Performance of Engineered Barriers: Lessons Learned

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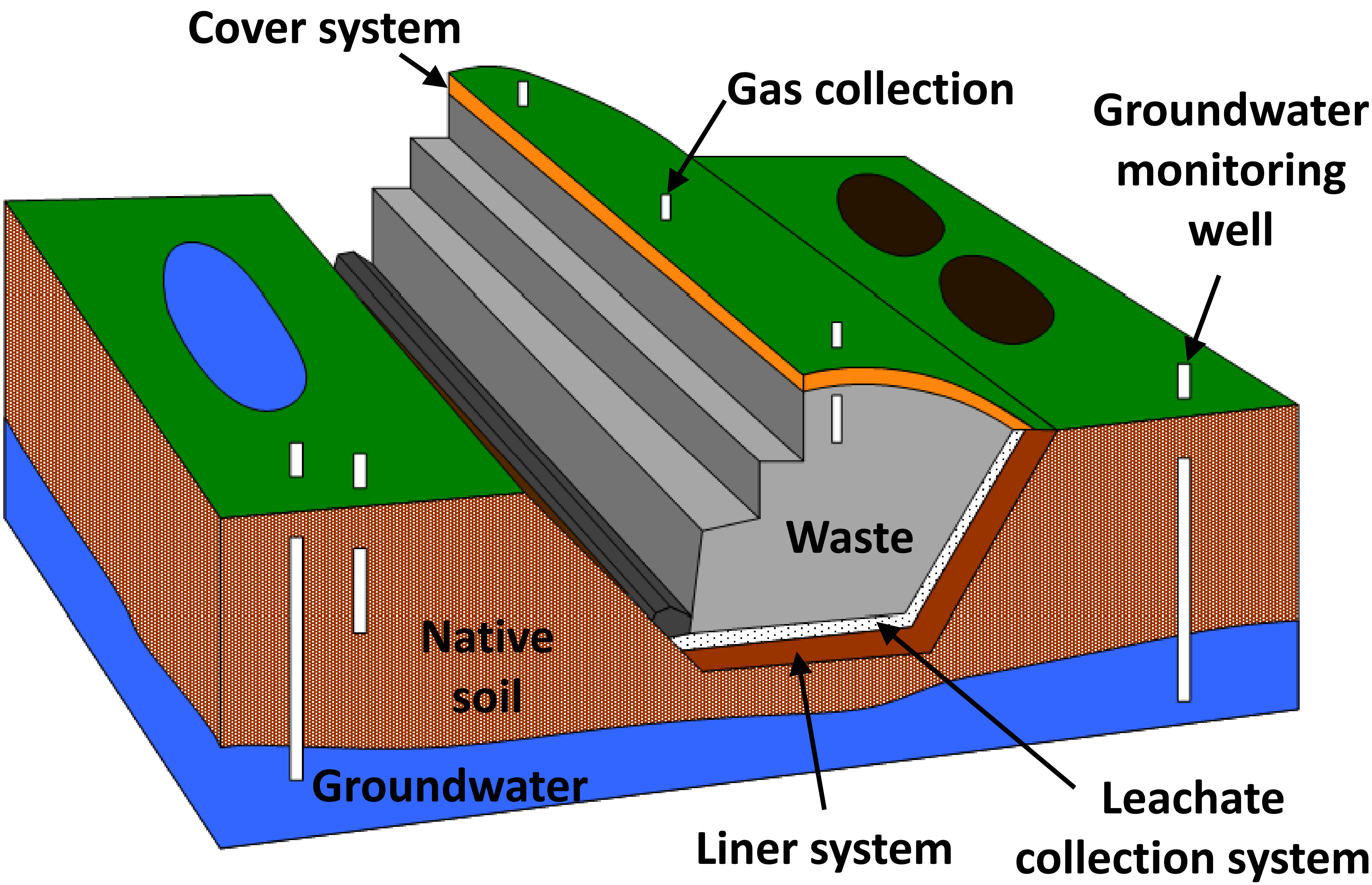
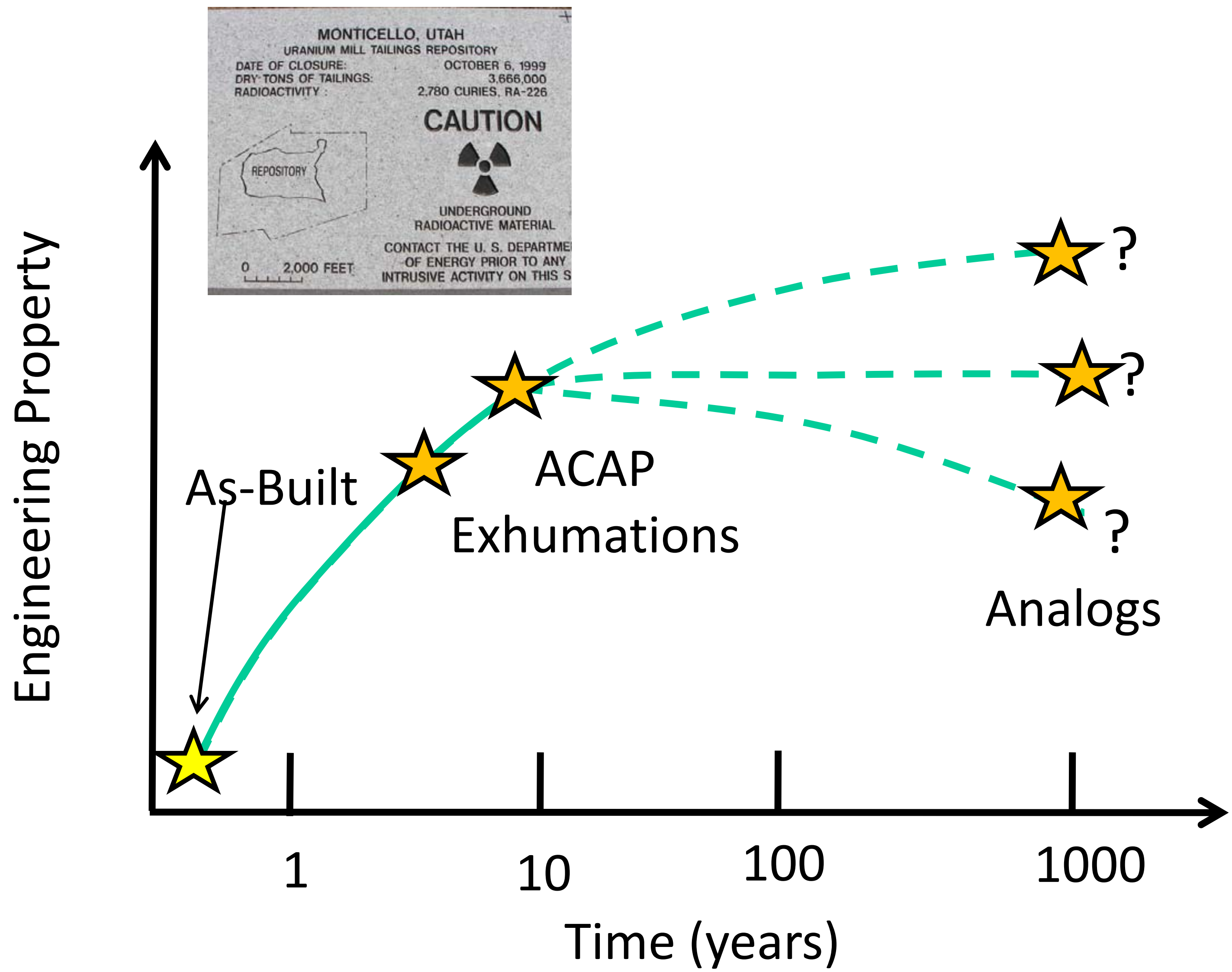
CRESP
Consortium For Risk Evaluation with Stakeholder Participation

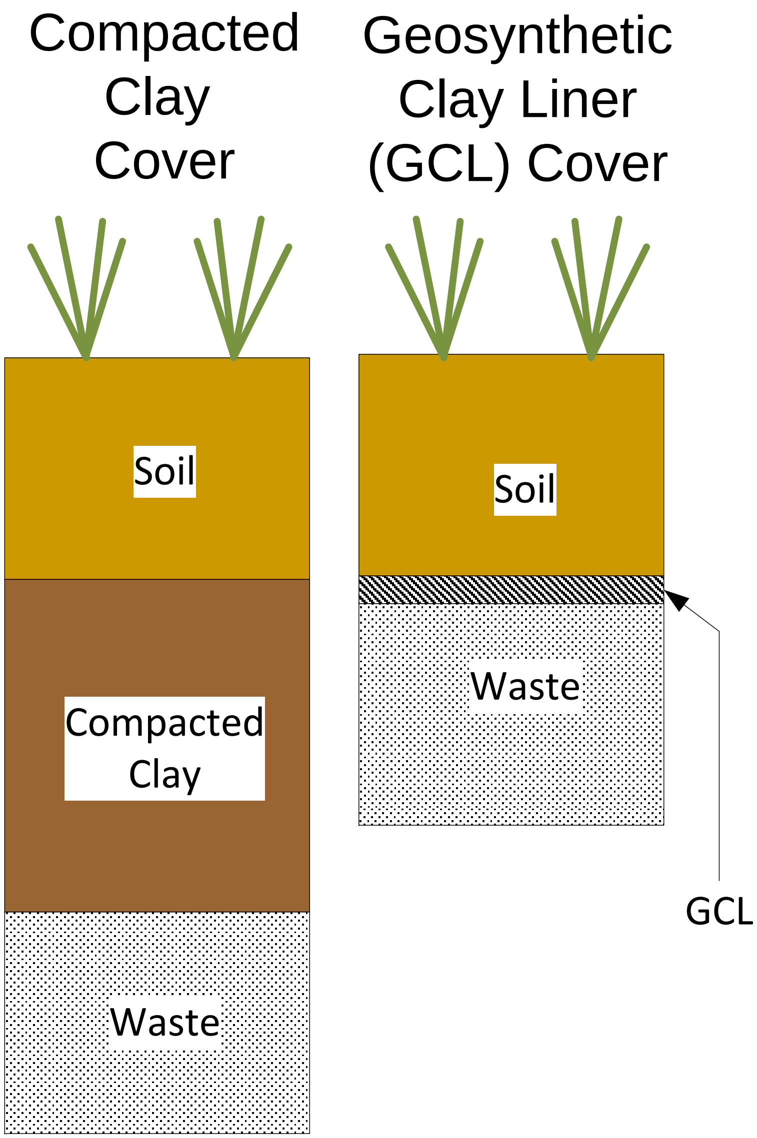
Barrier Systems for Waste Containment



Challenges – Predicting the Future

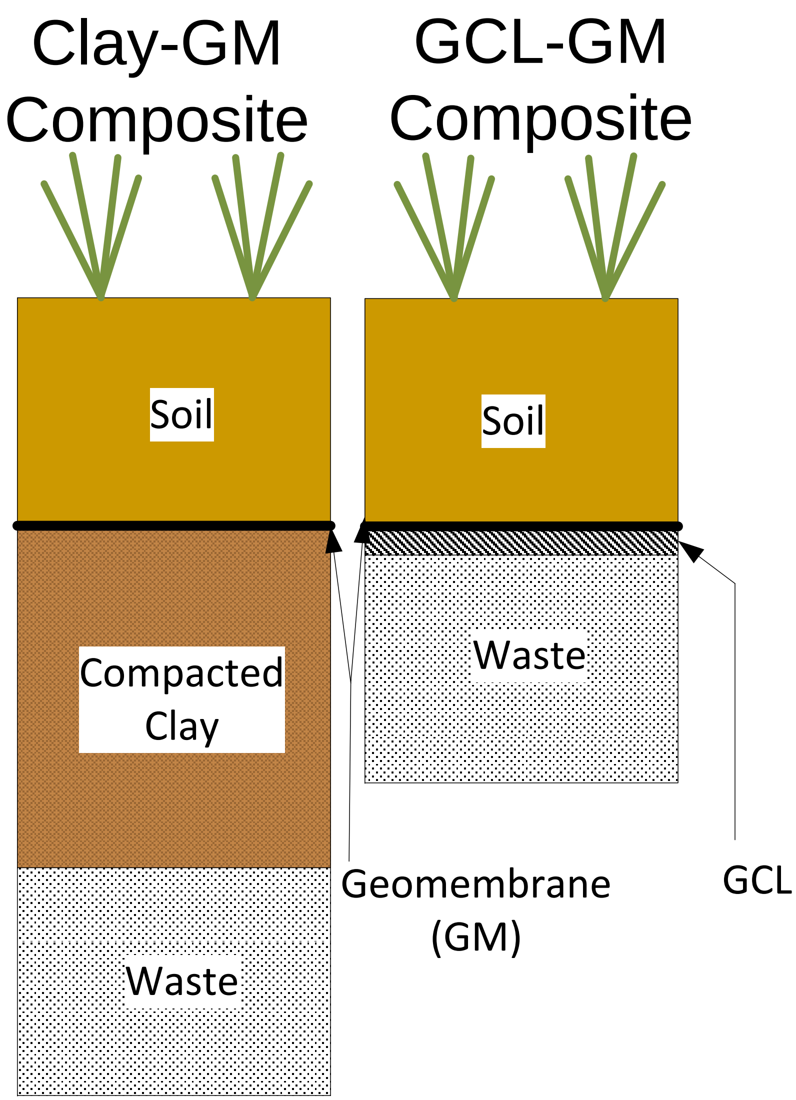


Conventional Resistive Covers with a Soil Barrier



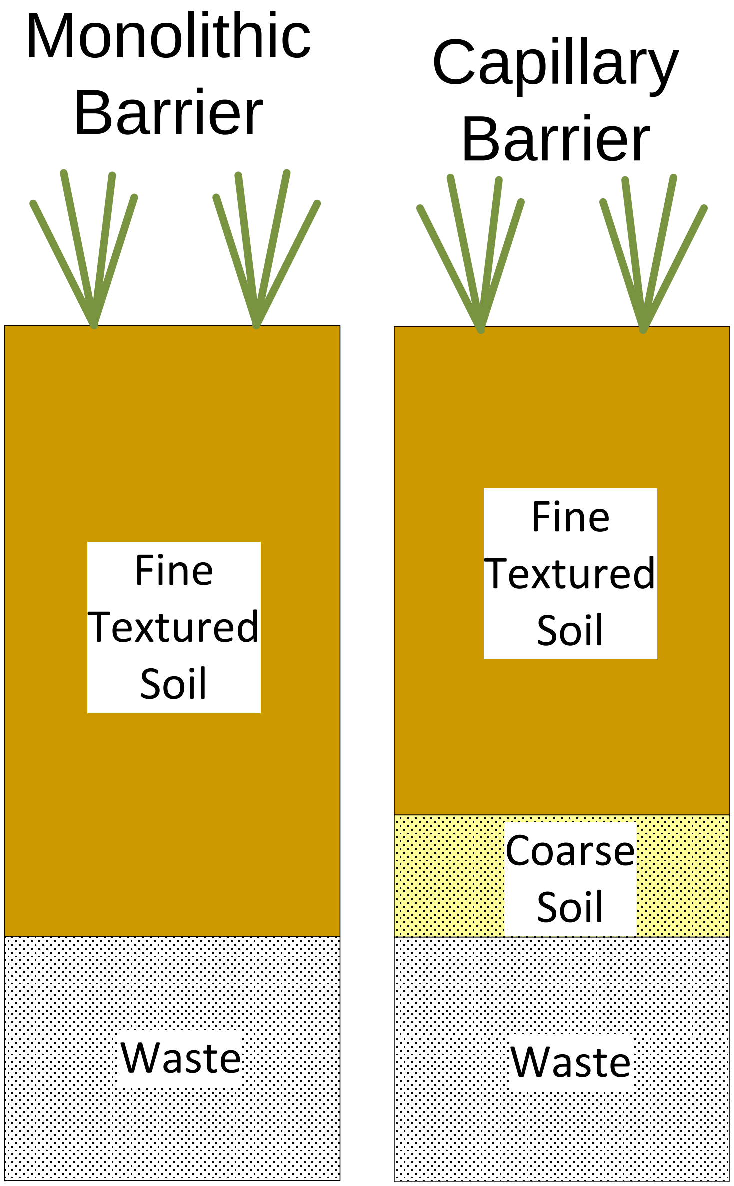
- Performance controlled by saturated hydraulic conductivity of clay barrier, either natural compacted clay or *geosynthetic clay liner*
- Install barrier to achieve hydraulic conductivity goal *and* protect barrier from damage that alters hydraulic conductivity.

