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

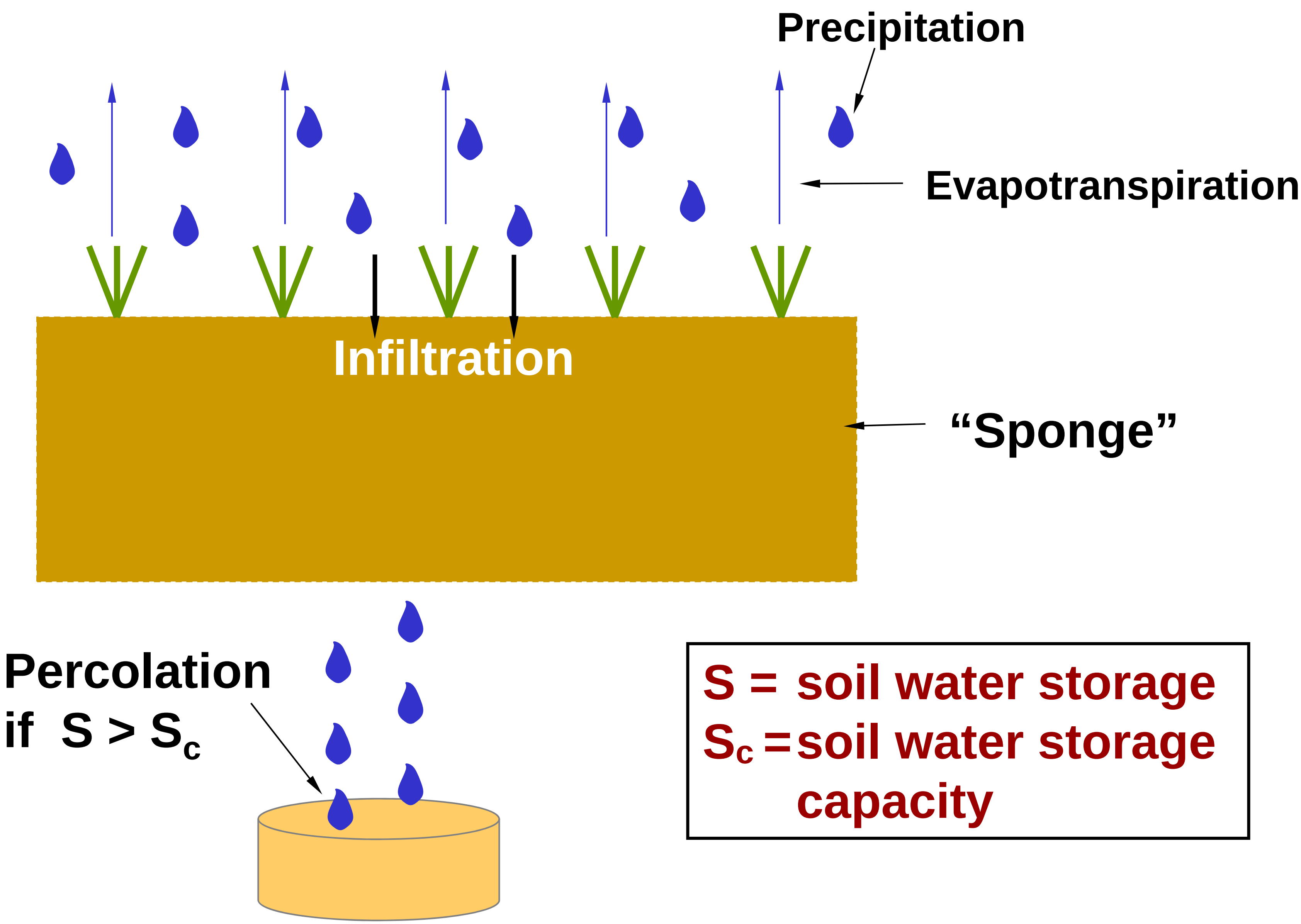
William H. Albright, PhD

Desert Research Institute
Reno, Nevada 89512 USA
www.acap.dri.edu

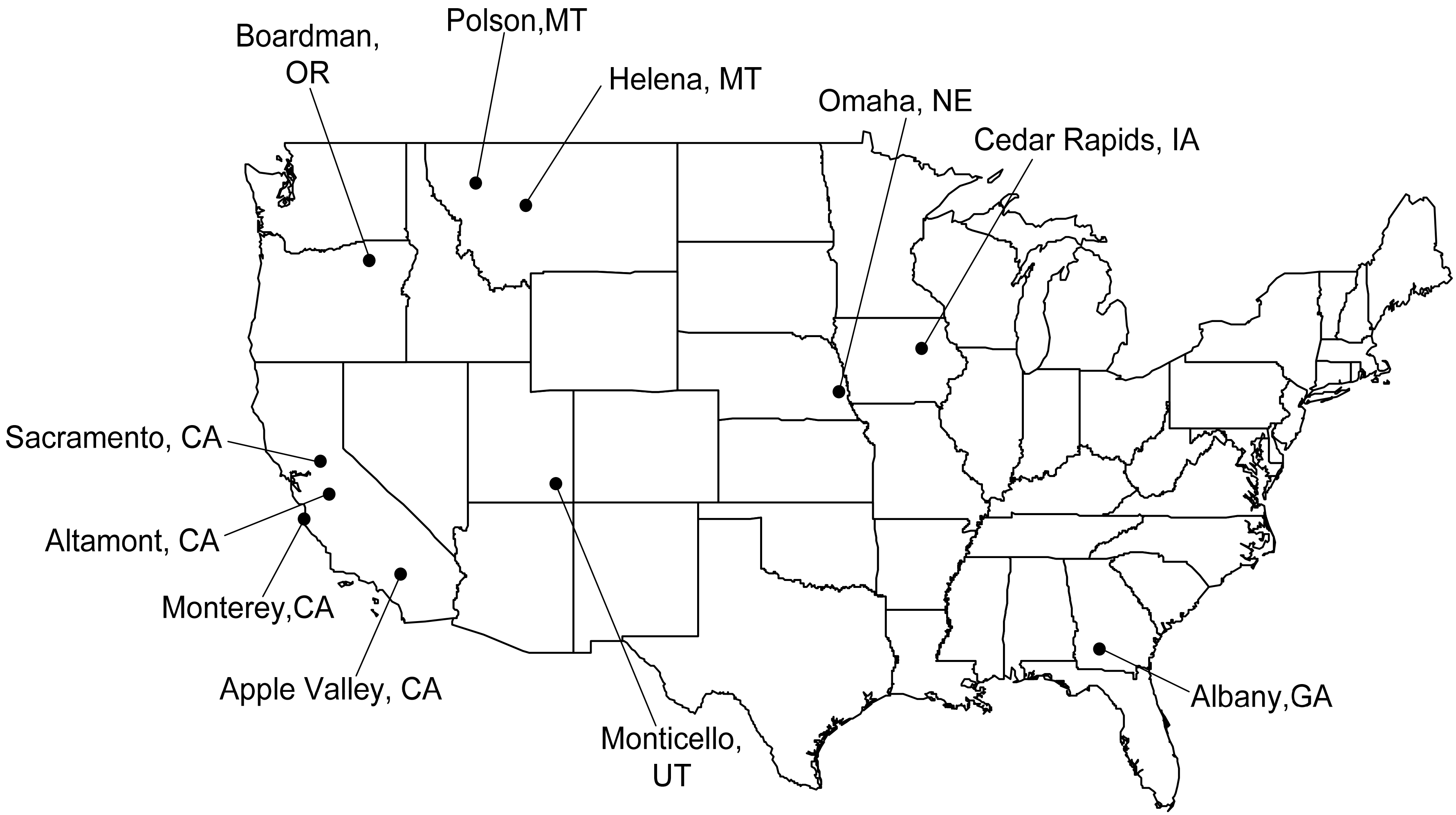
Craig H. Benson, PhD, PE, DGE

University of Wisconsin-Madison
Madison, Wisconsin 53706 USA

Water Balance Covers: Sponge Concept



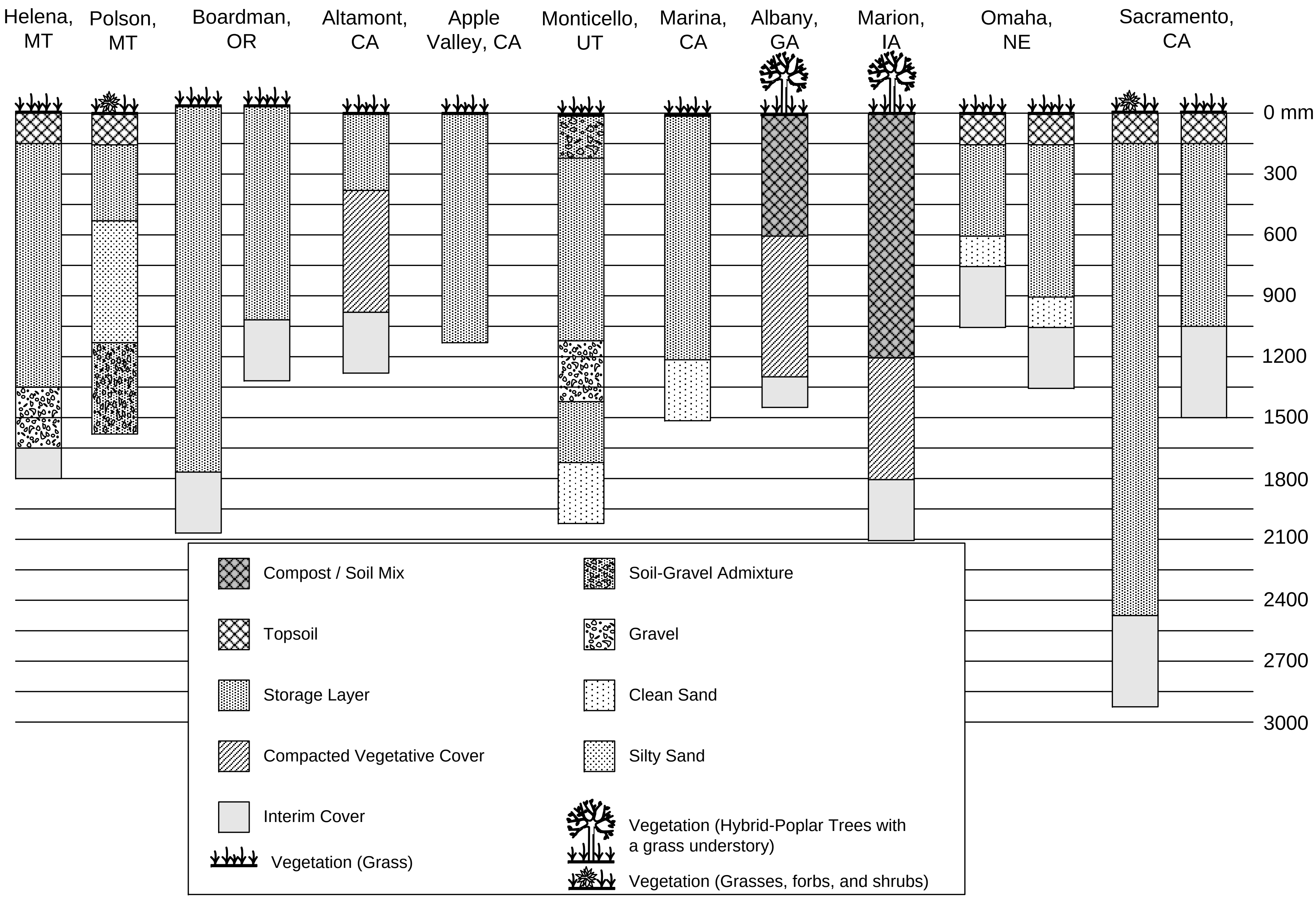
ACAP Site Locations



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



Full-scale equipment and methods

Undisturbed sample to capture as-built soil properties

Water content probe to monitor soil water status

Data Summary

Site	Maximum			Average	
	Precip. (mm)	Perc. (mm)	Year	Precip. (mm)	Perc. (mm)
Albany, GA	1380.2	218.3	4	1202.3	109.2
Altamont, CA	498.6	139.3	4	379.7	44.8
Apple Valley, CA	272.0	1.8	3	167.4	0.5
Boardman, OR (Thin)	210.8	0.0	3	181.4	0.0
Boardman, OR (Thick)		0.0			0.0
Cedar Rapids, IA	898.4	366.1	4	930.0	207.3
Helena, MT	351.5	0.1	5	272.4	0.0
Marina, CA	406.9	82.4	4	462.8	63.3
Monticello, UT	662.9	3.4	5	387.0	0.7
Omaha, NE (Thin)	612.4	101.0	1	732.5	56.1
Omaha, NE (Thick)		57.9			27.0
Polson, MT	308.1	0.4		349.1	0.2
Sacramento, CA (Thin)	361.2	108.4	-	422.0	54.8
Sacramento, CA (Thick)	455.7	8.5	3		2.7
Underwood, ND	585.2	9.4	1	384.1	7.1

