Preliminary Design of Water Balance Covers: A Method from the ACAP Data Set

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Water Balance Covers: Sponge Concept

- Precipitation
- Evapotranspiration

Infiltration

Percolation if $S > S_c$

$S = \text{soil water storage}$

$S_c = \text{soil water storage capacity}$
ACAP Site Locations

- Boardman, OR
- Polson, MT
- Helena, MT
- Omaha, NE
- Cedar Rapids, IA
- Sacramento, CA
- Altamont, CA
- Monterey, CA
- Apple Valley, CA
- Monticello, UT
- Albany, GA
ACAP: The Field Program

- Nationwide: 12 sites, 8 states
- Large (10 × 20 m) drainage lysimeters
- Conventional technology
  - Composite
  - Clay barrier
- Alternative technology
  - Water balance
  - Capillary barrier
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

Sacramento, CA

Storage Layer

Compacted Vegetative Cover

Clean Sand

Soil-Gravel Admixture

Gravel

Silty Sand

Interim Cover

Vegetation (Grass)

Vegetation (Hybrid-Poplar Trees with a grass understory)

Vegetation (Grasses, forbs, and shrubs)
Full-scale equipment and methods
Undisturbed sample to capture as-built soil properties
Water content probe to monitor soil water status
## Data Summary

<table>
<thead>
<tr>
<th>Site</th>
<th>Maximum Precip. (mm)</th>
<th>Maximum Perc. (%)</th>
<th>Year</th>
<th>Average Precip. (mm)</th>
<th>Average Perc. (%)</th>
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</thead>
<tbody>
<tr>
<td>Albany, GA</td>
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<td>Altamont, CA</td>
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<td>Apple Valley, CA</td>
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<td>3</td>
<td>167.4</td>
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<td>0.0</td>
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<td>Cedar Rapids, IA</td>
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<td>Marina, CA</td>
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<td>Monticello, UT</td>
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<tr>
<td>Omaha, NE (Thick)</td>
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<td>349.1</td>
<td>27.0</td>
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<tr>
<td>Polson, MT</td>
<td>308.1</td>
<td>0.4</td>
<td></td>
<td>349.1</td>
<td>0.2</td>
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<tr>
<td>Sacramento, CA (Thin)</td>
<td>361.2</td>
<td>108.4</td>
<td></td>
<td>422.0</td>
<td>54.8</td>
</tr>
<tr>
<td>Sacramento, CA (Thick)</td>
<td>455.7</td>
<td>8.5</td>
<td>3</td>
<td>422.0</td>
<td>2.7</td>
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<td>Underwood, ND</td>
<td>585.2</td>
<td>9.4</td>
<td>1</td>
<td>384.1</td>
<td>7.1</td>
</tr>
</tbody>
</table>
ACAP: The Products

• Nation-wide field-scale data set for composite, compacted clay and water balance covers
• Measured changes to soil hydraulic properties due to pedogenesis
• Published results
  – www.acap.dri.edu
• 25 workshops
• A new method for feasibility assessment and preliminary design
How Do Water Balance Covers Work?

• Natural water storage capacity of finer textured soils

• Soil water storage typically seasonal

• Water removal by evaporation and transpiration

• Percolation occurs when soil water storage exceed total storage capacity

• **Key:** Need to know required storage, $S_r$

• We always knew how to store water, we did not know how to determine ‘how much’

• The ACAP data set from a nation-wide network of field-scale test sections provides a method to determine $S_r$

• The method is based on data, not estimates from models
Water Balance Covers: How They Function

Cumulative Precipitation and Evapotranspiration (mm)

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

Total storage capacity = 300 mm

Required storage capacity ($S_r$)

Soil Water Storage

Precipitation

Percolation

Water Balance Covers: How They Function
We Answered 2 Questions: When & How Much

1. Determine **when** water accumulates.
2. Define **how much** water accumulates.

Example: for **fall-winter months at sites without snow**, water accumulates in the cover when the monthly precipitation \( (P_m) \) exceeds 21 mm, on average.

\[
\Delta S_{r,m} = -0.0014 P_m^2 + 0.899 P_m - 18.06
\]

\( R^2 = 0.59 \)
Thresholds for Water Accumulation

Examined P, P/PET, and P-PET as indicators of water accumulation and found P/PET threshold works best.

Data segregated into two climate types (with & without snow and frozen ground) and two periods in each year (fall-winter and spring-summer).

