Landfill Final Cover System Design – Not as Simple as One May Think


SustainTech 2018 Conference – March 22, 2018, Saskatoon, SK
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Presentation Outline

› Typical Municipal Solid Waste (MSW) Landfill Facilities and Characteristics
› Purpose and Design Functions of Landfill Final Cover Systems (LFCSs)
› Key Factors Influencing Design and Performance of LFCSs
› Review of LFCS Design Alternatives
› Learnings from Research on Mine Waste Storage Facility (MWSF) Cover Systems
› Landfill Closure in Saskatchewan
› Key Take-Away Messages
## Typical MSW Landfill Facilities in Saskatchewan

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>Typical Characteristics</th>
<th>Typical Environmental Control Systems</th>
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</table>
| **Dump or Legacy Site** | • Established prior to 1990s, typically remote or rural areas  
• Small waste quantities and serviced population  
• Minimal siting considerations                                                                                | • Minimal to none … rely on large buffer zones to manage exposure risks to receptors                     |
| **Natural Attenuation** | • Older and newer facilities  
• Small-medium waste quantities and serviced population  
• Relatively thick natural attenuation zone                                                                         | • Natural attenuation processes to reduce contaminant concentrations to acceptable levels  
• Surface water mgmt. (?)                                                                                       |
| **Engineered Landfill** | • Newer facilities  
• Larger waste quantities and serviced population  
• An *absolute must* when hydro-geological setting is poorer                                                  | • Leachate collection and management  
• Surface water mgmt.  
• Landfill gas collection (?)  
• Groundwater intercept. (?)                                                                                 |
Typical Characteristics of Landfilled MSW

› Mostly **household refuse**, but depends on age of the landfill
  › Large quantities of construction & demolition (C&D) waste at some sites

› High **ash** and **cinder content** at many legacy sites from open burning

› As organic matter decomposes, **landfill gases** are produced, comprised mostly of methane and carbon dioxide

› As rain and snowmelt water percolate through waste, **landfill leachate** is generated ... a water-based solution containing a variety of pollutants
### Typical Characteristics of MSW Landfill Leachate

- **Heavy metal concentrations** in leachate typically below most drinking water stds.

- Substances of potential concern (SOPCs) in most cases are **ammonia** and **salinity**, and where open burning has occurred, **PAHs**, **dioxins** and **furans**

- **Chloride** a good indicator of leachate plume leading edge, while **boron** is a good measure of mature portion of plume

<table>
<thead>
<tr>
<th>Leachate Pollutant Groups</th>
<th>Typical Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved organic matter</td>
<td>Acids, alcohols expressed as COD or TOC</td>
</tr>
<tr>
<td>Inorganic matters</td>
<td>Ca, Mg, Na, K, NH₄, Fe, Mn, Cl, SO₄, HCO</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Cd, Cr, Cu, Pb, Ni, Zn</td>
</tr>
<tr>
<td>Xenobiotic organic compounds (XOCs)</td>
<td>Aromatic hydrocarbons, phenols, chlorinated aliphatic hydrocarbons, pesticides &amp; plasticizers</td>
</tr>
<tr>
<td>Combustion products</td>
<td>Dioxins, furans</td>
</tr>
</tbody>
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Purpose and Design Functions of Landfill Final Cover Systems (LFCSs)

**Purpose:**
- Limit exposure and/or potential risks to human health and the environment post-closure
- Facilitate meeting aesthetic and end land-use objectives

**Typical Design Functions:**
- Limit potential for direct contact with contaminants
- Limit water infiltration to reduce volume of leachate
- Control landfill gas emissions so they can be minimized, or concentrated for collection and destruction or use
- Provide a growth medium for native plant species
Key Factors Influencing Design of a LFCS

› End land-use
› Substances of potential concern in waste
› Receptors and exposure pathways
› Extent / efficacy of leachate collection system
› Extent / efficacy of landfill gas–to–energy conversion system
› Potential for future differential settlement (i.e. density / thickness of waste and stage of organic waste decomposition)
› Physical / hydraulic characteristics of on-site or nearby soils in sufficient quantities

(Source: https://foresternetwork.com/daily/waste/waste-collection/revisiting-the-cover-on-final-cover-2/)
### LFCS Requirements from Various Jurisdictions

