Evolution of Soil Hydraulic Properties in Dry Covers: Lessons Learned from the Alternative Cover Assessment Program (ACAP)

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23 February 2009
ACAP Objectives

1. Collect field-scale hydrology data for conventional and water balance (aka store & release, or S&R) covers for broad range of climates and conditions.

2. Evaluate & develop design methods for S&R covers.

3. Evaluate numerical models and develop modeling strategies.

4. Develop design guidance and provide technology transfer on S&R cover design and construction.

10 yr and $10M later, mission (mostly) accomplished.
ACAP Network of Final Cover Test Sections

12 Sites, 8 States, 28 Test Sections

Covers designed to transmit < 3, 10, or 30 mm/yr depending conventional cover required by regulation.
## 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>
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<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>
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<tr>
<td>Underwood, ND</td>
<td>622</td>
<td>442</td>
<td>813</td>
<td>0.47</td>
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<td>-19, 28</td>
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<tr>
<td>Marina, CA</td>
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<td>466</td>
<td>0</td>
<td>0.46</td>
<td>semi-arid</td>
<td>6, 22</td>
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<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>
Conventional Covers Evaluated by ACAP

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

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

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

**Storage Layer**
- Compacted Vegetative Cover
- Interim Cover
- Vegetation (Grass)
- Vegetation (Hybrid-Poplar Trees with a grass understory)
- Vegetation (Grasses, forbs, and shrubs)

**Intermediates**
- Compost / Soil Mix
- Soil-Gravel Admixture
- Topsoil
- Clean Sand
- Silty Sand
- Gravel

**Base**
- Clean Sand
- Silty Sand
- Gravel
Typical Lysimeter Cross-Section
Aerial view of completed test sections at Kiefer Landfill, Sacramento County, California.
Kiefer Landfill Test Sections - In Service

ACAP field sites monitored 1999-2005 (one still being monitored).
S&R Cover in Sacramento, California

(a) Thin Alternative

Soil Water Storage

Precipitation

Evapotranspiration

Percolation

Surface Runoff

Cumulative Precipitation and Evapotranspiration (mm)

Soil Water Storage, Percolation, and Surface Runoff (mm)
Predicting the Future

• How do engineering properties of soils change over time?

• How does the vegetation community change over time and how does this affect hydrology?

• Can we predict how changes in soils and vegetation affect performance over time?
ACAP Exhumation Study

• **Elements**
  – Field testing of hydraulic properties of cover materials
  – Collect large-scale undisturbed samples for lab analysis
  – Collect geosynthetic materials (geomembranes, geocomposite drainage materials, GCLs) for lab analysis
  – Geomorphological surveys

• **Objectives**
  – Identify changes in engineering properties
  – Relate changes in properties to structural development
  – Identify how changes in properties affect performance
  – Recommend monitoring strategies to detect changes in performance
Barrier System Elements

• Earthen components
  – Store-and-release layers: saturated and unsaturated hydraulic properties
  – Hydraulic barrier layers (clays and geosynthetic clay liners, GCLs): saturated hydraulic conductivity

• Geosynthetic components
  – Geocomposite drainage layers: transmissivity, permittivity
  – Geomembranes: integrity
  – Geosynthetic clay liners: sat. hydraulic conductivity
Field Tests – Sat. Hydraulic Conductivity

**SDRI:** large infiltration test with careful control on mass

**TSB:** falling or constant head test in cased borehole
SDRI Being Installed – Iowa Site
Collecting Block Sample
Laboratory Testing – Saturated and Unsaturated Hydraulic Properties

- Collect large-scale (400 mm diameter) undisturbed samples from field for characterizing hydraulic properties.

- Saturated hydraulic conductivity ($K_s$) measured at different scales.

- Soil water characteristic curve (SWCC) measured at different scales (water content vs. water potential).
Preparing Blocks for Hydraulic Properties Tests

Block sample

Trimming roughly to take ring-off

Placing the block sample

Trimming to the pedestal size
Changes in Sat. Hydraulic Conductivity

If no change, data would scatter around 1:1 line.

Data coalesce into band with $K_s = 10^{-7} - 10^{-5}$ cm/s independent of initial $K_s$. 

In-Service Saturated Hydraulic Conductivity, $K_{si}$ (m/s)

As-Built Saturated Hydraulic Conductivity, $K_{sa}$ (m/s)
Effect of Climate

Alterations in $K_s$ often assumed to be unique to drier climates.

Similar increases in $K_s$ for humid and sub-humid climates.
Influence of Soil Composition

Soils with lower clay fraction more resilient

Fine-grained soils with greater silt fraction more resilient
Denser soils less resilient ... nature loosens dense soils
Wetter soils are less resilient ... nature adds structure
Hydraulic conductivity increases as more structure incorporated.

At some point, structure adequately represented & field hydraulic conductivity is obtained.

Data from Sacramento ACAP Site
Caisson Lysimeters – Monticello, UT

Bill Albright

Eric MacDonald
Roots seek out water in wet fine-grained soils, e.g., clay radon barriers, even at 1.6-1.9 m depth.
Field $K_s$ can be 10-1000 times higher than $K_s$ from lab test on specimen from sampling tube.

Assessment of in-service conditions based on samples collected in sampling tubes will be misleading.
Soil-Water Characteristic Curves

\( t_o \): initial condition

\( t_p \): after pedogenesis

Structure formed by pedogenesis expected to increase \( q_s \), increase \( a \) (lower \( y_a \)), & decrease \( n \).
Changes to the SWCC Due to Structure

Formation of larger pores in soil structure results in lower air entry pressure (higher $\alpha$) and broader pore size distribution (lower $n$) … net result is lower water retention. Looser soils (higher initial $a$ and lower initial $n$) resilient.
Effect of Specimen Size on SWCC

Air entry suction decreases ($\alpha$ increases) with test size.

Larger specimens contain more structure and larger pores.

n unaffected by test size.
Lessons Learned

• Nature alters engineered condition in short period: dense soils become looser and unstructured soils gain structure.

• Hydraulic properties of engineered fine-textured soils become similar over time, regardless of initial condition or climate. Use these longer term properties for design and modeling.

• Recognize that soil properties will change and construct covers to mimic the longer term condition.

• Chose soils with lower clay content if possible to ensure greater resiliency.
Challenges – Predicting the Future

![Graph showing challenges in predicting the future of engineering properties over time. The graph plots engineering property against time (years), with markers for As-Built, ACAP Exhumations, and Analogs. The future predictions are marked with question marks.]
Forthcoming Products

• USEPA Guidance Document on S&R covers (Region 8 sponsorship).

• Book by ASCE press.

• Webinar series as follow-on to ACAP technology transfer workshops.

Thank you to co-PI Bill Albright of Desert Research Institute in Reno, NV.
Research Sponsors

- US Environmental Protection Agency
- US National Science Foundation
- US Nuclear Regulatory Commission
- US Department of Energy
- Environmental Research and Education Foundation
- Industry partners (Veolia Environmental Services, Waste Management, Waste Connections, CETCO)
- Wisconsin Distinguished Professorship