Conventional Resistive Covers with a Composite Barrier



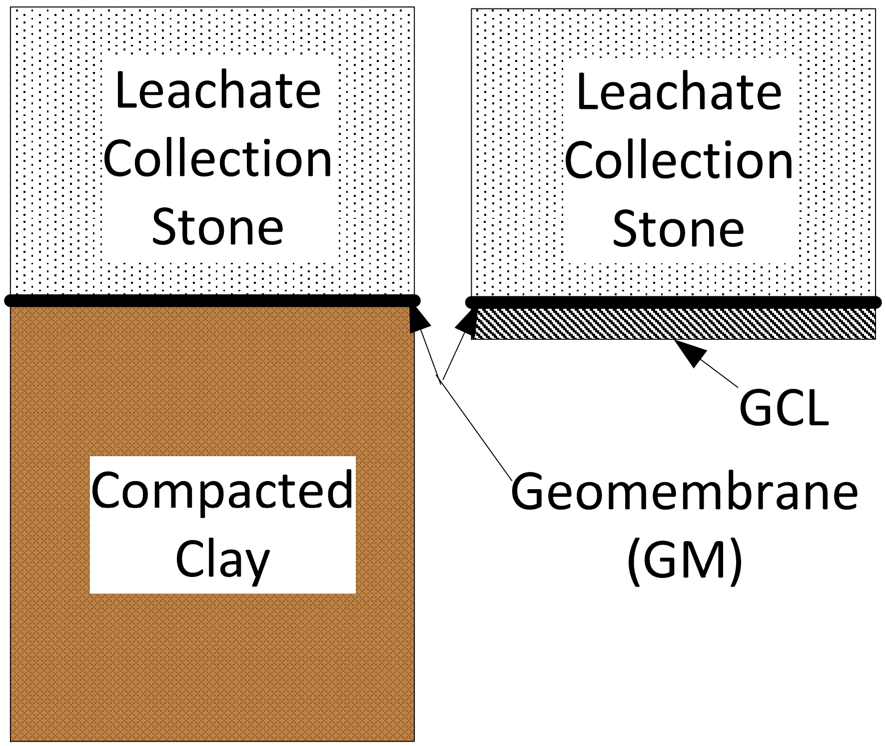
- Performance controlled by saturated hydraulic conductivity of clay barrier and integrity of geomembrane.
- Lifespan of geomembrane controls service life of cover.
- Current thinking 500-1500 yr.

Alternative Water Balance Covers

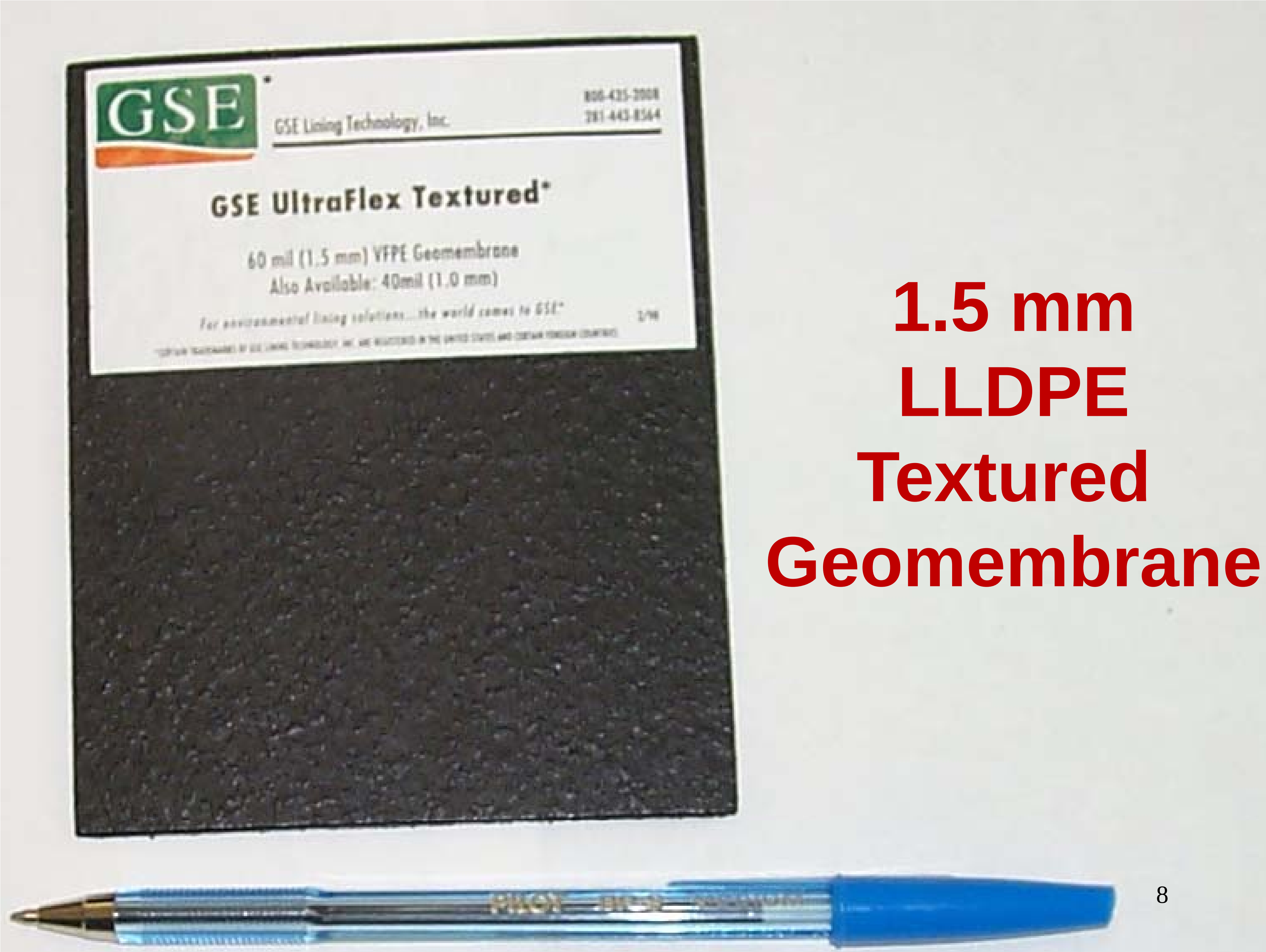


- Performance controlled by saturated and unsaturated hydraulic properties of cover soils.
- Physically and biologically active systems.
- Properties affected by environment, “pedogenesis.”

Composite Liner

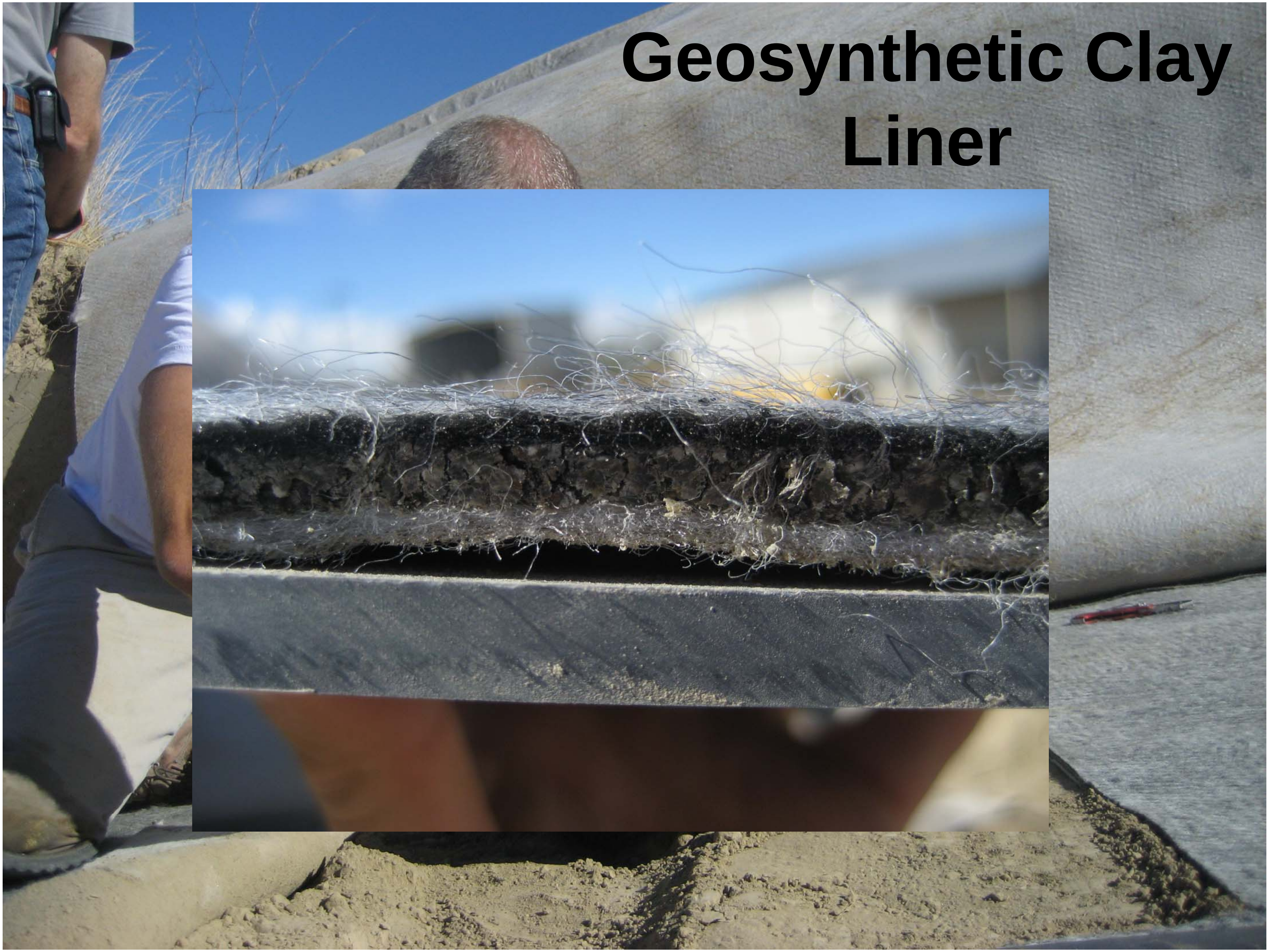


- Performance controlled by saturated hydraulic conductivity of clay barrier and integrity of geomembrane.
- Lifespan of geomembrane controls service life of barrier.
- Impact of LLW on GCLs and geomembranes unknown.



1.5 mm LLDPE Textured Geomembrane

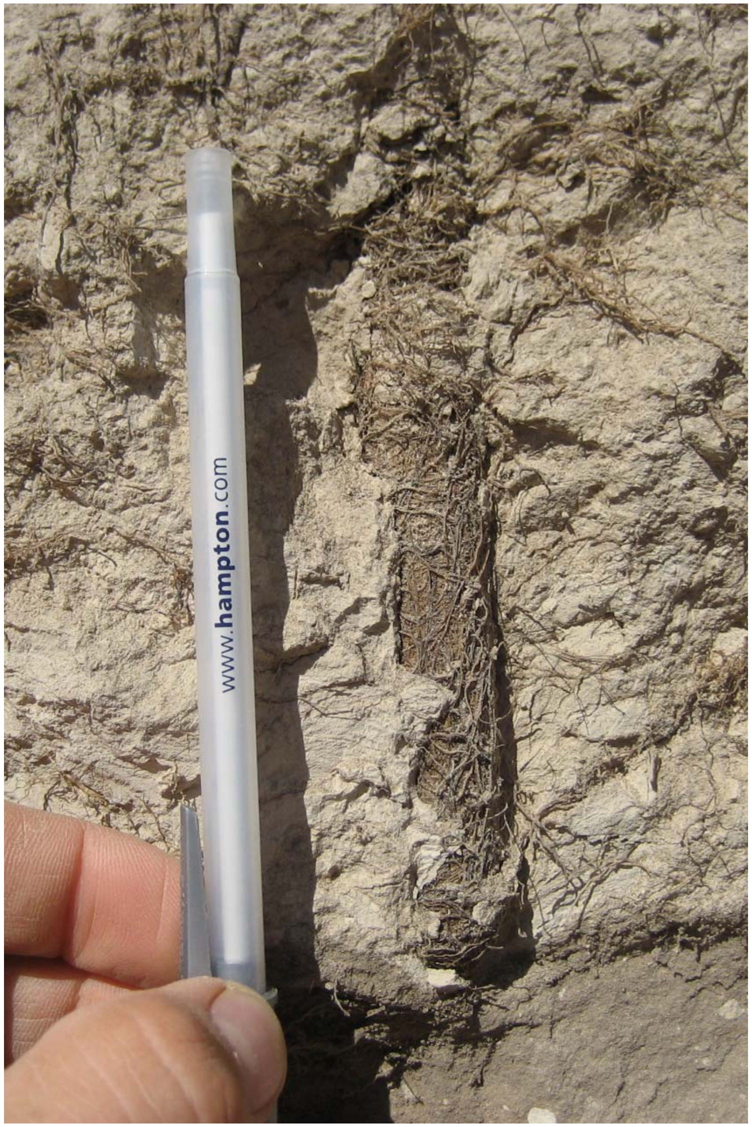
Geosynthetic Clay Liner



Focus for Today

- **Covers** -- hydraulic properties of soil barriers in conventional and water balance covers
  - o Saturated hydraulic conductivity
  - o Unsaturated hydraulic properties