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Date</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saskatchewan</td>
<td>(1998 Draft Guidelines)</td>
<td>Positive drainage, 0.5 m Clay Soil, 0.2 m Subsoil Layer, 0.6 m Organic Layer, 0.35 m Positive drainage</td>
</tr>
<tr>
<td>Alberta</td>
<td>(2010 Landfill Stds.)</td>
<td>5% to 30% Organic Layer, Subsoil Layer (0.8 m for cultivated land), 0.15 m Organic Layer, 0.5 m Subsoil Layer, 0.6 m Organic Layer</td>
</tr>
<tr>
<td>Manitoba</td>
<td>(2016 Landfill Stds.)</td>
<td>25% to 33% Organic Layer, Subsoil Layer (K_{sat} \leq 10^{-5} cm/s), 0.15 m Organic Layer, 0.5 m Subsoil Layer, 0.6 m Organic Layer</td>
</tr>
<tr>
<td>British Columbia</td>
<td>(2016 Landfill Criteria)</td>
<td>10% to 33% Organic Layer, Subsoil Layer (K_{sat} \leq 10^{-5} cm/s for semi-arid regions), 0.15 m Organic Layer, 0.5 m Subsoil Layer, 0.6 m Organic Layer</td>
</tr>
<tr>
<td>Ontario</td>
<td>(2012 Landfill Stds.)</td>
<td>5% to 25% Organic Layer, Subsoil Layer (soil type/compaction depends on NP_{max}), 0.15 m Organic Layer, 0.4 m Subsoil Layer, 0.9 m Compacted Clay Soil</td>
</tr>
<tr>
<td>North Dakota</td>
<td>(2009 – Guideline 10)</td>
<td>2% to 12% Organic Layer, Subsoil Layer, 0.15 m Organic Layer, 0.4 m Subsoil Layer, 0.9 m Compacted Clay Soil</td>
</tr>
<tr>
<td>Montana</td>
<td>(2017 – ARM 17.50.1403)</td>
<td>Not specified, Organic Layer, Subsoil Layer (K_{sat} \leq 10^{-5} cm/s), 0.15 m Organic Layer, 0.45 m Subsoil Layer, 0.45 m Compacted Clay Soil</td>
</tr>
<tr>
<td>Minnesota</td>
<td>(2017 – Rule 7035.2815)</td>
<td>2% to 25% Organic Layer, Subsoil Layer, 0.15 m Organic Layer, 0.4 m Subsoil Layer, 0.9 m Compacted Clay Soil</td>
</tr>
</tbody>
</table>

**Legend:**
- Organic Layer
- Subsoil Layer
- Barrier Layer (K_{sat} \leq 10^{-5} cm/s)
- Subsoil Layer (K_{sat} \leq 10^{-7} cm/s for semi-arid regions)
- Positive drainage
- Compacted Clay Soil
Most Common Types of LFCS Designs

“Evapotranspiration (ET) Cover System”
- Organic Layer
- Root Zone and Moisture Store & Release Layer (well-graded soil w/ >30% silt & clay)
  - 0.15 m
- 0.6 to 1.0 m

“Compacted Soil Barrier Cover System”
- Organic Layer
- Barrier Protection, Root Zone and Moisture Store & Release Layer (well-graded soil w/ >30% silt & clay)
  - 0.3 to 0.9 m
- 0.3 to 0.9 m
- 0.10 m
- 0.10 m

“Geosynthetic Barrier Cover System”
- Organic Layer
- Barrier Protection, Root Zone and Moisture Store & Release Layer (well-graded soil w/ >30% silt & clay)
  - 0.3 to 0.9 m
- 0.3 to 0.9 m
- 0.10 m
- 0.10 m

Final Cover Foundation Layer
- (interim soil cover, compacted firm, minimum 5% slope)

Design of this layer often overlooked!!
- [geocomposite drainage net (GDN) or sand/gravel]

Barrier Layer
- [geosynthetic clay liner (GCL) or 40- to 60-mil linear low-density PE (LLDPE) geomembrane]
Research on Mine Waste Storage Facility (MWSF) Cover Systems

› MEND (2004) – 5 volume set focused on design, construction, and performance monitoring of MWSF covers

› MEND (2007) – focused on design and performance monitoring of MWSF covers from a landform perspective

› MEND (2012) – focused on design and construction of MWSF covers situated in a cold region

› INAP (2017) – most recent MWSF cover technical guidance document with a global focus
Key Lessons Learned from MWSF Case Studies

1) Transfer the methodology, not the design, from site to site … account for site-specific waste, soil, climatic and vegetation conditions

2) Cover system performance should be linked to predicted impacts on receiving environment

3) Greatest physical risk to reclaimed landforms is gully erosion and re-established surface water drainage courses (McKenna & Dawson, 1997)

4) Thickness of root zone / barrier layer protection layer – needs to be thicker to provide adequate water for plant growth, and protect the barrier layer from various physical, chemical and biological processes

Equity Silver Mine (BC) WRSF Final Cover Case Study (INAP, 2003):

(Source: www.dailymail.co.uk)
So how do we Maximize the Potential for Sustained Performance of a LFCS?

