Fact or Fiction: Can we predict the water balance of alternative covers using numerical models?

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Model Evaluations:

- Evaluating five different models using field & laboratory data from ACAP

  UNSAT-H
  HYDRUS
  VADOSE/W
  LEACHM
  HELP

- Defining inputs using measured quantities to the greatest extent possible and comparing model predictions to field water balance measurements.

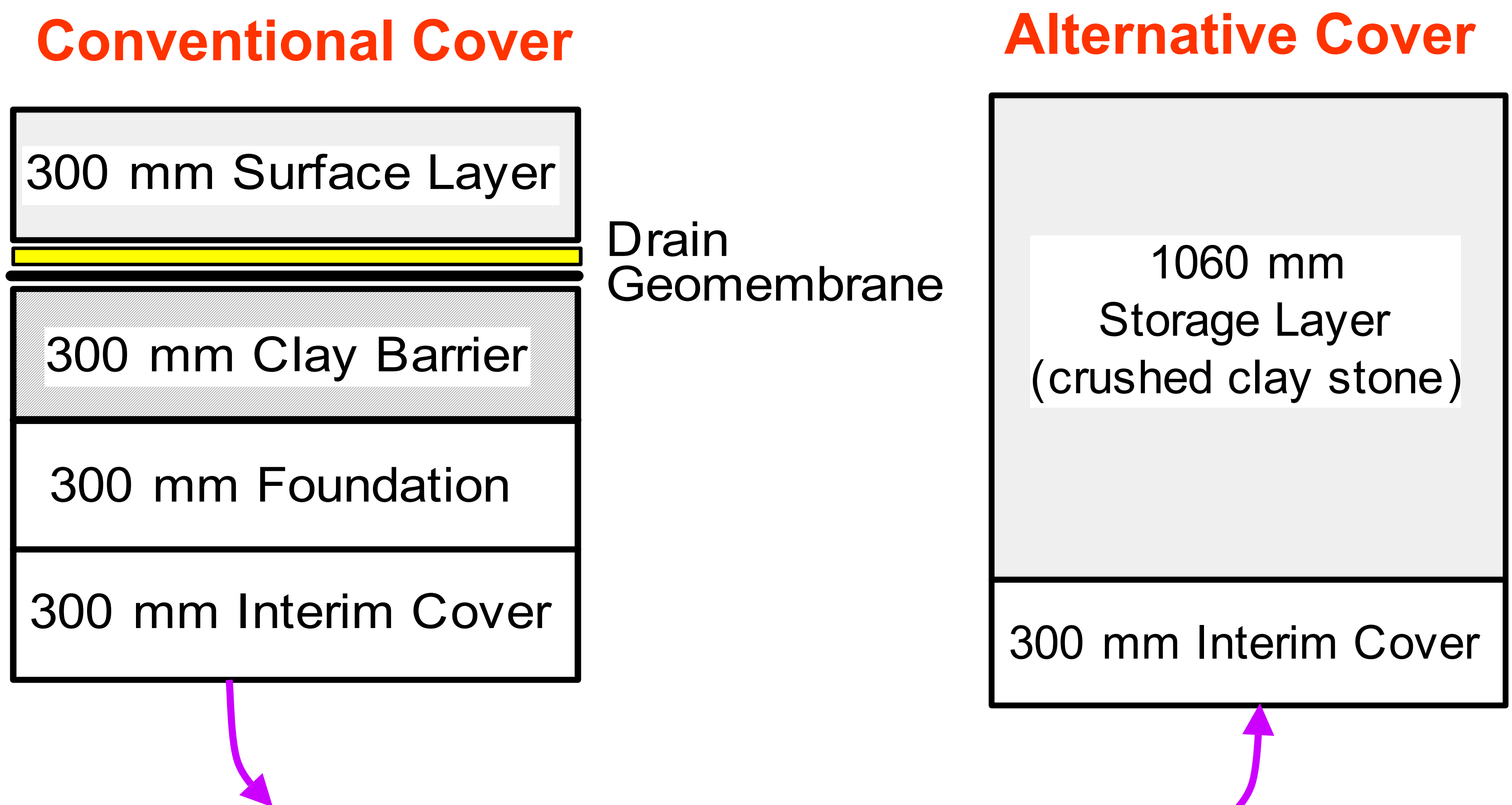
- Evaluating how parameters need to be scaled (and processes adjusted) to obtain reliable or conservative predictions.

Two Topics Presented:

1. Case history of monolithic cover designed using conventional calculations and numerical modeling and monitored by ACAP. Do the monitoring observations agree with model predictions?

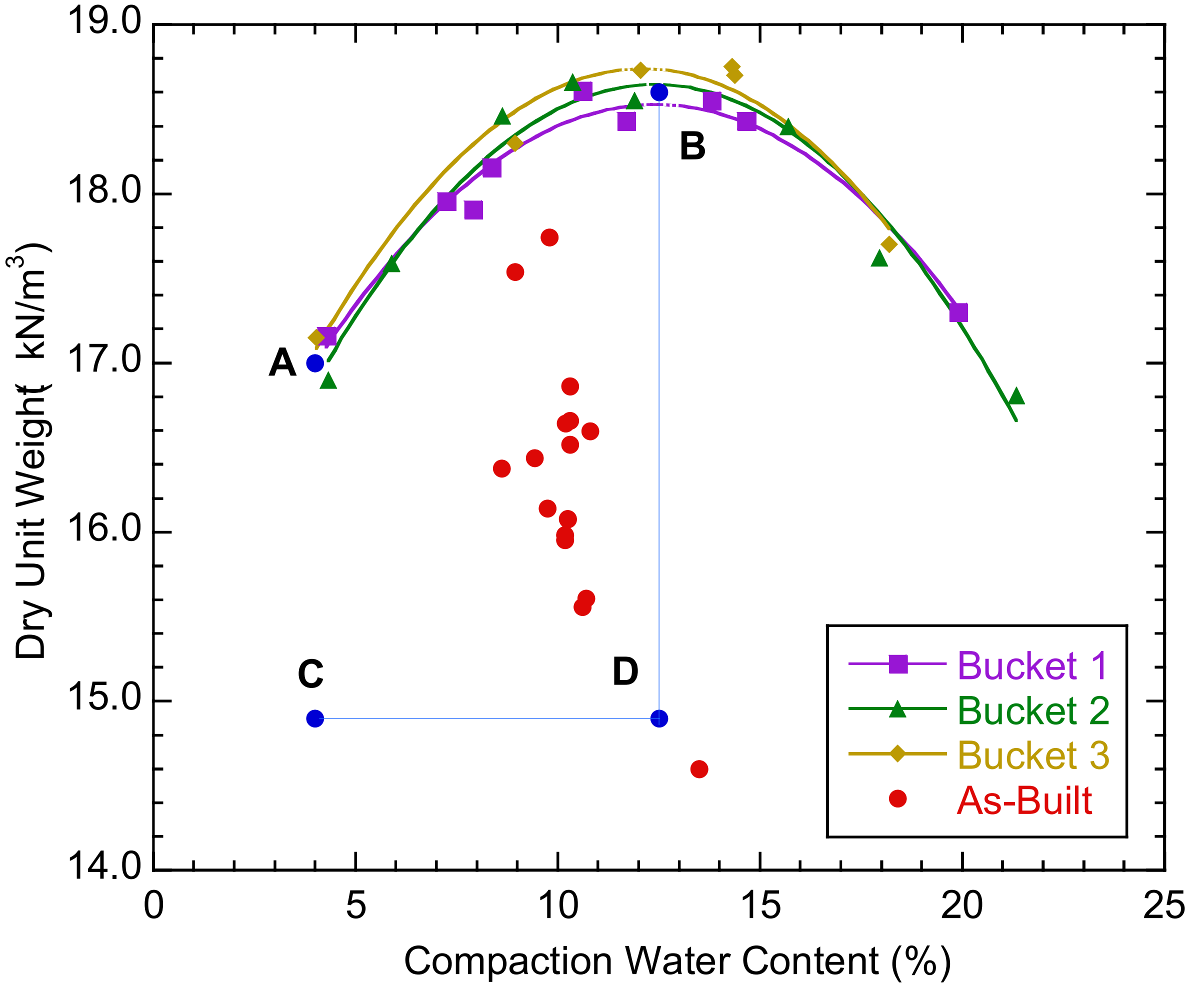
2. Discussion of sensitivity analyses to define parameters having the greatest influence on water balance predictions. Can design rules be formulated so that model predictions are accurate *or* conservative?

