



The AANDC Cover Systems in Cold Regions Guidance Document – Rationale for Advocating use of an FMEA for Design and Presentation of the Document's FMEA Case Studies



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Presentation Summary (Part 1)







- Overview / Highlights of the Guidance Document

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- Overview of the FMEA Process
- Description of Two Case Studies Outlined in the Guidance Document
- Presentation of Failure Modes
- Group Exercise—Failure Mode Ranking and Discussion of Mitigation Measures



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Background



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GIDM

Développement du Nord Canada No Background

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• Previous MEND Reports

> MEND 1.61.1. 1997

 Roles of Ice, in the Water Cover Option, and Permafrost in Controlling Acid Generation f Sulphide Tailings

> MEND 2.21.4. 2004

 Design, Construction and Performance Monitoring of Cover Systems for Waste Roc and Tailings

MEND 1.61.6. 2006

 Update on Cold Temperature Effects on Geochemical Weathering

> MEND 2.21.5. 2007

Macro-Scale Cover Design and Performance Monitoring Reference Manual

> MEND 1.61.5a. 2009

- Mine Waste Covers in Cold Regions
- > MEND 1.61.5b. 2010
 - > Cold Regions Cover Research Phase 2







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Affaires autochtones et Développement du Nord Canada **Technical Guidance Document**

- Chapter One: Introduction
 - General Purpose of Cover Systems
- Chapter Two: Geographic Extent and Key Attributes of Cold Regions
 - Key Failure Mechanisms for Cover Systems in Cold Regions
- Chapter Three: Cover System Design Philosophy for Cold Regions
 - > Utilizing Attributes of the Canadian North
 - > Assessment Period and Design Life
- Chapter Four: Basic Theory and Fundamental Concepts
- Chapter Five: Cover System Design Alternatives for Cold Regions
 - > Description of Cover System Design Alternatives
- Chapter Six: Cover System Design Methodology for Cold Regions
 - > Highlights on the Recommended Approach
 - Five Critical Factors Affecting Cover Performance in Cold Regions
- Chapter Seven: Application of the FMEA Process

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• Failure Modes and Effects Analysis

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- Objective of an FMEA is to identify and quantify risks in order to either avoid or mitigate them.
- Combines the likelihood of failure with the consequences of a failure to express the outcome as a risk.



Risk Level	Guidelines for Risk Matrix
Extreme	Eliminate, avoid, implement specific action plans / procedures to manage and monitor
High	Proactively manage
Medium	Actively manage
Low	Monitor and manage as apprpriate

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Risk Matrix



FMEA for Cold Regions

- FMEA (Robertson and Shaw, 2003) :
 - "a top down/ expert system approach to risk identification and quantification, and mitigation measure identification and prioritization"
- FMEA value and effectiveness depends on having participation of "experts" with the appropriate knowledge and experience.
- "Experts" are those who understand the geotechnique, hydrology, environmental impacts, and regulatory requirements as well as the past history of the mine's design, construction, operation and performance.





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FMEA for Cold Regions

- FMEA allows for a risk analysis early in the design process.
- FMEA is site-specific: incorporates local climate, available materials, and unique stakeholder needs.
- Cover designs with high potential failure rates can be omitted from consideration (e.g. long-term maintenance).
- Final risk rankings are comparable, defensible, and lead to constructive discussion of mitigation methods.





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FMEA for Cold Regions

• Failure Modes

- Naturally initiated (e.g. an 'act of God' such as an earthquake)
- Initiated by the failure of one of the engineered subsystems (e.g. instability of a dam)
- Result from operational failure
- A large number of potential failure modes could be included, but it is necessary to confine evaluations to those that represent a significant risk
- Failure modes can also be combinations of events (e.g. a small trigger event sets off a chain of events)





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FMEA for Cold Regions

- What Does Failure Mean?
 - TAG developed the following for the Canadian North (net percolation of cover systems as % of MAP):
 - Very low: <5%
 - Low: 5-10%
 - Moderate: 10-15%
 - High: 15-40%





Application of FMEA Process





- Case Study #1
 - Sporadic discontinuous permafrost (seasonal)
 - > Highly reactive (acidic) waste rock
- Case Study #3
 - Edge of continuous permafrost
 - Potentially acid forming tailings with arsenic release





- Tailings and WR in surface impoundments in continuous permafrost
- WR is potentially acid generating.
- Both WR and tailings have high concentrations of arsenic.
- Continuous permafrost: active layer depth varies between 1.5 m and 3.8 m



- 250 mm annual precipitation (40% as snow).
- Open water period is approximately 100 days.
- Potential evaporation 225–350 mm/yr.



