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

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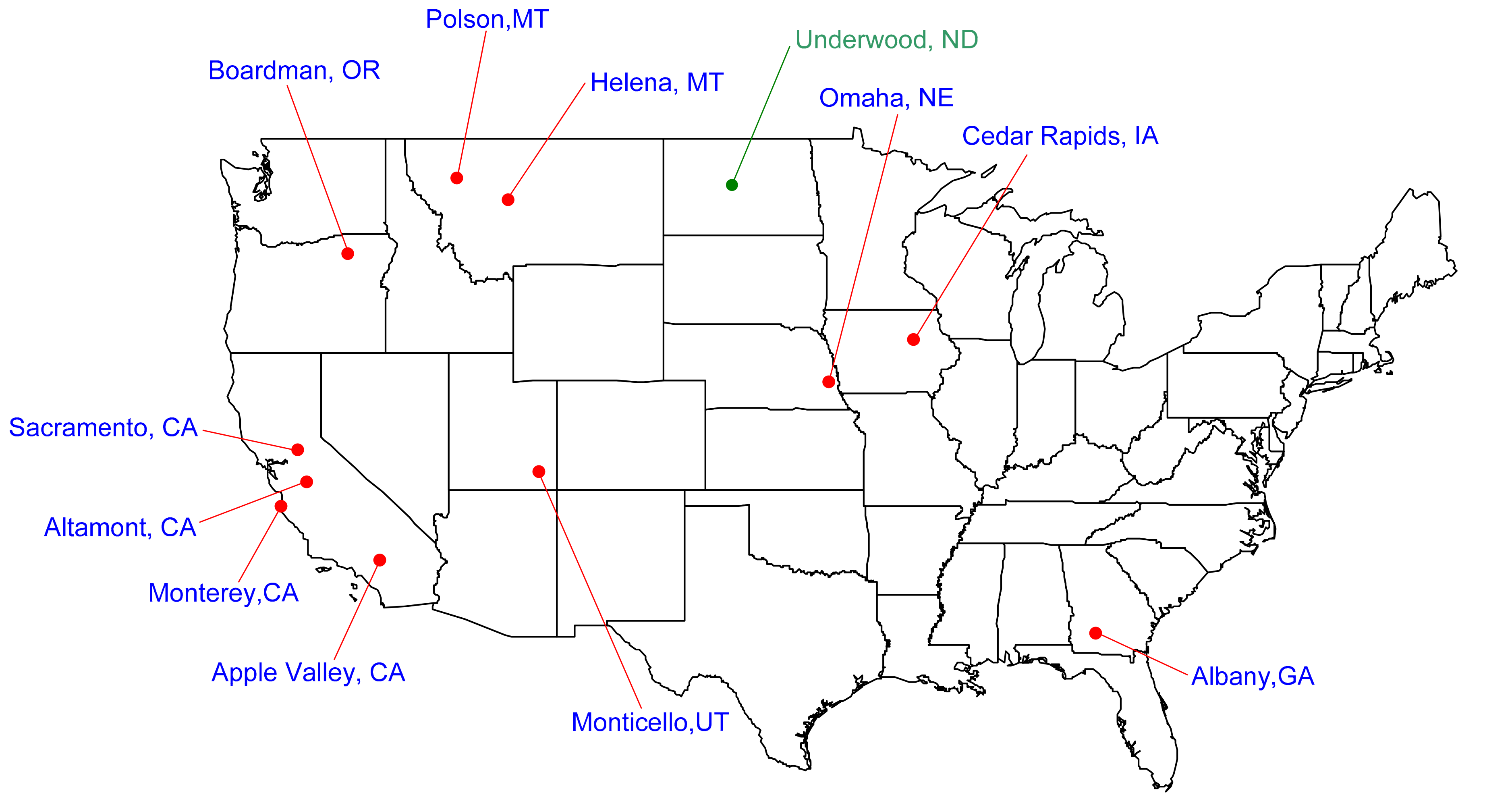
ACAP Objectives

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



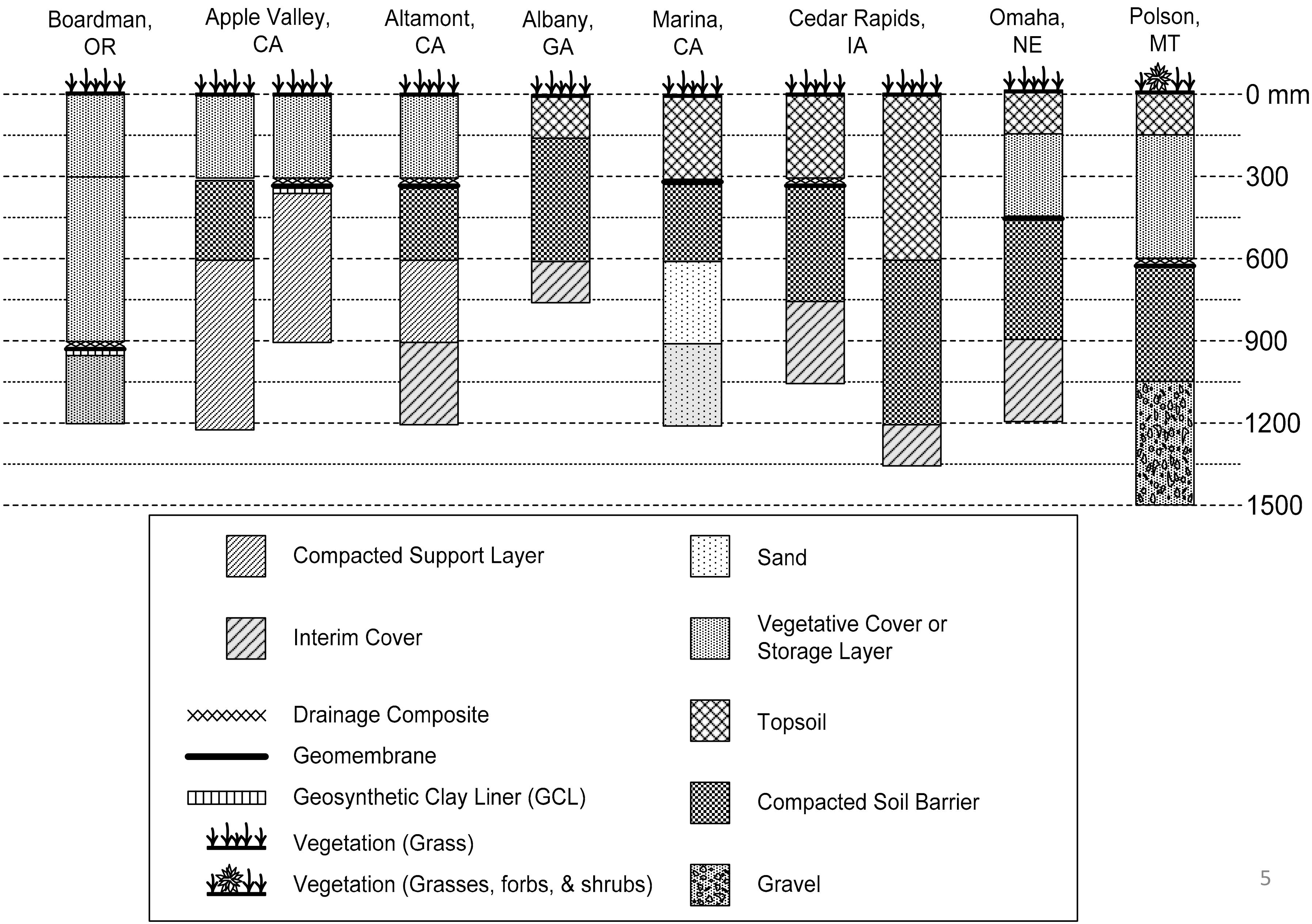
12 Sites, 8 States, 28 Test Sections

Covers designed to transmit < 3, 10, or 30 mm/yr depending conventional cover required by regulation.