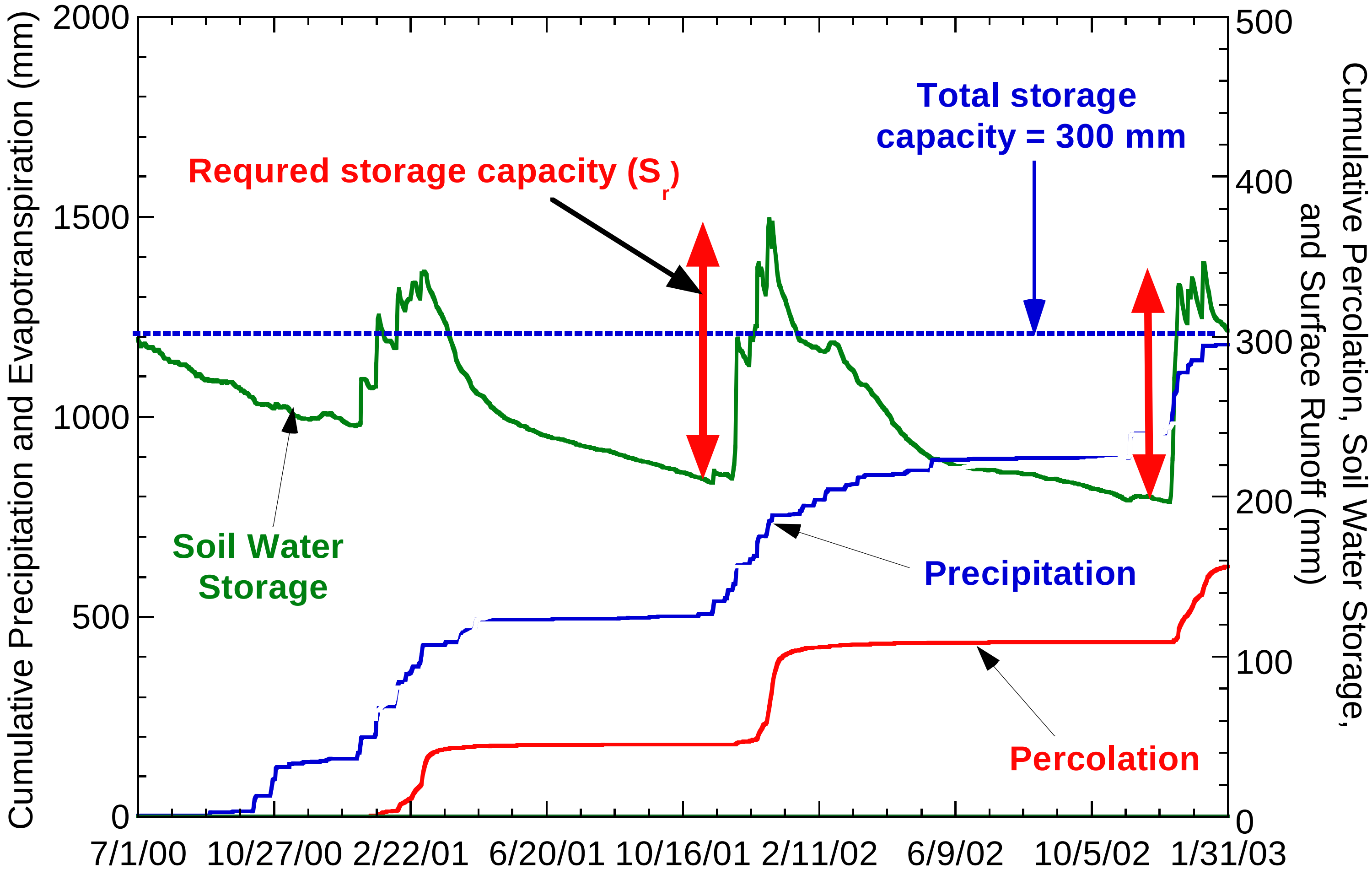
ACAP: The Products

- 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?

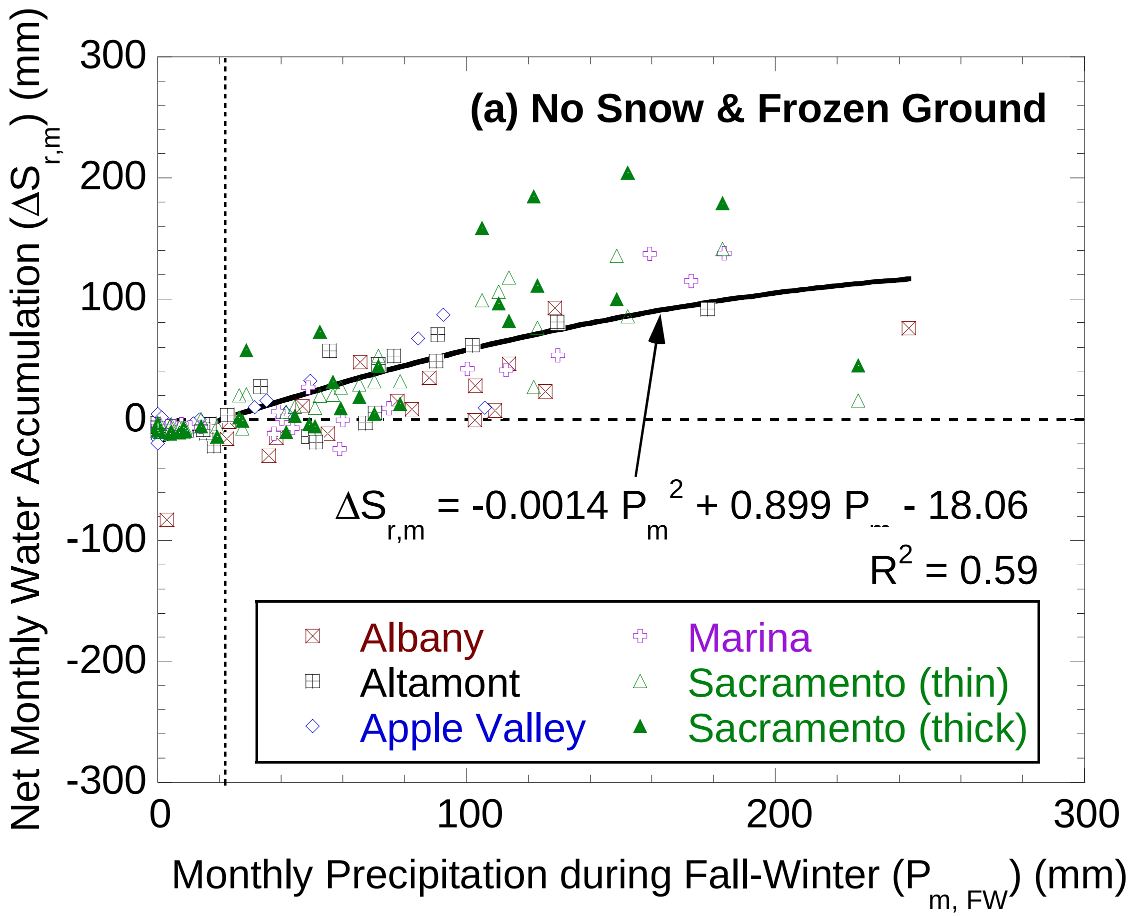
- **Natural water storage capacity of finer textured soils**
- **Soil water storage typically seasonal**
- **Water removal by evaporation and transpiration**
- **Percolation occurs when soil water storage exceed total storage capacity**
- **Key: Need to know required storage, S_r.**
- **We always knew 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



