Final Covers for Mine Tailings

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Functions of Covers

- Physical containment of waste
- Control percolation into waste
- Control gas movement
  Ingress (O₂)
  Egress (Rn, CH₄, CO₂)
- Control vector intrusion
- Persist for design life of containment facility
Categories of Engineered Covers

Conventional covers – cover designs where a barrier layer (clay, geomembrane, etc.) having low saturated hydraulic conductivity is the primary impediment to leakage and gas flow.

- clay covers, composite covers, GCL covers

Water balance covers – cover designs where leakage is controlled by balancing the water storage capacity of unsaturated finer-textured soils and the ability of plants and the atmosphere to extract water stored in the soil. Also known as water balance covers, evapotranspiration (ET) covers, store-and-release covers.

- monolithic covers, capillary barrier covers
Conventional Resistive Covers with a Soil Barrier

Simple Soil Cover

Compacted Clay Cover

Geosynthetic Clay Liner (GCL) Cover

Soil

Waste

Soil

Compacted Clay

Waste

Soil

Waste

GCL
Conventional Resistive Covers with a Composite Barrier

Clay-Geomembrane Composite

GCL-Geomembrane Composite
Water Balance Covers

Monolithic Barrier

Fine Textured Soil

Waste

Capillary Barrier

Fine Textured Soil

Coarse Soil

Waste
<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Percolation Rate</th>
<th>Gas Flux</th>
<th>Cost ($/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Soil</td>
<td>Highest</td>
<td>Highest</td>
<td>25,000</td>
</tr>
<tr>
<td>Clay</td>
<td>Modest</td>
<td>Modest</td>
<td>75,000</td>
</tr>
<tr>
<td>GCL</td>
<td>Modest</td>
<td>Modest</td>
<td>75,000</td>
</tr>
<tr>
<td>Composite</td>
<td>Very low</td>
<td>Very Low</td>
<td>125,000</td>
</tr>
<tr>
<td>ET Monolithic</td>
<td>Very low - low</td>
<td>Modest</td>
<td>50,000</td>
</tr>
<tr>
<td>Capillary Barrier</td>
<td>Very low - low</td>
<td>Modest</td>
<td>50,000</td>
</tr>
</tbody>
</table>
Design Philosophy

Conventional Designs
- regulatory engineering, not site specific
- methods & materials requirements
- no quantitative performance criterion

Alternative (Performance-based) Design
- determine performance criterion (e.g., percolation ≤ prescriptive cover)
- select layering to meet a quantitative performance criterion
- analyze to ensure alternative cover meets performance criterion
Issues with Prescriptive Regulation

1. With conventional designs typically no performance criteria
2. Alternative designs typically required to show equivalent performance (see 1)
3. Equivalency demonstration is difficult
4. Primary goal (protect HH&E) often neglected
5. Cost (to society) can be higher than necessary
6. An example of the rule of unintended, undesirable consequences
7. Common with indirect regulation
An Alternative Regulatory Philosophy

- Focus on primary goal (ex. protection of ground water)
- Prescriptive design *process*
  - Type of waste?
  - Waste packaging?
  - Climate?
  - Depth to groundwater?
  - Attenuation capacity of unsaturated zone?
  - Distance to nearest receptor (ex. pumping well)?
  - Any sensitive environments or species?
  - Each site will have a different list
- Require design engineer to demonstrate compliance with primary goal
- Require appropriate monitoring
USEPA’s Alternative Cover Assessment Program (ACAP)

- Twenty-four test covers at eleven sites in seven states.
- Ten conventional covers (seven composite and three clay)
- Fourteen alternative covers (eight monolithic barriers and six capillary barriers)
- Eight sites with side-by-side comparison of conventional and alternative covers
ACAP Drainage Lysimeters
Full-scale construction methods
Hundreds of samples and instruments
Lysimeters are the only method for direct measurement of drainage
Conventional Covers Evaluated by ACAP

- Boardman, OR
- Apple Valley, CA
- Altamont, CA
- Albany, GA
- Marina, CA
- Cedar Rapids, IA
- Omaha, NE
- Polson, MT

Legend:
- Compacted Support Layer
- Sand
- Interim Cover
- Vegetative Cover or Storage Layer
- Drainage Composite
- Topsoil
- Geomembrane
- Geosynthetic Clay Liner (GCL)
- Compacted Soil Barrier
- Vegetation (Grass)
- Grasses, forbs, & shrubs
- Gravel
Compacted Clay Covers

Objectives:

1. Construct a soil barrier (compacted clay) with low saturated hydraulic conductivity.

2. Protect the clay barrier from damage that may increase hydraulic conductivity.
Types of Damage

- Frost

- Desiccation

- Differential settlement (normally a problem with municipal solid waste, but not mining wastes, coal ash, etc.)