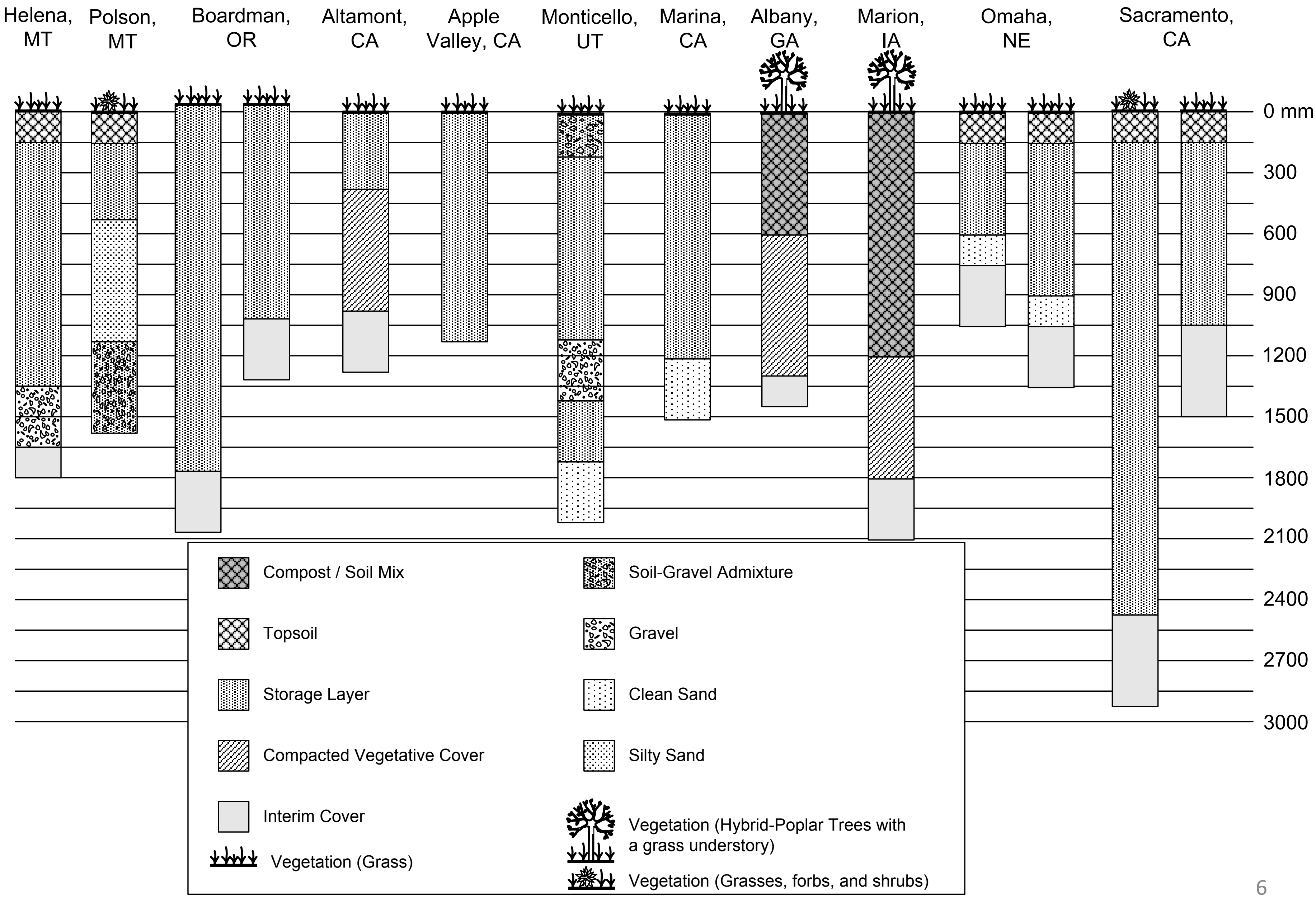
Site Characteristics

Site Location	Elev. (m)	Annual Precip. (mm)	Annual Snowfall (mm)	Annual P/PET	Climate	Monthly Avg. Air Temp.
Apple Valley, CA	898	119	38	0.06	arid	-1, 37
Boardman, OR	95	225	185	0.23	semi-arid	-2, 32
Helena, MT	15	312	1288	0.44	semi-arid	-11, 28
Altamont, CA	227	358	2	0.31	semi-arid	2, 32
Monticello, UT	1204	385	1498	0.34	semi-arid	-9, 29
Sacramento, CA	320	434	0	0.33	semi-arid	3, 34
Underwood, ND	622	442	813	0.47	semi-arid	-19, 28
Marina, CA	31	466	0	0.46	semi-arid	6, 22
Polson, MT	892	380	648	0.58	sub-humid	-7 ,28
Omaha, NB	378	760	711	0.64	sub-humid	-6, 25
Cedar Rapids, IA	290	915	724	1.03	humid	-8, 23
Albany, GA	60	1263	3	1.10	humid	8, 33