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.

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.

Climate Type	Season	Threshold
No Snow & Frozen Ground	Fall-Winter	P/PET > 0.34
	Spring-Summer	P/PET > 0.97
Snow & Frozen Ground	Fall-Winter	P/PET > 0.51
	Spring-Summer	P/PET > 0.32

Fall-winter = September - February
Spring-summer = March - August

How Much Water Accumulates?

1. Use water balance approach: $\Delta S = P - R - ET - L - P_r$

   ΔS = 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 (β) of PET: $ET = \beta\ PET$

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

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

4. Equation used to compute monthly accumulation of soil water storage if P, PET, β, and Λ are known.

Parameters for Water Accumulation Equation

$$\Delta S = P - \beta \, PET - \Lambda$$

Climate Type	Season	β (-)	Λ (mm)
No Snow & Frozen Ground	Fall-Winter	0.30	27.1
	Spring-Summer	1.00	167.8
Snow & Frozen Ground	Fall-Winter	0.37	~~-8.9~~ 0
	Spring-Summer	1.00	167.8

Two sets of β and Λ parameters (fall-winter & spring-summer) for a given climate type.

Monthly Computation of Required Storage (S_r)

$$S_r = \underbrace{\sum_{m=1}^{6}\{(P_m - \beta_{FW}PET_m) - \Lambda_{FW}\}}_{\text{Fall-Winter Months}}$$

$$+ \underbrace{\sum_{m=1}^{6}\{(P_m - \beta_{SS}PET_m) - \Lambda_{SS}\}}_{\text{Spring-Summer Months}}$$

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

β_{FW} = ET/PET in fall-winter

β_{SS} = ET/PET in spring-summer

Λ_{FW} = runoff & other losses in fall-winter

Λ_{SS} = runoff & other losses in spring-summer

Example: Idaho Site (snow & frozen ground)

PET and Precip Idaho Site.xlsx

	A	D	E	F	G	H	I
1	**Typical Year**						
2	Month	PET (mm)	P (mm)	P/PET	Exceed Threshold?	ΔS (mm) Compute	ΔS (mm) for Sum
3	Jan	26	5	0.20	NO	-53.4	0.0
4	Feb	69	10	0.15	NO	-162.5	0.0
5	March	177	8	0.04	NO	-586.2	0.0
6	April	318	0	0.00	NO	-1180.2	0.0
7	May	497	46	0.09	NO	-1390.4	0.0
8	June	596	15	0.03	NO	-2063.5	0.0
9	July	633	3	0.00	NO	-2326.6	0.0
10	Aug	537	23	0.04	NO	-1768.9	0.0
11	Sep	360	28	0.08	NO	-1059.7	0.0
12	Oct	201	5	0.03	NO	-703.1	0.0
13	Nov	77	66	0.86	YES	28.7	28.7
14	Dec	24	86	3.63	YES	68.7	68.7
15	**Annual Totals (mm)**	**3515**	**295**	**0.08**	-	-	**97**
16						**Typical Yr**	**Design**