Altamont Case History



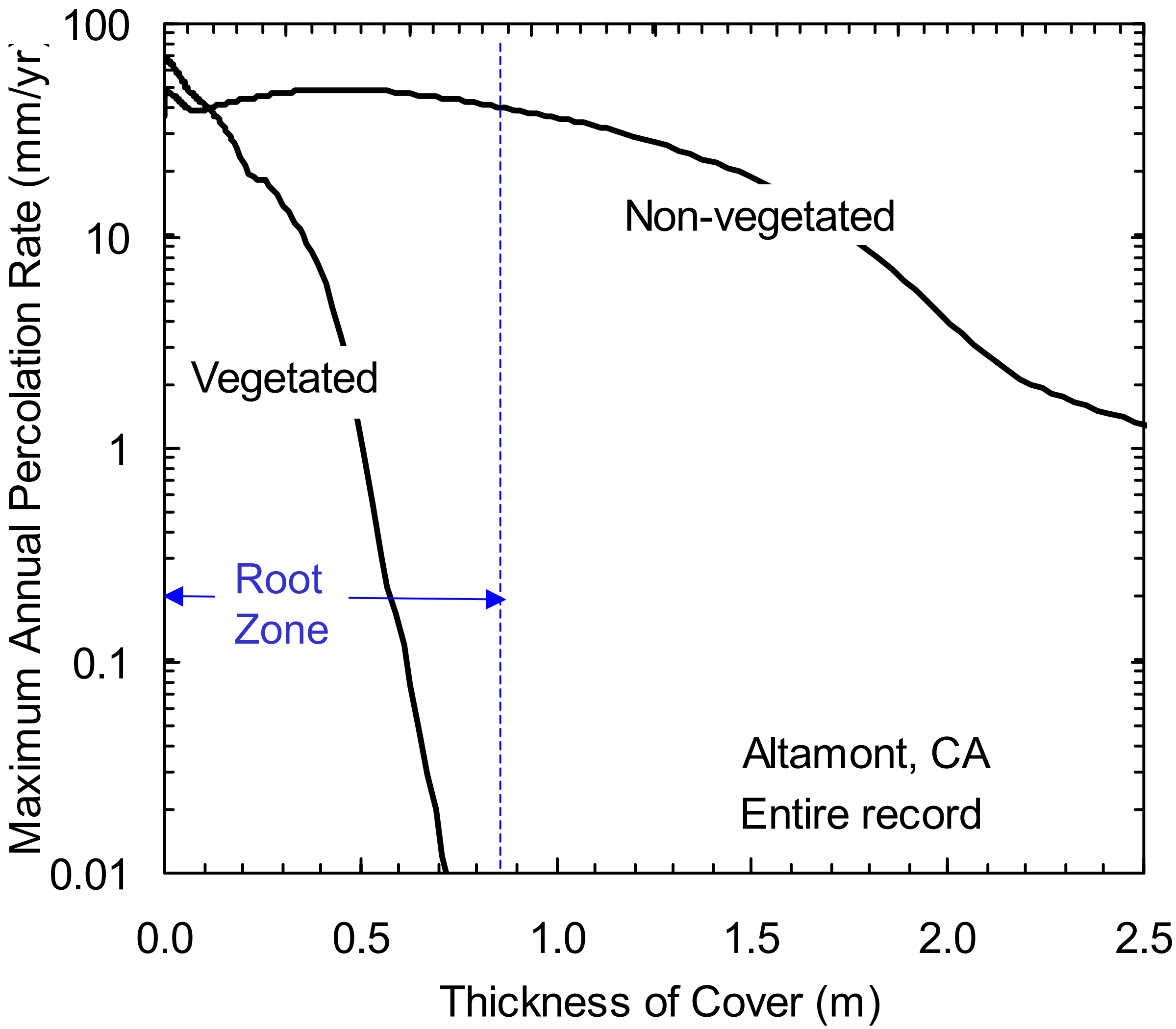
Designed alternative cover to meet a percolation criterion < 1 mm/yr