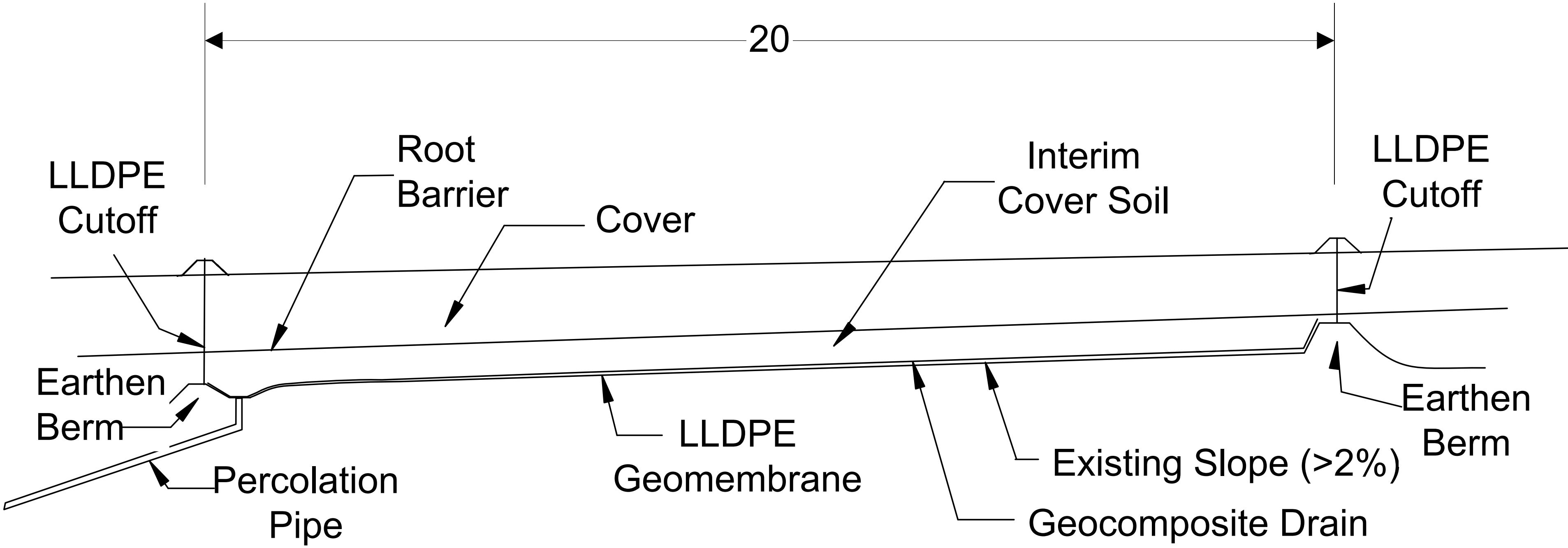
Conventional Covers Evaluated by ACAP



Store & Release Covers Evaluated by ACAP



Typical Lysimeter Cross-Section

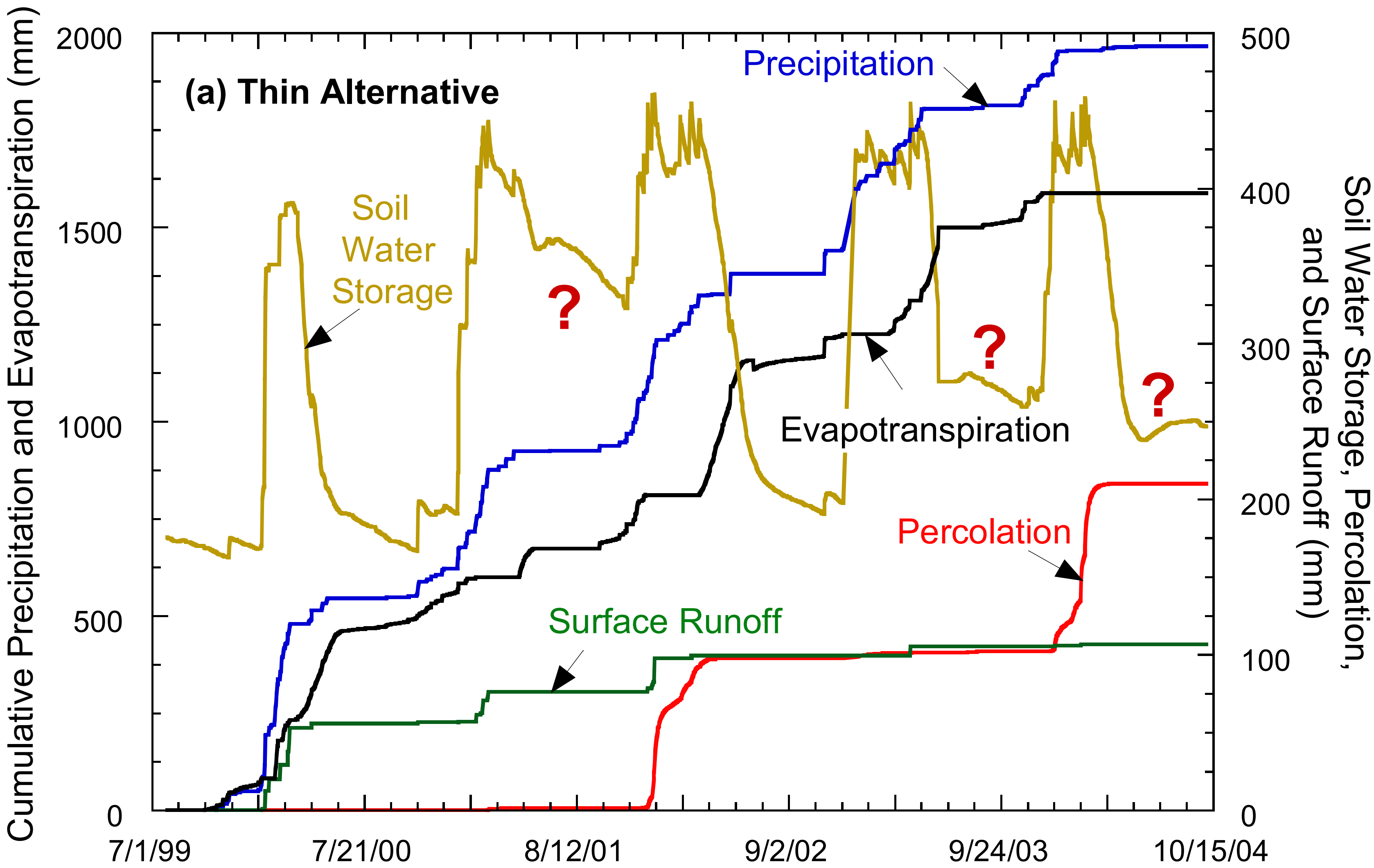


Aerial view of completed test sections at Kiefer Landfill, Sacramento County, California.

Kiefer Landfill Test Sections - In Service

ACAP field sites monitored 1999-2005 (one still being monitored).

S&R Cover in Sacramento, California



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

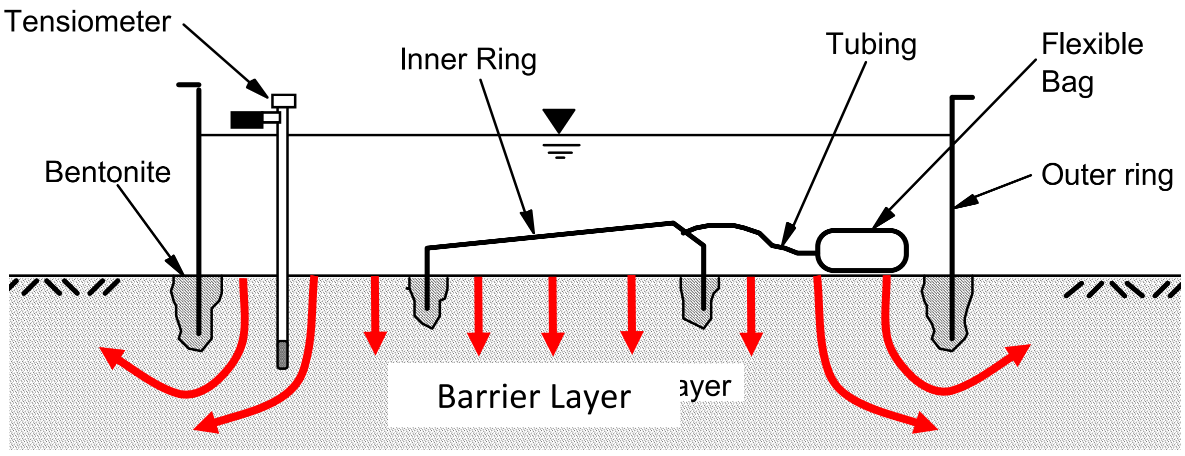
- **Elements**
  - Field testing of hydraulic properties of cover materials
  - Collect large-scale undisturbed samples for lab analysis
  - Collect geosynthetic materials (geomembranes, geocomposite drainage materials, GCLs) for lab analysis
  - Geomorphological surveys

- **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

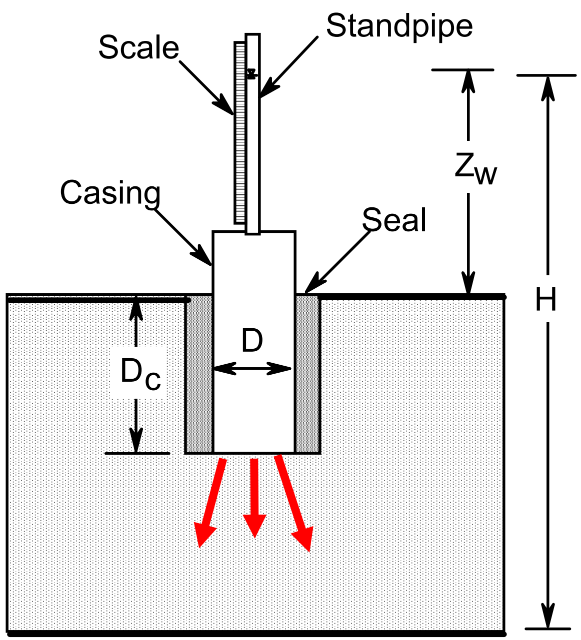
Barrier System Elements

- 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

SDRI Being Operated – Iowa Site

TSB Being Installed and Operated – Utah 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

