Field water balance of final landfill covers: The USEPA's Alternative Cover Assessment Program (ACAP)

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Final covers - the issues

- Lack of field-scale performance data
- Excessive uncertainty in modeled predictions
- No specified design process

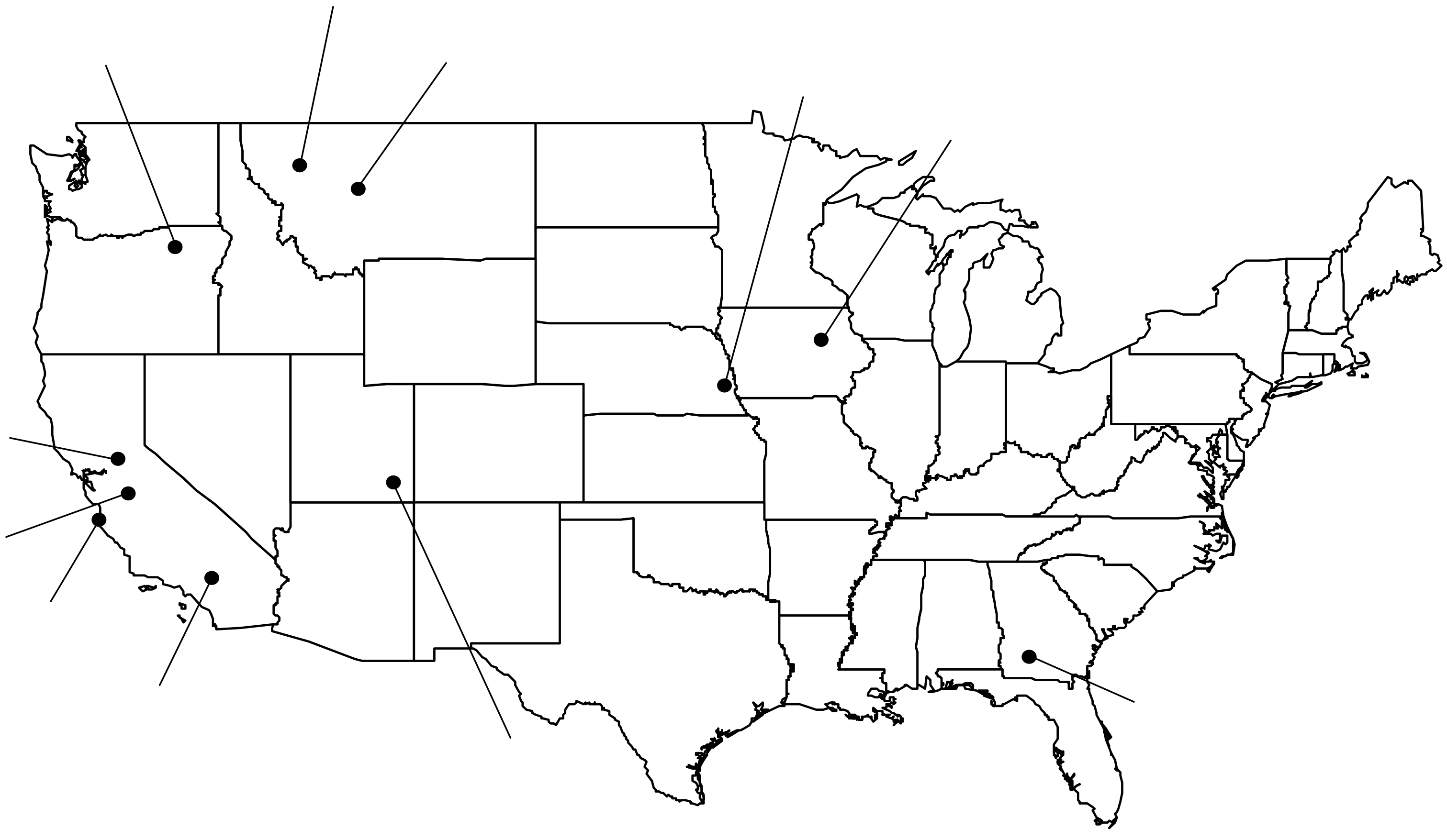
Presented here...

- Field data from ACAP
- A suggestion for acceptable use of models
- A design process for engineers and regulators

ACAP: The Field Program

- Nationwide: 11 sites, 7 states
- Large (10 X 20 m) drainage lysimeters
- Conventional covers
  - Composite
  - Soil barrier
- Alternative covers
  - Evapotranspiration (ET)
  - Capillary barrier
- Side-by-side demonstration at most sites