Hydraulic Properties of Crushed Claystone



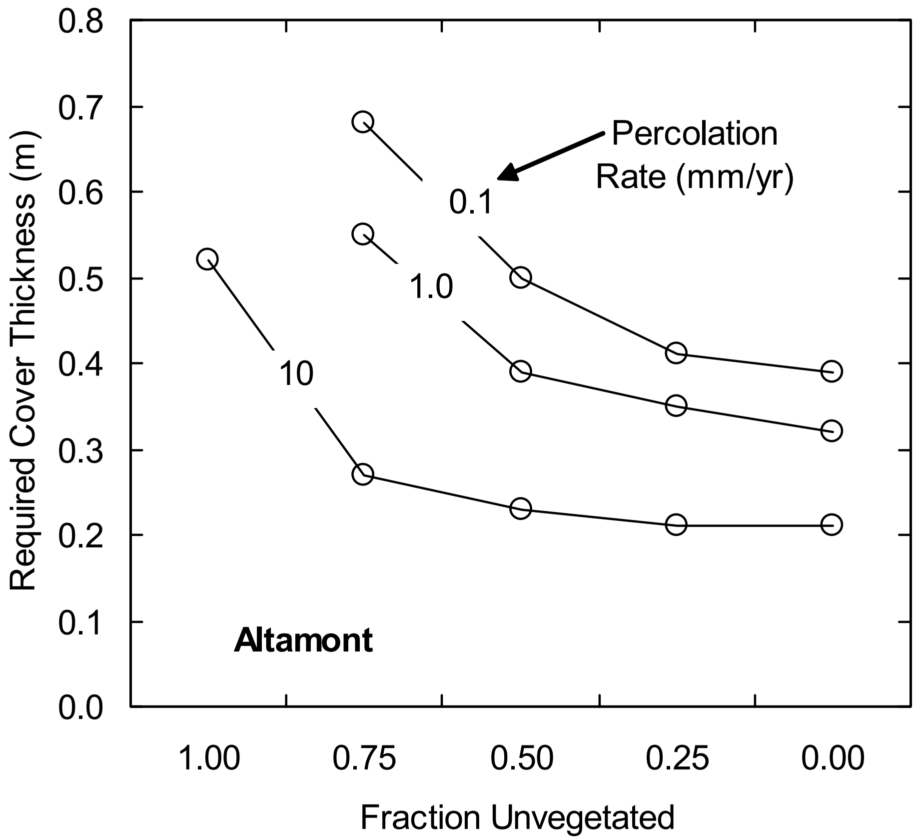
- Three samples collected from borrow source. Index properties and compaction curves essentially identical.
- Hydraulic properties measured at four possible compaction points to bracket field conditions
- Design based on properties at Pt. C, least storage capacity and highest saturated hydraulic conductivity (set at 10^{-5} cm/s).

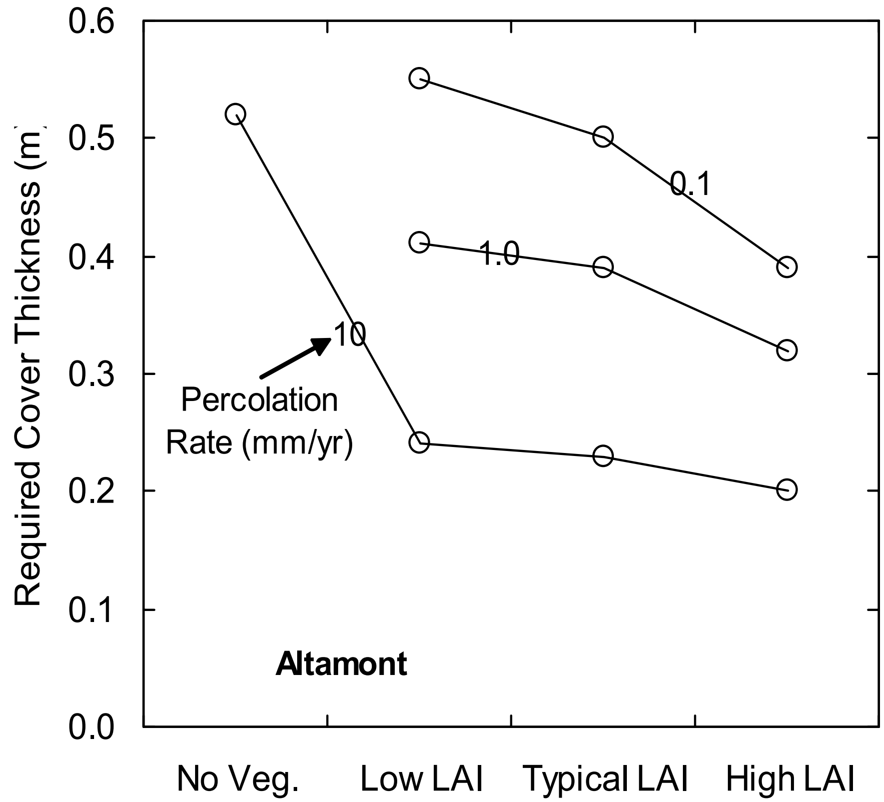
Cover Design Modeling Using UNSAT-H



- Numerical simulations with wettest year repeated 5x and wettest 10 yr period
- With and without vegetation
- Determined that a 1-m-thick cover should achieve 1 mm/yr percolation goal