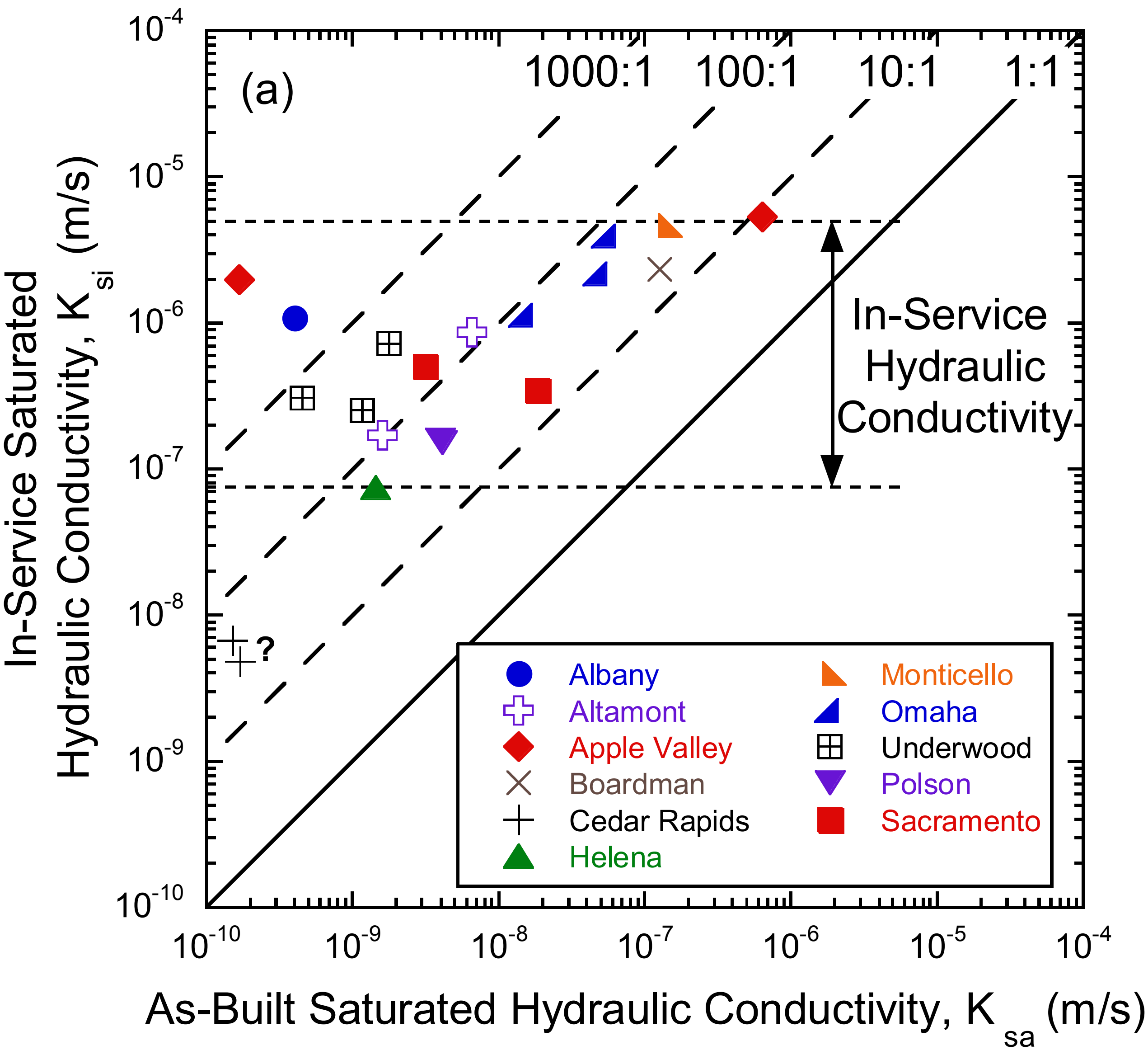
Block sample

Trimming roughly to take ring-off

Placing the block sample

Trimming to the pedestal size

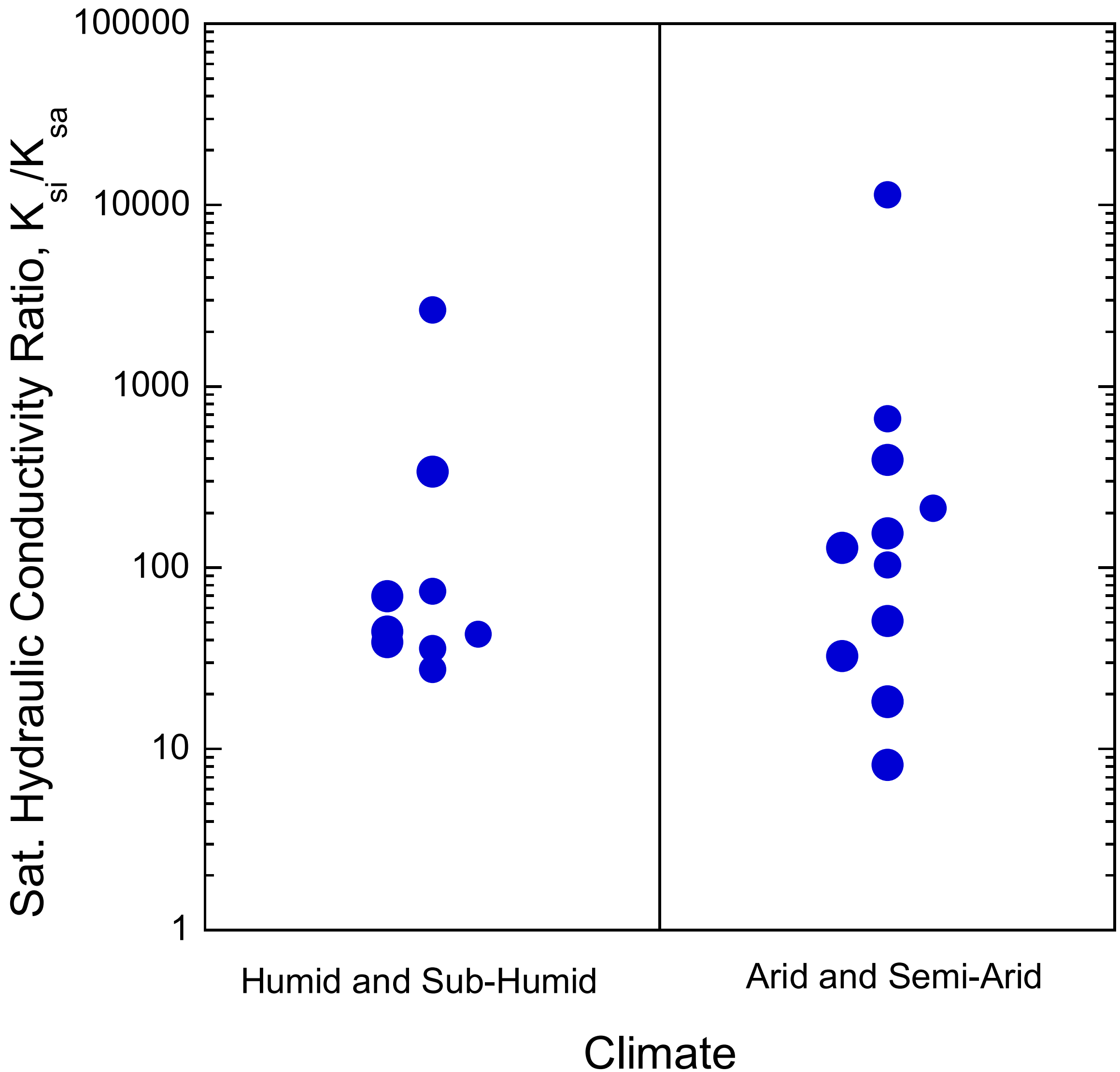
Changes in Sat. Hydraulic Conductivity



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

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

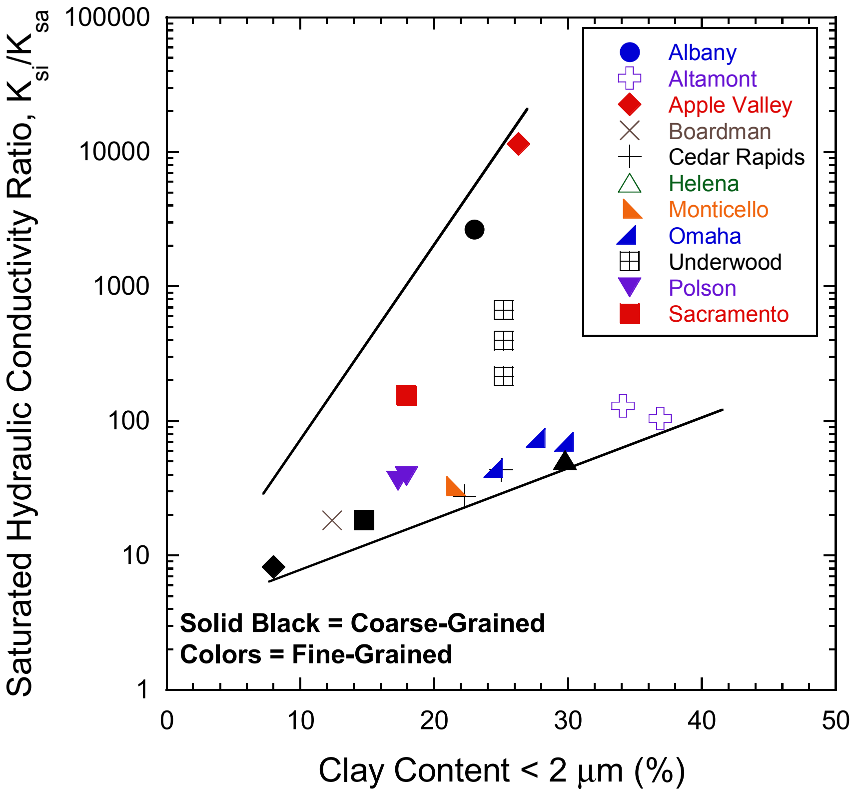
Effect of Climate