### Water accumulates when P/PET threshold exceeded.

<table>
<thead>
<tr>
<th>Climate Type</th>
<th>Season</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Snow &amp; Frozen Ground</td>
<td>Fall-Winter</td>
<td>P/PET &gt; 0.34</td>
</tr>
<tr>
<td></td>
<td>Spring-Summer</td>
<td>P/PET &gt; 0.97</td>
</tr>
<tr>
<td>Snow &amp; Frozen Ground</td>
<td>Fall-Winter</td>
<td>P/PET &gt; 0.51</td>
</tr>
<tr>
<td></td>
<td>Spring-Summer</td>
<td>P/PET &gt; 0.32</td>
</tr>
</tbody>
</table>

Fall-winter = September - February  
Spring-summer = March - August
How Much Water Accumulates?

1. Use water balance approach: \( \Delta S = P - R - ET - L - P_r \)
   \( \Delta S = \) change in soil water storage

   \( R = \) runoff

   \( P = \) precipitation

   \( ET = \) evapotranspiration

   \( L = \) lateral internal drainage (assume = 0)

   \( P_r = \) percolation

2. ET is unknown, but is a fraction (\( \beta \)) of PET: \( ET = \beta \ PET \)

3. R, L, and \( P_r \) can be lumped into losses (\( \Lambda \))

   Simplify to obtain: \( \Delta S = P - \beta \ PET - \Lambda \)

4. Equation used to compute monthly accumulation of soil water storage if \( P, PET, \beta, \) and \( \Lambda \) are known.
Parameters for Water Accumulation Equation

\[ \Delta S = P - \beta \text{PET} - \Lambda \]

<table>
<thead>
<tr>
<th>Climate Type</th>
<th>Season</th>
<th>( \beta ) (-)</th>
<th>( \Lambda ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Snow &amp; Frozen Ground</td>
<td>Fall-Winter</td>
<td>0.30</td>
<td>27.1</td>
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<tr>
<td></td>
<td>Spring-Summer</td>
<td>1.00</td>
<td>167.8</td>
</tr>
<tr>
<td>Snow &amp; Frozen Ground</td>
<td>Fall-Winter</td>
<td>0.37</td>
<td>-8.9</td>
</tr>
<tr>
<td></td>
<td>Spring-Summer</td>
<td>1.00</td>
<td>167.8</td>
</tr>
</tbody>
</table>

Two sets of \( \beta \) and \( \Lambda \) parameters (fall-winter & spring-summer) for a given climate type.
Monthly Computation of Required Storage ($S_r$)

\[
S_r = \sum_{m=1}^{6} \left\{ (P_m - \beta_{FW} \cdot PET_m) - \Lambda_{FW} \right\} + \sum_{m=1}^{6} \left\{ (P_m - \beta_{SS} \cdot PET_m) - \Lambda_{SS} \right\}
\]

- **Fall-Winter Months**
  \[
  \sum_{m=1}^{6} \left\{ (P_m - \beta_{FW} \cdot PET_m) - \Lambda_{FW} \right\}
  \]
- **Spring-Summer Months**
  \[
  \sum_{m=1}^{6} \left\{ (P_m - \beta_{SS} \cdot PET_m) - \Lambda_{SS} \right\}
  \]

Include only months that exceed $P/PET$ threshold

If $\Delta S_m < 0$, set $\Delta S_m = 0$

- $P_m = $ monthly precipitation
- $PET_m = $ monthly PET
- $\beta_{FW} = $ ET/PET in fall-winter
- $\beta_{SS} = $ ET/PET in spring-summer
- $\Lambda_{FW} =$ runoff & other losses in fall-winter
- $\Lambda_{SS} =$ runoff & other losses in spring-summer
Example: Idaho Site (snow & frozen ground)

For months below threshold, set $\Delta S = 0$

$\Delta S = P - 0.37 \times PET$

(Fall-Winter)

$\beta = 0.37, \Lambda = 0$

Store 97 mm for typical year, 230 mm for wettest year
Example: Texas Site (no snow & frozen ground)

For months below threshold, set $\Delta S = 0$

$\Delta S = (P - 0.37\times PET) - 27$

(Fall-Winter)

$\beta = 0.3$, $\Lambda = 27$

Store 188 mm for 95th percentile year, 548 mm for wettest year
Predicted and Measured $S_r$

Good agreement between computed and measured required storage.
Conclusion:
A Two-Step Method for Design of Water Balance Covers

1. Preliminary design: estimate required thickness 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

3. Read the book