- Erosion
Sensitivity to Frost Damage

Freezing of compacted clay barriers causes:

- formation of ice lenses: cracking

- formation of desiccation cracks as water moves to freezing front

- cracking that causes increases in hydraulic conductivity

Protect clay barrier with insulation (synthetic or burial).
Sensitivity of Compacted Clay to Desiccation Damage

Drying of compacted clay barriers causes desiccation cracks to form, increasing the hydraulic conductivity.

Large-scale cracks may form, as in this clay barrier in southern Georgia four years after construction.

Dye tracer test in soil barrier cover showing preferential flow path
Conventional Clay Cover Performance

- Soil dried for first time during 6-week drought
- Change in response of percolation to precipitation events
  - Quantity
  - “Stair step” response
- No evidence that defects in clay barrier healed when soil water increased

Data from ACAP field site in Albany GA
# Field Hydraulic Conductivity Measurements on Clay Barrier 4 Years After Construction

<table>
<thead>
<tr>
<th>Test</th>
<th>Hydraulic Conductivity (cm/s)</th>
<th>$K_{\text{final}}/K_{\text{as-built}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-Built</td>
<td>4.0x10^{-8}</td>
<td>1.0</td>
</tr>
<tr>
<td>SDRI</td>
<td>2.0x10^{-4}</td>
<td>5000</td>
</tr>
<tr>
<td>TSB - 1</td>
<td>5.2x10^{-5}</td>
<td>1300</td>
</tr>
<tr>
<td>TSB - 2</td>
<td>3.2x10^{-5}</td>
<td>800</td>
</tr>
<tr>
<td>TSB - 3</td>
<td>3.1x10^{-3}</td>
<td>77,500</td>
</tr>
</tbody>
</table>
Typical Composite Cover

150-1000 mm thick (6 – 40 inches)

- Drainage Layer
- Geomembrane

- Compacted Clay
  - 450-900 mm thick (18 – 36 inches)

- Surface Layer

• Geomembrane added directly on top of clay barrier or GCL
• Drainage layer frequently added on top of geomembrane to enhance stability by limiting pore water pressures.
1.5 mm LLDPE Textured Geomembrane
Geocomposite Drain
For covers, chemical compatibility normally is not a concern when selecting geomembrane polymer. Key issues are:

- constructibility
- durability
- cost
- availability with texturing

All of the cited geomembranes can be welded in the field using wedge or extrusion techniques to obtain welds with higher strength than parent material.

LLDPE and HDPE geomembranes are most commonly used for covers.
Drainage Layers

Functions:
- Reduce Head on Barrier Layer
- Reduce Pore Pressure Build Up

Materials:
- Coarse-Grained Soil (clean sand, crushed rock)
- Geocomposite Drain

Design Approach:
- Select drain that provides acceptable head
- Adequate hydraulic conductivity
- HELP, conservative (over-predicts lateral drainage)
- Giroud & Houlihan's Method
Conventional Composite Cover Performance

- Percolation correlated with
  - Heavy precipitation events
  - Surface flow
  - Lateral flow on geomembrane

Data from ACAP field site in Cedar Rapids IA
Damage to Geomembrane Affects Performance

- No cushion between the geomembrane and the soil, punctures likely in geomembrane
- Relatively high rate of percolation
- Illustrates importance of careful geomembrane installation

Data from ACAP field site in Marina CA
Summary: Conventional Designs

• Composite designs
  – Restrict percolation to low (\(<5 \text{ mm/yr}\)) levels at all locations
  – Percolation typically coincides with flow on membrane
  – Require careful construction practice and QA

• Clay barrier designs
  – Performance quickly (\(<2 \text{ yrs}\)) degrades
  – Percolation probably due to preferential flow through macro-features related to desiccation, freeze/thaw, roots
  – Damage likely to persist
  – Probably not suitable for near-surface applications that require low-permeability barrier
UW Desiccation Study:
Effect on Hydraulic Conductivity of GCLs

Divalent for monovalent cation exchange results in inability to close desiccation cracks, resulting in large increase in K.

UW Desiccation Study: Effect on Swelling of GCLs*

Divalent for monovalent exchange results in loss of swelling capability … and potentially healing capability

UW Study: GCLs Exhumed from In-Service Caps

All specimens underwent Ca/Mg for Na exchange.

Only those with \( w > 120\% \) maintained low K.

