water management. |
| 6a | Insufficient dewatering of tailings areas during fill material placement | Larger volumes of fill required to reach design grades leading to higher capex costs and/or construction delays. | M | L | L | L | L | L | L | Mo | Mo-H | Mo | Mo-H | L | L | H | Mo-H | Likelihood is moderate due to difficulty in fully characterizing the in-situ tailings. Have contingencies in place to deal with higher than expected porewater conditions. Rigorous detailed design required. |
| 6b | | Higher volume of tailings pore water directed northward resulting in SSRO exceedance in Langley Bay. | NL | Mi | L | L | L | L | L | L | L | L | L | L | L | H | L | Some water directed northwards is expected during construction but volumes are expected to be very low and therefore likelihood of impacts to Langley Bay were considered to be not likely. |

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| 7a | Freeze / thaw cycling of the cover system | Formation of cracks in the cover leads to gamma radiation levels exceeding SSRO. | L | L | L | Mi | L | Mo | Mo | Mi | L | Mi | L | Mi | L | M | Mo | The likelihood of freeze/thaw cycling occurring and causing minor structural changes in the cover system is high. However, the likelihood of minor structural changes leading to cracks of sufficient depth to cause gamma exceedances is considered low. |
| 7b | | Differential frost heave results in standing water on the reclaimed landforms. | M | Mi | Mo | Mi | Mo | Mi | Mo | Mo | Mo-H | Mo | Mo-H | Mi | Mo | M | Mo-H | The likelihood of freeze/thaw cycling occurring and causing minor structural changes in the cover system is high. The likelihood that this would lead to some standing water within the assessment period (500 years) is considered moderate. Mitigation methods are monitoring and maintenance to surface water management system. |
| 7c | | Frost boils result in tailings migration to surface, leading to gamma radiation and loadings of COPCs to Langley Bay in exceedance of SSROs | L | L | L | Mi | L | Mo | Mo | Mi | L | Mi | L | Mi | L | M | Mo | The likelihood of frost boils occurring within the fine textured cover materials is moderate. However, the likelihood of tailings materials migrating all the way to the surface is considered low. |
| 8 | Sediment build-up reduces effectiveness of drainage channels | Ineffective drainage channels lead to erosion of cover material leads to gamma radiation levels exceeding SSRO | L | L | L | Mi | L | Mo | Mo | Mi | L | Mi | L | Mi | L | M | Mo | Some erosion is expected over assessment period (500 years) but the likelihood that this erosion would lead to gamma exceedance considered low. Mitigation methods are monitoring and maintenance of surface water management. |
| 9a | Beaver dam activity | Catastrophic failure of beaver dam leads to damage to downstream landforms. | H | Mi | Mo | Mi | Mo | Mi | Mo | Mo | Mo-H | Mo | Mo-H | Mi | Mo | L | Mo-H | Beaver activity occurring over assessment period (500 years) considered high and eventual dam failure likely but landform damage not expected to have major consequences. Mitigation methods are monitoring and maintenance of surface water management. |
| 9b | | ponding upstream resulting in increased heads leading to SSRO exceedance in Langley Bay | L | Mi | L | Mi | L | Mi | L | Mo | Mo | Mo | Mo | Mi | L | M | Mo | Beaver activity occurring over assessment period (500 years) considered high but the likelihood ponding would lead to SSRO exceedance considered low. Mitigation methods are monitoring and maintenance of surface water management. |
| 10 | Differential settlement of fill materials beyond tolerance levels | Differential settlement results in standing water on the reclaimed landforms. | M | Mi | Mo | Mi | Mo | Mi | Mo | Mo | Mo-H | Mo | Mo-H | Mi | Mo | M | Mo-H | Likelihood of some differential settlement occurring post construction is high. However, the design has been completed with hillslopes of >0.75% and channel slopes >1% to ensure drainage even if some settlement occurs. However, over the entire assessment period (500 years) it was estimated that the appearance of some standing water has a moderate likelihood. Mitigation methods are monitoring and maintenance of surface water management. |
| 11a | Poor early vegetation establishment due to dry site conditions | Loss of cover material due to rill/gully erosion results in SSWQO exceedance of TSS limit in Langley Bay. | L | Mi | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. |
| 11b | | Loss of cover material due to rill erosion results in COPCs in Langley Bay in exceedance of SSROs | NL | Mo | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. |
| 11c | | Loss of cover materials due to erosion results in gamma radiation exposure exceeding SSRO | L | L | L | Mi | L | Mo | Mo | Mi | L | Mi | L | Mi | L | M | Mo | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. |