Physical Integrity:
› High degree of compaction of underlying fill materials
› Proper management of surface water (runoff and runon)

Lower Infiltration / Leachate Rates:
› Promote runoff of snowmelt and storm waters
› Increase ET w/ diverse, sustained vegetation cover
› Adequately protect a barrier layer from degradation

Lower Landfill Gas Emissions:
› Maintain physical integrity of cover system
› Thicker final cover or include a barrier layer
Work to Support Landfill Closure in SK

Environmental Site Assessment (ESA):

› Typically a limited Phase II ESA investigation to characterize physical site conditions and identify existing and potential future environmental impacts

› Involves monitoring well installation, water analyses and comparison to relevant standards, and identification of SOPCs, receptors, and exposure pathways

Corrective Action Plan (CAP):

› “a CAP details the methods used to prevent, minimize, mitigate, remedy or reclaim adverse effects” (SK MOE, 2015)

› Includes plans for site remediation, final cover profile and grading, and post-closure care and monitoring

This forms the basis of a Landfill Closure Plan, which, for most sites, will be “monitored natural attenuation”
Let’s Consider the Water Balance for a Site near Saskatoon *(mean annual basis; units of mm)*

\[ \text{Net Percolation (NP)} = \text{Water Input (WI)} - \text{Runoff (R)} - \text{Evapotranspiration (ET)} \]

\[ \text{WI} = \text{rain (277)} + \text{snow (91)} - \text{snowpack losses (15-25% of snow)} \]

\[ \text{Max. ET} \approx 50-60\% \text{ of Potential or Lake Evaporation (720)} \]

These WB fluxes similar to those measured at the St. Denis study site, 40 km east of Saskatoon – net recharge of 1-3 mm/year *(Hayashi et al., 1998)*
Cost-Benefit Analysis of Various LFCS Designs

Water Balance for Pre-Closure Conditions (mm):
- 345-355 (WI)
- 20-40 (R)
- 160-200 (ET)

Typical LFCS Construction Costs (SK):
- Evapotranspiration: $12 to $17 per m²
- Compacted soil barrier: $17 to $25 per m²
- Geosynthetic barrier: $25 to $40 per m²

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Mean Annual NP (% reduction compared to current conditions)</th>
<th>LFCS Construction Cost for 5 ha Site (% cost increase compared to ET option)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evapotranspiration</td>
<td>20 mm/yr (86%)</td>
<td>$725,000</td>
</tr>
<tr>
<td>Compacted soil barrier</td>
<td>10 mm/yr (93%)</td>
<td>$1,050,000 (45%)</td>
</tr>
<tr>
<td>Geosynthetic barrier</td>
<td>3 mm/yr (98%)</td>
<td>$1,625,000 (124%)</td>
</tr>
</tbody>
</table>
Additional Reasons why a Simpler Cover System is Preferred for Landfill Closure

The lower the net percolation rate, the longer it takes for waste stabilization ...

› Potential for differential settlement of LFCS is prolonged … additional maintenance liability for landfill owner
When should a Barrier-Type LFCS be given more consideration for Landfill Closure in SK?

› Sites with a poor hydrogeological setting

› Northern sites where snowfall is higher and ET rates are lower

› Sites surrounded by trees where a thicker than normal snowpack accumulates (e.g. Boreal forest)

› Sites where the predominant slope aspect is north
Typical Work to do Before Implementing a LFCS

› Cover material borrow investigation
› Delineation of waste footprint (if unknown)
› Topographic surveying of waste footprint and surrounding landscape
› Cost-benefit analysis of various LFCS design alternatives
› Design drawings and technical specs for construction
› Potential relocation of waste on surface to off-site facility or below final cover area
› Construction of final landform to support the LFCS
Key Take-Away Messages

› LFCSs need to be “engineered” … designed and constructed with appropriate consideration for site-specific conditions

› Use lessons learned from MWSF closure industry to design LFCSs to improve their potential for sustained performance

› An Evapotranspiration-type LFCS is ideally suited for Saskatchewan’s semi-arid climate and clay-rich soils

› *For most landfill sites in SK …* while the design process may be complex, the actual final cover system design should be “simpler”

(Source: https://servicehospitality.com/safety-keep-it-simple/)
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