Cover Systems and Landforms for Closure of Mine Waste Storage Facilities – Practical Insights with a Focus on Saskatchewan

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Our vision

We strive to be the premier engineering solutions partner, committed to delivering complex projects from vision to reality for a sustainable lifespan.
Mine Waste Storage Facilities (MWSF)

**Varying Landforms:**
- Ponds of finer, wetter tailings
- Stockpiles of coarser, drier tailings
- Stockpiles of waste rock

**Varying Landform Attributes:**
- Geochemistry … reactivity, solubility, etc.
- Geotechnical … grain size, strength, etc.
- Geometry … footprint, height, slopes

**Varying External Factors:**
- Climatic conditions (seasonal)
- Hydrogeological setting

*From a closure / reclamation perspective …*
- Cover system design will be influenced by numerous factors
- Detailed site characterization is paramount
MWSF Cover System Technology – Evolution over Time

- Mine reclamation started in earnest in 1970s
- Early designs based on landfill liner designs, with unrealistic expectations of performance
- Cover system technology advanced with considerable research since early 1990s
  - MEND (2004) – Cover design manual
  - MEND (2007) – Macro-scale focus
  - MEND (2012) – Cold regions focus
  - INAP (2017) – Global focus

### Fundamental Changes in Cover System Technology over Past 40 Years:

- Improved software to numerically simulate cover system performance
- Advancements in modelling methodology
- Much greater appreciation for evolution of cover materials / systems
- Field performance monitoring – evolved from small test plots, to larger-scale field trials, and now watershed-scale focus
- Overall design … more emphasis on how cover system integrates w/ final landform
Objectives and Design Functions of MWSF Cover Systems

Objectives:
› Support agreed-upon end land use
› Minimize degradation of receiving environment post-closure

Most Common Design Functions:
› Waste isolation ("keep clean water clean")
› Re-establish vegetation and ecosystems
› Control wind and water erosion of waste material
› Limit influx of oxygen to reactive waste material
› Limit net percolation of meteoric water through the waste
Example where a Cover System Increased Net Percolation Rates compared to No Cover Scenario

Tailings Impoundment at a Legacy Mine Site in Northern SK

Finer-textured tailings

Ppt $\approx 450\text{mm}$

RO $\approx 150\text{mm}$

AE $\approx 250\text{mm}$

$<0.5\text{m}$

$\{1.0\text{m} \text{ silty-sand till}\}$

NP $\approx 50\text{mm}$

NP $\approx 75\text{mm}$

Cont. Runoff | Cont. Seepage | Total Potential Cont. Flow
--- | --- | ---
No Cover | 150mm | 50mm | 200mm
1m Till Cover | 0 | 75mm | 75mm

Ppt $\approx 450\text{mm}$

RO $\approx 100\text{mm}$

AET $\approx 275\text{mm}$

Finer-textured tailings

Tailings Impoundment at a Legacy Mine Site in Northern SK

Ppt $\approx 450\text{mm}$

AET $\approx 275\text{mm}$

NP $\approx 50\text{mm}$

NP $\approx 75\text{mm}$
Cover System Design Alternatives

Moisture Store & Release (S&R)
- Growth Medium Layer
- Waste Material

Enhanced S&R
- Growth Medium Layer
- Alternate Layer
- Waste Material

Barrier Type
- Growth Medium/Protective Layer
- Barrier Layer
- Waste Material

Covers w/ Geosynthetics
- Growth Medium/Protective Layer
- Drainage/Cushion
- Geosynthetic Material
- Waste Material

Can all of these alternatives function over the long term under SK’s extreme climatic conditions?
Case Study – Cluff Lake Tailings Management Area (TMA)

- TMA received ~2.67 Mm$^3$ (~80 ha) of uranium tailings between 1980 and 2002
- Main Dam – till-bentonite core down to bedrock

**Major Concerns for Closure:**
1. Ra-226 and Uranium source terms
2. Proximity to sensitive aquatic receptor
3. Limited cover materials – local sandy till (~15% fines)

(Source: COGEMA 2001 Cluff Lake Project Comprehensive Study Report)
Case Study – Cluff Lake Tailings Management Area (TMA)

› Initial thinking was a cover system w/ compacted sand-bentonite layer would be needed to limit net percolation and radon gas emissions

› Concerns arose about the longevity of a barrier-type cover design in a cold region over a tailings deposit

› Through detailed site characterization and analyses, COGEMA demonstrated that a 1.0 m till cover (min.) would be acceptable

› Reclaimed TMA performing as-designed
Example of Enhanced Moisture S&R Cover System

- Compacted waste rock overlain by 1.0 m silty-sand till
- Claude waste rock pile at the former Cluff Lake Mine (Orano Canada)
- B-zone waste rock pile at Cameco’s Rabbit Lake Mine

(Source: Ayres et al., 2013)
Cover Systems with Capillary Break Effects (CCBE)

They work great provided …
› Appropriate textural contrast between adjacent layers
› Capillary break layer remains in a drained state

How can we ensure a CCBE performs as intended over the long term?
› Increase thickness of overlying water storage layer … especially on long slopes
› Use CCBEs where the water table is deeper
Cover Systems with Geosynthetics

Which Product is Right for Your Site?