- Tailings surface runoff is directed through a discharge channel to one of many nearby lakes.
- Elevated levels of arsenic and slightly acidic pH are present in groundwater below and downgradient of tailings impoundment.



- Potential cover materials include a sand and gravel esker material.
- Bedrock outcrops are common with a discontinuous veneer of till.
- Available quantities of materials are a limiting factor.

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Example: Case Study #3

<u>Cover system performance</u> <u>criteria:</u>

- Very low net percolation (<5% of precipitation)
- Dust control
- Vegetation establishment
- Isolation of contaminants





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Example: Case Study #3

Cover system design:

- Relocate WR to tailings pond to minimize surface area to be covered.
- BGM overlain by 75 cm of well-graded, sandy gravelly esker material.







- Abandoned zinc and lead mine.
- 32 Mt of sulphidic WRDs with both north- and south-facing slopes.
- WRDs composed of free draining coarse rock (potential for convective gas transport).
- Surrounding landforms include morainal till veneers and till blankets along with galciofluvial and glaciolacustrine deposits.



- Climate is semi-arid with 300 mm annual precipitation (1/3 as snow).
- AET ranges from 75 mm/yr (north facing) to 200 mm/yr.





- Cover material suitable for low permeability layer is available as is a granular cover material.
- Till material becomes dense and hard-packed leading to erosion and vegetation challenges
- Coarse rock fill and organic soils are not readily available.









<u>Cover system performance</u> <u>criteria:</u>

- Low net percolation (5-10% of precipitation)
- Dust control
- Erosion control
- Geotechnical stability
- Vegetation establishment
- Control / reduce convective gas transport







Cover system design:

- 0.5 m compacted till placed on WR surface
- 0.5 m non-compacted till





FMEA: Group Exercise





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FMEA: Group Exercise

Case Study 1:

- **1.** Erosion of spillway-ponding and bypass
- 2. Freeze/thaw wet/dry degrading cover performance
- 3. Vegetation effects on cover performance
- 4. Cracking at top of dump leading to venting of lethal gas
- 5. Egress of lethal gas









Wireless: SFUNET Open browser and enter: ID: lw926 Password: u8PU#66@

https://www.surveymonkey.com/s/8QFT39Q

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<u>1. Erosion to the extent that spillway performance is</u> <u>degraded and ponding and bypass occurs :</u>



2. Freeze/thaw cycles, wet/dry settlement, and development of hummocks leading to cracking of the cover:



3. Vegetation effects on cover performance due to root penetration, blow down, etc.:



4. Cracking of top of dump cover leading to venting of lethal gas and accumulation in enclosures on top of dump.:





5. Egress of lethal gas from waste storage facility:







- 1. Erosion to the extent that spillway performance is degraded and ponding and bypass occurs :
 - •Design erosion resistant channels leading into the spillway.
 - •Observe/measure cover performance under site climatic conditions.
 - Inspection of cover following a storm event.
 - •Maintenance of rills/gullies.





<u>1. Erosion to the extent that spillway performance is</u> <u>degraded and ponding and bypass occurs :</u>

From a design perspective:

- increase the thickness of cover (growth medium)
- increase design storm event criteria
- vegetation capable of controlling erosion in the long-term?
- surface erosion control measures (e.g. rock mulch) to control erosion until vegetation is established
- re-designing the landform and/or surface water management system





2. Freeze/thaw cycles, wet/dry settlement, and development of hummocks leading to cracking of the cover:

Inspect landform at regular intervals; and

•Perform routine maintenance to repair cracks.

From design perspective:

Incorporate change in hydraulic characteristics of cover materials due to frost action into the design.





3. Vegetation effects on cover performance due to root penetration, blow down, etc.:

Increase the thickness of the growth medium layer.