Sensitivity Analyses

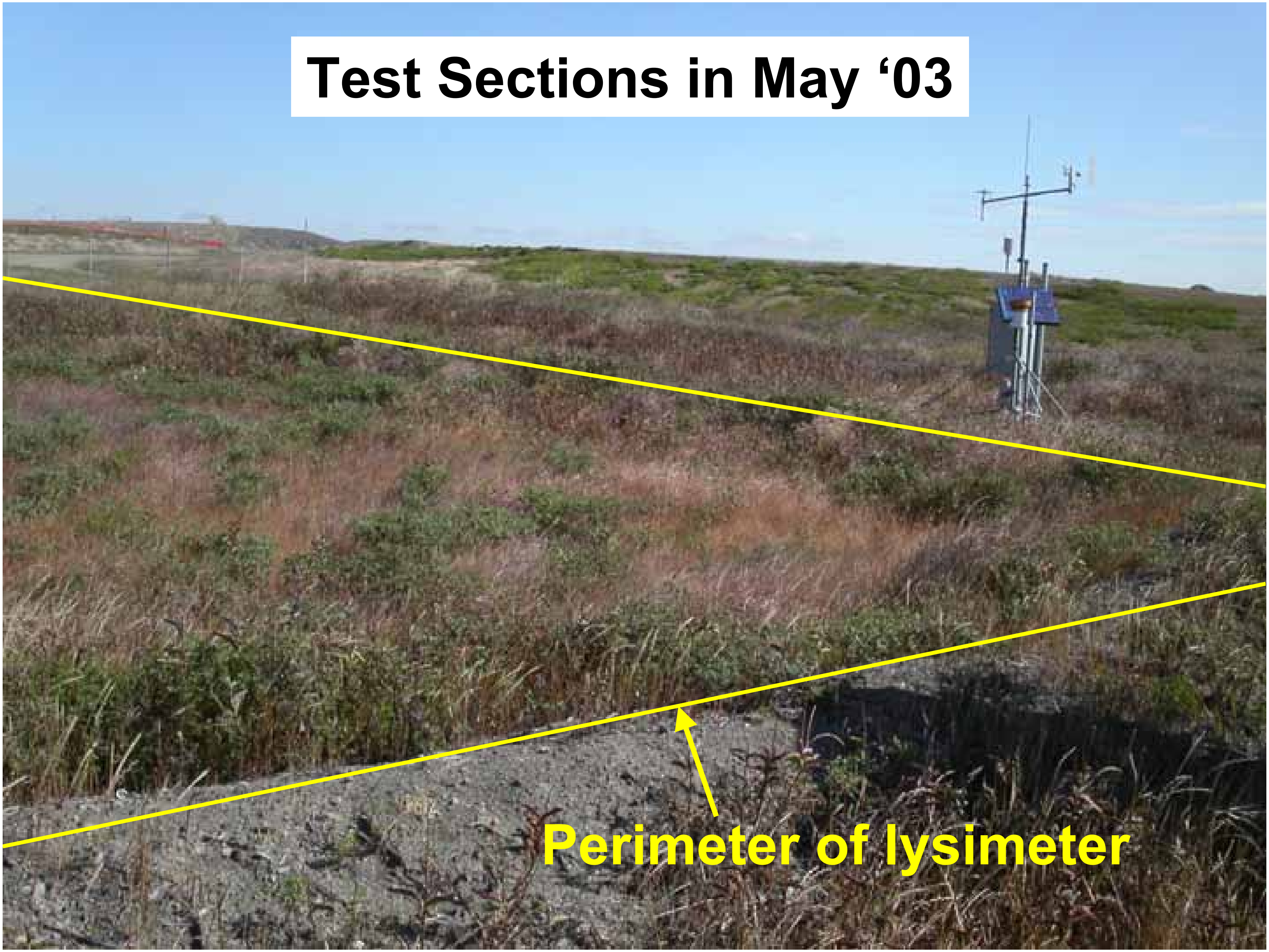




Sensitivity analyses indicated that 1-m-thick cover should achieve 1 mm/yr percolation goal for broad variety of conditions.

Test Sections Constructed in September ‘00

Test Sections in May '03



Model Evaluation

Purpose:

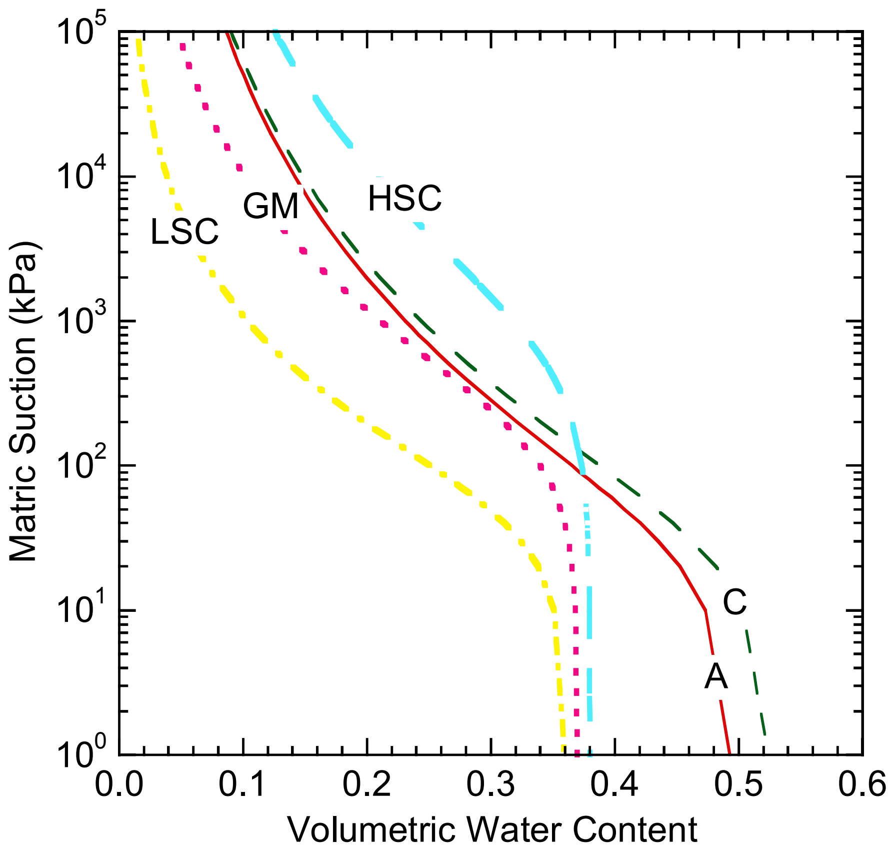
Determine accuracy with which model predicts field water balance using measured hydraulic properties, existing vegetative conditions, and on-site meteorological data.

Input:

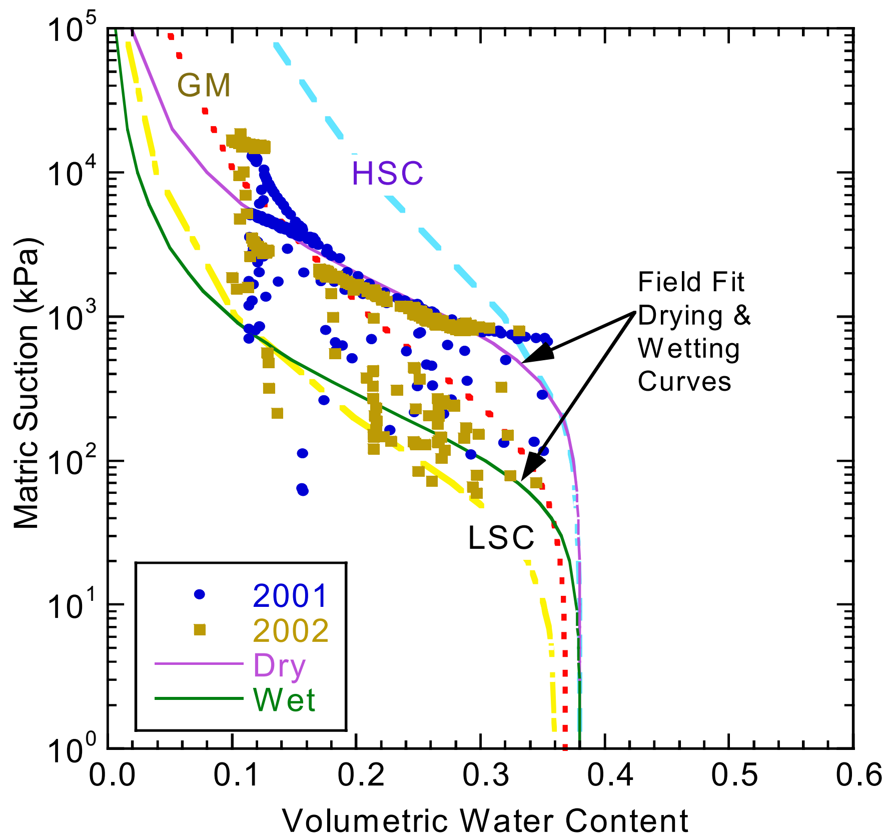
- Hydraulic properties: design (pts. A and C), as-built, in situ measurements
- Vegetation: on-site measurements of RLD and LAI
- Meteorological data: on-site and NWS.