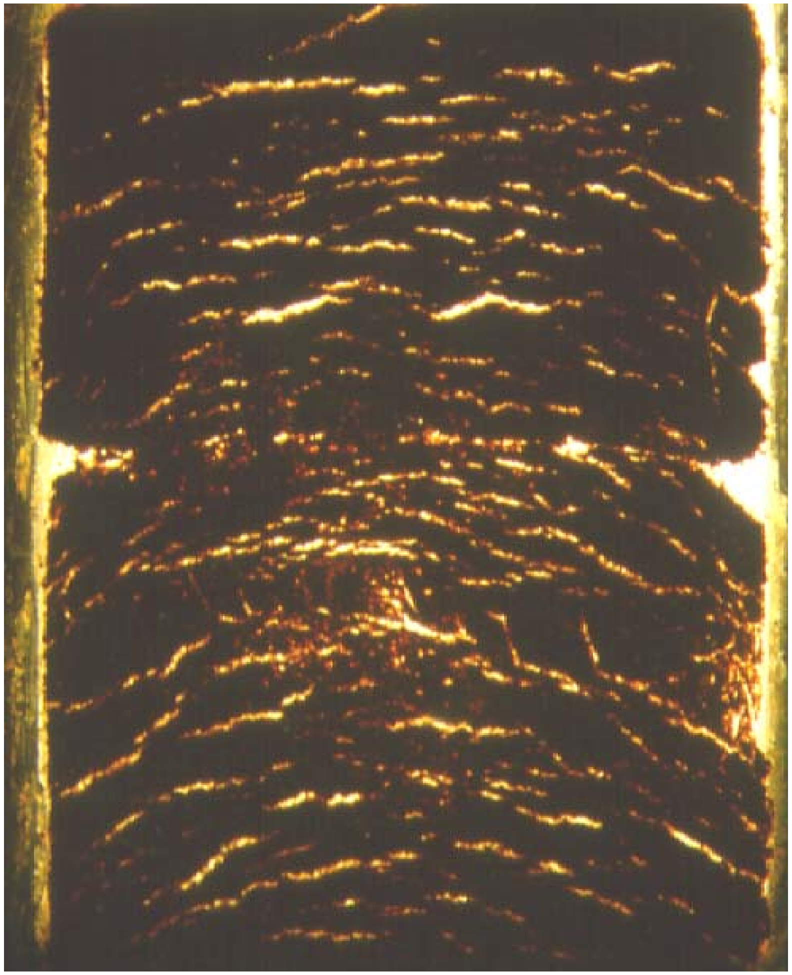
- **Liners** – hydraulic properties of GCLs & service life of geomembranes in LLW

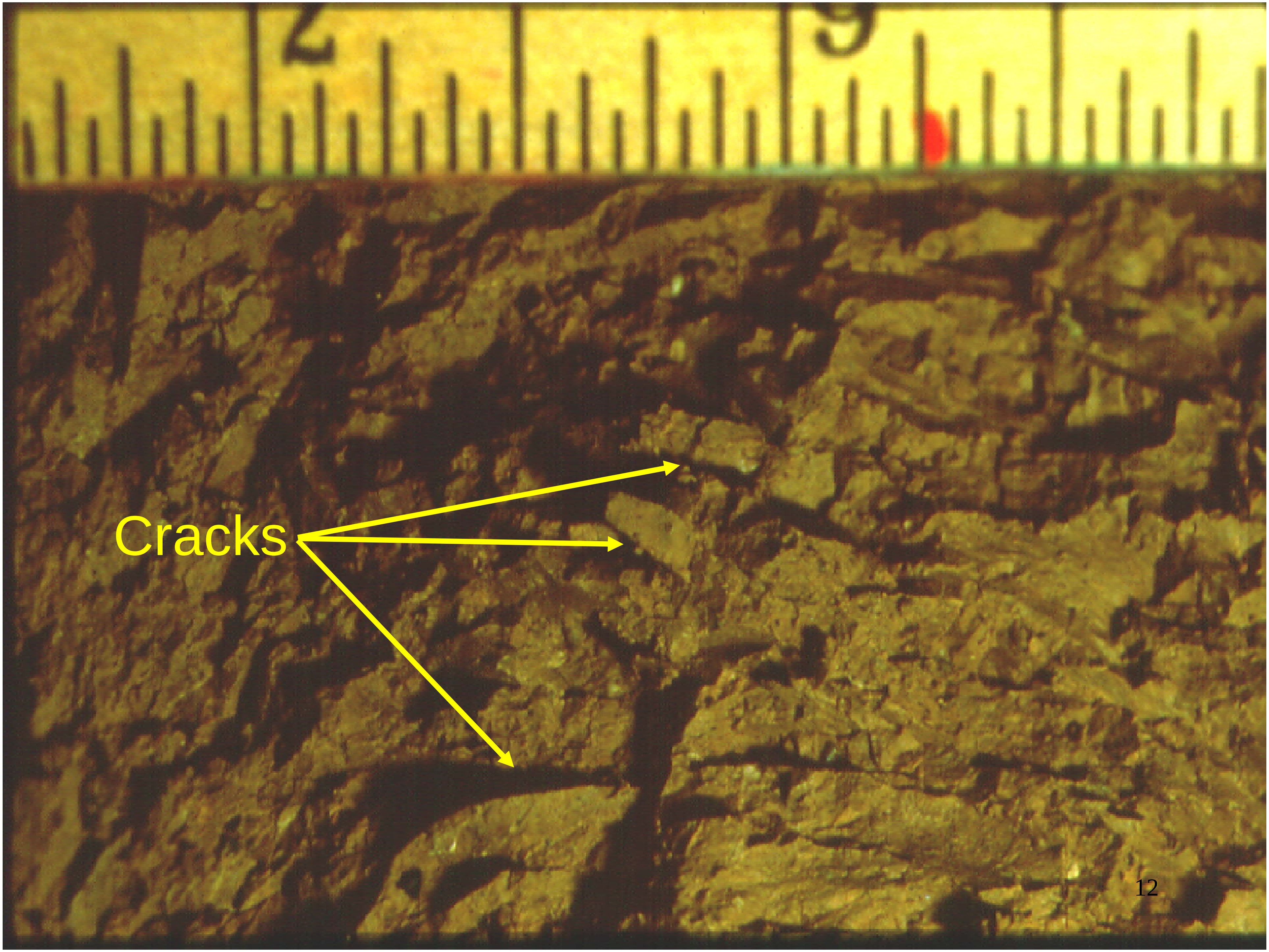


Clay Barriers in Covers

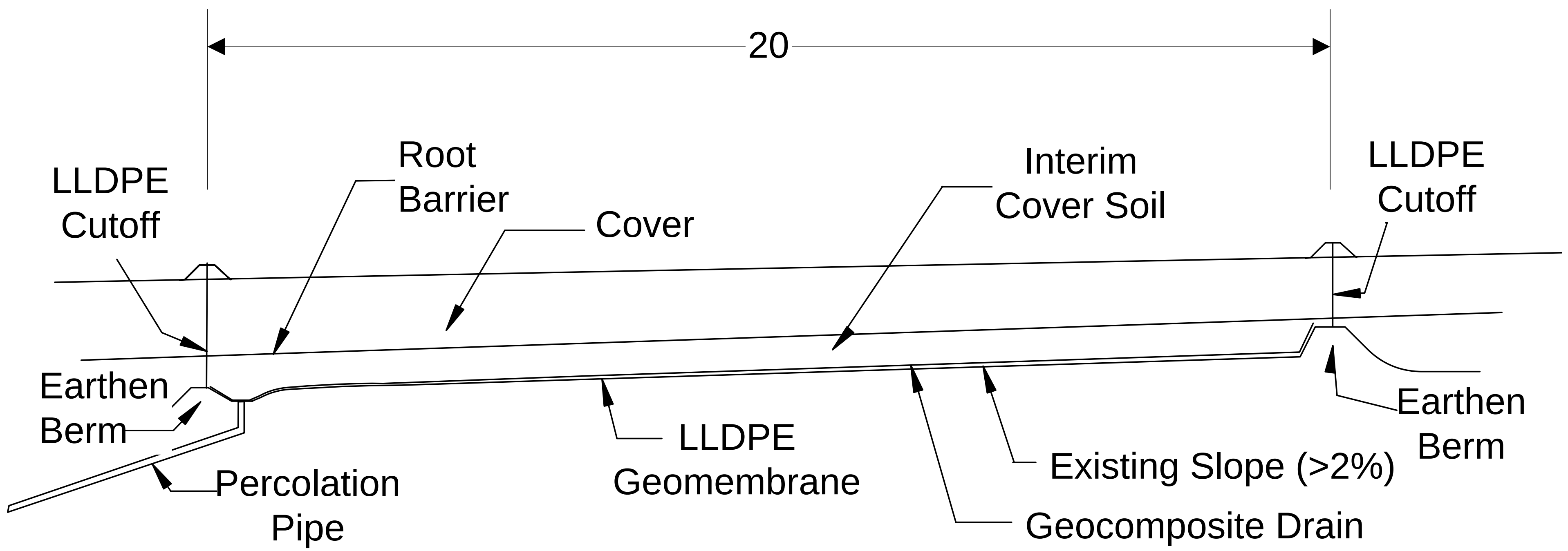
Factors affecting long-term performance include:

- Cracks caused by wet-dry cycling
- Cracks caused by freeze-thaw cycling
- Cracks caused by differential settlement
- Biota intrusion
- Long-term mineralogical change