- 4. Cracking of top of dump cover leading to venting of lethal gas and accumulation in enclosures on top of dump.:
- Implement institutional controls (e.g. fencing);
- Prevent camping;
- Prevent placement of structures on WRDs; and
- Install warning signs that dangerous conditions may exist.







5. Egress of lethal gas from waste storage facility:

 Factors that may contribute to lethal gas accumulation, such as poor air circulation and mixing, need to be evaluated





Considerations

Temperate Climate

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Focus on water balance, but response to snowmelt is critical component of water balance



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Considerations

Cold Region

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- Hydrology strongly controlled by the presence, distribution and timing of ground frost relative to snowmelt
- Strongly influenced by slope and aspect (radiation), snowpack accumulation and melt, material type, and antecedent moisture conditions prior to freeze-up
- Potential development of frost phenomena that might have a detrimental effect on cover performance?
- **Result of changes in energy balance (freeze or** thaw) caused by disturbance of the thermal regime during cover placement or landform development and the resulting thermal disequilibrium
- Reliance on seasonal or permanent development of ground frost to control water and/or gas movement.









Design Methodology for Cold Regions

Not Just About....





Design Methodology for Cold Regions





Design Methodology for Cold Regions

Thermal (energy) and Water Balance Evaluation a <u>MUST</u> to Properly Design a Cover System for a Cold Region

1) Frost,

Longer duration of the year and to a greater depth than in temperate regions where many covers systems are being evaluated

2) Slope / Aspect,

Magnified compared to warmer climates; sun angle is lower and seasonal variation in net radiation greater Slope aspect affects snow accumulation, frost penetration, and results in delayed snowmelt.

3) Water Availability,

Precipitation vs. Potential Evaporation Must consider PPT and PE on a seasonal or monthly basis rather than on an annual basis (PROBABILITY)

4) Vegetation, and

Aesthetics, Erosion, S&R Cover Performance, Water Availability Native vs. Agronomic Short frost-free period... short growing season No vegetation..... Is that Realistic??

5) Cover Material.

Finer vs. Coarser, Availability, Erosion, Establishment of Vegetation, LANDFORM DESIGN All Factors are Interrelated



Cover System Design Alternatives

Capillary Break (form of enhanced S&R)

Growth Medium (finer textured)

overlying

Coarse Textured Material





- Enhance moisture retention
- Reduce net percolation
- Mitigate against upward movement of salts etc.





Seasonally Frozen Capillary Break Diversion (SFCBD) 44

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Summary Discussion





- Document available at:
 - > www.mend-nedem.org
 - ► MEND 1.61.5c





- Taking Advantage....
- Thermal (Energy) and Water Balance
- FMEA Process
- Design Life and Assessment Period
 - > Minimum of 100 year performance
 - > Risk-based approach: 1 in 1000

Claypool (2009)





- 1. Exposure of tailings
- 2. Surface water management and erosion
- 3. Glaciation
- 4. Frost Jacking
- 5. Constructibility