ACAP Site Locations

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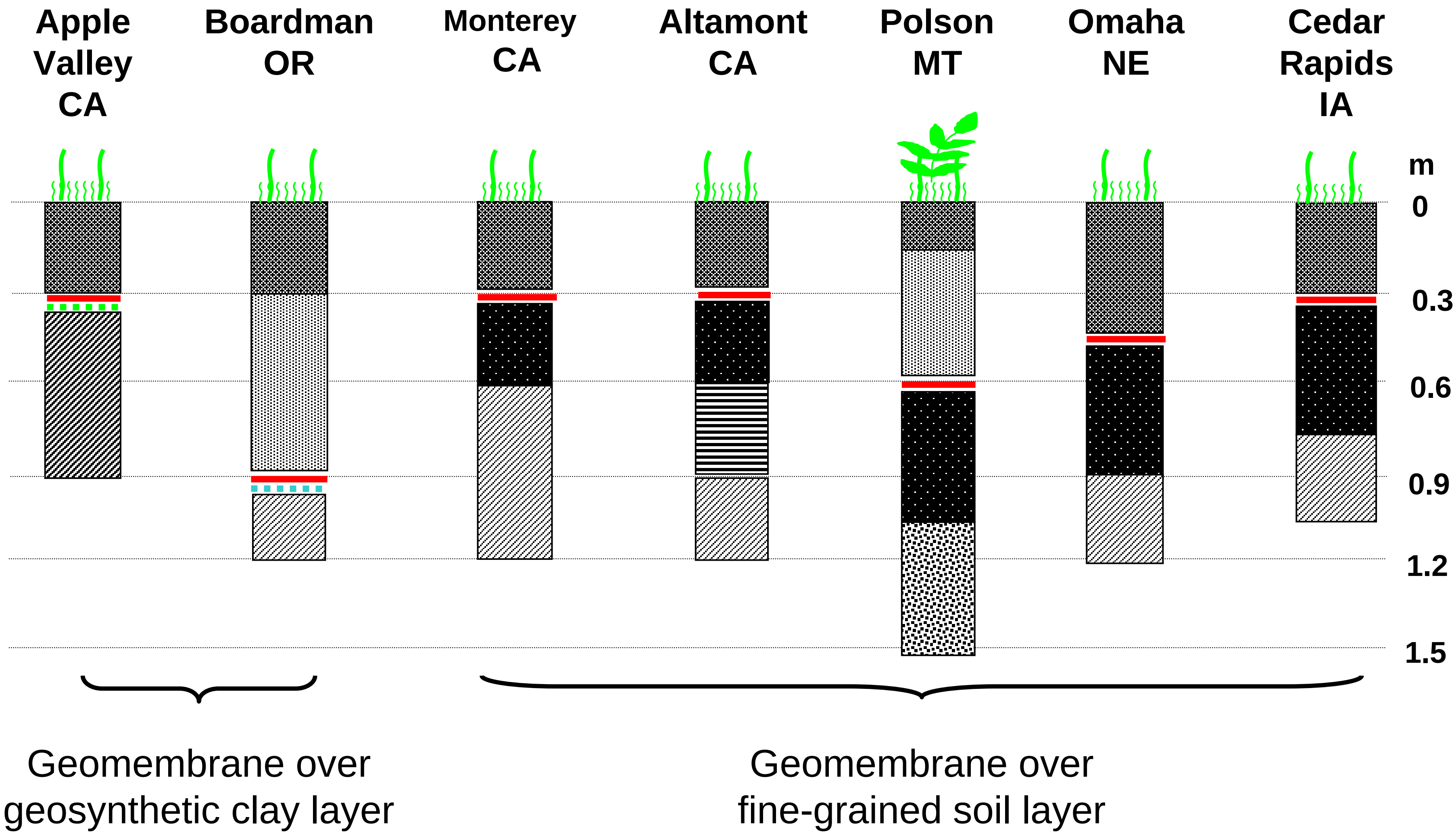
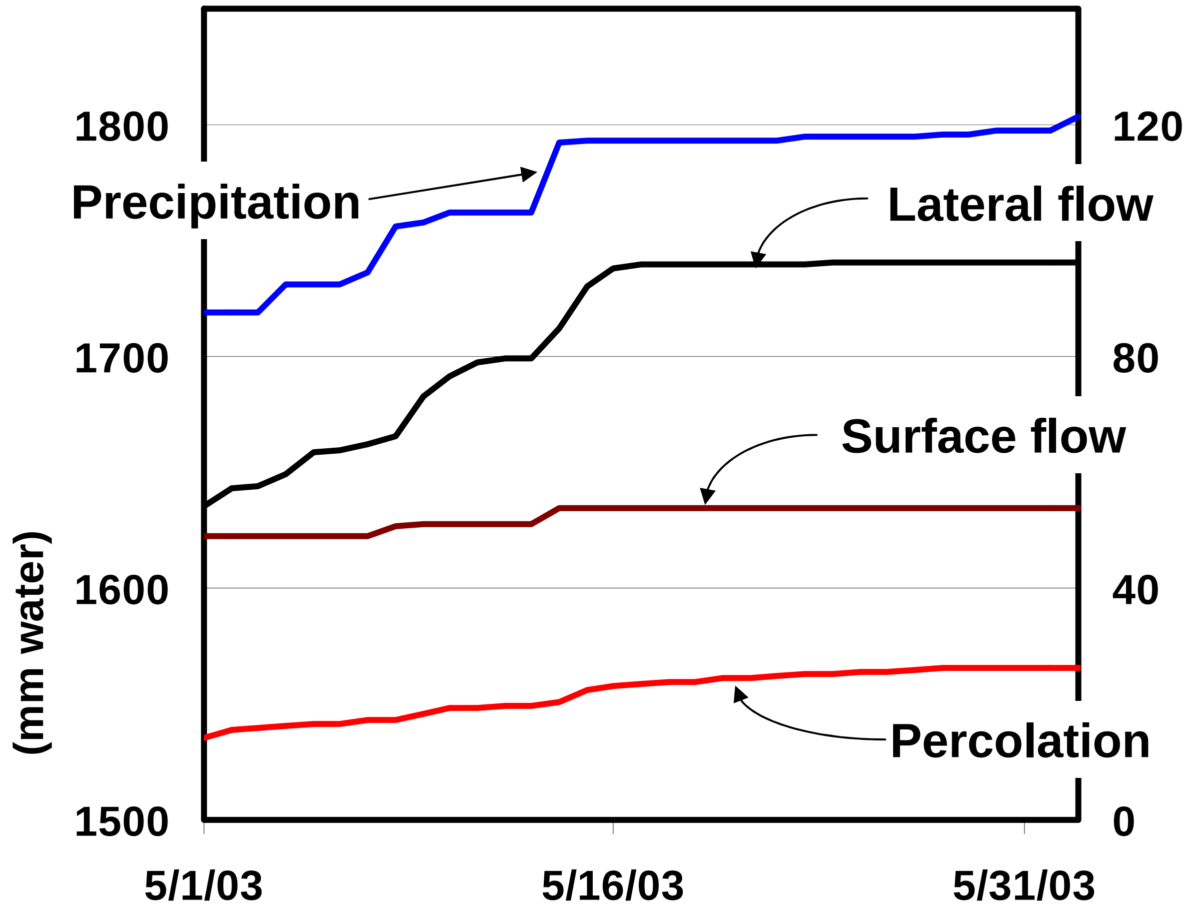
Conventional Composite Designs



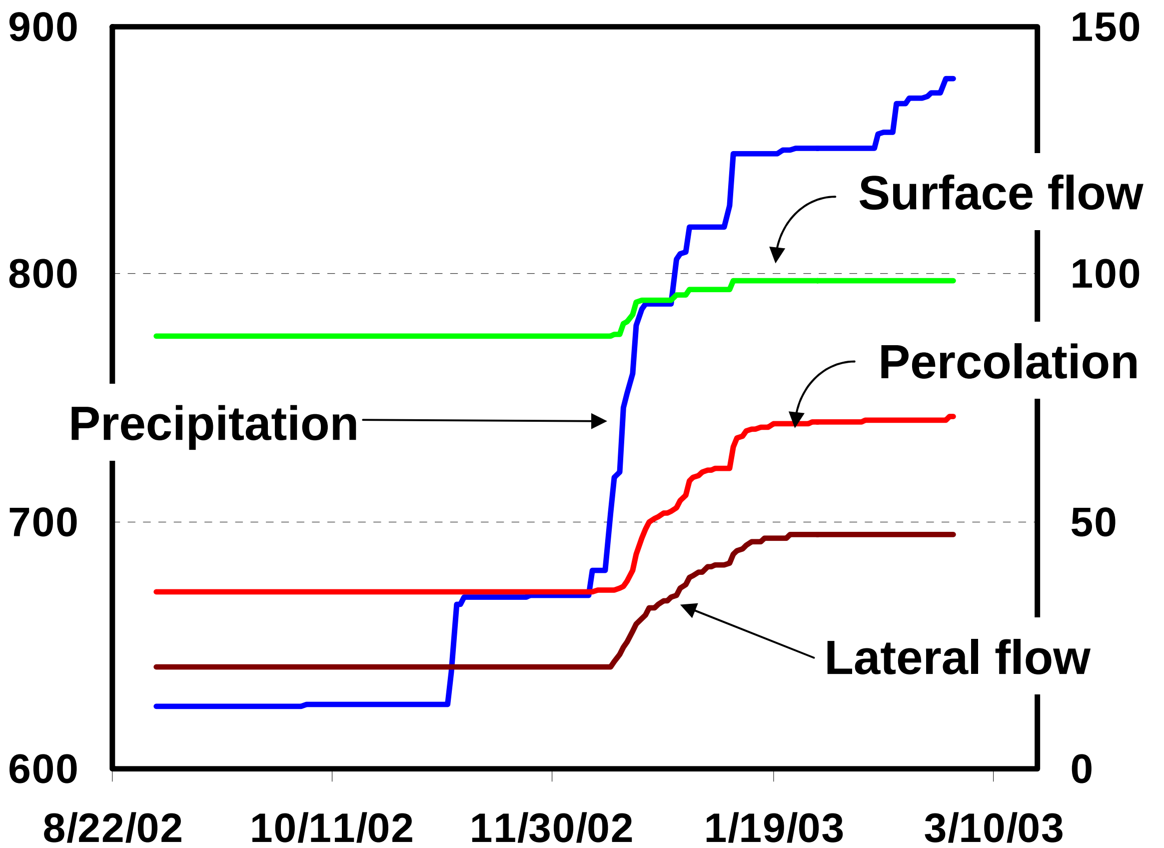
Water Balance Components
Conventional Composite Cover, Cedar Rapids IA