2
3
Cracks

Field Cover Performance: ACAP Lysimeters



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

Borehole Test – Monticello U Tailings Repository

Collecting Block Samples

Preparing Blocks for Hydraulic Properties Tests

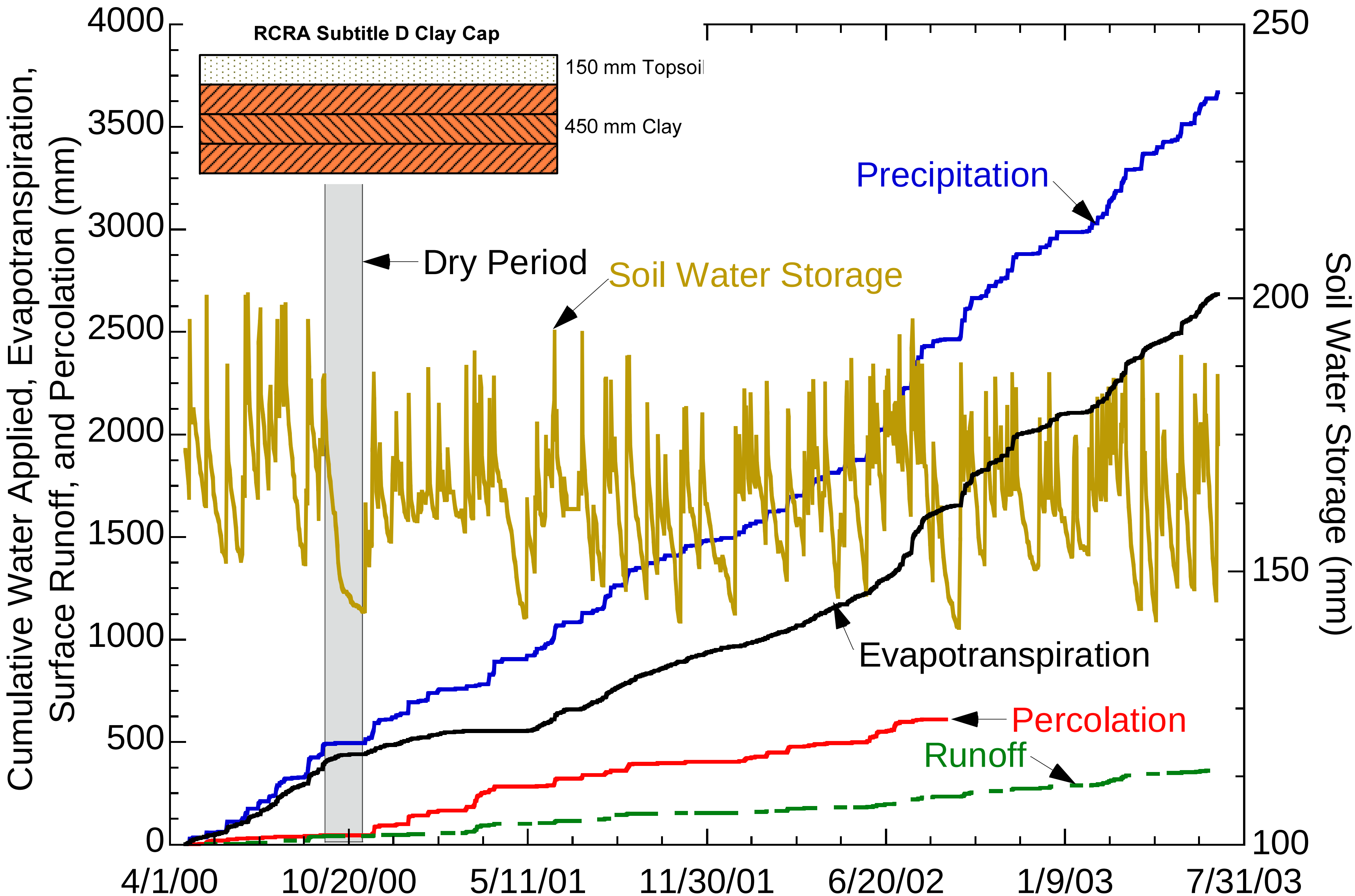
Block sample

Trimming roughly to take ring-off

Placing the block sample

Trimming to the pedestal size

Field Site in Albany, GA

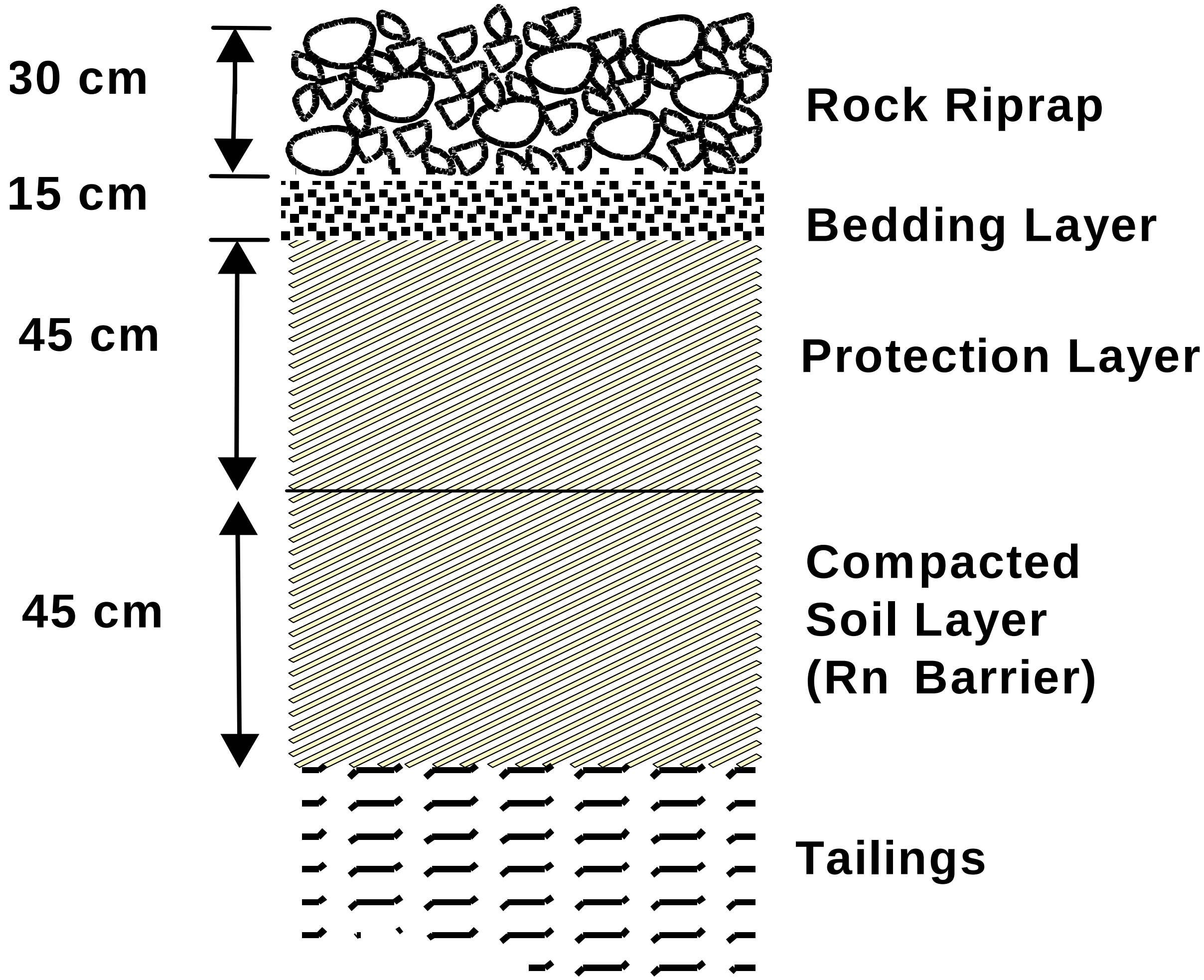


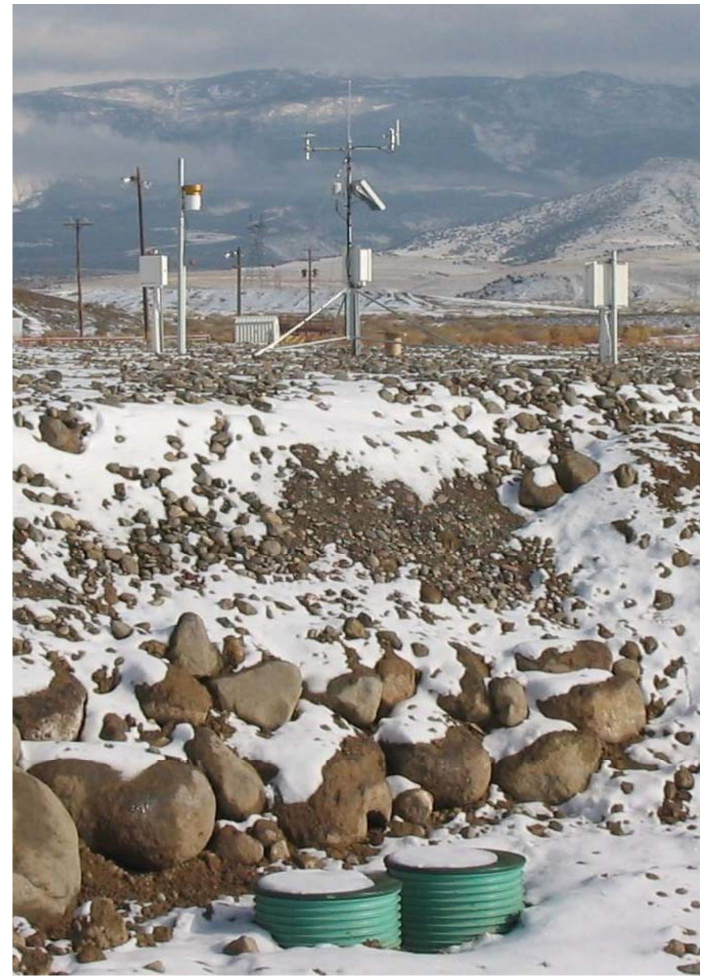
Percolation constituted 8.6% of precipitation before drought, 29.3% afterwards.

Field Hydraulic Conductivity Measurements on Clay Barrier - February 2004

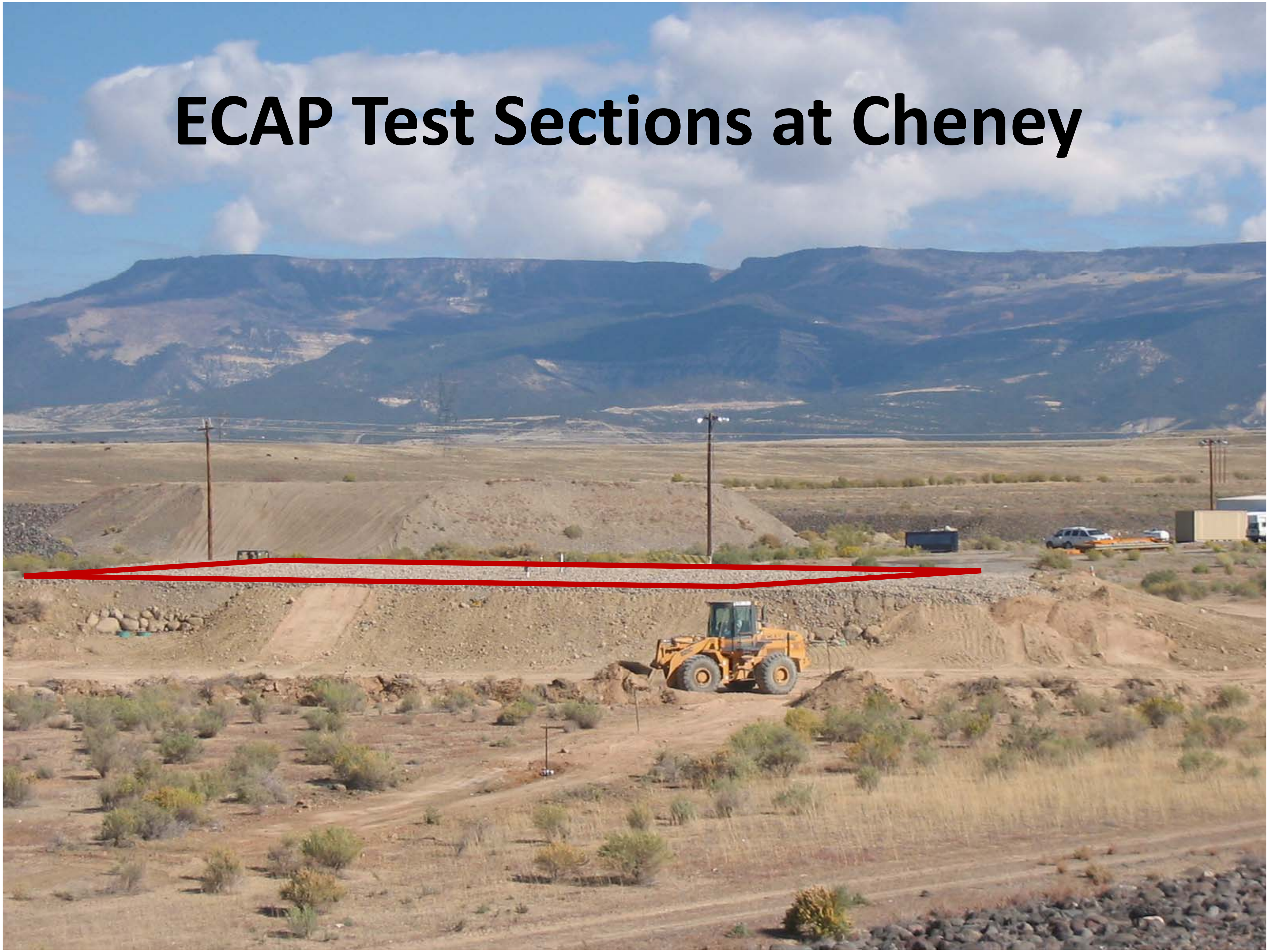
Test	Hydraulic Conductivity (cm/s)	K_f/K_o
As-Built	$4.0x10^{-8}$	1.0
SDRI	$2.0x10^{-4}$	5000
TSB - 1	$5.2x10^{-5}$	1300
TSB - 2	$3.2x10^{-5}$	800
TSB - 3	$3.1x10^{-3}$	77,500

Rock Armor Covers – Cheney Field Experiments



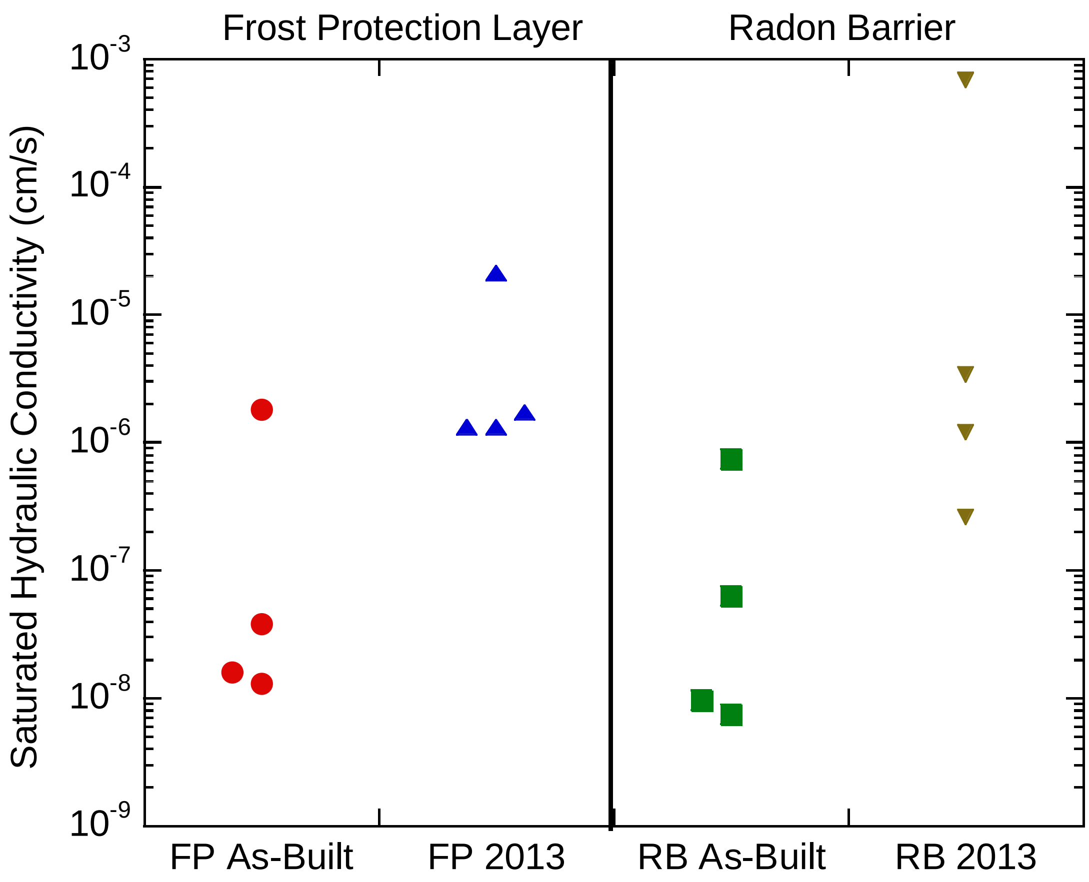


ECAP Test Sections at Cheney



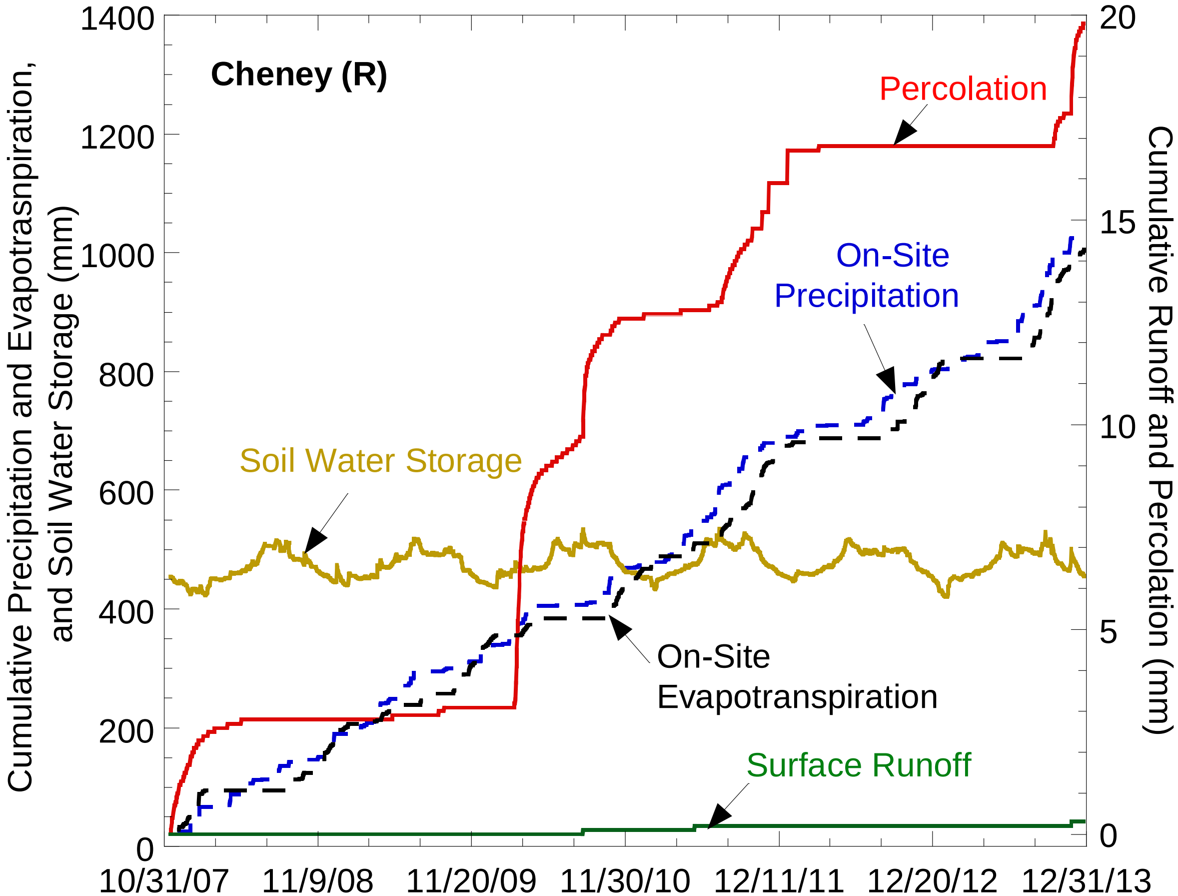
Collecting Block Samples for Hydrologic Properties