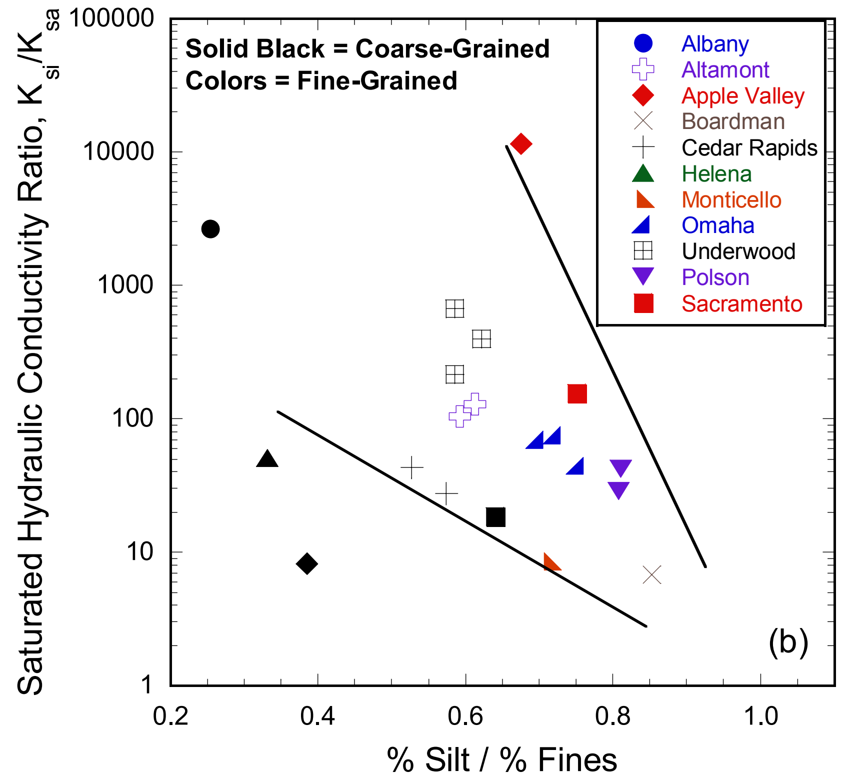


Alterations in Ks often assumed to be unique to drier climates.

Similar increases in Ks for humid and sub-humid climates.

Influence of Soil Composition



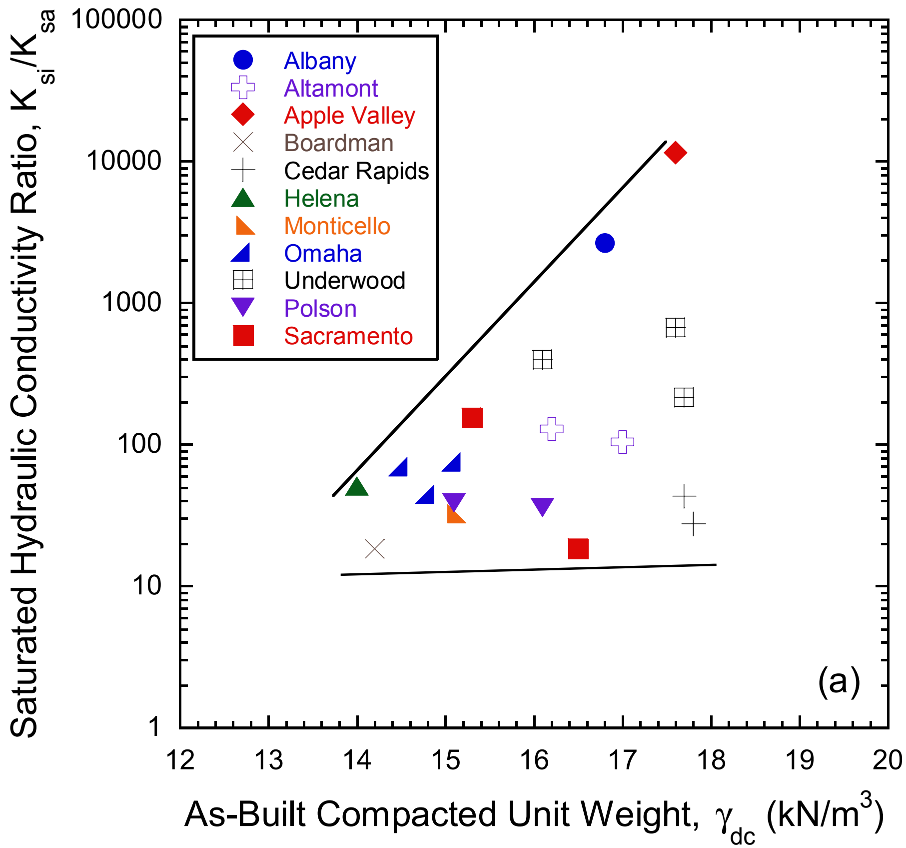


Soils with lower clay fraction more resilient

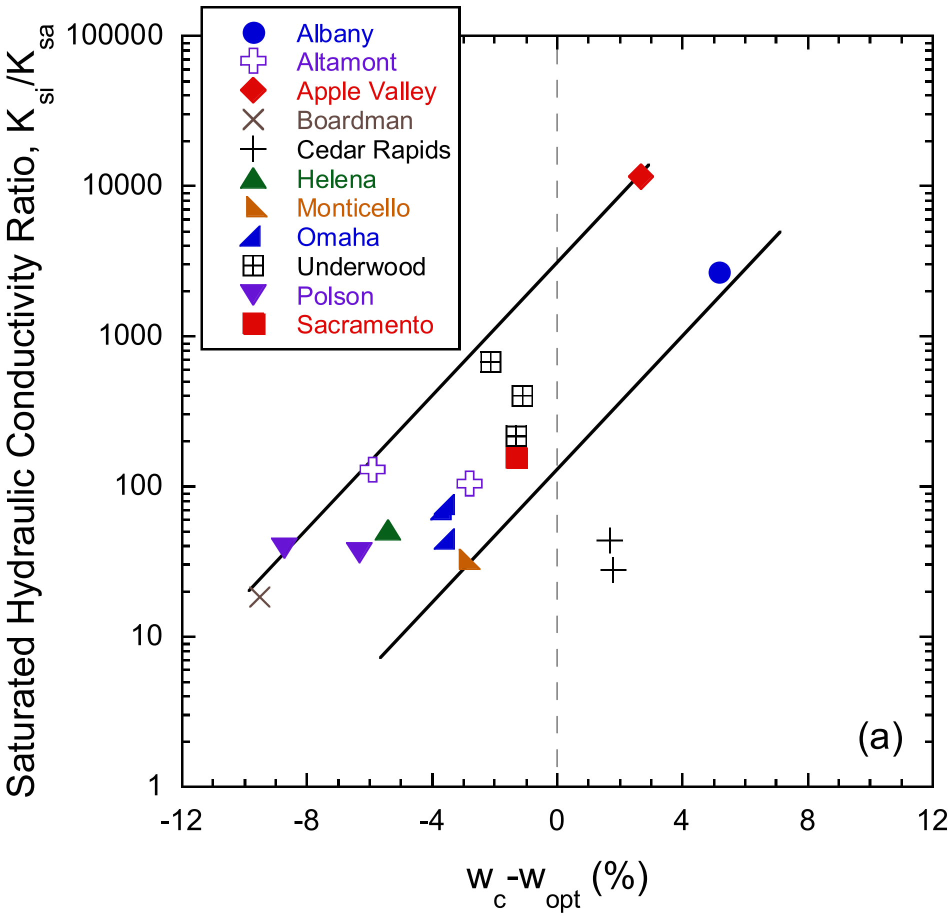
Fine-grained soils with greater silt fraction more resilient