Soil Water Characteristic Curves

Design & As-Built



"Field Fit" & As-Built



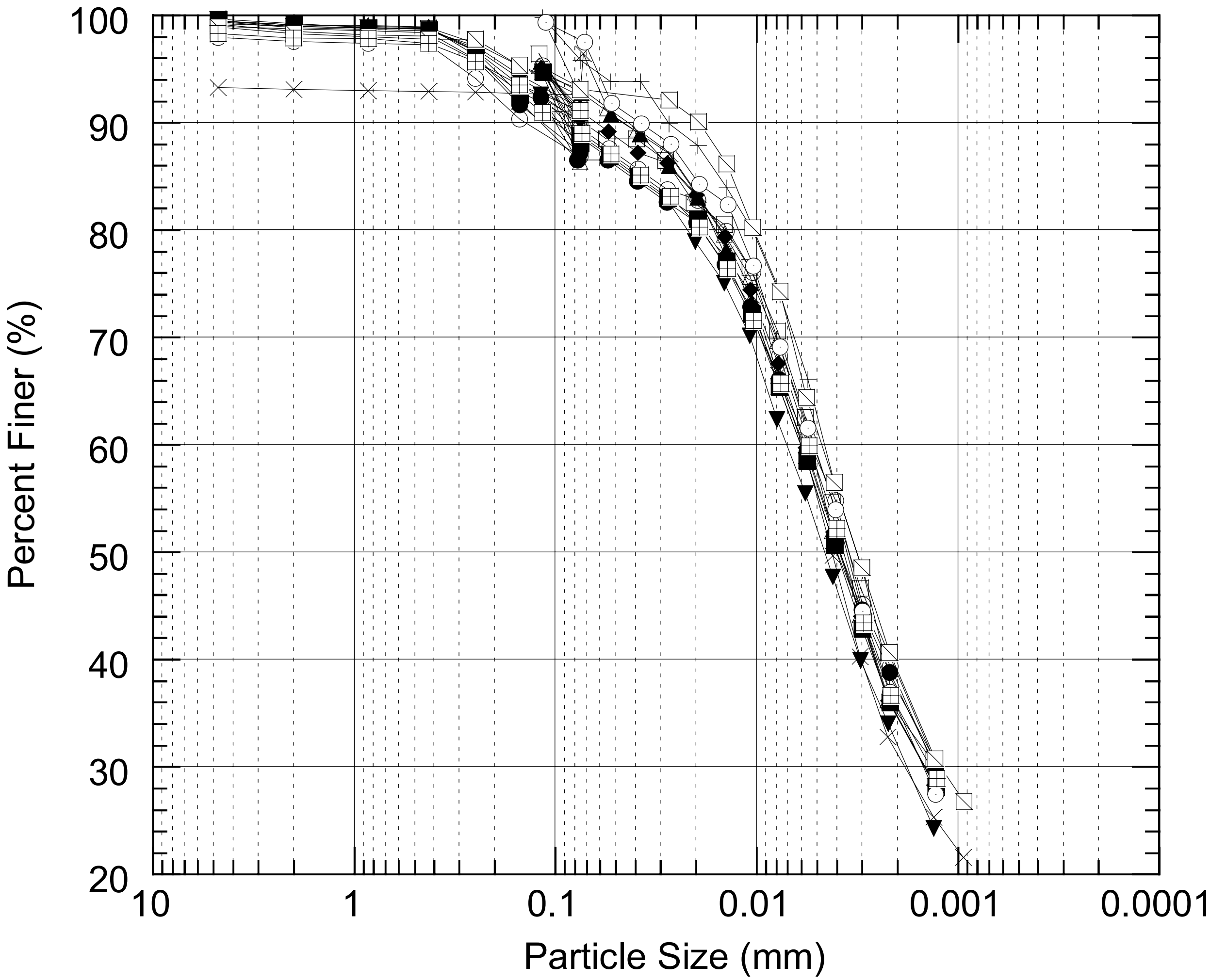
Considerable spatial variability: α varies by 10x

Field Fit & GM SWCCs comparable; bias not appreciable

Hydraulic Properties

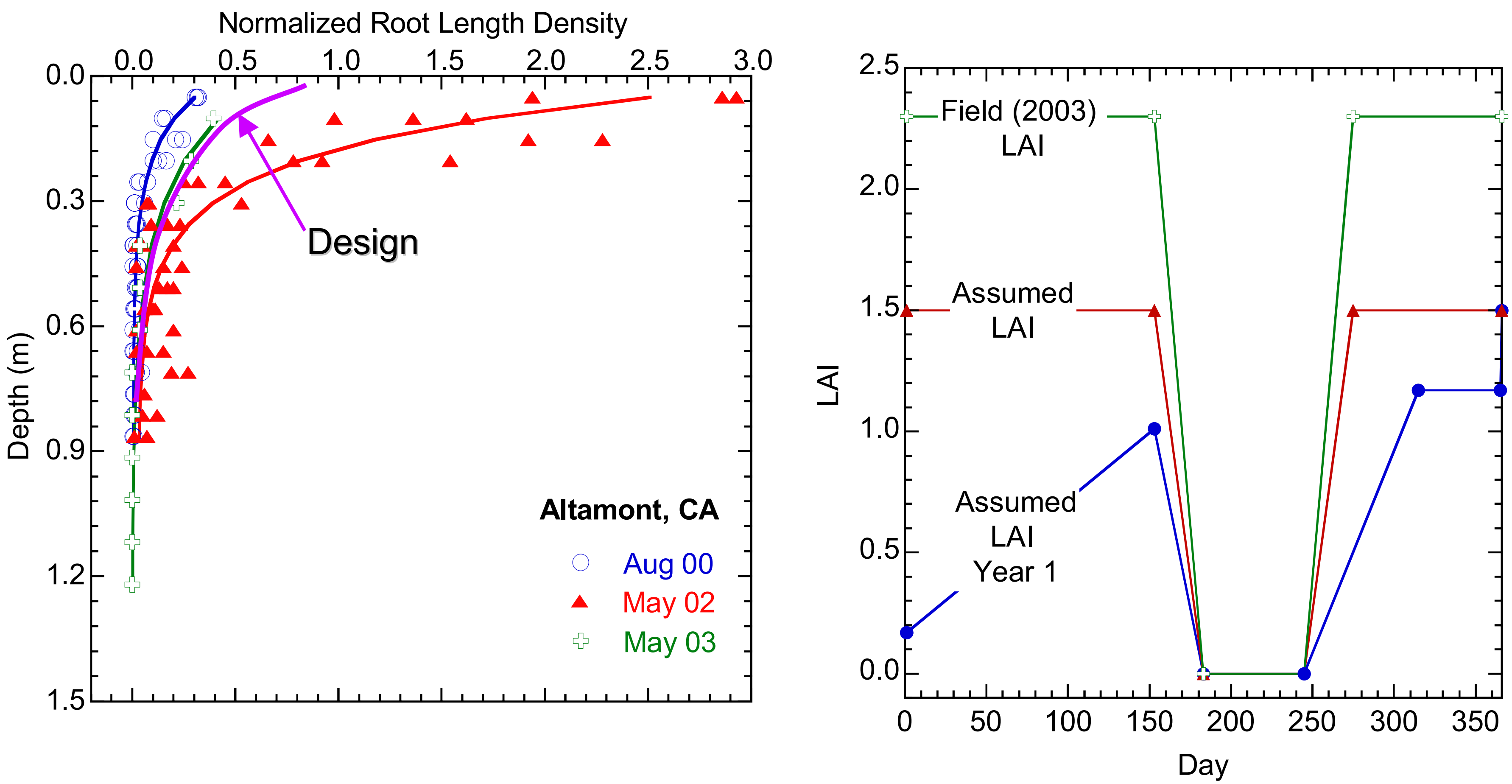
Condition	θ_s	α (m^{-1})	n	K_s(cm/s)
A	0.49	0.34	1.21	1.1×10^{-7}
B	0.44	0.039	1.30	2.1×10^{-9}
C	0.53	0.34	1.22	6.0×10^{-6}
D	0.47	0.034	1.22	2.7×10^{-7}
LSC	0.36	0.18	1.43	2.8×10^{-7}
GM	0.37	0.050	1.32	4.5×10^{-7}
HSC	0.38	0.015	1.22	5.5×10^{-8}
FF	0.38	0.044	1.50	-