Evolution of Frost Protection Layer and Radon Barriers 2007-13



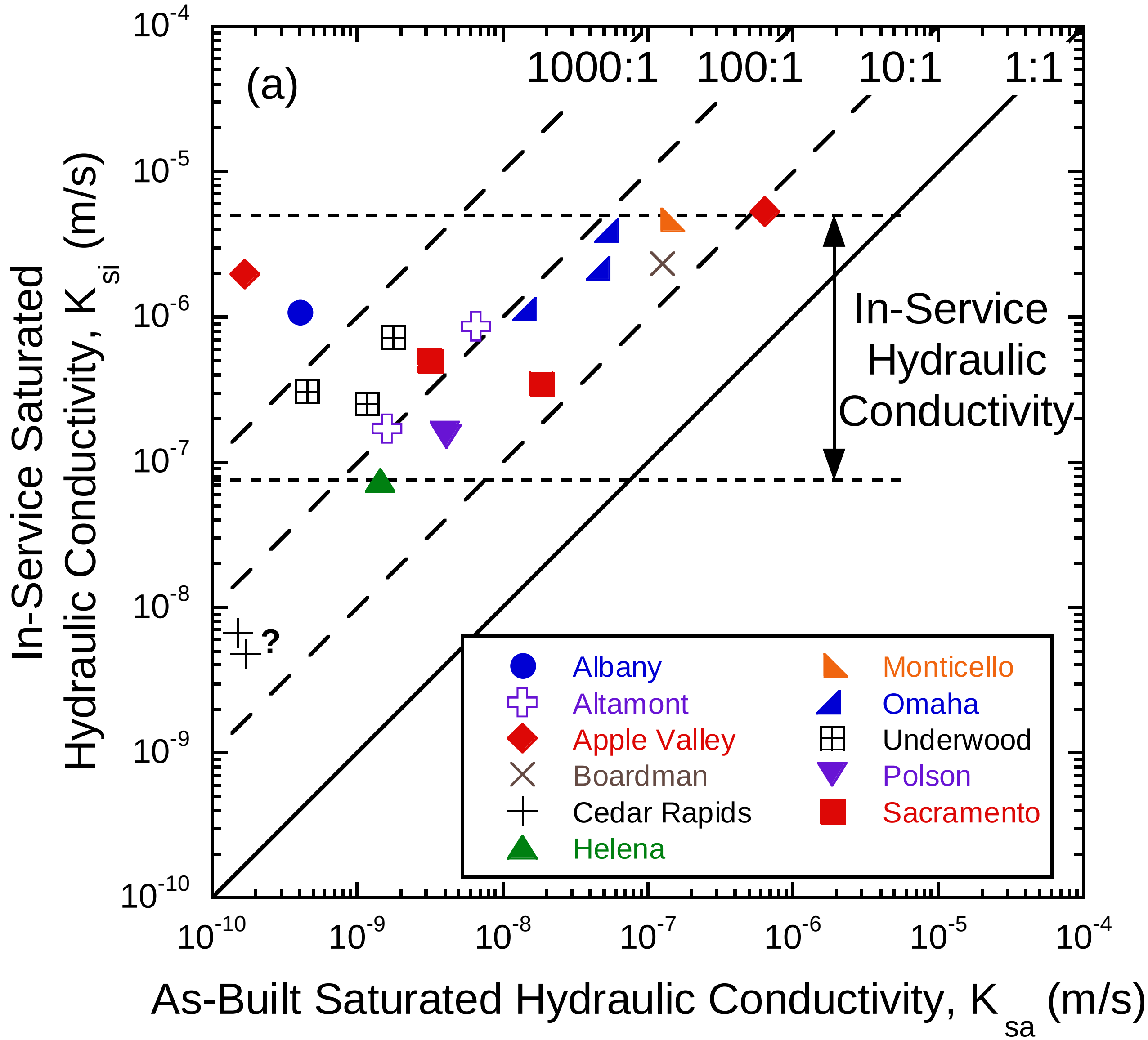
- Hydraulic conductivity of frost protection and radon barrier increased, approx. 10^{-7} cm/s as-built to 10^{-6} cm/s (10x)
- Preliminary, more testing currently being conducted.

Cheney Water Balance Data



- Episodic percolation indicative of macro-structure in radon barrier and frost protection layer.
- Performance still excellent, avg. percolation = 1.0 and 2.8 mm/y