Influence of Placement Condition

Dry Unit Weight



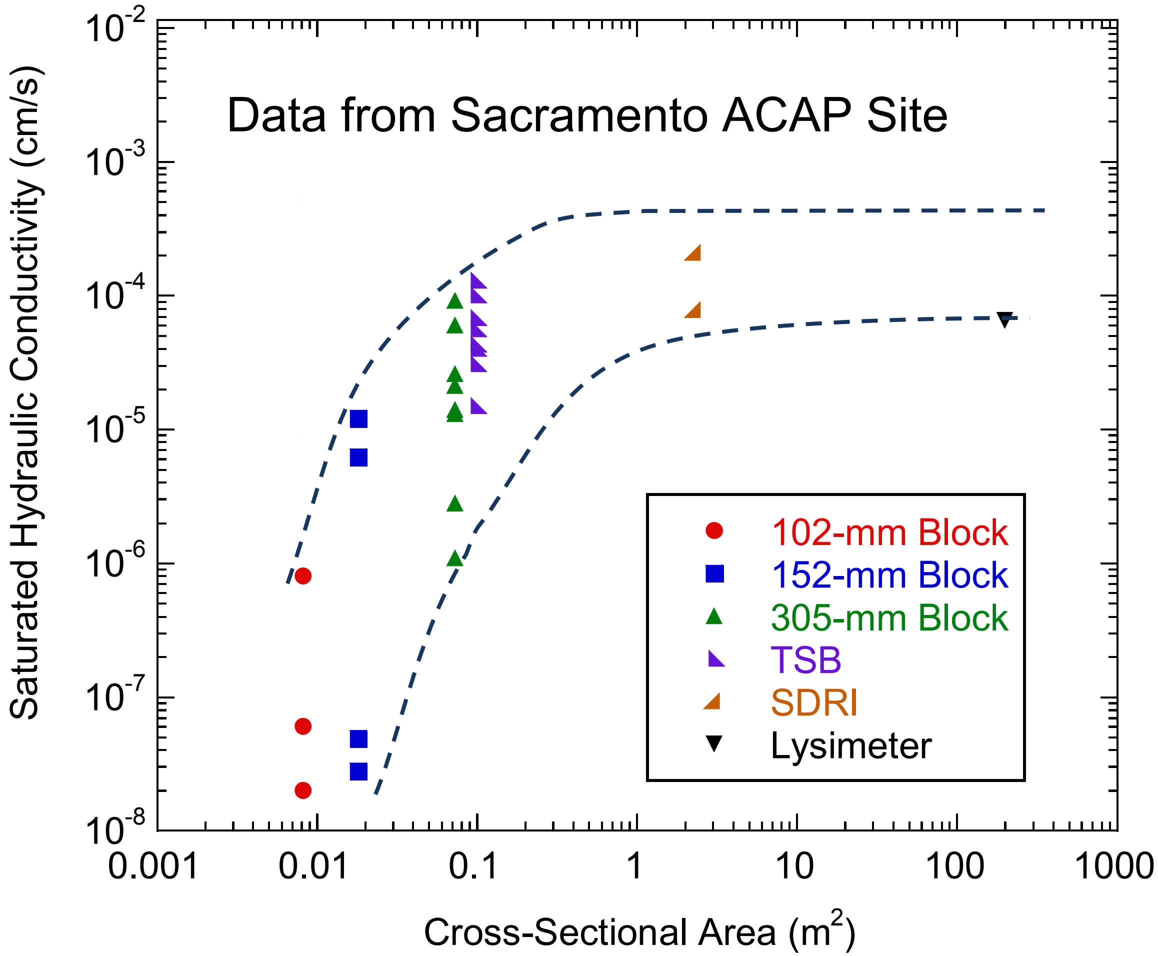
Water Content



Denser soils less resilient … nature loosens dense soils

Wetter soils are less resilient … nature adds structure

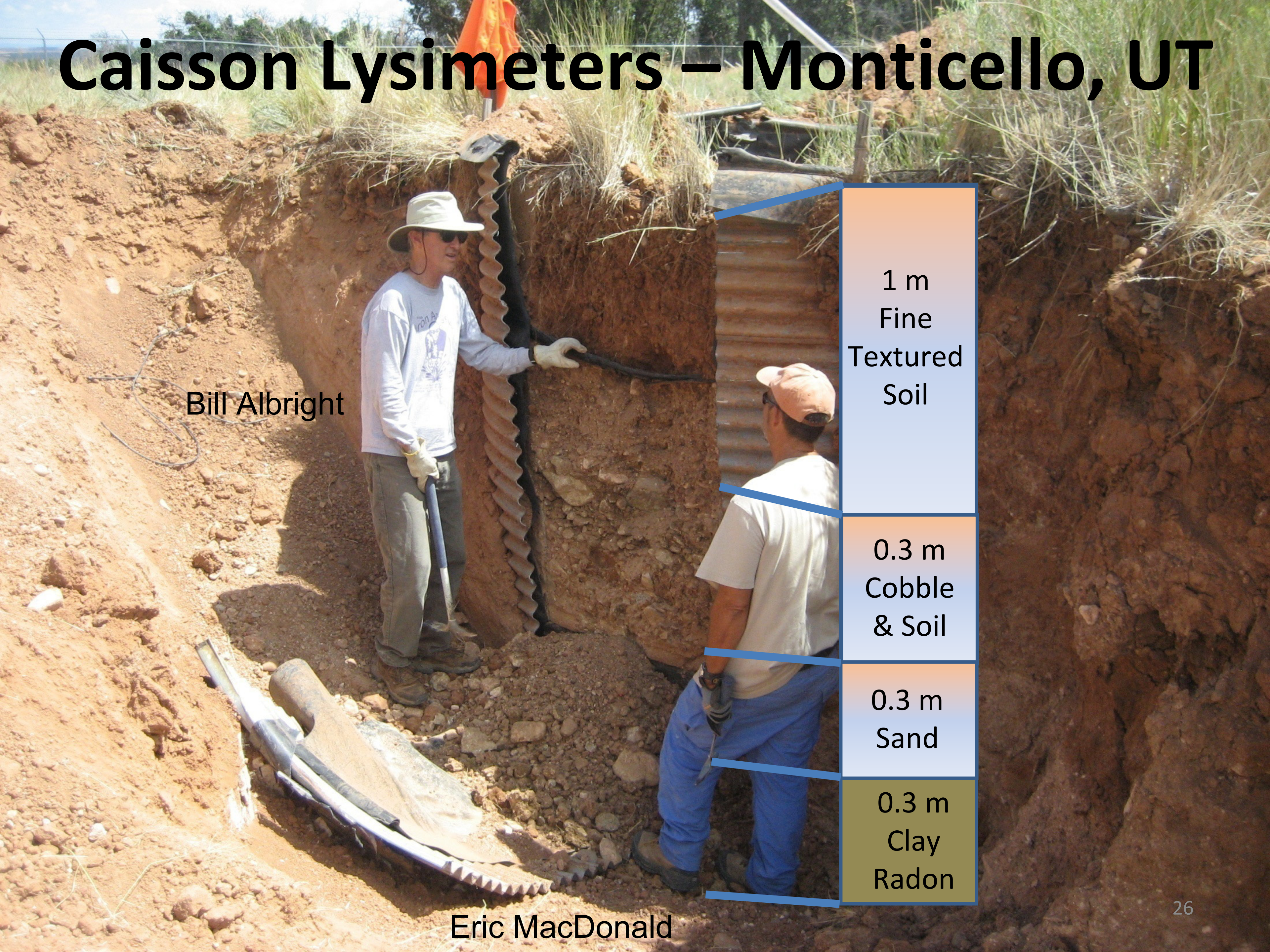
Scale Effect in K_s - Caused by Structure



Hydraulic conductivity increases as more structure incorporated.