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| | | | | | | | | | | | | | | | | | | |
| 12a | Poor vegetation establishment due to lack of nutrients | Loss of cover material due to rill/gully erosion results in SSWQO exceedance of TSS limit in Langley Bay. | M | Mi | Mo | Mi | Mo | Mi | Mo | Mi | Mo | Mi | Mo | L | L | M | Mo | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. Revegetation plan will include addition of fertilizer ammendments to ensure early establishment. |
| 12b | | Loss of cover material due to rill erosion results in COPCs in Langley Bay in exceedance of SSROs | L | Mo | Mo | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | Mo | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. Revegetation plan will include addition of fertilizer ammendments to ensure early establishment. |
| 12c | | Loss of cover materials due to erosion results in gamma radiation exposure exceeding SSRO | M | L | L | Mi | Mo | Mo | Mo-H | Mi | Mo | Mi | Mo | Mi | Mo | M | Mo-H | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. Revegetation plan will include addition of fertilizer ammendments to ensure early establishment. |
| 13a | Poor vegetation establishment due to insufficient water holding capacity | Loss of cover material due to rill/gully erosion results in SSWQO exceedance of TSS limit in Langley Bay. | NL | Mi | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. Based on vegetation trials, vegetation establishment on site materials is good, regardless of material type. |
| 13b | | Loss of cover material due to rill erosion results in COPCs in Langley Bay in exceedance of SSROs | NL | Mo | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. Based on vegetation trials, vegetation establishment on site materials is good, regardless of material type. |
| 13c | | Loss of cover materials due to erosion results in gamma radiation exposure exceeding SSRO | NL | L | L | Mi | L | Mo | L | Mi | L | Mi | L | Mi | L | M | L | Considering first 3-5 years post-construction. Ensure revegetation plan is in plan that includes adaptive management. Based on vegetation trials, vegetation establishment on site materials is good, regardless of material type. |
| 14a | Brush / forest fire leads to near complete loss of vegetation cover | Loss of cover material due to rill/gully erosion results in SSWQO exceedance of TSS limit in Langley Bay. | NL | Mi | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Forest fires are expected but the likelihood of fire leading to erosion is very low. Fire increases surface biomass and organic matter. |
| 14b | | Loss of cover material due to rill erosion results in COPCs in Langley Bay in exceedance of SSROs | NL | L | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Forest fires are expected but the likelihood of fire leading to erosion is very low. Fire increases surface biomass and organic matter. |
| 14c | | Loss of cover materials due to erosion results in gamma radiation exposure exceeding SSRO | NL | L | L | Mi | L | Mo | L | Mi | L | Mi | L | Mi | L | M | L | Forest fires are expected but the likelihood of fire leading to erosion is very low. Fire increases surface biomass and organic matter. |
| 15a | Unacceptable salinization of the cover system rooting zone causing loss of vegetation. | Loss of cover material due to rill/gully erosion results in SSWQO exceedance of TSS limit in Langley Bay. | NL | Mi | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Neither tailings nor cover materials have salts that lead to salinization. This is not anticipated to be an issue. |
| 15b | | Loss of cover material due to rill erosion results in COPCs in Langley Bay in exceedance of SSROs | NL | L | L | Mi | L | Mi | L | Mi | L | Mi | L | L | L | M | L | Neither tailings nor cover materials have salts that lead to salinization. This is not anticipated to be an issue. |
| 16 | Bioaccumulation of metals or radionuclides in the food chain via plant uptake. | Unacceptable levels of metals or radionuclides in local flora and fauna. | L | L | L | Mo | Mo | L | L | Mi | L | Mo | Mo | Mo | Mo | Mo | Mo | Based on reclamation design, uptake of contaminants is considered low likelihood. Monitoring will be carried out. |

