Evaluation of Hydrologic Models for Alternative Covers

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What are Alternative Covers?

- Soil covers consisting of one or more layers used in place of a prescribed cover and having equivalent hydrologic performance.
- Replace clay caps & composite caps (RCRA C & D)
- Significant cost savings (~$50 to $75k per acre)
- Employ natural materials and principles… fit well with nature and likely are to have a long service life.
How do alternative covers work?

Exploit (i) natural water storage capacity of finer soils and (ii) water removal capabilities of evaporation and transpiration.

Key: Design for sufficient storage capacity to retain water that accumulates during winter with limited drainage.
Conventional Alternative Cover Profiles

**Capillary Barrier**
- 150 mm Topsoil
- 460 mm Silt
- 600 mm Sand
- Interim Cover

**Monolithic Barrier**
- 150 mm Topsoil
- 1200 mm Sandy Clay
- 300 mm Interim Cover
Design Methodology

- Characterize unsaturated hydraulic properties of borrow soils and growing characteristics of plants
- Preliminary sizing of cover profile by hand calculations
- Demonstrate performance standard is met (e.g., < 1 mm/yr percolation) by numerical modeling or field demonstration.
Advantages of Modeling

- Assess a wide range of scenarios that may affect cover during service life
- Fast and inexpensive (relative to field studies)

Disadvantages of Modeling

- Accuracy of models has not been assessed… critical since performance criteria limit percolation to small quantities (∼ 1 mm/yr)
- Potential to mislead by careful input selection
# Models Being Evaluated

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>HELP</td>
<td>USEPA</td>
<td>Unit Gradient Bucket Model</td>
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<tr>
<td>UNSAT-H</td>
<td>PNNL/USDOE</td>
<td>Richards’ Equation</td>
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<tr>
<td>HYDRUS-2D</td>
<td>USDA Salinity Laboratory</td>
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<td>Vadose/W</td>
<td>MEND and Geo-Slope Ltd.</td>
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<tr>
<td>LEACHM</td>
<td>Cornell Univ.</td>
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Tasks

I: Baseline Assessment of Hydrologic Models

II: Comparison of Field Data and Model Predictions

III: Model Improvement

IV: Algorithms for Long-Term Performance Assessment
I: Baseline Assessment of Hydrologic Models

- Comparison of model predictions for a suite of contrasting climates (Las Vegas, NV; Richland, WA; Albuquerque, NM; Denver, CO; Columbus, OH; and Savannah, GA)

- Identify range of predictions obtained for a given set of input conditions.

- Identify algorithms having greatest impact on predictions

II: Comparison of Field Data and Model Predictions

- Unbiased assessment of model accuracy

- Identify changes needed to improve accuracy

- Guides work in Task III
Sources of Field Data

- University of Wisconsin Field Study (Khire et al. 1997, 1999)

- Sandia Alternative Landfill Cover Demonstration (Steve Dwyer of Sandia)

- USEPA’s Alternative Cover Assessment Program (Bill Albright of Desert Research Institute and Craig Benson of UW)
ACAP Test Sites:

- 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) --- used in this study
- Eight sites with side-by-side comparison of conventional and alternative covers
Test Section

Plan View

All dimensions in meters

Large bathtub filled with cover soil and instruments.

ACAP

SRO

Diversion

Berm

Down Slope

SRO

Pipe

Perc. Pipe

0.6

10

20

5

5

4

20

30

0.6
Typical Lysimeter Cross-Section

- Earthen Berm
- Percolation Pipe
- LLDPE Cutoff
- Root Barrier
- Cover
- Interim Cover Soil
- Existing Slope (>2%)
- Geocomposite Drain
- Earthen Berm
- LLDPE Cutoff

LLDPE Geomembrane
Near Full-Scale Construction

Sidewalls and interim cover layer for test section at Altamont, CA site.

Placing cover soils using D7 dozer at Altamont, CA site.
Interior of dosing siphon for percolation showing tipping bucket.
Post-filling installation of instruments.
Installed weather station & datalogger with cellular telecommunications.
Trimming block sample from cover soil.
Sample of below ground biomass to define root density distribution…
Sacramento site 5-03

Relative Root Density

Depth (m)

R = 0.61e^{-10.7z} + 0.007

Kiefer Landfill
Sacramento, CA
June '01

Sample A
Sample B
Aerial view of completed test sections at Kiefer Landfill, Sacramento County, California.
Kiefer Site:
Eight months after construction
Kiefer Site – Sacramento, CA
Warm semi-arid climate (precipitation ~ 434 mm/yr)
1080-mm-thick monolithic covers

(a) Thin Alternative

Cumulative Precipitation and Evapotranspiration (mm)

Soil Water Storage, Percolation, and Surface Runoff (mm)

Precipitation
Soil Water Storage
Evapotranspiration
Percolation
Surface Runoff
Missing Data
HYDRUS-2D

Uncoupled mass & heat transfer. For liquid flow (Richards’ Eq.):