	A	D	E	F	G	H	I
17	**Wettest Year**						
18	Month	PET (mm)	P (mm)	P/PET	Exceed Threshold?	ΔS (mm) Compute	ΔS (mm) for Sum
19	Jan	26	66	2.56	YES	47.6	47.6
20	Feb	73	53	0.73	YES	17.5	17.5
21	March	181	25	0.14	NO	-424.1	0.0
22	April	324	28	0.09	NO	-926.7	0.0
23	May	502	43	0.09	NO	-1434.5	0.0
24	June	599	13	0.02	NO	-2097.5	0.0
25	July	632	0	0.00	NO	-2346.6	0.0
26	Aug	533	5	0.01	NO	-1929.7	0.0
27	Sep	354	8	0.02	NO	-1241.8	0.0
28	Oct	196	10	0.05	NO	-634.0	0.0
29	Nov	74	119	1.61	YES	83.0	83.0
30	Dec	22	99	4.41	YES	81.9	81.9
31	**Annual Totals (mm)**	**3515**	**470**	**0.13**		-	**230**
32						**Wettest Yr**	**Design**

Wettest year PE | Wettest year PT | Wettest Year Precip | Summary | Sheet3

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

$\Delta S = P - 0.37 * PET$
(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)

PET and Precip Austin.xlsx

95th Percentile Year

Month	PET (cm)	P (cm)	P/PET	Exceed Threshold?	ΔS (mm) Compute	ΔS (mm) for Sum	
							Thresholds
Jan	41	96	2.34	YES	56	56	FW=0.34
Feb	64	58	0.91	YES	12	12	SS=0.97
March	101	68	0.67	NO	-201	0	
April	148	201	1.36	YES	-115	0	Accum FW
May	203	154	0.76	NO	-217	0	β = 0.3
June	221	34	0.15	NO	-355	0	λ =27.1
July	238	38	0.16	NO	-369	0	Accum SS
Aug	204	85	0.42	NO	-287	0	β = 1
Sep	139	153	1.10	YES	84	84	λ =168
Oct	108	41	0.38	YES	-18	0	
Nov	63	200	3.19	YES	154	154	
Dec	29	69	2.41	YES	33	33	
Annual Totals (mm)	1559	1197	-	-	-	188	
					95th% Yr	Design	