Need to protect GCL from drying and/or cation exchange.
Differential Settlement

• Distortion
  – ~300 mm V
  – ~450 mm H
• No damage to GM
• Large increase in K to soil barrier
• GCL
  – Extensive cation exchange
  – Retained very low hydraulic conductivity
  – Humid climate and overlying GM – hydrated quickly, did not experience desiccation
• This case study has relatively small distortion
• Differential settlement an issue with waste containers
• Need more research
• Cover likely retained function due to intact GM and GCL
### ACAP Data for Conventional Covers

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Site</th>
<th>Precipitation Average (mm/yr)</th>
<th>Surface Runoff Average (mm)</th>
<th>Lateral Flow Average (mm)</th>
<th>ET Average (mm)</th>
<th>Percolation Average (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>Altamont</td>
<td>379</td>
<td>59.0</td>
<td>4.0</td>
<td>1.5</td>
<td>0.1*</td>
</tr>
<tr>
<td></td>
<td>Apple Valley</td>
<td>169</td>
<td>6.8</td>
<td>0.0</td>
<td>0.0</td>
<td>Trace</td>
</tr>
<tr>
<td></td>
<td>Boardman</td>
<td>177</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0*</td>
</tr>
<tr>
<td></td>
<td>Marina</td>
<td>433</td>
<td>98.7</td>
<td>47.4</td>
<td>23.1</td>
<td>28.3</td>
</tr>
<tr>
<td></td>
<td>Polson</td>
<td>350.0</td>
<td>17.7</td>
<td>40.5</td>
<td>0.4</td>
<td>Trace</td>
</tr>
<tr>
<td></td>
<td>Cedar Rapids</td>
<td>981</td>
<td>54.1</td>
<td>96.2</td>
<td>12.2</td>
<td>2.8*</td>
</tr>
<tr>
<td></td>
<td>Omaha</td>
<td>731</td>
<td>86.8</td>
<td>43.3</td>
<td>6.0</td>
<td>0.7*</td>
</tr>
<tr>
<td>Soil Barrier</td>
<td>Apple Valley</td>
<td>169</td>
<td>3.4</td>
<td>0.0</td>
<td>0.0</td>
<td>7.4 (4.1%)</td>
</tr>
<tr>
<td></td>
<td>Albany</td>
<td>1263</td>
<td>359.4</td>
<td>NA</td>
<td>195.2</td>
<td>195.2 (17.1%)</td>
</tr>
<tr>
<td></td>
<td>Cedar Rapids</td>
<td>981</td>
<td>79.6</td>
<td>29.5</td>
<td>51.6</td>
<td>51.6 (6.0%)</td>
</tr>
</tbody>
</table>

*Composite percolation data are scaled from field measurements to account for x10 increase in geomembrane flaws. Marina data not scaled due to geomembrane damage during construction.

= semi-arid/sub-humid/arid.  = humid.
Summary: Field Performance of Conventional Covers

- Percolation rates for composites are very low:
  - < 1 mm/yr in semi-arid and arid climates
  - < 5 mm/yr in humid climates

- Percolation rates for soil covers much higher than expected:
  - 195 mm/yr at Albany, GA
  - Appears dominated by preferential flow

- Surface runoff is a small fraction of the water balance (<10%)

- Lateral drainage is a small fraction of the water balance (< 5%)
Water Balance Covers Evaluated by ACAP

Helena, MT  Polson, MT  Boardman, OR  Altamont, CA  Apple Valley, CA  Monticello, UT  Marina, CA  Albany, GA  Marion, IA  Omaha, NE  Sacramento, CA

Compost / Soil Mix  Soil-Gravel Admixture  Gravel  Topsoil  Storage Layer  Clean Sand  Compacted Vegetative Cover  Silty Sand  Interim Cover  Vegetation (Grass)  Vegetation (Hybrid-Poplar Trees with a grass understory)  Vegetation (Grasses, forbs, and shrubs)