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i} \left[ K(K_{ij}^A \frac{\partial h}{\partial x_j} + K_{iz}^A) \right] - S
\]

where \( K_{ij}^A \) and \( K_{iz}^A \) are anisotropy factors
Boundary Conditions

- Variable flux --- upper boundary for atmospheric interaction (evaporation)
- Prescribed head (constant or variable)
- Prescribed flux
- Seepage face (requires saturation) – lower boundary for lysimeter
- Deep drainage (unit gradient) – conventional lower boundary for cover modeling
Evaporation in HYRUS-2D

Potential Flux = Precipitation – Potential Evaporation (PE)

Precipitation < PE, calculate actual evaporation (AE)
Precipitation > PE, No evaporation

Solve Richards’ Equation
w/ interchangeable surface head/flux BC

Flux BC based on hydraulic gradient

Head BC if
\( h_p \leq h_{\text{min}} \) or \( h_p \geq h_{\text{sat}} \)
Transpiration in HYDRUS-2D

1. **Read Input for Potential Transpiration (PT)**
2. **Read Input for Root Length Density Function (RLD)**
3. **Obtain Plant Stress factor ($\alpha$) corresponding to Pressure heads in the root zone**
4. **Calculate Actual Transpiration (AT) as a sink term $f(PT, \alpha, RLD)$**
Example of HYDRUS-2D
Predictions: Marina, CA site

Costal sub-humid climate with 466 mm/yr. Seasonal, but no snow or freezing

Capillary barrier with ~ 1.2 m of fine textured soil for storage

Four primary water balance quantities: runoff, evapotranspiration, soil water storage, and percolation
Model Predictions and Field Data

- **Runoff**
  - Marina Alternative Cover
  - Precipitation: HYDRUS-2D SRO vs. Field SRO

- **Evapotranspiration (ET)**
  - Field vs. HYDRUS-2D

- **Soil Water Storage**
  - HYDRUS-2D vs. Field
    - Field Capacity
    - Wilting Point

- **Percolation**
  - HYDRUS-2D vs. Field
## Predicted and Measured Runoff: HYDRUS-2D

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Test Site</th>
<th>Field SRO (mm)</th>
<th>Predicted SRO (mm)</th>
<th>(K_s) Surface Layer (cm/d)</th>
<th>Mean Intensity I (cm/d)</th>
<th>(I/K_s)</th>
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<tbody>
<tr>
<td>Over-prediction</td>
<td>Albany, GA</td>
<td>14.9</td>
<td>420</td>
<td>0.017</td>
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<td></td>
<td>Altamont, CA</td>
<td>1.34</td>
<td>26.5</td>
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<td>1.65</td>
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<tr>
<td></td>
<td>Marina, CA</td>
<td>0.00</td>
<td>47.4</td>
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<td>Sacramento, CA</td>
<td>90.4</td>
<td>289</td>
<td>0.077</td>
<td>2.24</td>
<td>29</td>
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<tr>
<td></td>
<td>CA (thin)</td>
<td></td>
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<tr>
<td></td>
<td>Sacramento, CA</td>
<td>67.5</td>
<td>318</td>
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<td>CA (thick)</td>
<td></td>
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<tr>
<td>Under-prediction</td>
<td>Cedar Rapids, IA</td>
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<td>Almost match</td>
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<td></td>
<td>(thin)</td>
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<tr>
<td></td>
<td>Boardman, OR</td>
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<td>0.8</td>
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<tr>
<td></td>
<td>(thick)</td>
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Surface Runoff Calibration by Simultaneous Adjustment of Ksat and $\alpha$

Scaling to field condition is a key issue!
Model Calibration to Runoff

Adjusting $K_{\text{sat}}$ & $\alpha$ permits accurate prediction of runoff...

....but percolation still under-predicted
Sensitivity Analysis

Most influential factors:

$K_{sat}$, $\alpha$ and $n$ parameters (affect infiltration & storage)

Growing season (affects water removal)

Lower boundary condition (opposite of expected)

Errors in meteorological data (precipitation errors)

Less influential factors:

Pore interaction term, hysteresis

Wilting point, root depth, and root density distribution
Example - Effect of n Parameter

- Marina Alternative Cover
- Precipitation
- Surface Runoff
- Evapotranspiration
- Soil Water Storage
- Percolation

Values for n = 1.3, 1.4, and 1.5 are shown for each graph.
Accomplishments to Date

Tasks:

- Task I – 25% complete (on schedule)
- Task II – 50% complete (on schedule)

Key Findings:

- Model predictions can deviate greatly from field condition (critical issue for regulatory acceptance of designs)
- Hydraulic property scaling is a key issue (pedogenesis will be critical)
- Growing season is a key issues (affect long-term predictions)
Near Future Work

• Complete comparisons between field data and model predictions (HYDRUS-2D, UNSAT-H, HELP complete, Vadose/W and LEACHM in progress)

• Complete sensitivity analysis with all models (HYDRUS-2D, UNSAT-H, HELP complete, Vadose/W and LEACHM in progress)

• Complete baseline comparisons (all models about 25% complete)