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



Water Balance Components
Conventional Composite Cover, Marina CA

- Percolation coincides with precipitation, surface and lateral flow
- Relatively high rate of percolation
- No cushion between the geomembrane and the soil, punctures likely in geomembrane



- Illustrates importance of careful geomembrane installation

Conventional Composite Covers Discussion

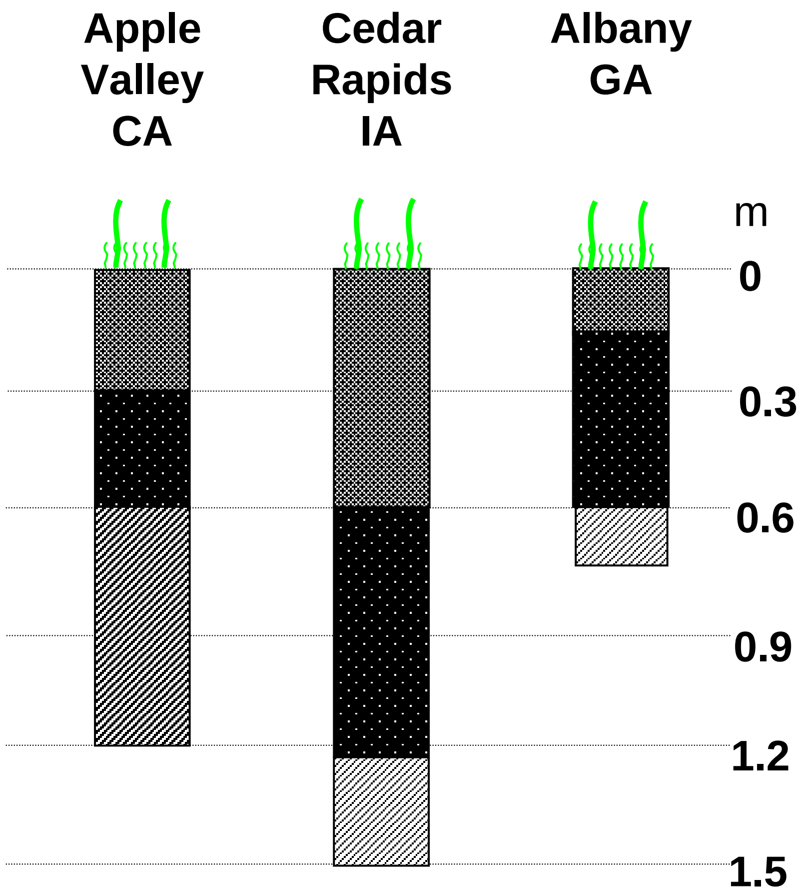
- Perform well at all locations
- Average percolation typically <1.5% of precipitation
  - <1.5 mm/yr at arid/semi-arid/subhumid sites
  - <12 mm/yr at humid locations
- Percolation often linked to heavy precipitation events and lateral flow
- Damage to geomembrane greatly increases percolation rate
- Construction practice and quality control are very important

Conventional Composite Cover Data

Site	Duration (Days)	Slope (%)	Total Precipitation (July 1– June 30) (mm)			Surface Runoff (mm)	Lateral Flow (mm)	ET (mm)	Percolation (Water Year: July 1– June 30)				
			00-01	01-02	02-03				Total (mm)	00-01 (mm/yr)	01-02 (mm/yr)	02-03 (mm/yr)	Average (mm/yr)
Altamont CA	781	5	NF	291.1	394.2	59.0 (6.5%)	4.0 (0.4%)	825.0 (91%)	4.0 (0.4%)	NF	0.0 (0.0%)	4.0 (1.0%)	1.5 (0.4%)
Apple Valley CA	251	5	NA	NF	148.0	6.8 (4.6%)	0.0 (0.0%)	134.14 (91%)	0.0 (0.0%)	NA	NF	0.0 (0.0%)	0.0 (0.0%)
Boardman OR	747	25	NF	134.4	125.5	0.0 (0.0%)	0.2 (0.1%)	366.4 (109%)	0.0 (0.0%)	NF	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Marina CA	947	25	288.0	335.0	343.7[d]	98.7 (10.%)	47.4 (4.9%)	789.6 (82%)	71.0 (7.3%)	9.0 (3.1%)	25.3 (7.6%)	36.2 (10.5%)	23.1 (7.3%)
Polson MT	1137	5	350.0	292.1	290.6	17.7 (1.6%)	40.5 (3.6%)	1052.5 (94%)	1.5 (0.1%)	1.2 (0.3%)	0.0 (0.0%)	0.0 (0.0%)	0.4 (0.1%)
Cedar Rapids IA	621	5	NF	NF	791.2	54.1 (2.8%)	96.2 (5.0%)	1725.5 (91%)	26.9 (1.4%)	NF	NF	21.0 (2.7%)	12.2 (1.4%)
Omaha NE	815	25	NF	561.4	474.5	86.8 (5.8%)	43.3 (2.9%)	1266.0 (85%)	16.5 (1.1%)	8.5[c] (1.4%)	1.0 (0.2%)	9.2 (1.9%)	6.0 (1.1%)

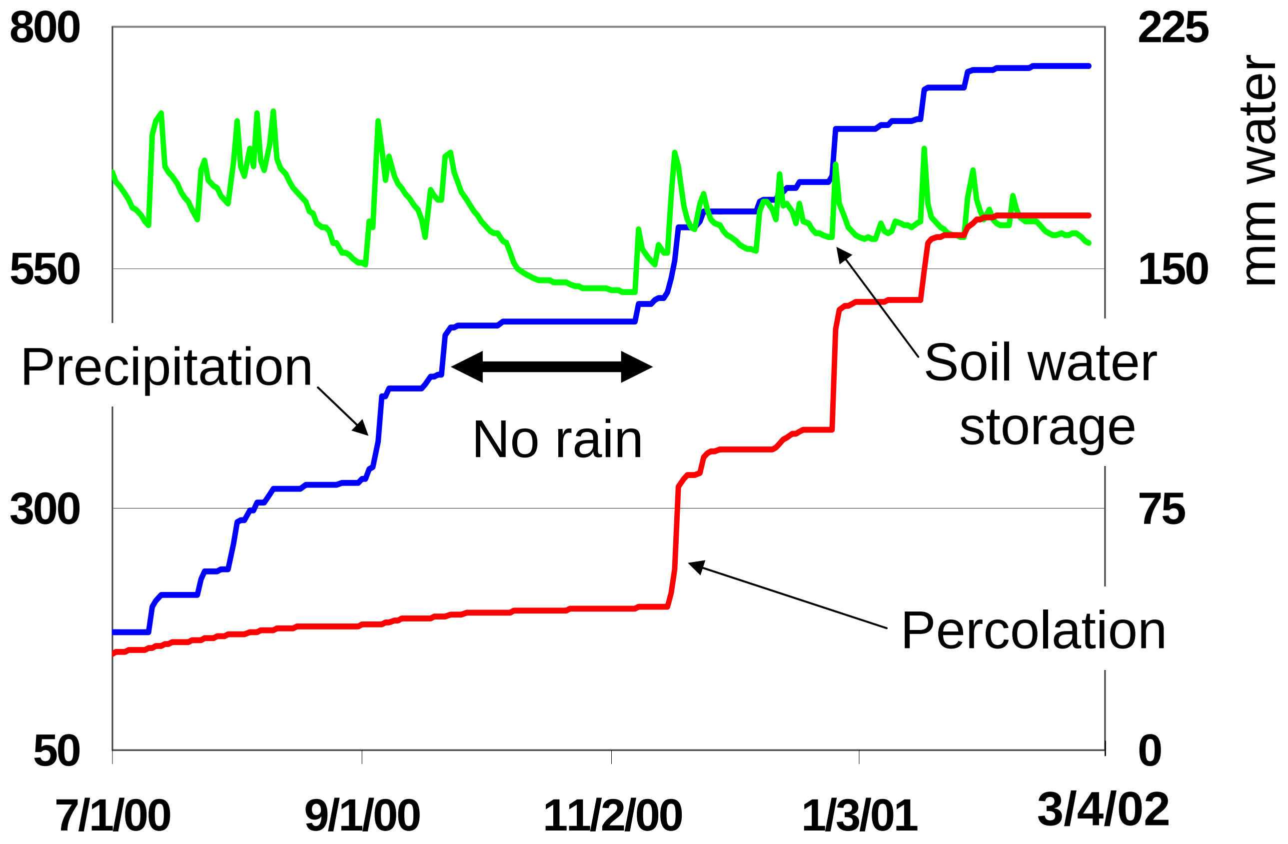
(% = percent of precipitation)