› Chemical compatibility w/ waste & cover pore-waters?
› Texture of sub-grade material?
› Length of construction season?

Key Cover Design Aspects:

› Lateral drainage / diversion capacity
› Geotechnical stability
› Serviceable lifespan of geomembrane

(Source: www.agru.at/en/products/lining-systems/)
(Source: www.titanenviro.ca)
(Source: www.passel.unl.edu)
Cover System Construction Considerations

Over-Compaction of Growth Medium Layer

› Decreases water storage capacity and limits deeper root development
› Winter construction or use lighter equipment

Revegetation Method

› Higher seed germination rates w/ drill seeder

Potential for Material Segregation

› Gap-graded materials prone to segregation
› Place in thinner lifts, doze for homogeneity

Adequate construction QA/QC!
Performance Monitoring of Reclaimed Mine Waste Landforms

Direct *In Situ* Monitoring:

- Enables tracking *trajectory* of cover system performance
- Feedback during operations (field trials or full-scale areas)

Meteorological station

Subsurface hydrologic station
(w/c, soil suction, temperature)

Runoff station

Groundwater monitoring

Surface water monitoring
Quantifying Net Percolation Rates

› Key input for numerical assessments of contaminant transport

› Simple parameter for stakeholders to understand

Gravity-drainage Lysimeters …

› Conceptually simple, but proper design, installation, and operation can be challenging
Traditional MWSF Reclaimed Landforms vs. Natural Landforms

Traditional MWSF reclaimed landforms:
› uniform shapes w/ linear slopes
› drainage courses highly engineered, typically along contours
› artificial revegetation designs

Natural soil-mantled landforms:
› variety of shapes w/ non-linear slopes
› drainage courses meandering and follow natural drop lines
› vegetation dependant on hillslope hydrology and incident solar radiation

(Source: www.miningfocus.org)
(Source: https://www.nrcs.usda.gov)
Geomorphic Approach to MWSF Landform Reclamation Design

› Emulate the natural landscape that is in equilibrium w/ local climate, soils, vegetation
› Incorporate “forms” that fit the “function”
› Incorporate diversity to promote resiliency, leading to a sustainable ecosystem

Is there a business case to build landforms with a more natural appearance?

1) Reduced maintenance liability post-closure
2) Earlier transfer to custodial care
3) Public relations value (e.g. AB oil sands)
Geomorphic Approach to MWSF Landform Reclamation Design

- Benched slope profiles are prone to failure over the long term.
- Concave slopes are more stable than linear slopes.

Cameco’s Rabbit Lake BZWRP Reclaimed Landform (2010)

(Source: www.ausimmbulletin.com)
Surface Water Management

Why is this important?
› Gully erosion and re-established surface water drainage courses are greatest physical risk to reclaimed landforms (McKenna and Dawson, 1997)
› Erosion gullies have a high visual effect
› Erosion can lead to increased contaminant loading

Key Design Aspects for MWSF Reclamation:
› Incorporate climate change into design storm event
› Clearly defined catchments w/ high drainage density
› Limit drainage channels / outlets on north-facing slopes

(Source: www.dailymail.co.uk)
(Source: www.emnrd.state.nm.us/)
MWSF Landform Design w/ Closure in Mind

“Contour-Terraced Stockpile” (Ayres et al., 2006)

- Facilitates curvilinear slope profile and creation of ridges and swales at closure
Key Take-Away Messages

› Various cover system design alternatives exist, but **simple yet robust designs** are preferred for SK’s climatic conditions

› Use appropriate **landforms** to support design functions of mine waste cover system

› Reclaimed mine waste landforms will **evolve over time** ... design for this fact

› A **business case** exists for building mine waste landforms with a more **natural appearance**

(Source: www.westmoreland.com/)

(Photo courtesy of Orano Canada)
List of References


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**SAFETY**

We put safety at the heart of everything we do, to safeguard people, assets and the environment.

**INTEGRITY**

We do the right thing, no matter what, and are accountable for our actions.

**COLLABORATION**

We work together and embrace each other’s unique contribution to deliver amazing results for all.

**INNOVATION**

We redefine engineering by thinking boldly, proudly and differently.