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

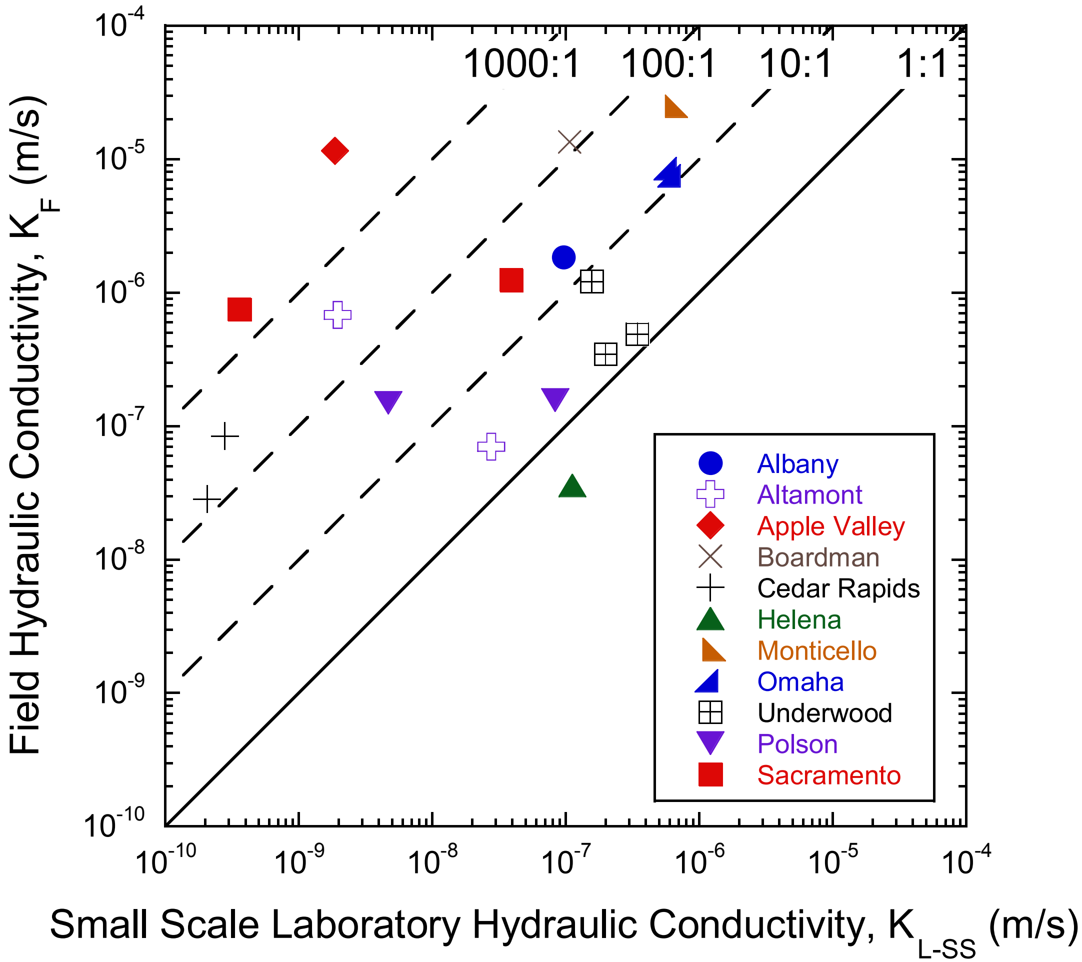
Caisson Lysimeters – Monticello, UT



Radon Barrier – Monticello, UT

Roots seek out water in wet fine-grained soils, e.g., clay radon barriers, even at 1.6-1.9 m depth