Particle Size Analyses



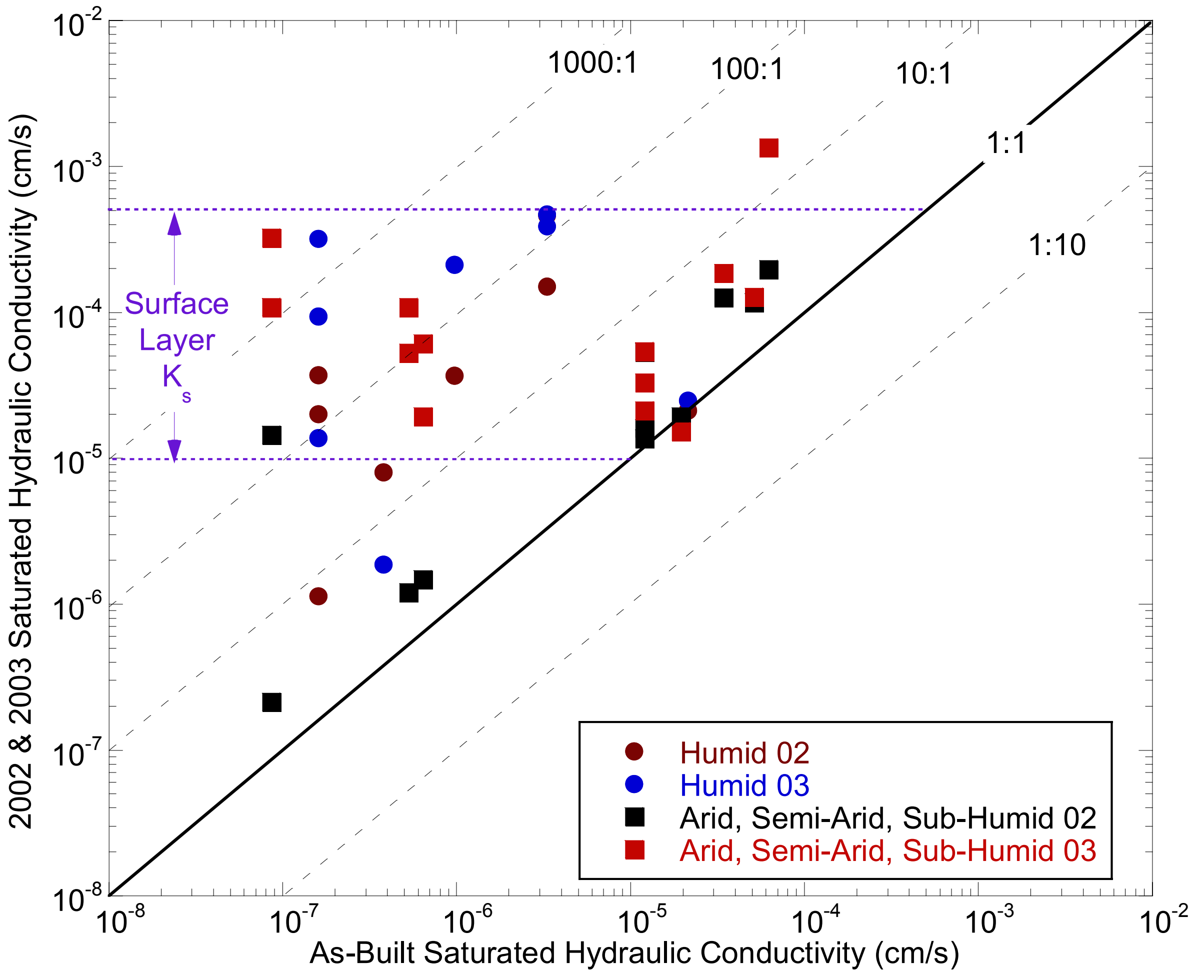
- Index properties suggest the soil is reasonably uniform
- Hydraulic properties exhibit considerable heterogeneity
- Need more than "a few tests" to characterize hydraulic properties

Vegetation



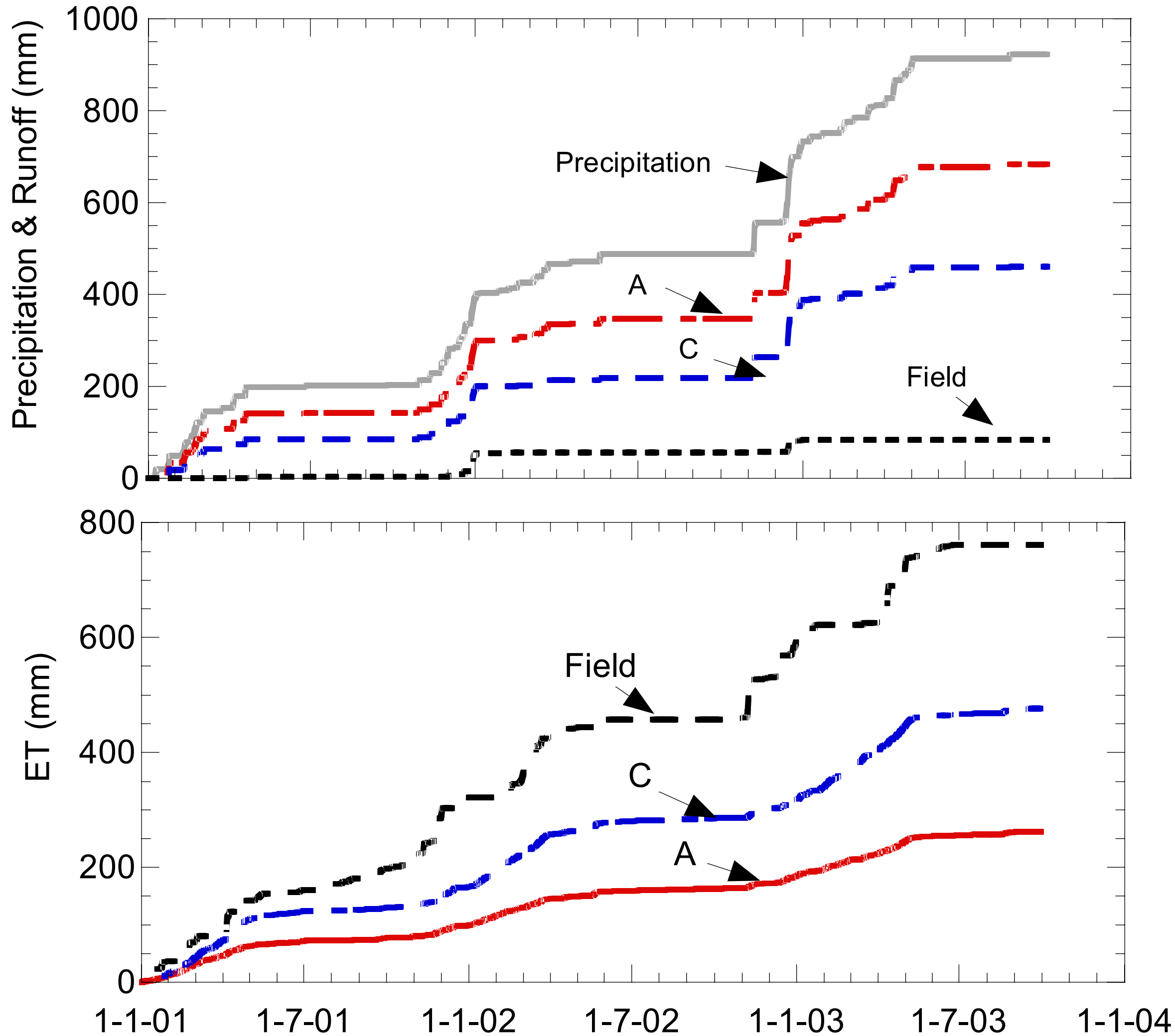
Properties of vegetation assumed during design relatively consistent with measurements