Conventional Soil Barrier Designs



Water Balance Components
Conventional Soil Barrier Cover, Albany GA

- 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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10-Feb-2004

Change in saturated hydraulic conductivity in a compacted clay barrier

- Albany GA
- Cover installed March 2000
- Final sampling Feb. 2004

Test	Hydraulic Conductivity (K) (cm/s)	K_f/K_o
As-Built	4.0×10^{-8}	1.0
SDRI	2.0×10^{-4}	5000
TSB - 1	5.2×10^{-5}	1300
TSB - 2	3.2×10^{-5}	800
TSB - 3	3.1×10^{-3}	77,500

Conventional Soil Barrier Covers Discussion

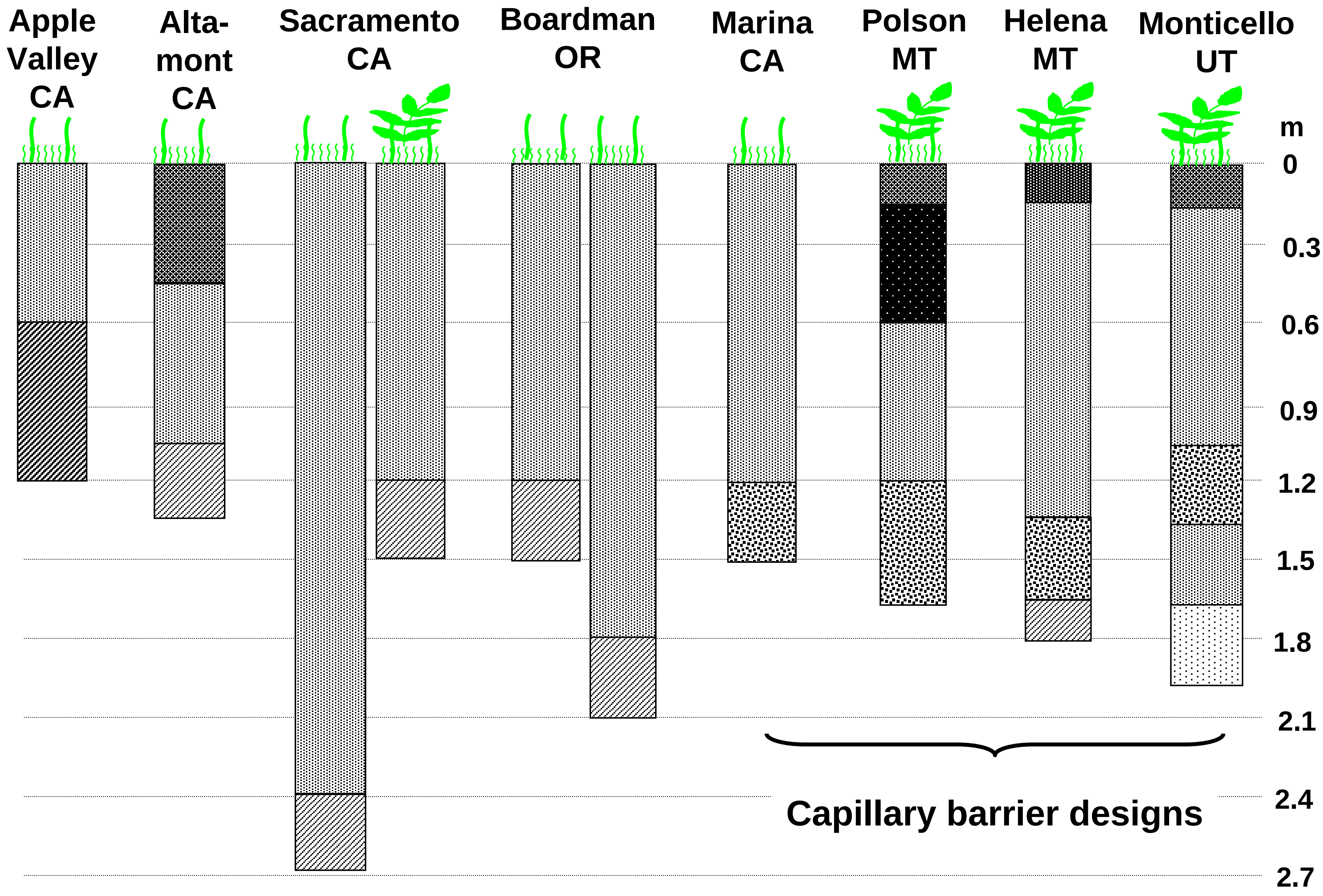
- Percolation at humid locations
  - ➢ 52 - 195 mm/yr
  - ➢ 6 – 17 % of precipitation
- Percolation response to precipitation events changed at both humid sites
  - Percolation quantity increased
  - Temporal response increased
- Clay barrier properties changed significantly over a relatively short time