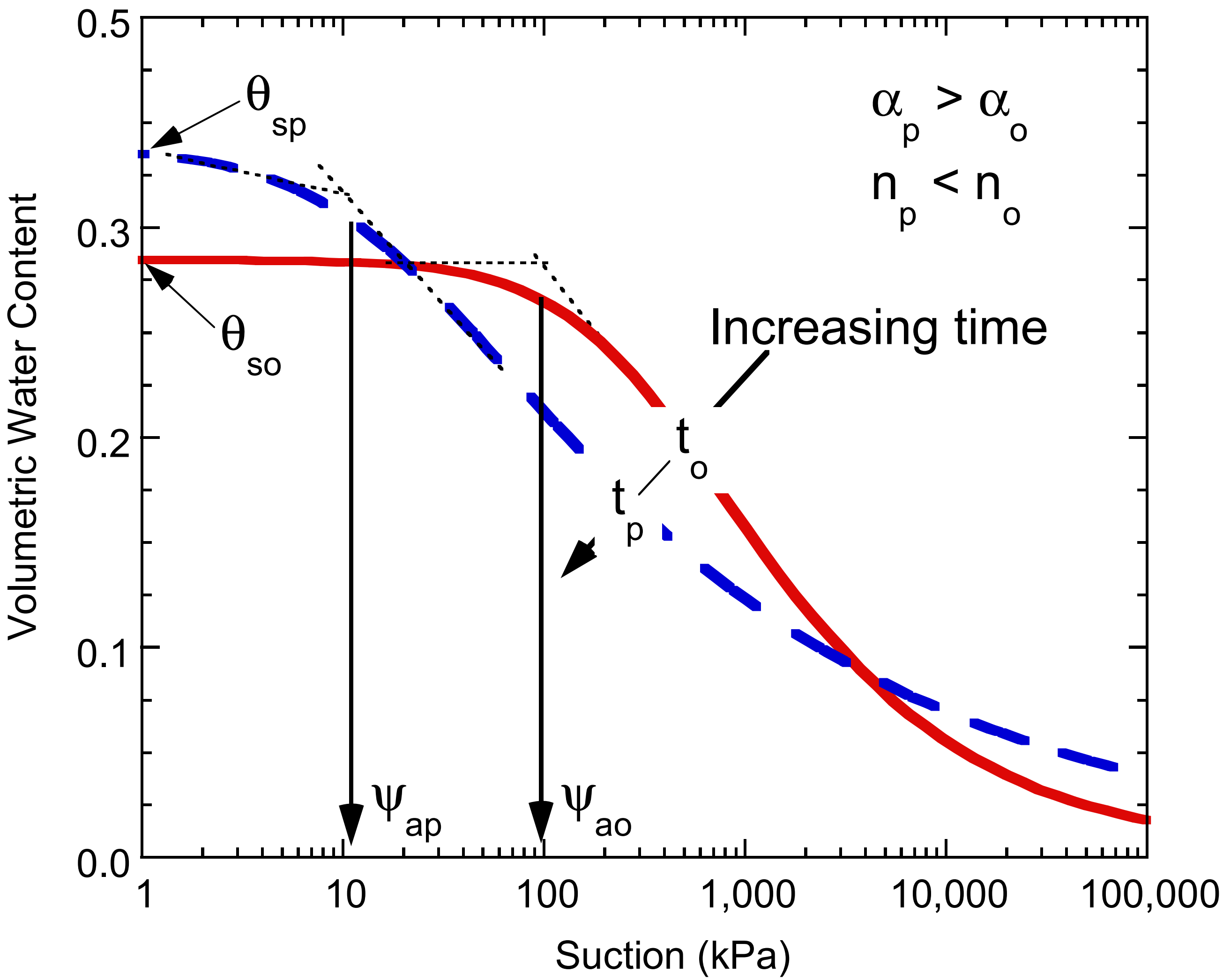
Scaling - Implications for Evaluation



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

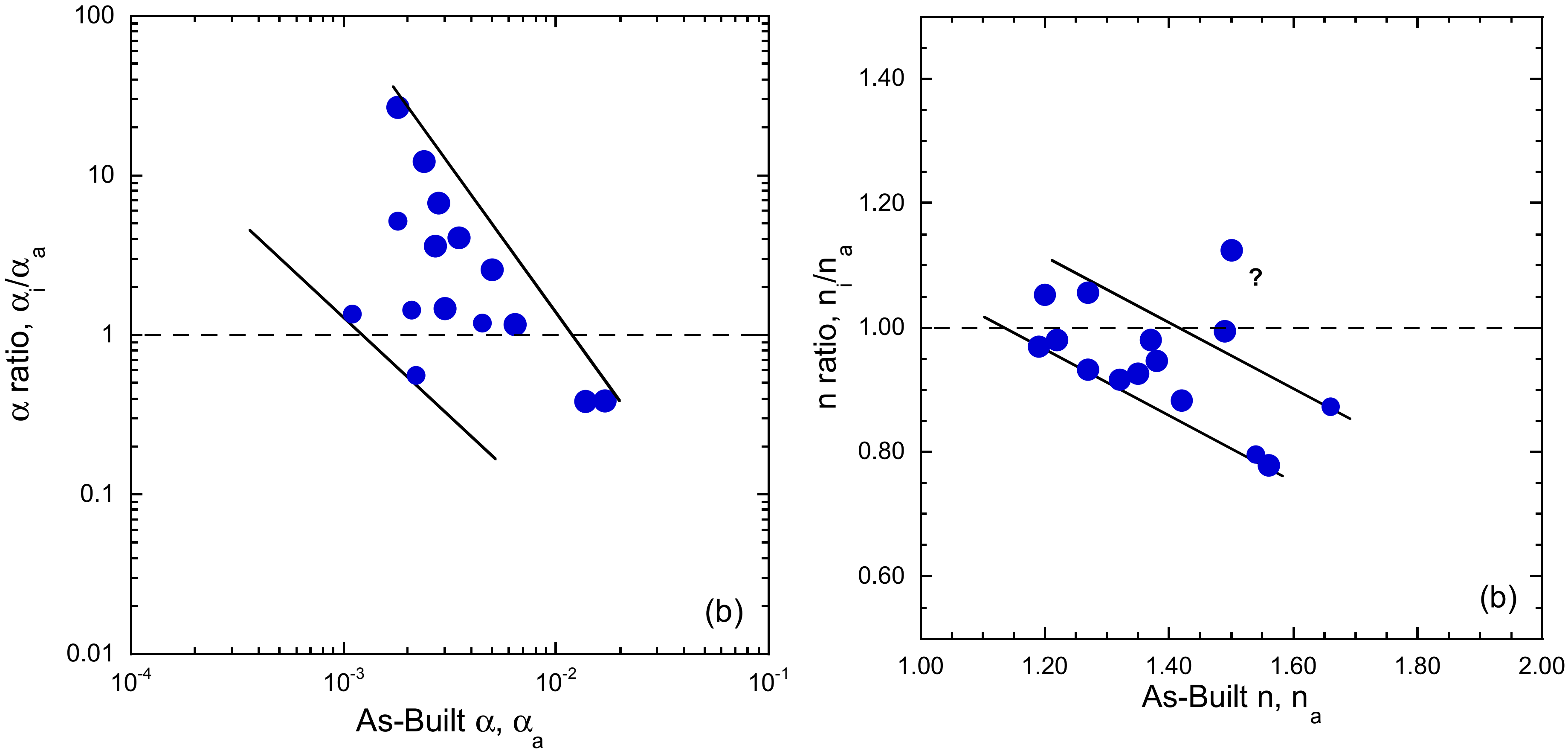


t_o: initial condition

t_p: after pedogenesis

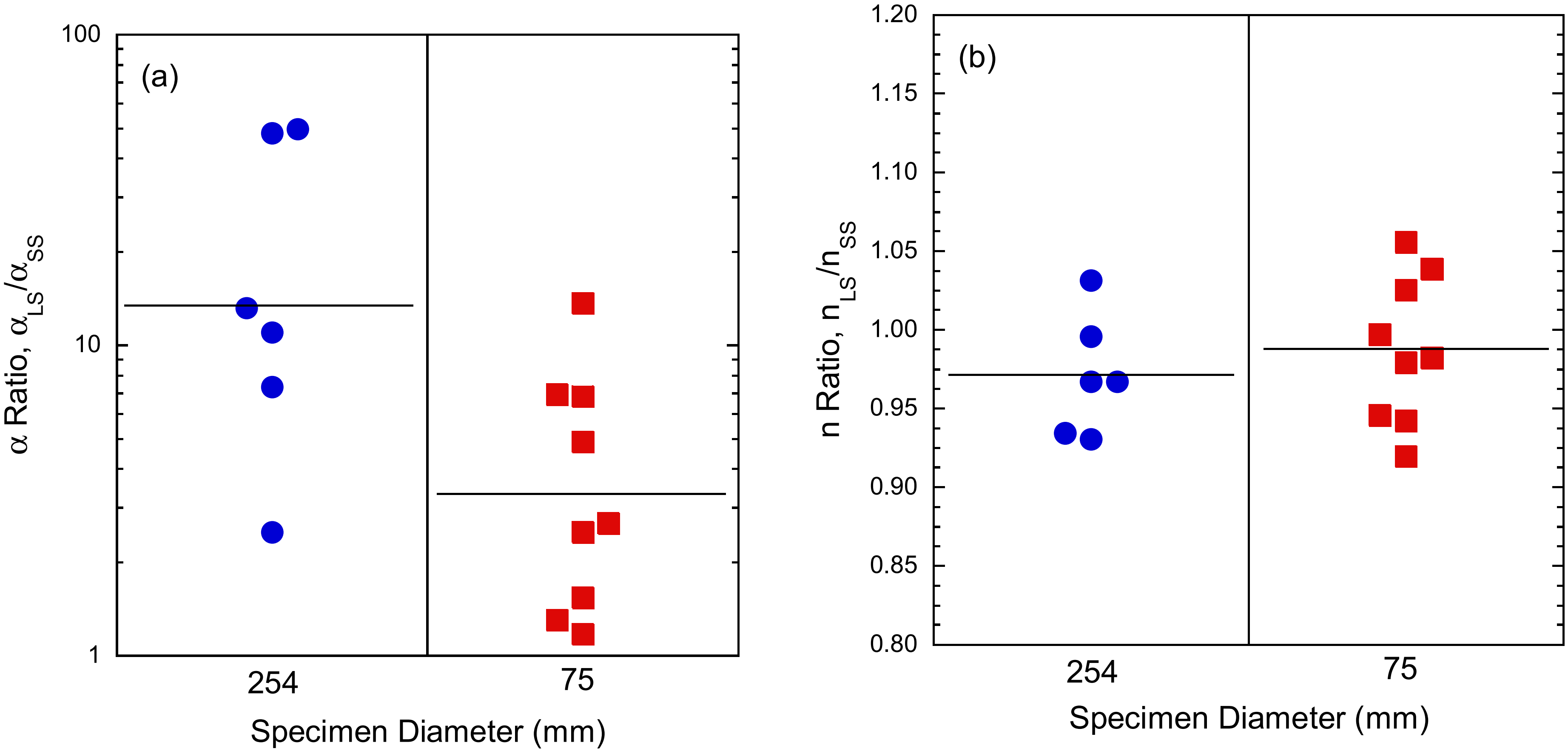
Structure formed by pedogenesis expected to increase q_s, increase a (lower y_a), & decrease n.

Changes to the SWCC Due to Structure



Formation of larger pores in soil structure results in lower air entry pressure (higher α) 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 (α increases) with test size

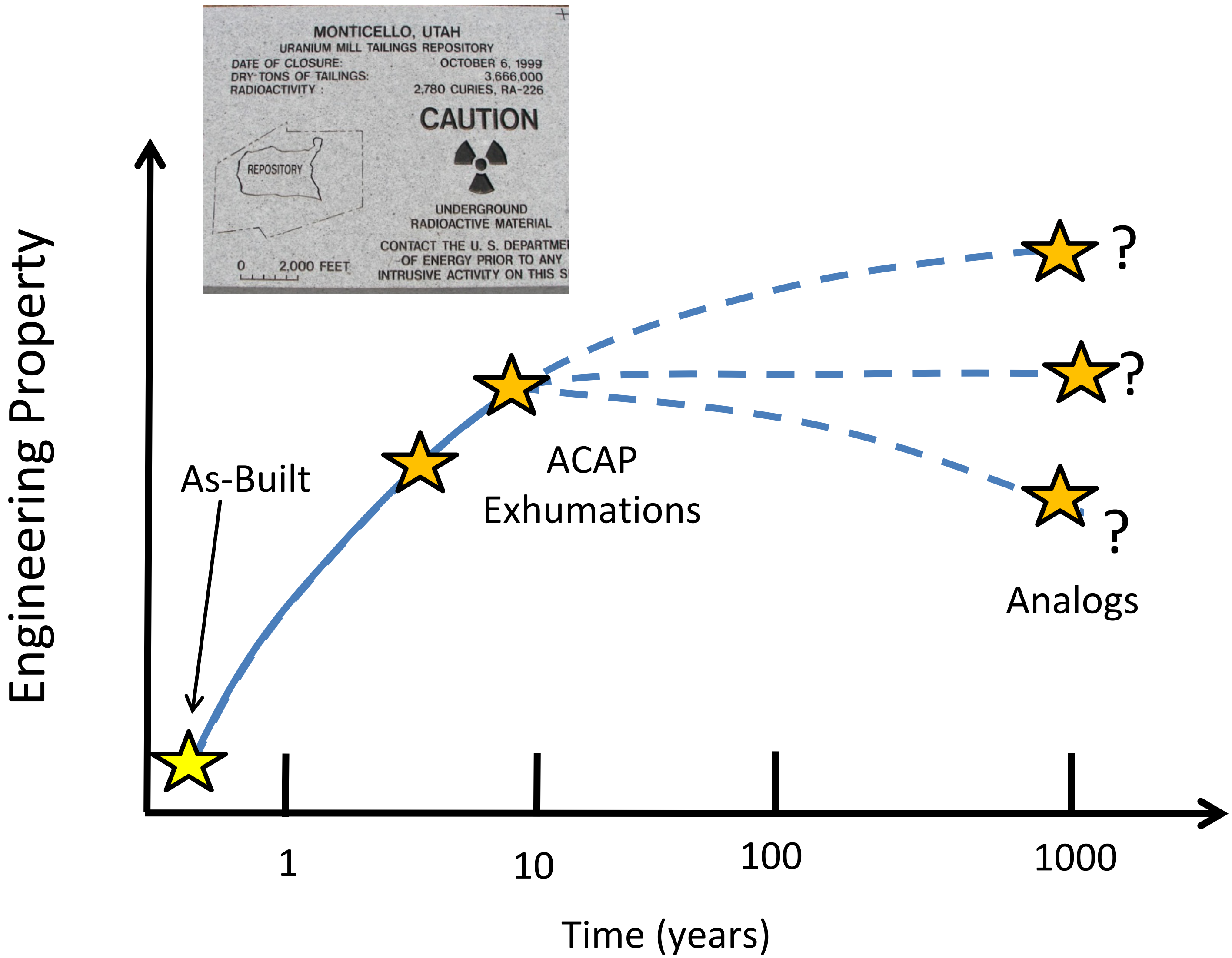
n unaffected by test size

Larger specimens contain more structure and larger pores.

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



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.

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