	Failure Mode	Effects and Bathering	High
ID ID	Description	crece and radiways	bsue
1	Erosion due to mintell and enowmelt to the extent that over profile is breached	Exposure of veste material. Results in supcess of eats / coldation products and potential for contamination of surface water. Also results in decrease of cover effectiveness and higher net percelation mass.	low
2	Erosion due to minfail and enowmelt to the extent that cover performance does not meet design ortients	Exposure of veste material. Results in supcours of eats / outdation products and potential for contamination of surface water. Also results in decrease of cover effectiveness and higher net percelation materia.	moderate
•	Erosion due to an extreme event to the extent that the cover profile is breached	Bitom event autase stration of cover and exposure of water material. Use of laciation and material (BUTTHIS SHOULD on necessary by eac CONSIDEREN DO BE AN INSTANCIUS EVENT (the externe event may cause the watereas and them a subsequent event results in the actual fathum). Results in seposure of assist in olderion products and potential for contamination of surface water. Also results in decrease of over effectiveness and higher net percolation mate.	modenate
٠	Enceion to the extent that apilway performance is degraded such that ponding and bypase occurs (pollway may be other than the dam apilway; it is simply a location where water is focuaed on the over system to transport water of the oover system to transport water	Results in erosion extending back up into / onto the cover system and breach of the cover system, loss of isolation of tailings and transport of tailings into environment.	moderately high
5	Prezethaw, welldry settlement, hummocks leading to crecking	Expect deterioration leading to one-order magnitude higher NP than expected from intact (uncreaced) DGM liner.	moderately Ngh
0	Diockage of surface water drainage swales and/or channels due to addimentation	Limits drainage of cover system during spring meit and/or extreme minifail events, which can lead to entation as a result of focused water. May also result in higher neit percolation rates due to ponding. Failure mode 'enhanced' with diminage swales and/or channels that are north- facing as these suales and/or channels will meit bat.	moderate
7	Diockage of surface water drainage swales and/or channels due to vegetation	Units drainage of cover system during spring met and/or subteme alight events, which can lead to enable na a next of bounde water. Way also next in higher net perclution intelse due to ponding. Failure mode infranced with drainage availas and/or charmals that are north- facing as these sensions and/or charmals will met that.	moderate
8	Diockage of surface water drainage swales and/or channels due to anow / ice	Units drainage of cover system during spring met and/or subteme ainfail events, which can lead to extend on as a next of bounde vestor. Way also next in higher net perclation intes due to ponding. Failure mode infranced with drainage availes and/or charmals that are north- hicing as these sensies and/or charmals will met last.	Ngh
04	Diockage of surface water drainage swales and/or channels due to animals (beavers)	Units drainage of cover system during spring met and/or subteme alinfail events, which can lead to extend on as a next of boundet water. Way also next in higher net perclation into due to porting. Failure mode infranced with drainage availae and/or channels that are north- hicing as these sensies and/or channels will met last.	low
9	Attention of surface water drainage sweles and/or channels due to disruption (frost hasve, settlement, including themoleants, etc.)	Umos standage of cover system dump spring met and/or externe sumsi evens, which can lead to extend as a next of boundet water. Way site next in higher net perclation intee due to ponding. Failure mode infranced with desings evalue and/or charmels that are north- facing as these sensions and/or charmels will met last.	moderately high
10	Cover system constructability	Additional cost to overcome difficult access for material removal and replacement, requires additional rockfil for access, geotextile for support.	high
	inappropriate / incorrect quality assurance		
11	Inadequate and/or inexperienced quality control during construction	Some increased seepage for the period of repair until repair occurs or could have chronic adverse impacts on performance latter being less likely.	moderately high
11	Indequate and/or integrationed quality control during construction	Some increased except for the participation of repair until repair cours or could have chronic advance impacts on performance latter being less lixely. Firs huma large acclines of vegetation on the cover surface. Polantial change to permethod regime and klope stability identifiation. Polantial increases if vegetation is miled on the revision control. Increases in auditment releases of of over surface. Polantial discrease in cover performance (net perceisation), if vegetation is miled on bill intel perceisation.	moderately high moderate
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- **1. Erosion to the extent that spillway performance is** degraded and ponding and bypass occurs :
- Design erosion resistant channels leading into the spillway.
- •Observe/measure cover performance under site climatic conditions.
- Inspection of cover following a storm event.
- Maintenance of rills/gullies.





2. Surface water management:

•Observe / measure cover performance under site climatic conditions;

Inspect cover following storm events; and

•Perform routine maintenance to repair rills and gullies.

From design perspective:

Increase design storm event criteria and re-design the landform and/or surface water management system.



Mitigation Methods: Case Study #3 <u>3. Glaciation:</u>

- •Design wider channels and include erosion protection in swales;
- •Construct erosion resistant channels leading into the spillway;
- •Observe / measure cover performance under site climatic conditions;
- Inspect cover following storm events; and
- Perform routine maintenance to repair rills and gullies.





4. Freeze/thaw cycles, wet/dry settlement, and development of hummocks leading to cracking of the cover:

Inspect landform at regular intervals; and

•Perform routine maintenance to repair cracks.

From design perspective:

Incorporate change in hydraulic characteristics of cover materials due to frost action into the design.





5. Cover system constructability:

•No way to reduce these expected costs.

•TAG's recommendation for mitigation is limited to a change in cover design to avoid these constructability issues.