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| | | | | Environmental Impact | Special Considerations | Legal and Other Obligations | Consequence Costs | Community / Media / Reputation | Human Health and Safety | | | | | | | | | | |
| 17 | Disruption of the cover system surface due to tree blow-down (bioturbation); | Formation of cracks/holes/voids in the cover leads to gamma radiation levels exceeding SSRO. | L | L | L | L | L | L | L | L | L | L | L | L | L | L | H | L | The likelihood of tree blow-down on cover system resulting in shallow voids over assessment period (500 years) considered high. However, due to shallow rooting depths of trees, cover thickness, and extremely small affected area, it is not anticipated that this would lead to gamma exceedance. |
| 18 | Burrowing animals create substantial holes / macropores in the cover system profile | Formation of cracks/holes/voids in the cover leads to gamma radiation levels exceeding SSRO. | L | L | L | L | L | L | L | L | L | L | L | L | L | L | H | L | The likelihood of burrowing animals creating small holes on cover system over assessment period (500 years) considered high. However, due to the extremely small affected area, it is not anticipated that this would lead to gamma exceedance. |
| 19 | Substantial damage to integrity of cover system due to anthropogenic activities. | Formation of cracks/holes/voids in the cover leads to gamma radiation levels exceeding SSRO. | L | L | L | Mi | L | Mi | L | L | L | L | L | Mi | L | L | L | L | The likelihood of people digging around on the cover system over the assessment period (500 years) considered low due to institutional controls (signage) and previous usage of the area. However, due to the small affected area, it is not anticipated that this would lead to gamma exceedance. |
| 20 | Climate change leading to wetter conditions than addressed during the EIS stage. | Increased net percolation into tailings mass leading to loading rates of COPCs to Langley Bay in exceedance of SSROs. | L | Ma | Mo-H | Mo | Mo | Mo | Mo | C | Mo-H | Ma | Mo-H | L | L | L | L | Mo-H | Climate change was incorporated into the design therefore this failure mode is only if the current climate change models underestimate what occurs over the assessment period. Therefore, the likelihood of this occurrence is considered low. |
| 21a | Excessive erosion of Back Bay and/or Langley Bay landform due to ice scour | Exposure of tailings leading to gamma radiation levels exceeding SSRO | M | L | L | Mi | Mo | Mo | Mo-H | Mi | Mo | Mi | Mo | Mi | Mo | L | Mo-H | Mitigation is routine monitoring and maintenance of Langley Bay landform. | |
| 21b | Excessive erosion of Back Bay and/or Langley Bay landform due to ice scour | Exposure of tailings leads to exceedance of SSROs in Langley Bay | M | Mi | Mo | Mi | Mo | Mi | Mo | Mo | Mo-H | Mo | Mo-H | Mi | Mo | L | Mo-H | Mitigation is routine monitoring and maintenance of Langley Bay landform. | |
| 22a | Excessive erosion of Back Bay and/or Langley Bay landform due to wave action | Exposure of tailings leading to gamma radiation levels exceeding SSRO | L | L | L | Mi | L | Mo | Mo | Mi | L | Mi | L | Mi | L | L | Mo | Mitigation is routine monitoring and maintenance of Langley Bay landform. | |
| 22b | Excessive erosion of Back Bay and/or Langley Bay landform due to wave action | Exposure of tailings leads to exceedance of SSROs in Langley Bay | L | Mi | L | Mi | L | Mi | L | Mo | Mo | Mo | Mo | Mi | L | L | Mo | Mitigation is routine monitoring and maintenance of Langley Bay landform. | |
| 23 | Capillary rise of water into rooting zone | COPCs from the underlying waste are transported into the cover system leading to loading rates of COPCs to Langley Bay in exceedance of SSROs | E | Mo | H | Mi | Mo-H | Mo | H | Mo | H | Mo | H | Mi | Mo-H | M | H | Capillary rise is expected to occur into the cover system in areas where there is a shallow water table and fine textured cover/fill materials are used exclusively. Mitigation of this will be to modify the detailed cover design materials to add coarse textured material in the cover or increase the fill thickness (or a combination of both). The waste rock fill will provide this function in the areas where this material is designated to be used. The materials to be used in other areas of the landform will be finalized in the detailed design. Additional confidence in this assessment will be gained following the modelling for the detailed design. | |