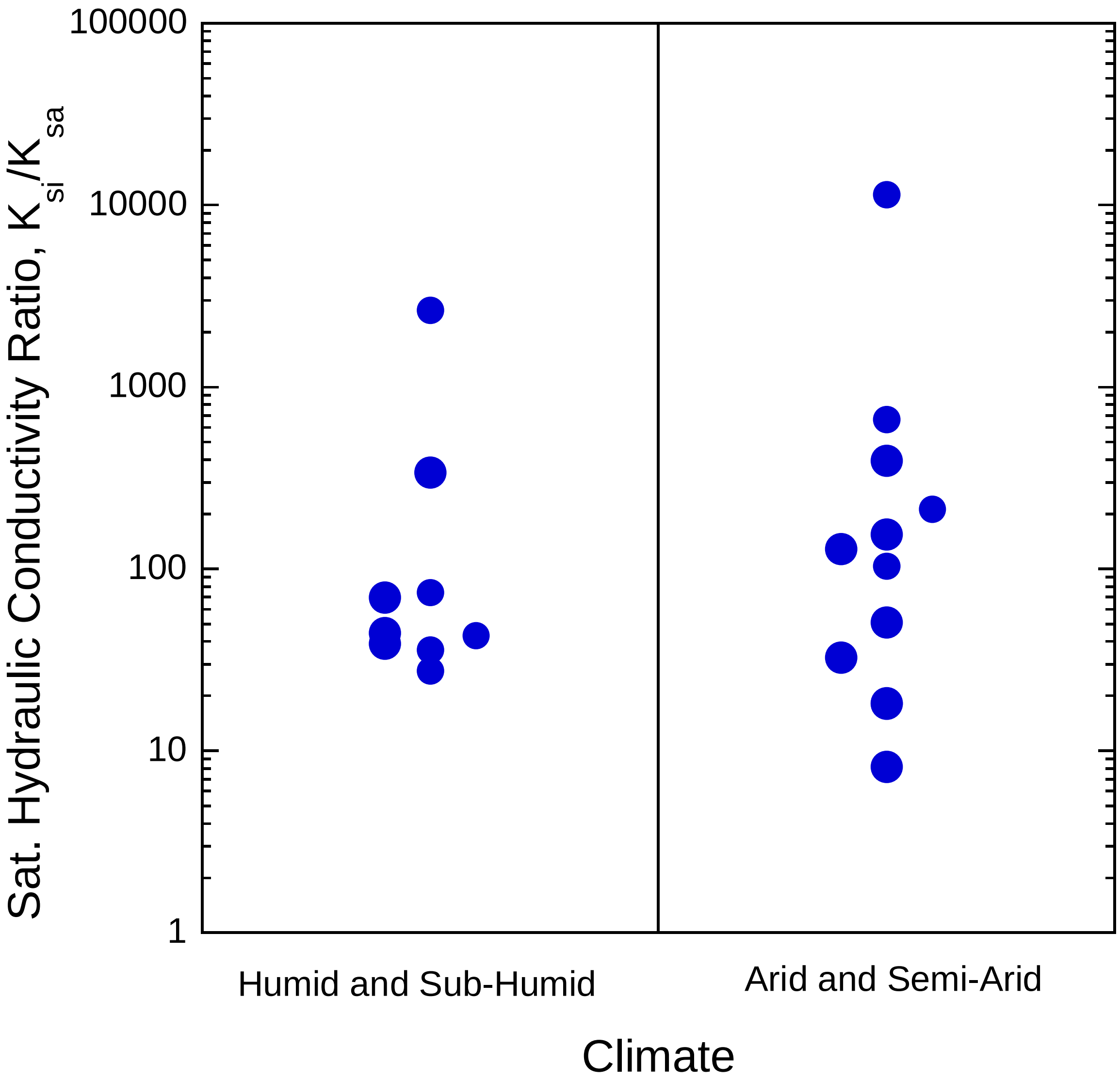
Changes in Sat. Hydraulic Conductivity



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

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

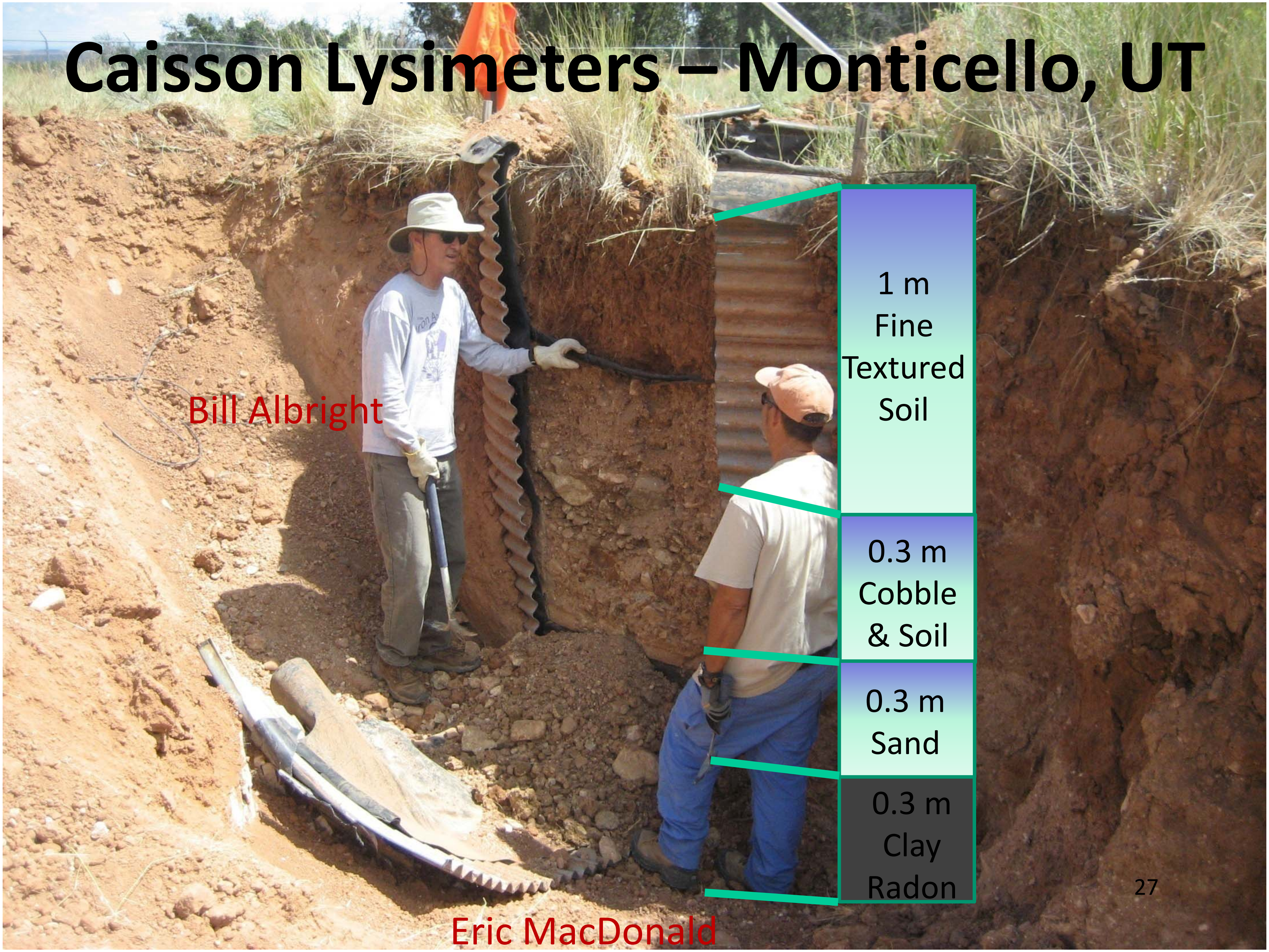
Effect of Climate



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

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

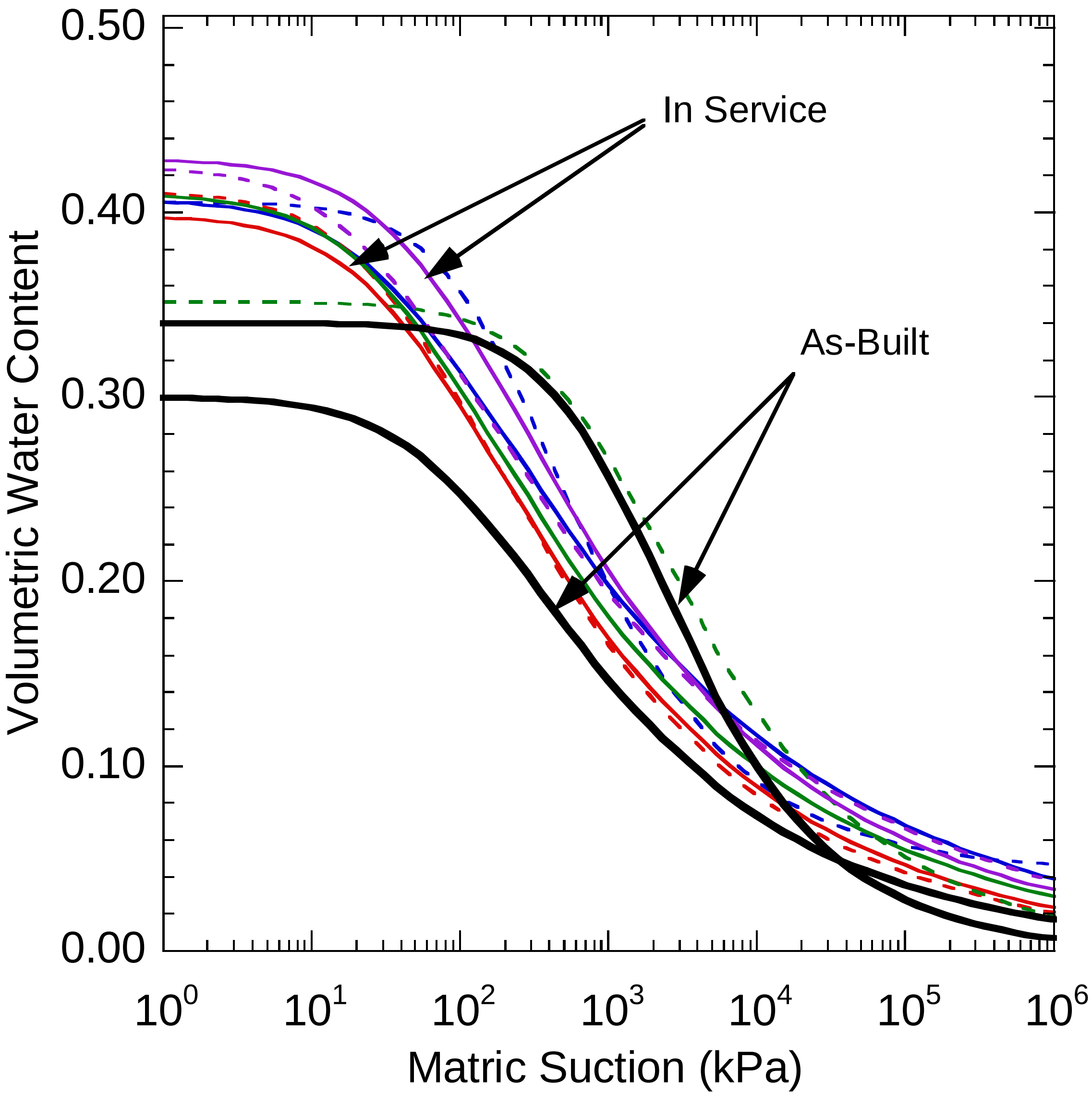
Caisson Lysimeters – Monticello, UT



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

Unsaturated Hydraulic Properties – Soil Water Characteristic Curve

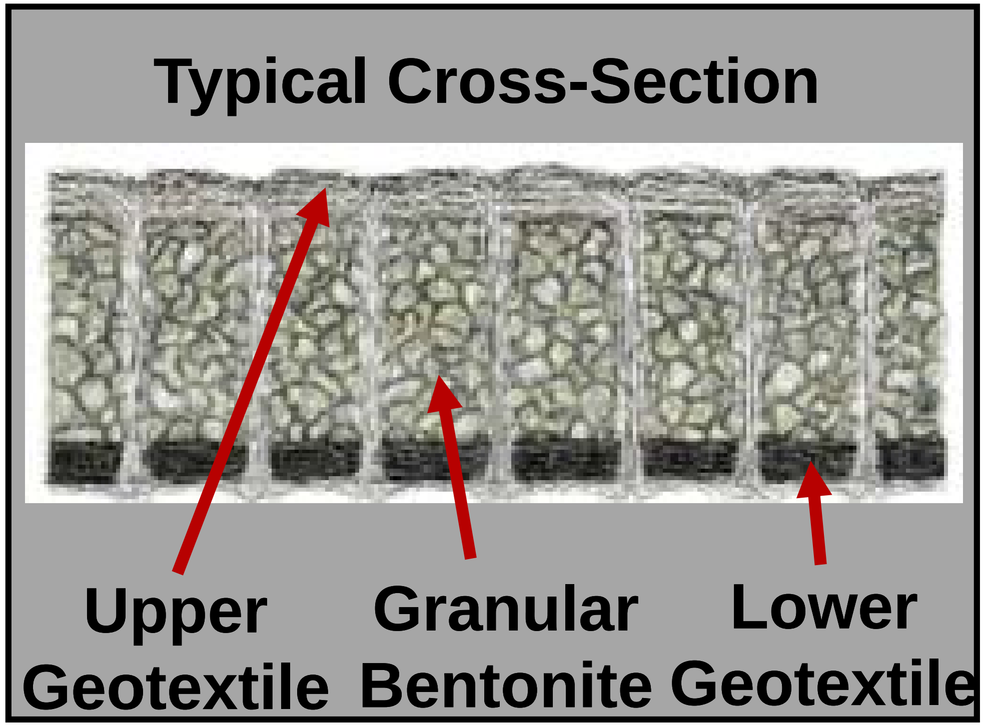


Soil becomes less dense (higher porosity or saturated water content) and has broader distribution of pore sizes.

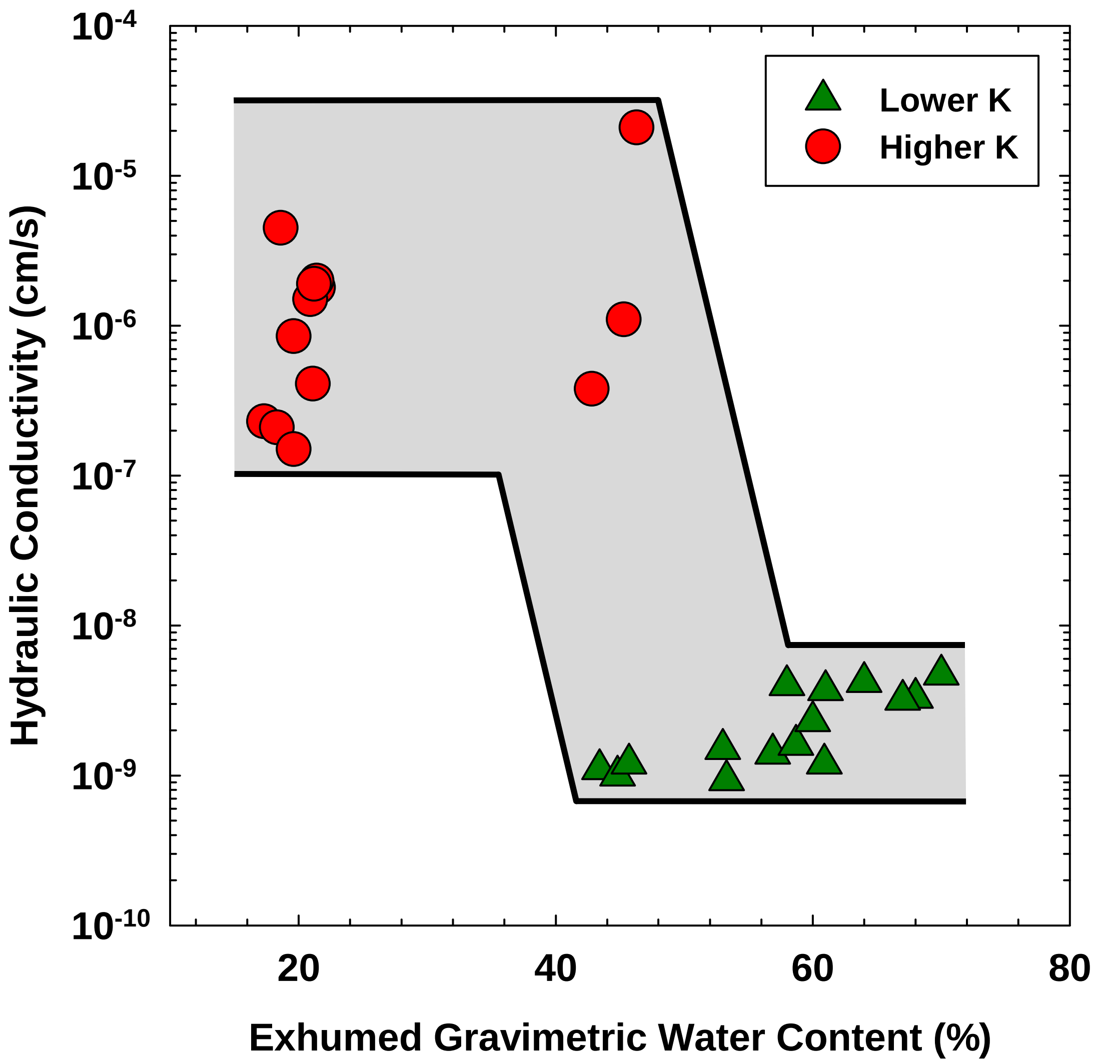
Impact on water storage and percolation depends on site specific conditions.

Geosynthetic Clay Liners

- For low hydraulic conductivity, Na-bentonite granules must swell to from a gel (paste).
- Gel must be maintained to retain low hydraulic conductivity (~ 10^{-9} cm/s) .
- If granules do not swell and form gel, higher hydraulic conductivity (>10^{-9} cm/s).

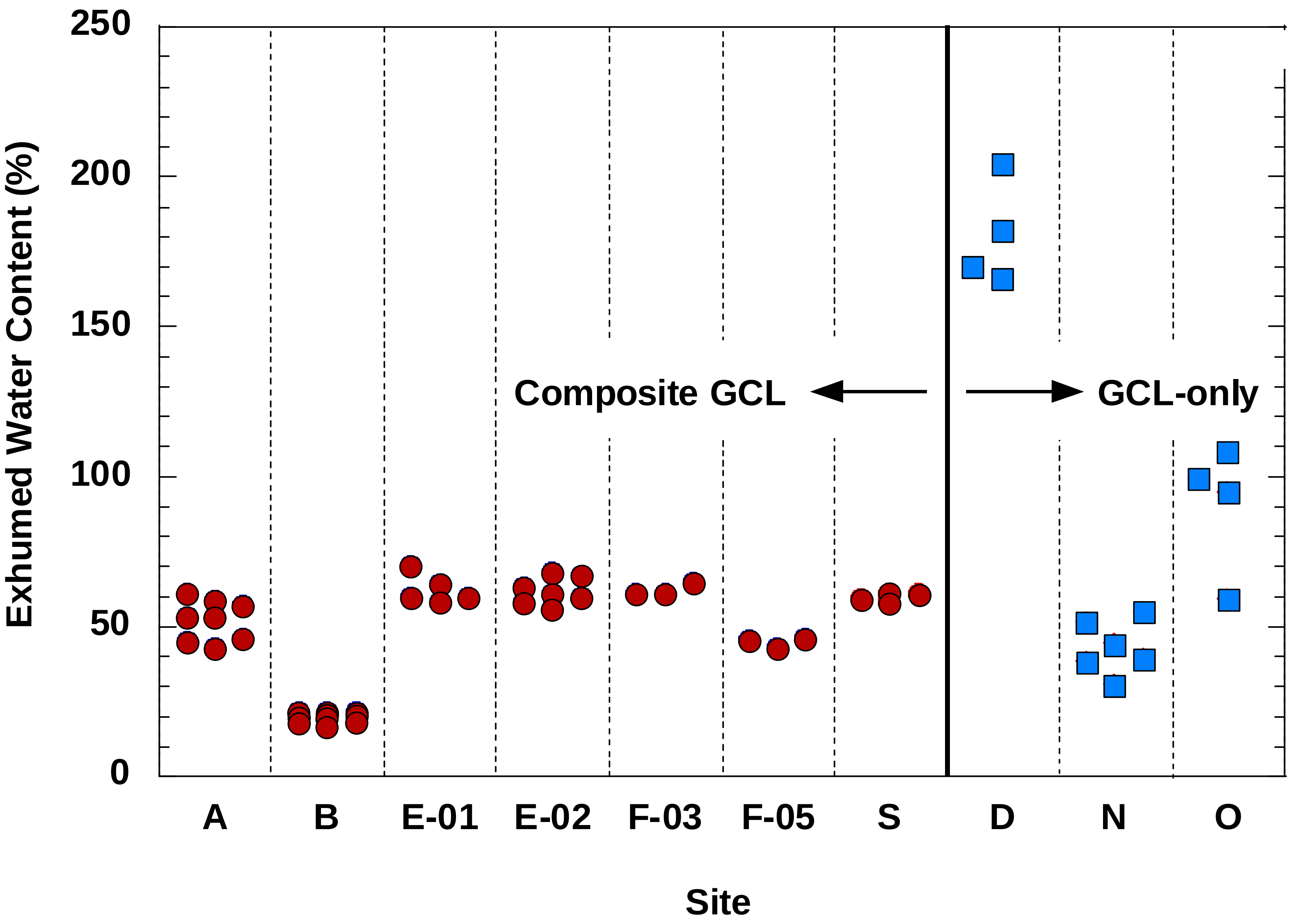


Hydraulic Conductivity of Exhumed GCLs

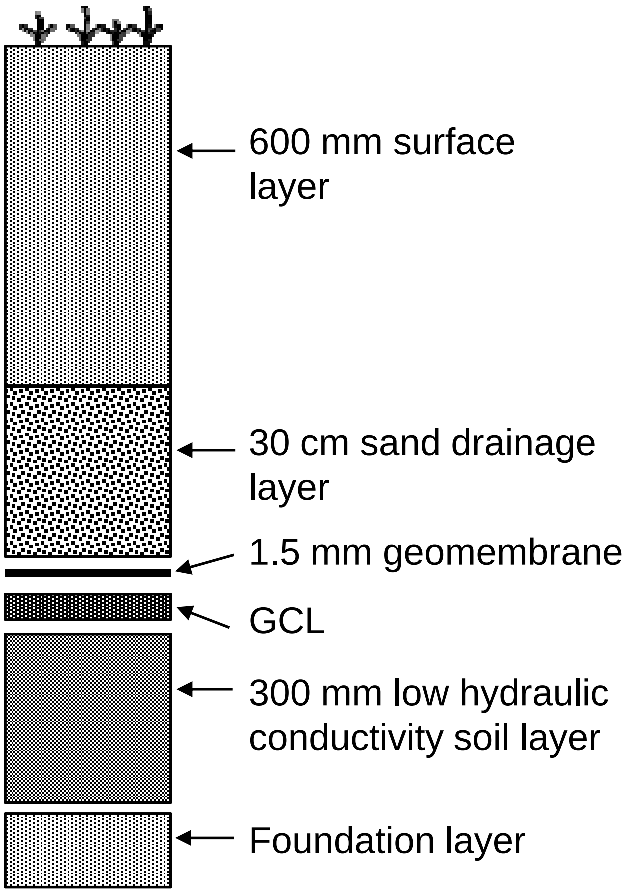


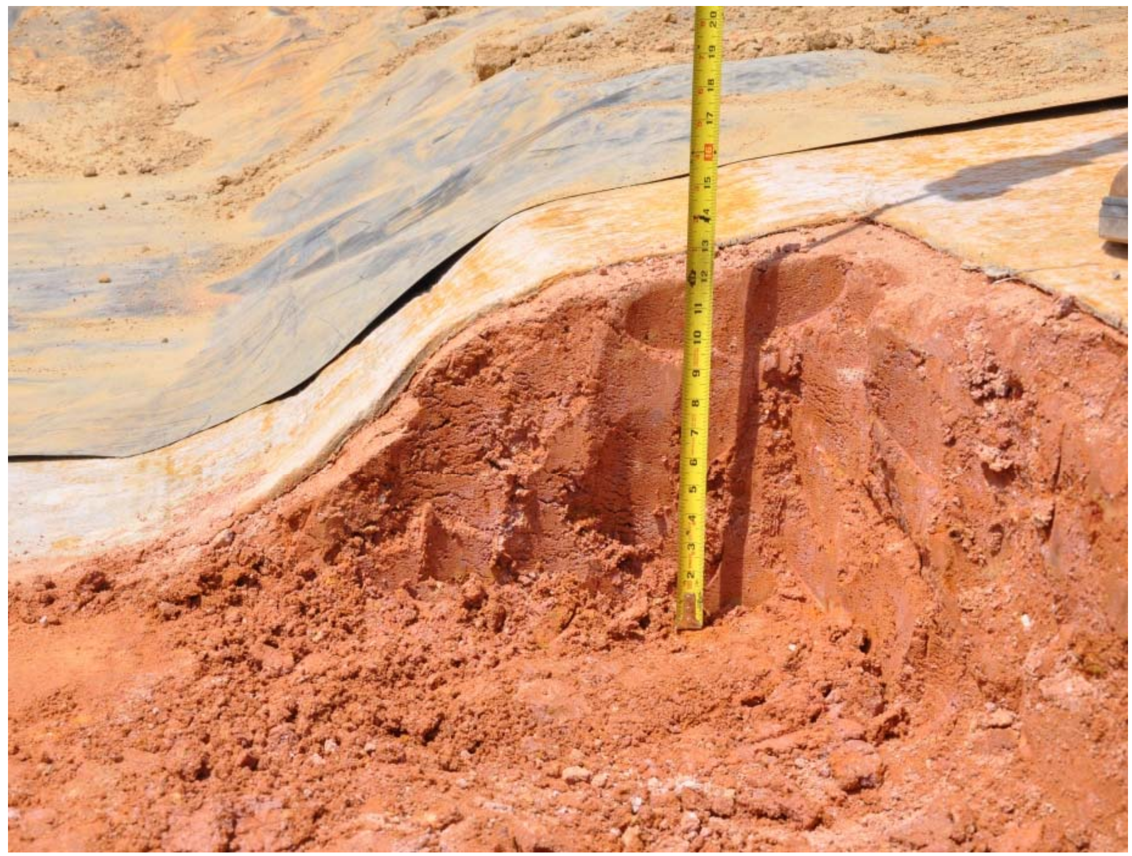
- Strong relationship with water content
- Transition point lower, but sufficient water for osmotic swell (> 50%)
- Rapid and sufficient hydration yield low hydraulic conductivity