Target percolation rates ~ 3 mm/yr or less.
## ACAP Site Characteristics

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Elev. (m)</th>
<th>Annual Precip. (mm)</th>
<th>Annual Snowfall (mm)</th>
<th>Annual P/PET</th>
<th>Climate</th>
<th>Monthly Avg. Air Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple Valley, CA</td>
<td>898</td>
<td>119</td>
<td>38</td>
<td>0.06</td>
<td>arid</td>
<td>-1, 37</td>
</tr>
<tr>
<td>Boardman, OR</td>
<td>95</td>
<td>225</td>
<td>185</td>
<td>0.23</td>
<td>semi-arid</td>
<td>-2, 32</td>
</tr>
<tr>
<td>Helena, MT</td>
<td>15</td>
<td>312</td>
<td>1288</td>
<td>0.44</td>
<td>semi-arid</td>
<td>-11, 28</td>
</tr>
<tr>
<td>Altamont, CA</td>
<td>227</td>
<td>358</td>
<td>2</td>
<td>0.31</td>
<td>semi-arid</td>
<td>2, 32</td>
</tr>
<tr>
<td>Monticello, UT</td>
<td>1204</td>
<td>385</td>
<td>1498</td>
<td>0.34</td>
<td>semi-arid</td>
<td>-9, 29</td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>320</td>
<td>434</td>
<td>0</td>
<td>0.33</td>
<td>semi-arid</td>
<td>3, 34</td>
</tr>
<tr>
<td>Underwood, ND</td>
<td>622</td>
<td>442</td>
<td>813</td>
<td>0.47</td>
<td>semi-arid</td>
<td>-19, 28</td>
</tr>
<tr>
<td>Marina, CA</td>
<td>31</td>
<td>466</td>
<td>0</td>
<td>0.46</td>
<td>semi-arid</td>
<td>6, 22</td>
</tr>
<tr>
<td>Polson, MT</td>
<td>892</td>
<td>380</td>
<td>648</td>
<td>0.58</td>
<td>sub-humid</td>
<td>-7, 28</td>
</tr>
<tr>
<td>Omaha, NB</td>
<td>378</td>
<td>760</td>
<td>711</td>
<td>0.64</td>
<td>sub-humid</td>
<td>-6, 25</td>
</tr>
<tr>
<td>Cedar Rapids, IA</td>
<td>290</td>
<td>915</td>
<td>724</td>
<td>1.03</td>
<td>humid</td>
<td>-8, 23</td>
</tr>
<tr>
<td>Albany, GA</td>
<td>60</td>
<td>1263</td>
<td>3</td>
<td>1.10</td>
<td>humid</td>
<td>8, 33</td>
</tr>
</tbody>
</table>
- Costal semi-arid climate
- Precipitation = 466 mm/yr
- P/PET = 0.46
- Capillary barrier (theory), but effectively a monolithic barrier
Percolation occurs every year when storage capacity is exceeded.
Polson, MT

Cool and Seasonal Semi-Humid Climate

Capillary Barrier

Precipitation ~ 380 mm/yr)

P/PET = 0.58
Capillary Barrier: Polson, MT

0.8 mm percolation over 5 yr! Less than composite.
# ACAP Data for Water Balance Covers

<table>
<thead>
<tr>
<th>Site</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Precip. (mm)</td>
<td>Perc. (mm)</td>
</tr>
<tr>
<td>Albany, GA</td>
<td>1380.2</td>
<td>218.3</td>
</tr>
<tr>
<td>Altamont, CA</td>
<td>498.6</td>
<td>139.3</td>
</tr>
<tr>
<td>Apple Valley, CA</td>
<td>272.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Boardman, OR (Thin)</td>
<td>210.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Boardman, OR (Thick)</td>
<td>210.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Cedar Rapids, IA</td>
<td>898.4</td>
<td>366.1</td>
</tr>
<tr>
<td>Helena, MT</td>
<td>351.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Marina, CA</td>
<td>406.9</td>
<td>82.4</td>
</tr>
<tr>
<td>Monticello, UT</td>
<td>662.9</td>
<td>3.4</td>
</tr>
<tr>
<td>Omaha, NE (Thin)</td>
<td>612.4</td>
<td>101.0</td>
</tr>
<tr>
<td>Omaha, NE (Thick)</td>
<td>612.4</td>
<td>57.9</td>
</tr>
<tr>
<td>Polson, MT</td>
<td>308.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Sacramento, CA (Thin)</td>
<td>361.2</td>
<td>108.4</td>
</tr>
<tr>
<td>Sacramento, CA (Thick)</td>
<td>455.7</td>
<td>8.5</td>
</tr>
<tr>
<td>Underwood, ND</td>
<td>585.2</td>
<td>9.4</td>
</tr>
</tbody>
</table>
Key to design is available storage capacity (soil properties and cover thickness) must equal or exceed required storage (climate characteristics).
A Two-Step Method for Design of Water Balance Covers

1. Preliminary design: estimate required thickness by matching required and available storage using ACAP approach based on a robust, nation-wide field data set.

2. Refine the design with numerical simulations to evaluate:
   • Important design parameters
   • “what if?” assessments
A Regulatory Framework

Regulatory Requirements

• The goal: Protect human health and environment!

• Factors to consider
  • Waste characteristics
  • Hazardous life of waste
  • Waste packaging
  • Depth to ground water
  • Attenuation capacity of geostrata
  • Distance to nearest receptor or sensitive environment
  • Climate
  • Stakeholder views, public acceptance
  • Containment Philosophy
    • Minimize release
    • Controlled release
  • Modify list to be site-specific

Site and Engineer Responsibilities

• Conduct prescribed site and waste analysis
• Define required closure performance
  • Percolation
  • Gas release
  • Erosion
  • Containment life
• Select appropriate closure concept (composite, water balance, ?)
• Result is site-specific, performance-based design
• Monitor and maintain
• Engineer and regulator must develop long-term relationship based on past performance, trust, and a shared dedication to the ‘real’ goals.
Publications