Conventional Soil Barrier Cover Data

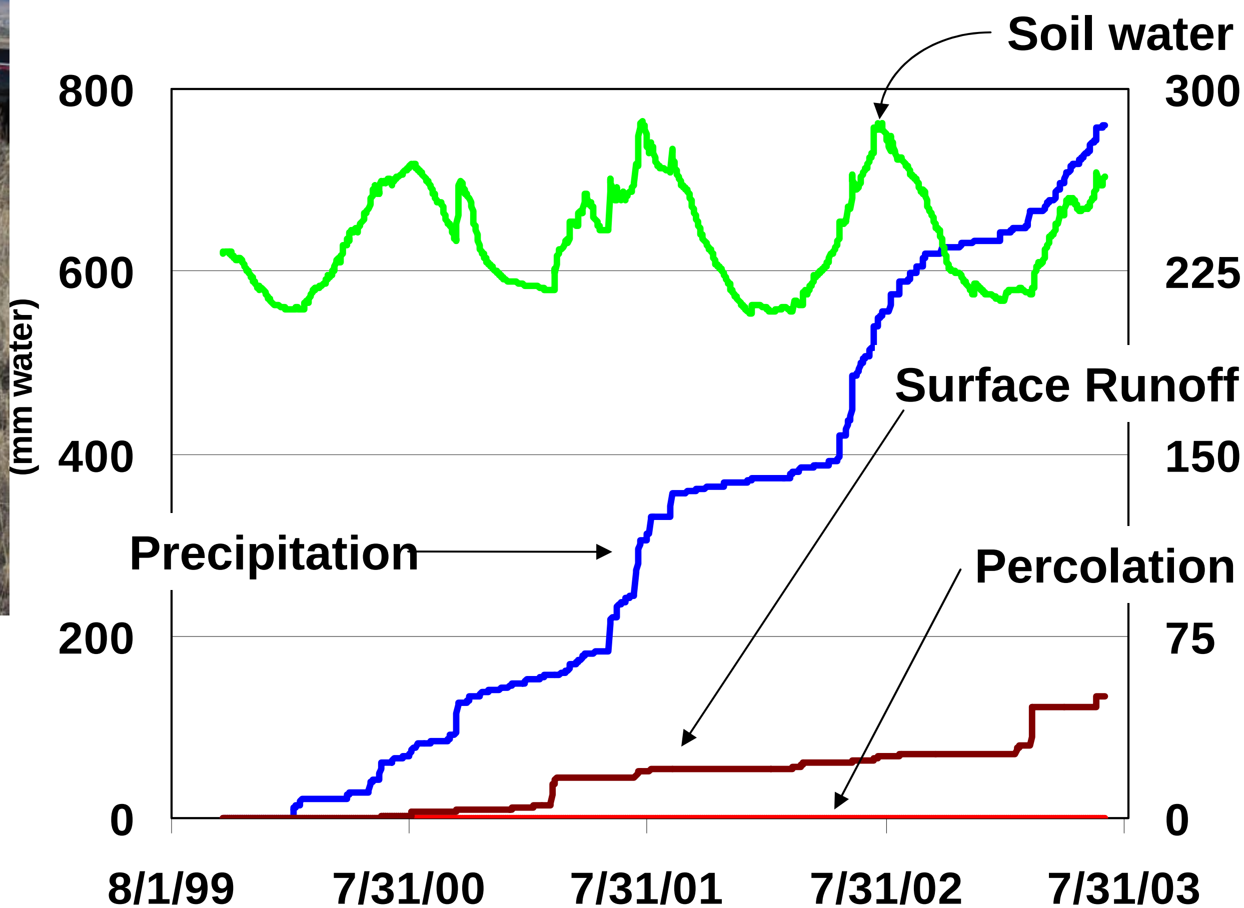
Site	Duration (Days)	Slope (%)	Total Precipitation (July 1– June 30) (mm)			Surface Runoff (mm)	Lateral Flow (mm)	ET (mm)	Percolation (Water Year: July 1– June 30)				
			00-01	01-02	02-03				Total (mm)	00-01 (mm/yr)	01-02 (mm/yr)	02-03 (mm/yr)	Average (mm/yr)
Apple Valley CA	251	5	NA	NF	148.0	3.4 (2.3%)	0.0 (0.0%)	120 (81%)	0.0 (0.0%)	NA	NF	0.0 (0.0%)	0.0 (0.0%)
Albany GA	985	5	909 (909[b])	798 (996[b])	1448 (1560[b])	359 (9.9%)	NA	2683 (74%)	624 (17%)	292 (32%)	238 (24%)	52 (3.4%)	195.2 (17%)
Cedar Rapids IA	621	5	NF	NF	791.2	79.6 (4.2%)	29.5 (1.5%)	1596 (84%)	114 (6.0%)	NF	NF	94 (12%)	52 (6.0%)

(% = percent of precipitation)

Alternative Designs: Arid/Semi-Arid/Sub-Humid Locations



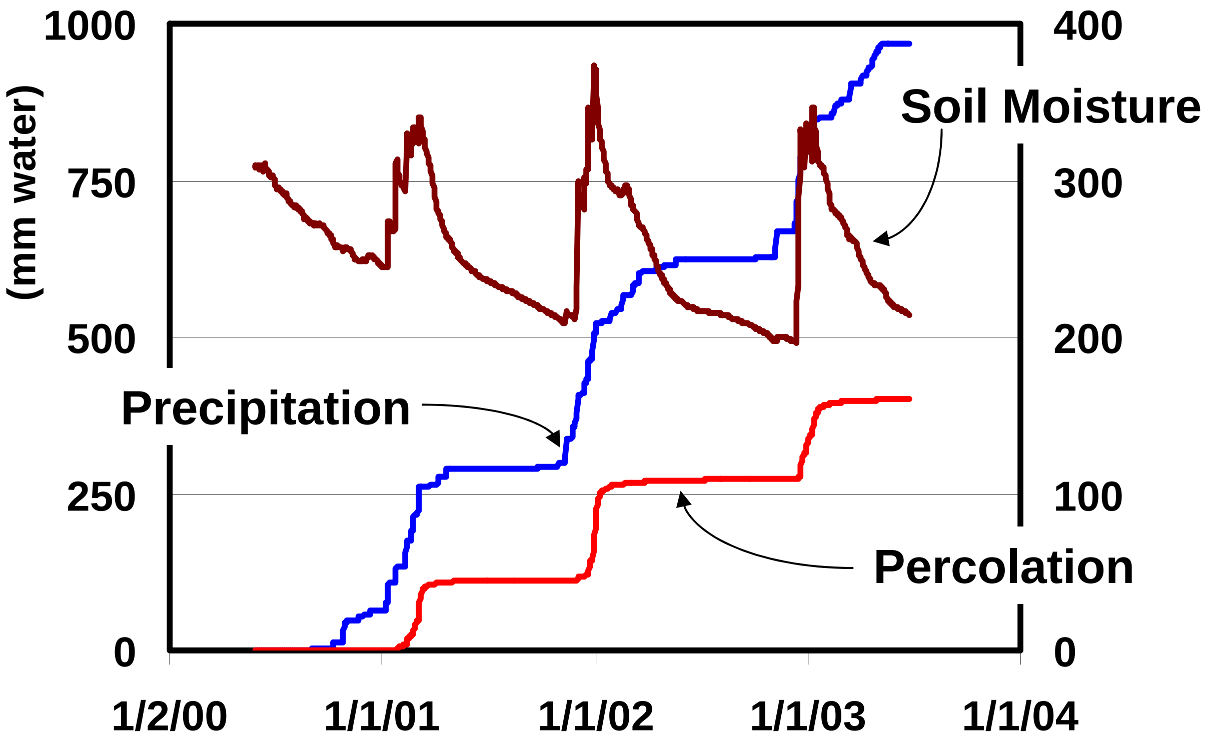
Water Balance Components Alternative Cover, Helena MT