Exhumed Water Content

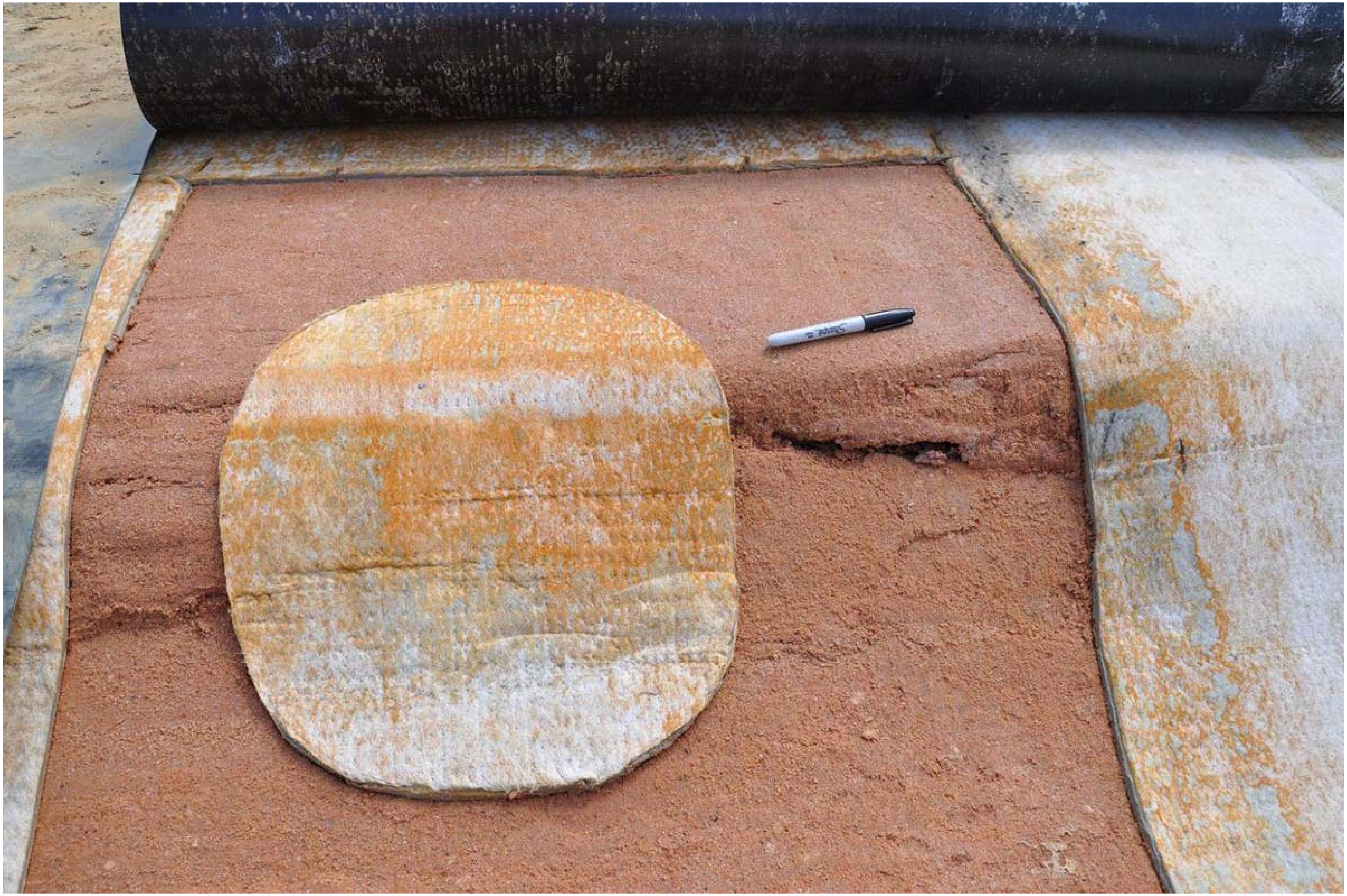


Cover Exhumation at LLW Disposal Site in Southeastern USA






Sharpie
Permanent Marker
FINE POINT
AP



Hydraulic Conductivity of GCLs

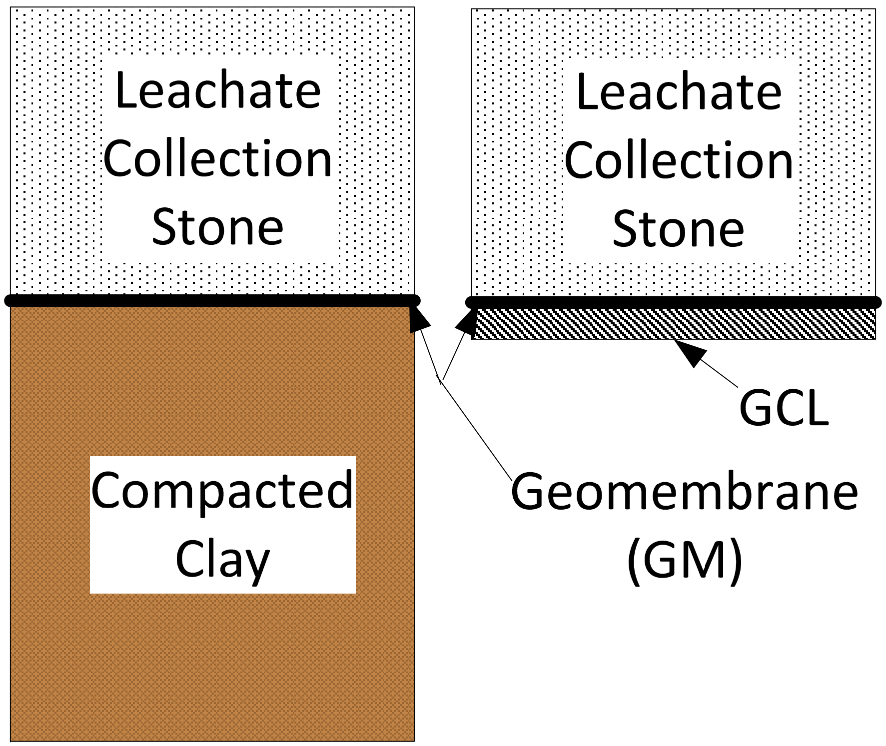
Sample	Water Content (%)	Hydraulic Conductivity (cm/s)
GCL1a	112.2	$9.6x10^{-10}$
GCL1c	115.0	$8.6\ x10^{-10}$
GCL2a	110.4	$9.5\ x10^{-10}$
GCL2c	119.6	$7.0\ x10^{-10}$
GCL3a	102.6	$8.6\ x10^{-10}$
GCL4a	129.4	$9.0\ x10^{-10}$
GCL4b	151.5	$8.6\ x10^{-10}$

Hydraulic Conductivity of Soil Barrier

Sample	Sampling Location	Condition	Gravimetric Water Content (%)	Hydraulic Conductivity (cm/s)
BS1	Away from Distortion	No cracks	15.2	2.2×10^{-5}
BS2	Away from Distortion	Contains small cracks	16.0	1.5×10^{-5}
BS3	Middle of Distortion	Contains large crack, **GCL overlay**	ND	**8.4×10^{-8}**
BS4	Immediately Below Distortion	No cracks	13.2	4.7×10^{-5}
BS5	Away from Distortion	No cracks	14.0	1.1×10^{-5}
BS6	Top of Distortion	**Contains large crack**	14.0	**3.0×10^{-4}**

Notes: ND = not determined. Specimens fragile due to cracks.

Composite Liner



- Performance controlled by saturated hydraulic conductivity of clay barrier and integrity of geomembrane.
- Lifespan of geomembrane controls service life of barrier.
- Impact of LLW on GCLs and geomembranes unknown.

Accelerated Geomembrane Testing

- Immersed at 25, 50, 70, and 90 °C
- Synthetic LLW leachate with (RSL) and without (NRL) radionuclides

Leachates

Major Cations/Anions (mM)	
Ca	4
Mg	6
Na	7
K	0.7
Sulfate	7.5
Cl	8
Nitrate	1.5
Alkalinity	3.5

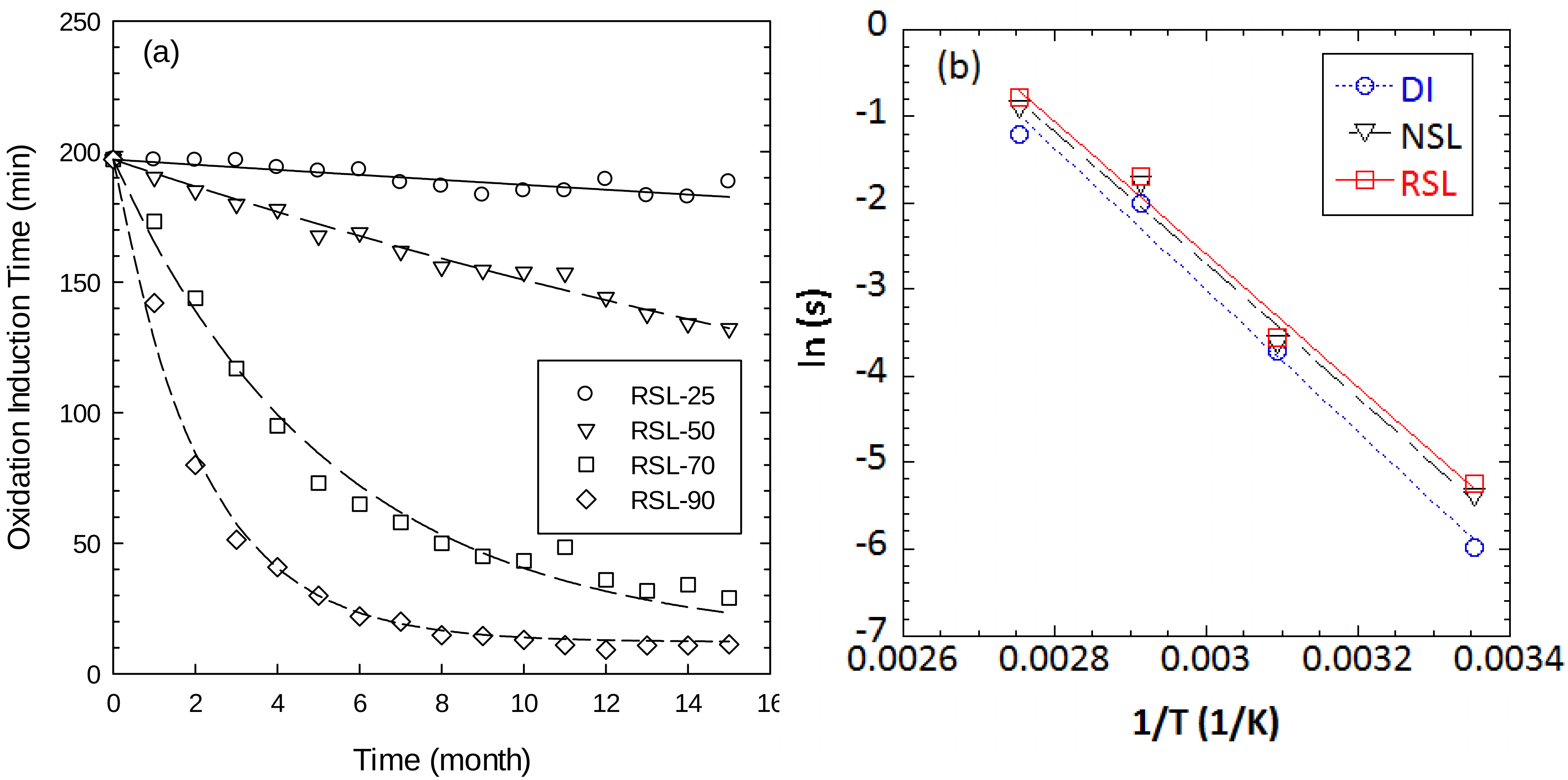
Radionuclides	
U-238 (µg/L)	1500
H-3 (pCi/L)	120000
Tc-99 (pCi/L)	800

Trace Metals (mM)			
As	0.001	Al	0.03
Ba	0.002	Mn	0.01
Cu	0.0002	Ni	0.0003
Fe	0.04	Sr	0.02
Li	0.02	Zn	0.0005