Risk Matrix

| | | Consequence Severity | | | | |
|-------------------|------------------------|-----------------------------|-------------------|----------------------|------------------|---------------------|
| | | <i>Low (L)</i> | <i>Minor (Mi)</i> | <i>Moderate (Mo)</i> | <i>Major (M)</i> | <i>Critical (C)</i> |
| Likelihood | <i>Expected (E)</i> | Moderate | Moderately High | High | Critical | Critical |
| | <i>High (H)</i> | Moderate | Moderate | Moderately High | High | Critical |
| | <i>Moderate (M)</i> | Low | Moderate | Moderately High | High | High |
| | <i>Low (L)</i> | Low | Low | Moderate | Moderately High | Moderately High |
| | <i>Not Likely (NL)</i> | Low | Low | Low | Moderate | Moderately High |

Intolerable Region

ALARP Region

Broadly Acceptable Region

Likelihood of Risk

| Likelihood Class | Likelihood of Occurrence for Environmental and Public Concern Consequences over Assessment Period (500 yrs) |
|-------------------------|--|
| Not Likely (NL) | < 0.1% chance of occurrence |
| Low (L) | 0.1 - 1% chance of occurrence |
| Moderate (M) | 1 - 10% chance of occurrence |
| High (H) | 10 - 50% chance of occurrence |
| Expected (E) | > 50% chance of occurrence |

Severity of Effects

| Consequence Categories | Low | Minor | Moderate | Major | Critical |
|-------------------------------------|--|--|---|--|--|
| Environmental Impact | No exceedance of SSROs in Langley Bay. No exceedance of SSWQO for TSS in Langley Bay. | Single exceedance of COPC concentration above SSROs in Langley Bay. Single exceedance of SSWQO for TSS in Langley Bay. | Multiple exceedances of COPC concentrations above SSROs in Langley Bay. Multiple exceedances of SSWQO for TSS in Langley Bay. | Regular exceedances of COPC concentrations above SSROs in Langley Bay. Regular exceedances of SSWQO for TSS in Langley Bay. | Constant exceedances of COPC concentrations above SSROs in Langley Bay. Constant exceedances of SSWQO for TSS in Langley Bay. Stable negative trends in COPC concentrations. |
| Special Considerations | Some disturbance but no affect on traditional land use. | Minor or perceived affect on traditional land use. | Some mitigatable affect on traditional land use. | Temporary deleterious affect on traditional land use. | Catastrophic permanent affect on traditional land use. |
| Legal and Other Obligations | No non-compliance but lack of conformance with department policy requirement. Informal advice from a regulatory agency. | Technical/ administrative non-compliance with permit, approval or regulatory requirement. Warning letter issued. | Breach of regulations, permits, or approvals (e.g. 1 day violation of discharge limits). Order or direction issued. | Substantive breach of regulations, permits, or approvals (e.g. multi-day violation of discharge limits). Prosecution and court order. | Major breach of regulation--willful violation. Prosecution and sentencing or fine. |
| Consequence Costs | <\$100,000 | \$100,000 - \$500,000 | \$500,000 - \$2 million | \$2 million - \$10 million | >\$10 million |
| Community/ Media/ Reputation | Local concerns, but no local complaints or adverse press coverage. | Public concern restricted to local complaints or local adverse press coverage. | Heightened concern by local community or adverse local/ regional media attention. | Wide-spread adverse national public or media attention. | Serious public outcry/ demonstrations or adverse international media coverage. |
| Human Health and Safety | No gamma exposure beyond background dose. Low-level short-term subjective symptoms. No measurable physical effect. No medical treatment required. | Gamma exposure dose above local background but less than 1mSv/yr from localized areas (annual public dose). Objective but reversible disability/impairment and/or medical treatment. Injuries requiring first aid or hospitalization. | Gamma exposure dose above local background but less than 1mSv/yr (annual public dose). Moderate irreversible disability or impairment to one or more people. | Gamma exposure dose above 1mSv/yr (annual public dose). Severe irreversible disability or impairment to one or more people. | A fatality or identifiable radiation-caused health effects. |

Level of Confidence

| Confidence | Description |
|-------------------|---|
| Low (L) | Do not have confidence in the estimate or ability to control during implementation. |
| Medium (M) | Have some confidence in the estimate or ability to control during implementation, conceptual level analyses. |
| High (H) | Have lots of confidence in the estimate or ability to control during implementation, detailed analyses following a high standard of care. |