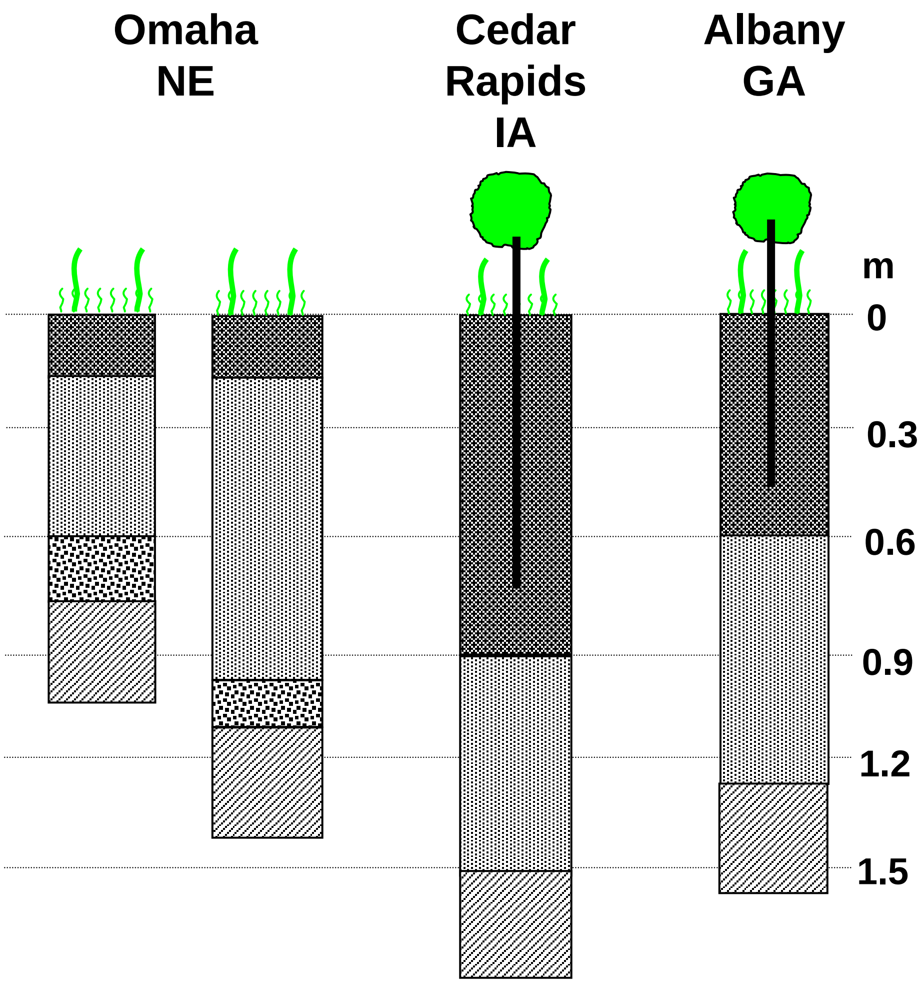
- Seasonal precipitation pattern
- Seasonal fluctuations in soil water content
- No percolation

Water Balance Components
Alternative Cover, Marina CA

- Water storage capacity lower than expected
- Effective storage capacity (300 mm) lower than calculated (385 mm)
- Drainage when storage capacity exceeded

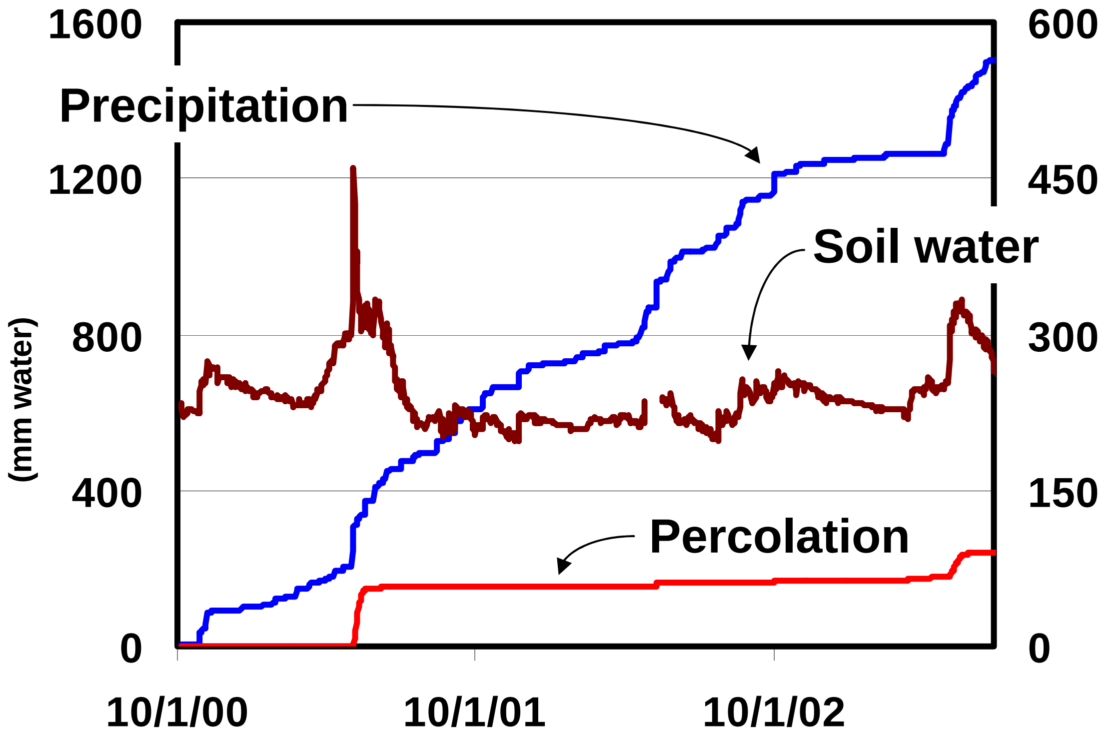


Alternative Designs: Humid Locations



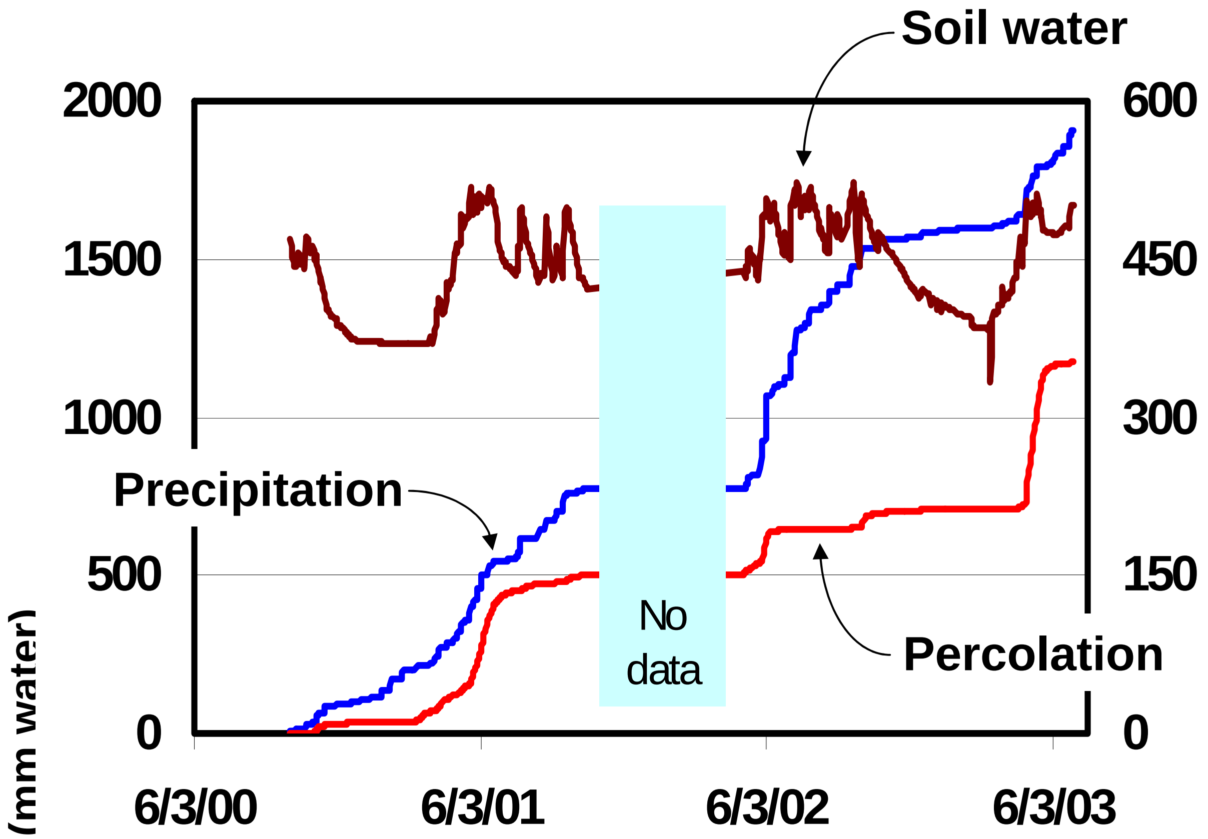
Water Balance Components
Alternative Cover, Omaha NE