Surface Layer Hydraulic Conductivity



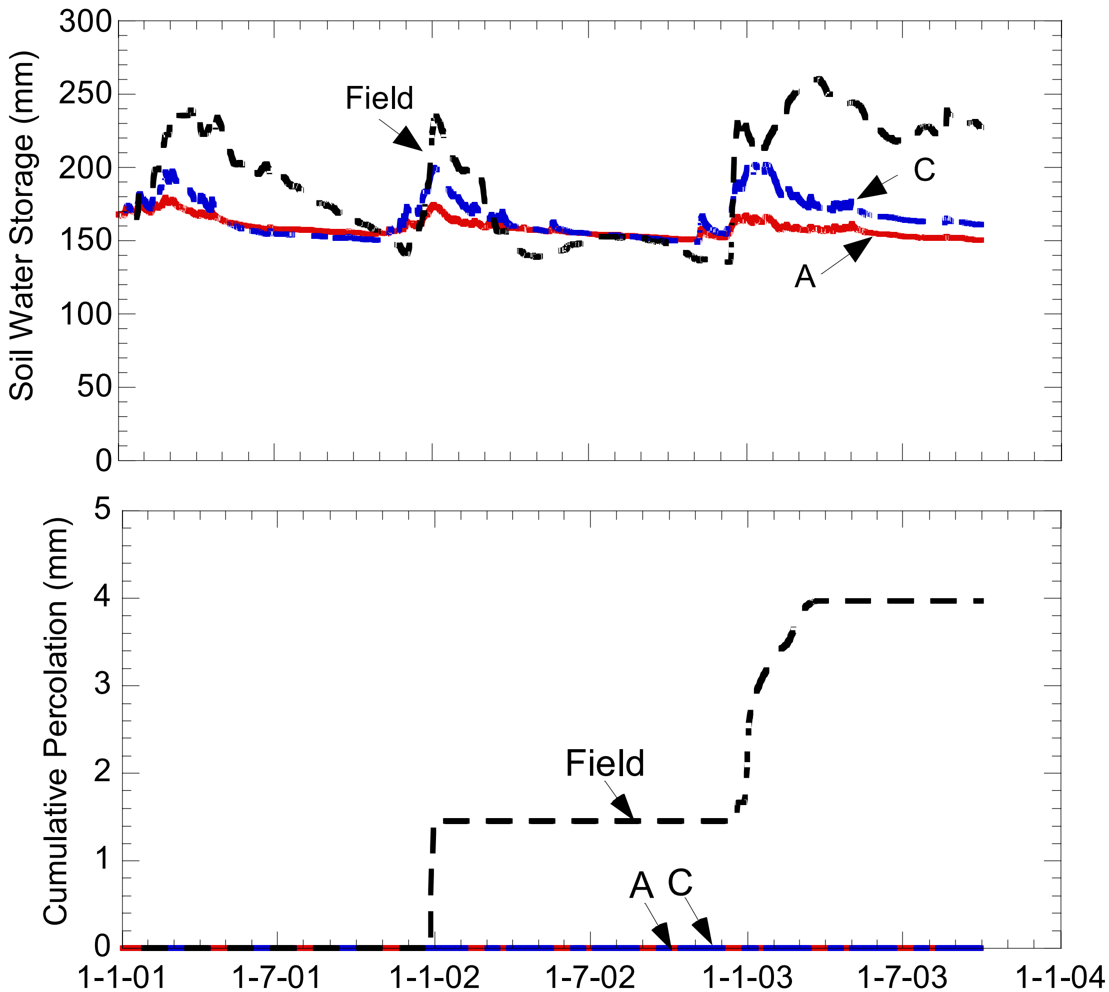
- Large undisturbed block samples collected in '02 & '03 for K_s testing
- Hydraulic conductivity of surface increased by 10-1000x due to weathering and biota intrusion
- Reasonable K_s for surface layer is 10^{-4} cm/s