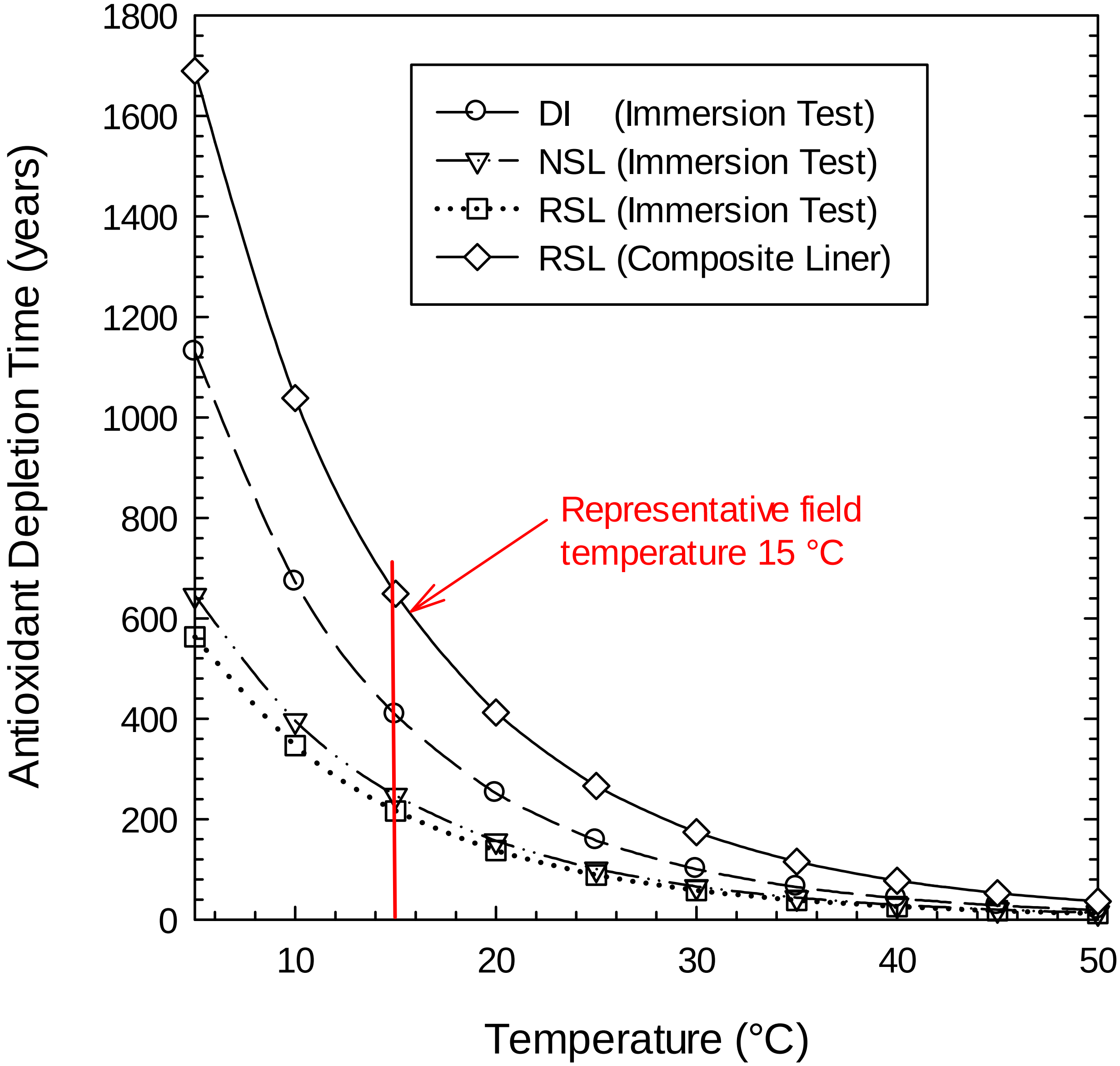
Chemical Characteristics	
TOC (mg/L)	8
ORP (mv)	120
pH	7.2
Ionic Strength (mM)	***43.6***
Ratio of monovalent to divalent cations ($M^{1/2}$) (Kolstad et al. 2004)	***0.077***

5 mg/L surfactant and 3 mg acetate

Antioxidant Depletion in Geomembranes

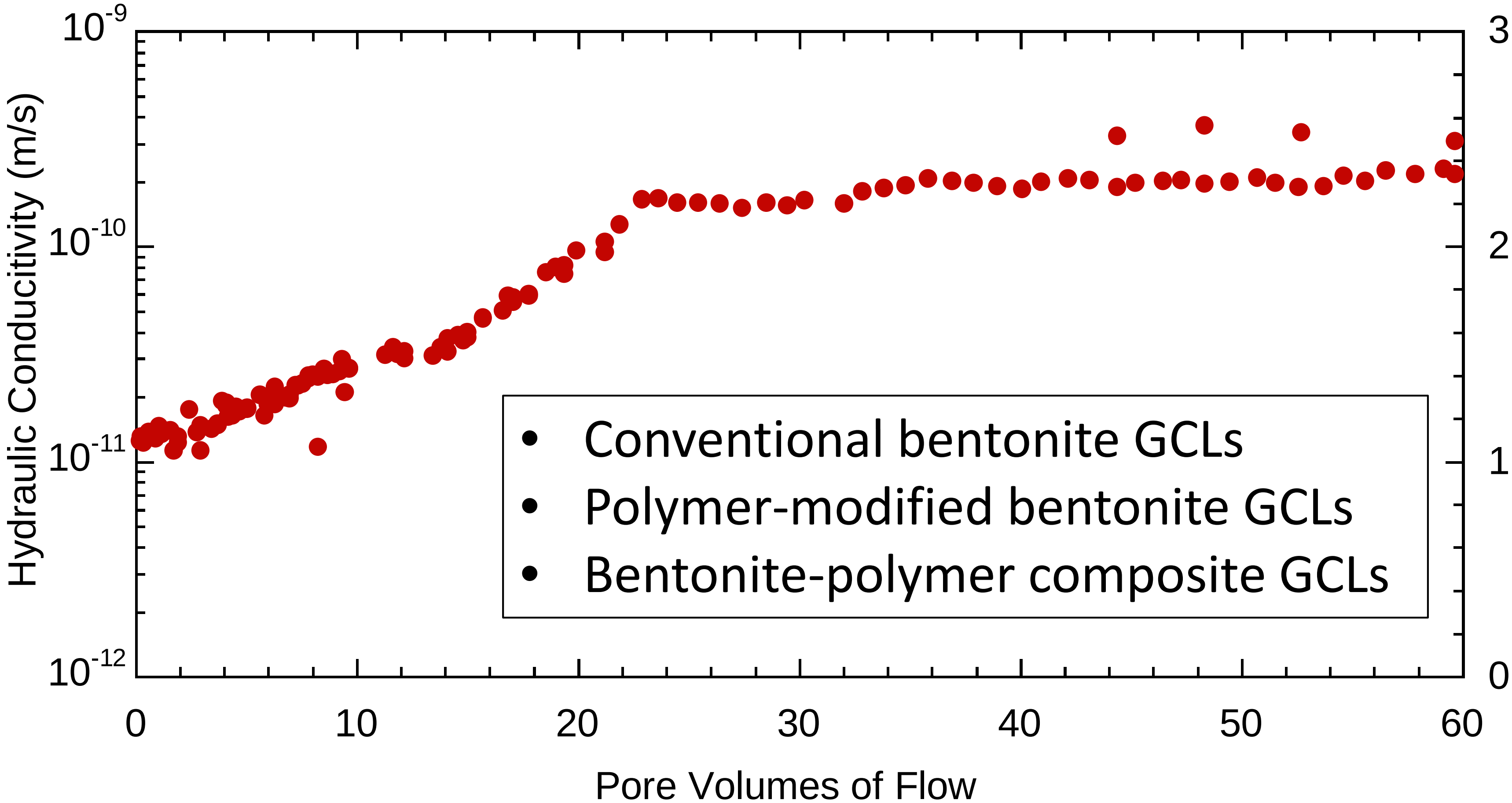


Service Life Predictions

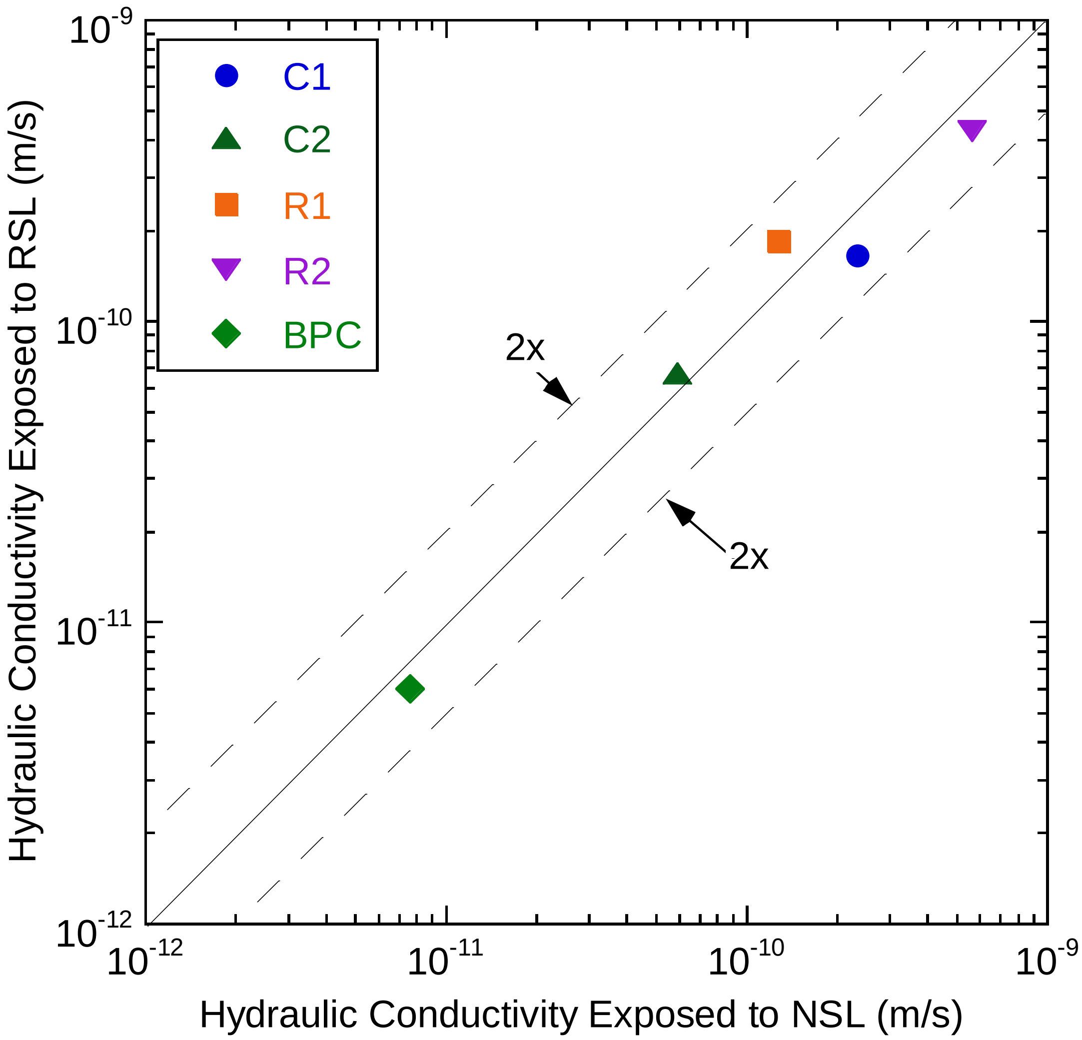


- Antioxidant depletion in approx. 700 yr, *first degradation phase*.
- Actual lifespan longer; induction & polymer oxidation phases, 1000-1500 yr.

GCLs in Synthetic LLW Leachate

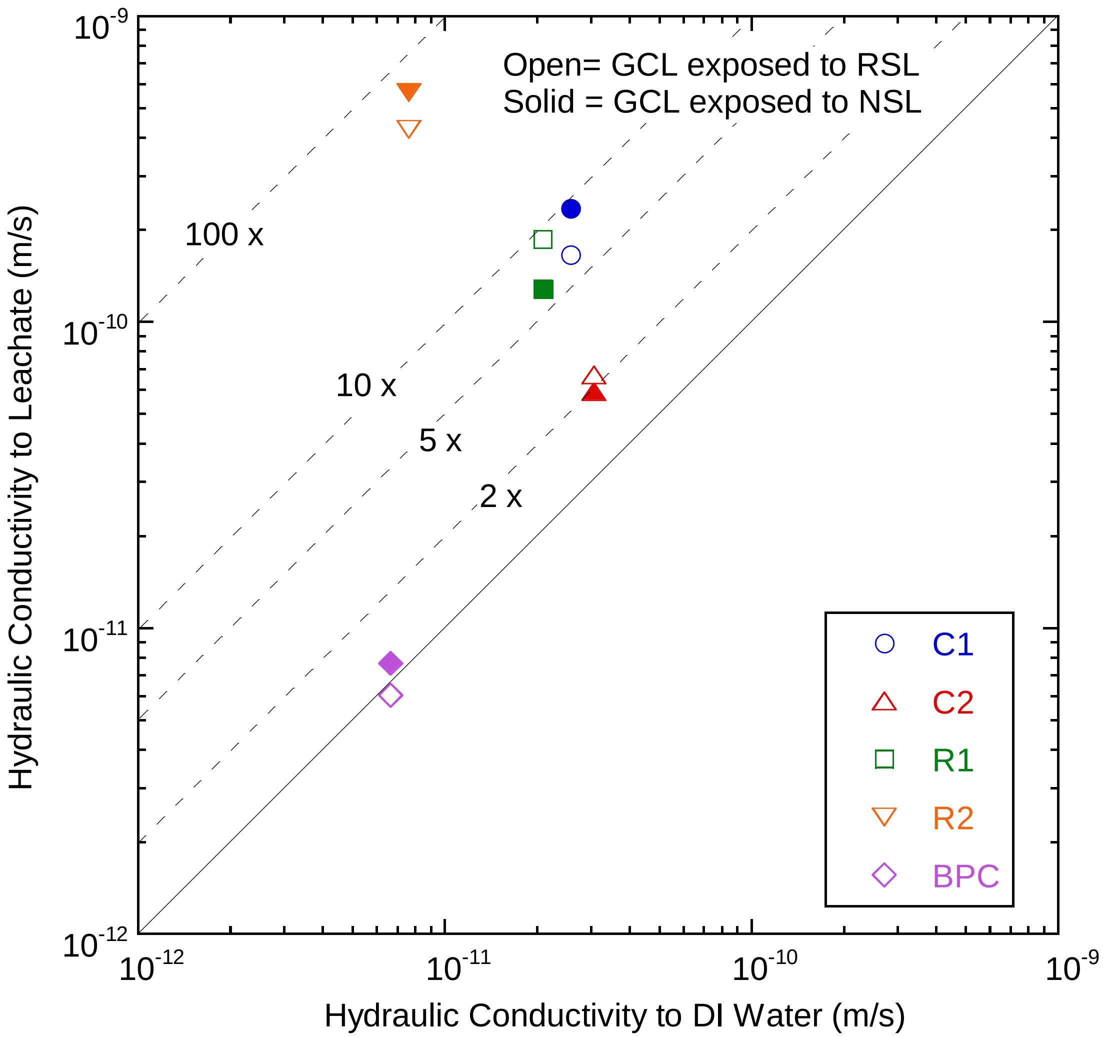


Impact of Radionuclides



- Essentially the same hydraulic conductivity with or without radionuclides in leachate.
- Major cations control swelling and hydraulic conductivity.

Impact of LLW Leachate on Hydraulic Conductivity of GCLs



Hydraulic Conductivity Relative to DI Water

- Conventional bentonite: ~ 100x
- Polymer-modified bentonite: ~ 10x
- Composite: ~ 2x

Conclusions: Soil Barriers & GCLs in Covers

- Soil barriers undergo pedogenesis, altering their hydraulic properties. Plan for this in design and account for long-term properties in PA.
- Impact of changes on performance highly site specific, from substantial to insignificant. Avoid generalizations about impact.
- Changes occur in all climates (not just arid), and occur at depth. Depth dependence is an issue requiring more study.

Conclusions: Soil Barriers & GCLs in Covers

- GCLs can maintain very low hydraulic conductivity in covers even with cation exchange if they are adequately hydrated initially and they are protected from desiccation.
- GCLs and other geosynthetics can bridge distortion due to differential settlement.

Conclusions: Liners

- Impact of LLW leachate on geomembranes and GCLs is due to primary cations and metals in solution. Radionuclides not important from perspective of degradation.
- Geomembrane service life at least 700 yr, probably > 1000 yr when all three phases considered.
- GCLs are more permeable in LLW leachates than to water and other more common leachates (e.g., solid waste). Can address with polymer modified bentonites. Account for in PA.