Wettest Year

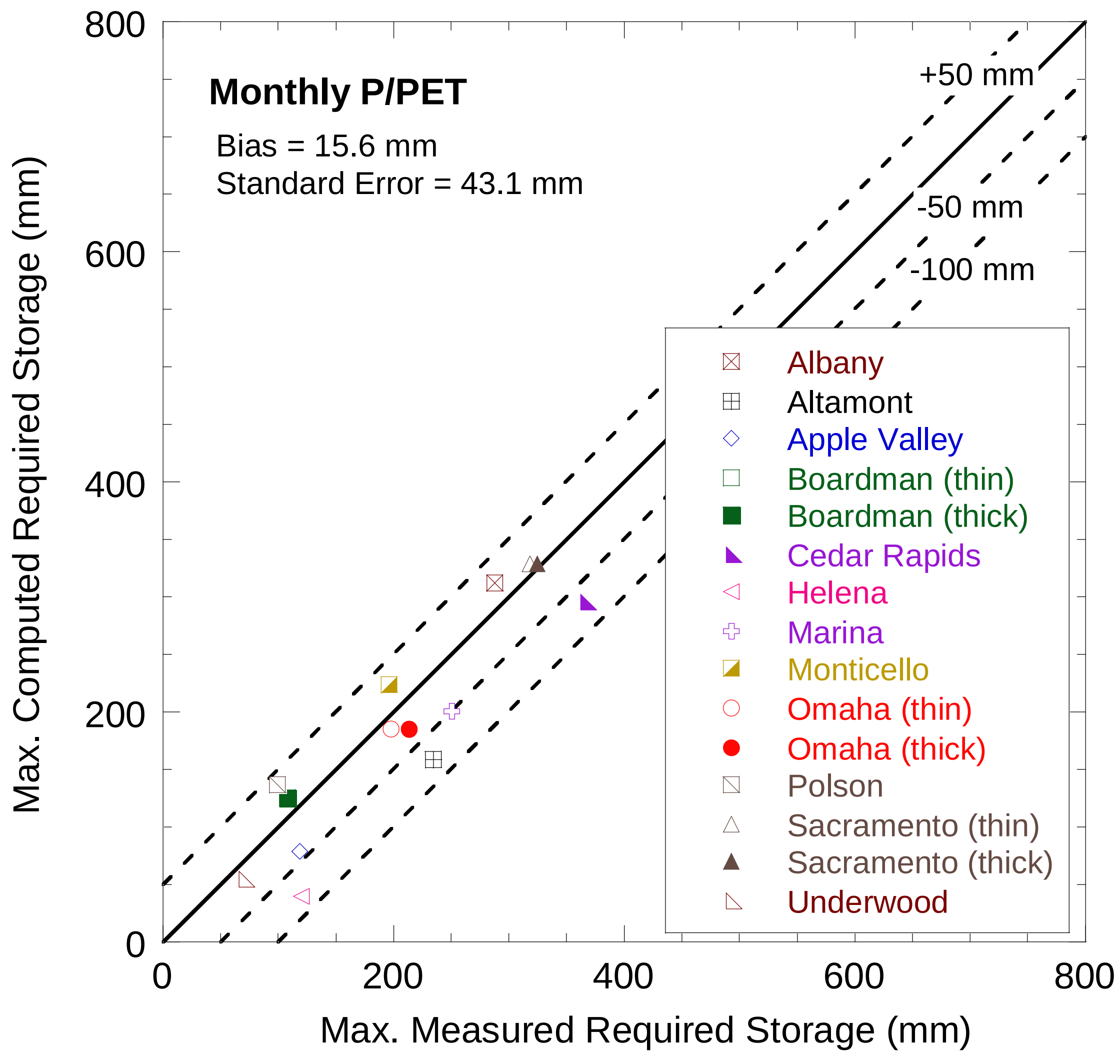
Month	PET (mm)	P (mm)	P/PET	Exceed Threshold?	ΔS (mm) Compute	ΔS (mm) for Sum	
							Thresholds
Jan	41	234	5.72	YES	195	195	FW=0.34
Feb	64	76	1.19	YES	30	30	SS=0.97
March	101	23	0.23	NO	-247	0	
April	148	125	0.84	NO	-191	0	Accum FW
May	203	101	0.50	NO	-270	0	β = 0.3
June	221	112	0.50	NO	-278	0	λ =27.1
July	238	29	0.12	NO	-377	0	Accum SS
Aug	204	109	0.53	NO	-263	0	β = 1
Sep	139	57	0.41	YES	-12	0	λ =168
Oct	108	78	0.72	YES	18	18	
Nov	63	23	0.37	YES	-23	0	
Dec	29	360	12.60	YES	324	324	
Annual Totals (mm)	1559	1326	-	-	-	548	
					Wettest Yr	Design	

For months below threshold, set ΔS = 0

ΔS = (P – 0.37*PET)-27 (Fall-Winter)
β = 0.3, Λ = 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**