- Moderate precipitation
- Percolation occurs late spring
- Improvements in design and factor-of-safety considerations may provide acceptable performance



Water Balance Components
Alternative Cover, Cedar Rapids IA

- High precipitation
- Extended periods when precipitation > ET
- Probably exceeds capacity of soil/plant system to achieve low percolation rates



Alternative Designs
Discussion

- Very low (<2mm/yr) percolation rates at 7 of 10 covers at arid/semi-arid/sub-humid locations
  - Annual variation in transpiration capacity at Sacramento CA cause of anomalous behavior
  - Insufficient soil water storage capacity at Marina CA
- Higher (33-160 mm/yr) percolation rates at humid locations.
- Preliminary calculations of water holding capacity can underestimate apparent capacity by 0-25%
- Successful design requires careful attention to:
  - Site characterization
  - Water balance mechanisms

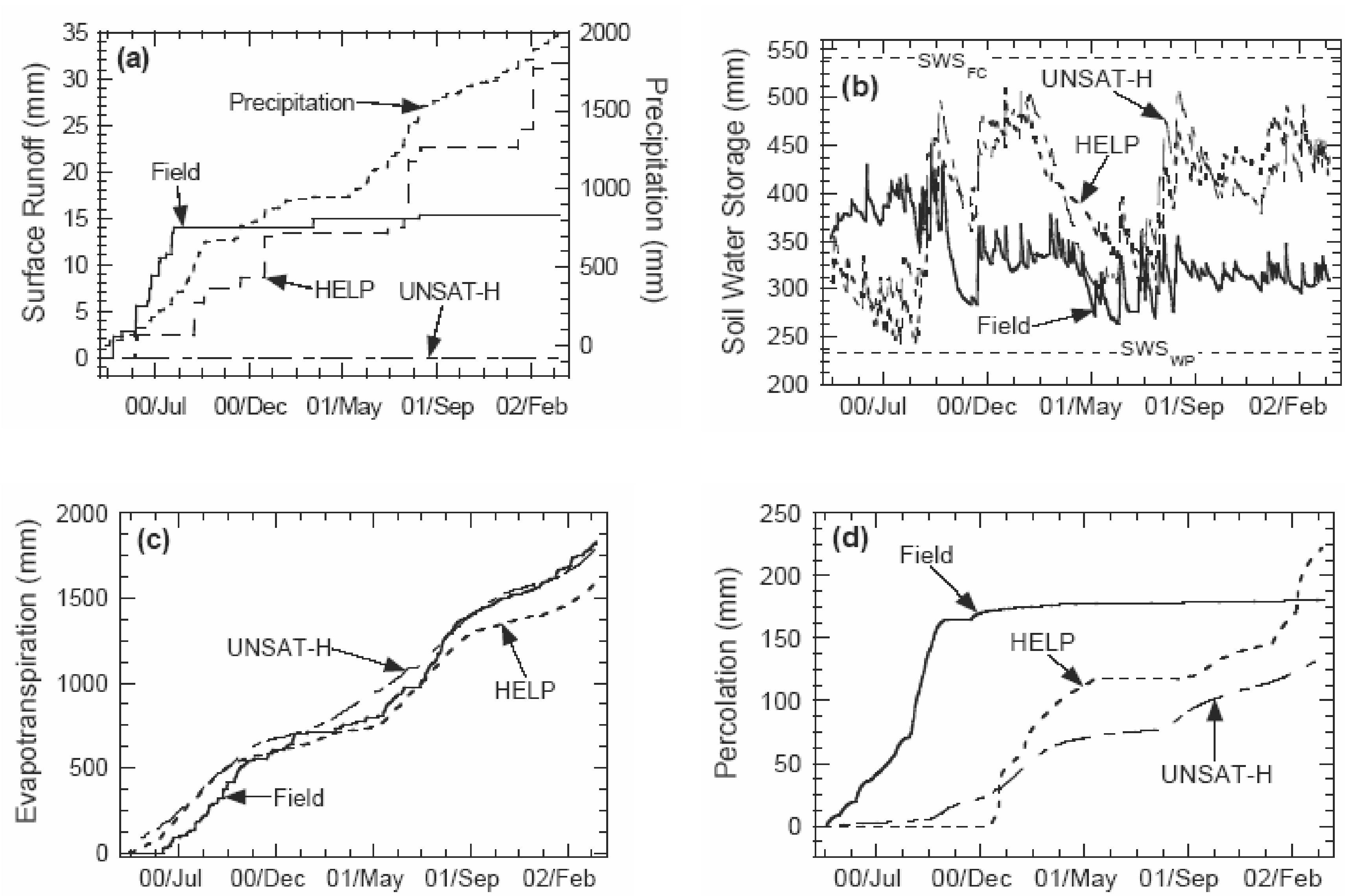
Alternative cover data

Table 6. Summary of water balance data: alternative covers. Percentage of precipitation in parenthesis.

Cover Type	Site	Duration (Days)	Slope (%)	Total Precipitation (July 1– June 30) (mm)				Surface Runoff (mm)	Evapo-transpiration (mm)	Percolation (Water Year: July 1– June 30)					
				00-00	00-01	01-02	02-03			Total (mm)	99-00 (mm/yr)	00-01 (mm/yr)	01-02 (mm/yr)	02-03 (mm/yr)	Average (mm/yr)
Monolithic Barrier	Altamont	781	5	NA	NF	291.1	394.2	84.1 (9.3%)	770.1 (85.3%)	4.0 (0.4%)	NA	NF	1.5 (0.5%)	2.5 (0.6%)	1.5 (0.4%)
	Apple Valley	251	5	NA	NA	NF	148.0	0.0 (0.0%)	79.5 (0.5%)	0.0 (0.0%)	NA	NA	NF	0.0 (0.0%)	0.0 (0.0%)
	Boardman (1220 mm)	747	25	NA	NF	134.4	125.5	0.0 (0.0%)	348.6 (103.9%)	0.0 (0.0%)	NA	NF	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
	Boardman (1840 mm)							0.0 (0.0%)	398.5 (118.8%)	0.0 (0.0%)	NA	NF	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
	Sacramento (1080 mm)	1228	5	517.9	356.6	277.1	245.1	105.5 (7.6%)	1064.2 (77.1%)	101.5 (7.4%)	0.0 (0.0%)	1.4 (0.4%)	96.2 (34.7%)	3.9 (1.7%)	26.8 (7.4%)
	Sacramento (2450 mm)							66.9 (4.8%)	1089.4 (78.9%)	8.5 (0.6%)	0.0 (0.0%)	0.0 (0.0%)	8.5 (3.1%)	0.0 (0.0%)	2.2 (0.6%)
	Albany	985	5	NF	909.0 (1078.5[b])	798.3 (1038.6[b])	1447.8 (1455.9[b])	18.5 (0.5%)	3445.6 (92.0%)	394.0 (10.5%)	NF	134.1 (12.4%)	3.1 (0.3%)	218.3 (15.0%)	123.3 (10.5%)
	Cedar Rapids	621	5	NA	NF	NF	791.2	59.9 (3.1%)	1463.7 (76.8%)	351.6 (18.4%)	NA	NF	NF	157.1 (20.0%)	159.6 (18.4%)
Capillary Barrier	Helena	1169	5	NF	180.9	265.2	252.0	50.1 (6.6%)	680.2 (89.5%)	0.0 (0.0%)	NF	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
	Marina	947	25	NF	288.0	335.0	343.7[c]	0.0 (0.0%)	902.5 (93.3%)	159.9 (22.9%)	NF	44.7 15.5%)	64.2 (19.2%)	51.1 (14.9%)	52.0 (16.5%)
	Monticello	872	5	NA	343.7	167.6	382.8	10.2 (1.2%)	938.3 (104.7%)	0.0 (0.0%)	NA	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
	Omaha (1060 mm)	815	25	NA	NF	561.4	474.5	88.7 (6.0%)	1258.9 (84.6%)	155.3 (10.4%)	NA	137.0[g] (22.5%)	3.4 (0.6%)	50.9 (10.7%)	56.9 (10.4%)
	Omaha (1360 mm)							56.5 (3.8%)	1311.9 (88.1%)	90.7 (6.1%)	NA	78.6[g] (12.9%)	4.2 (0.7%)	28.7 (6.0%)	33.3 (6.1%)
	Polson	1137	5	NF	350.0	292.1	290.6	17.8 (1.6%)	1133.2 (1.0%)	0.2 (0.0%)	NF	0.2 (0.1%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)

Notes: NA = Not Applicable, NF = Data not available for full year, [a]average annual precipitation from NOAA historical data, [b]total precipitation for Albany includes irrigation.

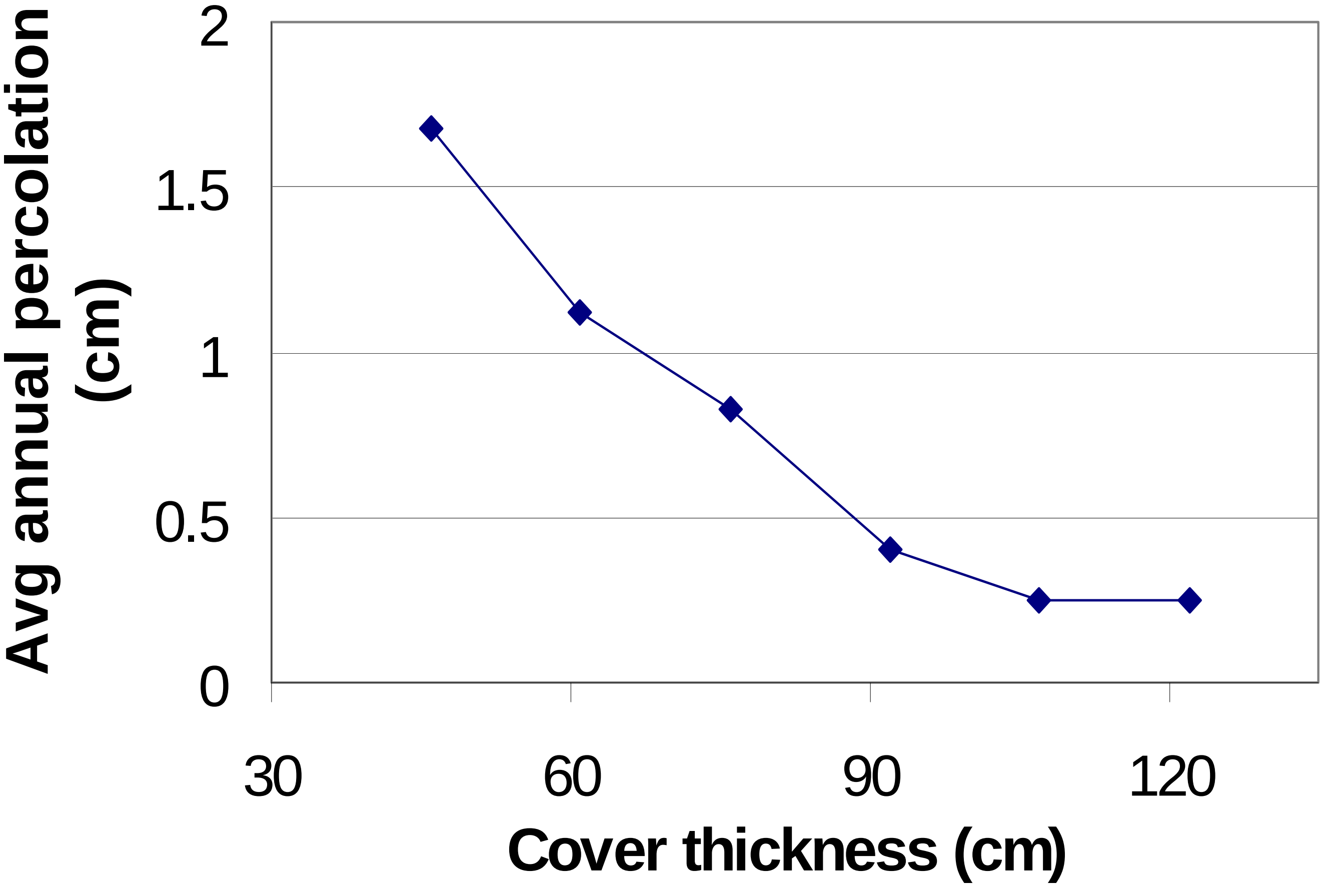
The problem with models: excessive uncertainty in results



Sensitivity analysis as a design tool

- Design sensitivity analysis (DSA) is performed by comparing results from systematic variation of a single parameter
- DSA helps designer and regulator understand relative contribution of various design features or environmental stresses to cover performance
- DSA can provide valuable information for negotiations in a regulatory environment

DSA example
Evaluate the effect of cover thickness



A design process from the Interstate Technology Regulatory Council (ITRC)

1. Define performance criteria
   - No flux
   - Bioreactor operation
2. Select and validate design concept
   - natural analogs
   - lysimeter data (ACAP)
3. Characterize site (soil, plants, climate)
4. Model with DSA to understand important design parameters and environmental stresses
5. Final design considerations (final land use, etc)

- www.itrcweb.org