UNSAT-H Predictions: Design Properties



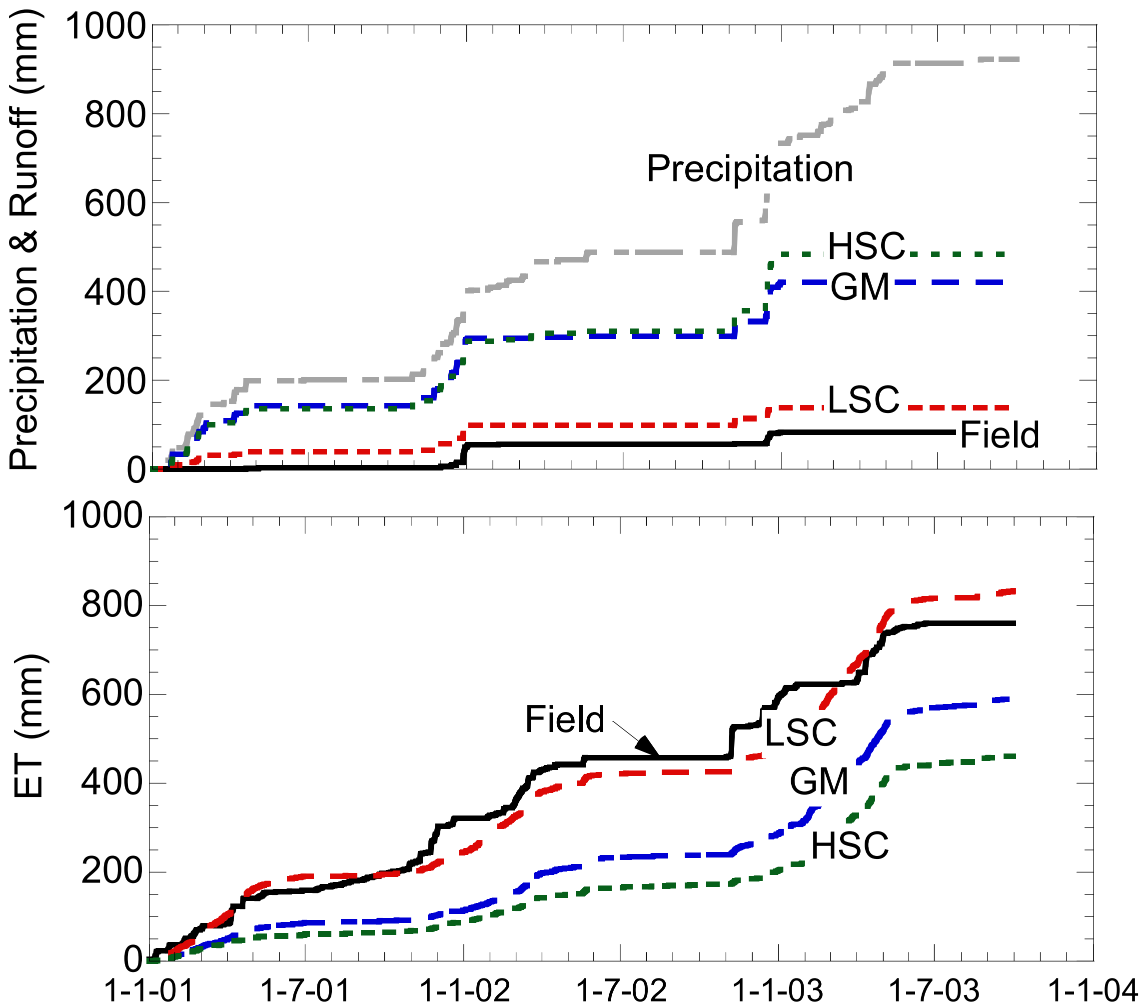
- Predictions follow seasonal trends
- Runoff grossly over-predicted (common occurrence)
- ET under-predicted because too little water entered the cover
- Predicting runoff and infiltration is one of the most difficult modeling exercises.

UNSAT-H Predictions: Design Properties



- Seasonal fluctuations in SWS suppressed due to over-prediction of runoff
- Percolation is under-predicted partly because too little water enters the cover
- Some of the percolation is preferential flow

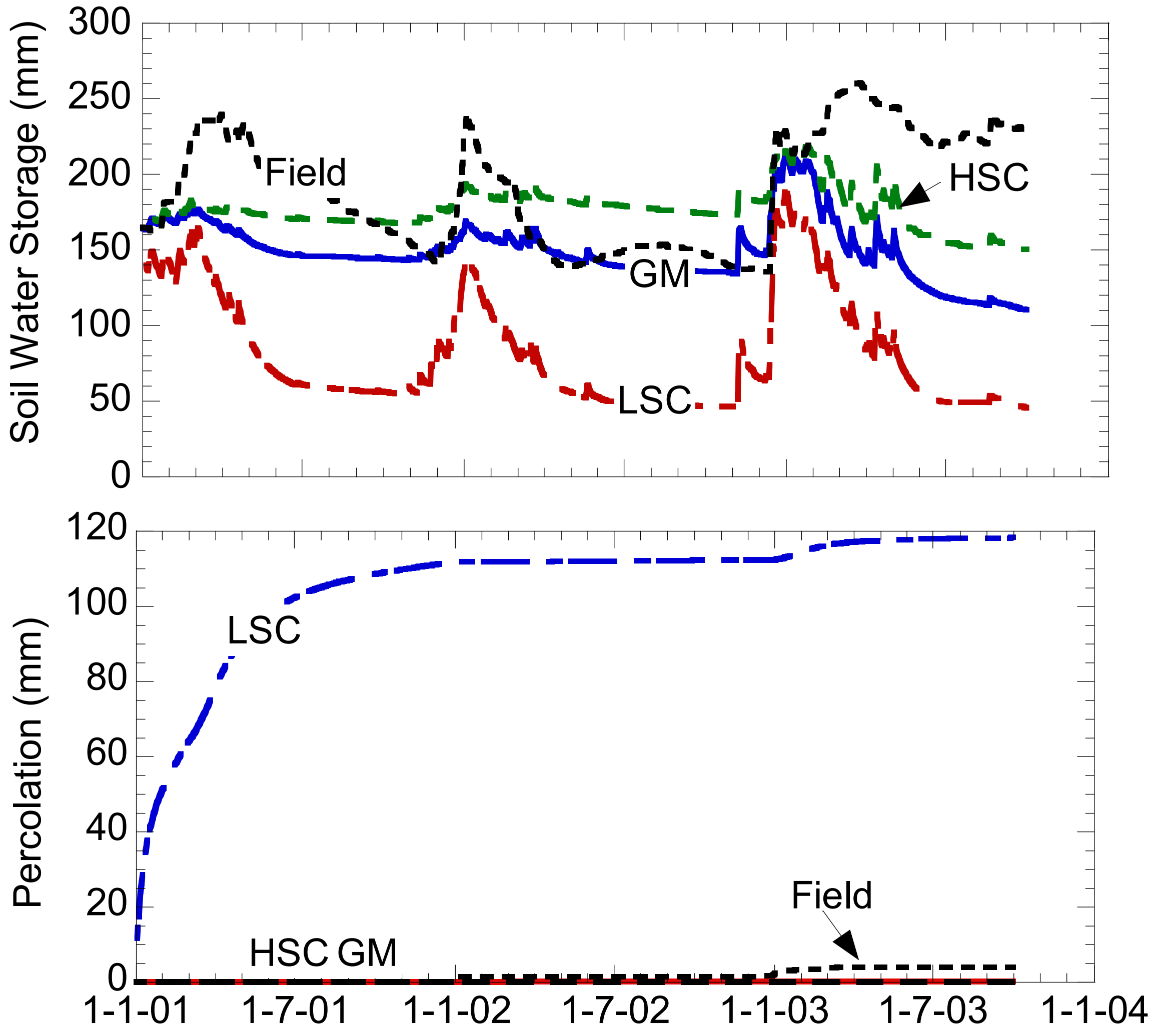
UNSAT-H Predictions: As-Built Properties



- Better prediction of runoff and ET using LSC properties

- Higher K_s allows more water to enter cover, reducing runoff and increasing ET

UNSAT-H Predictions: As-Built Properties

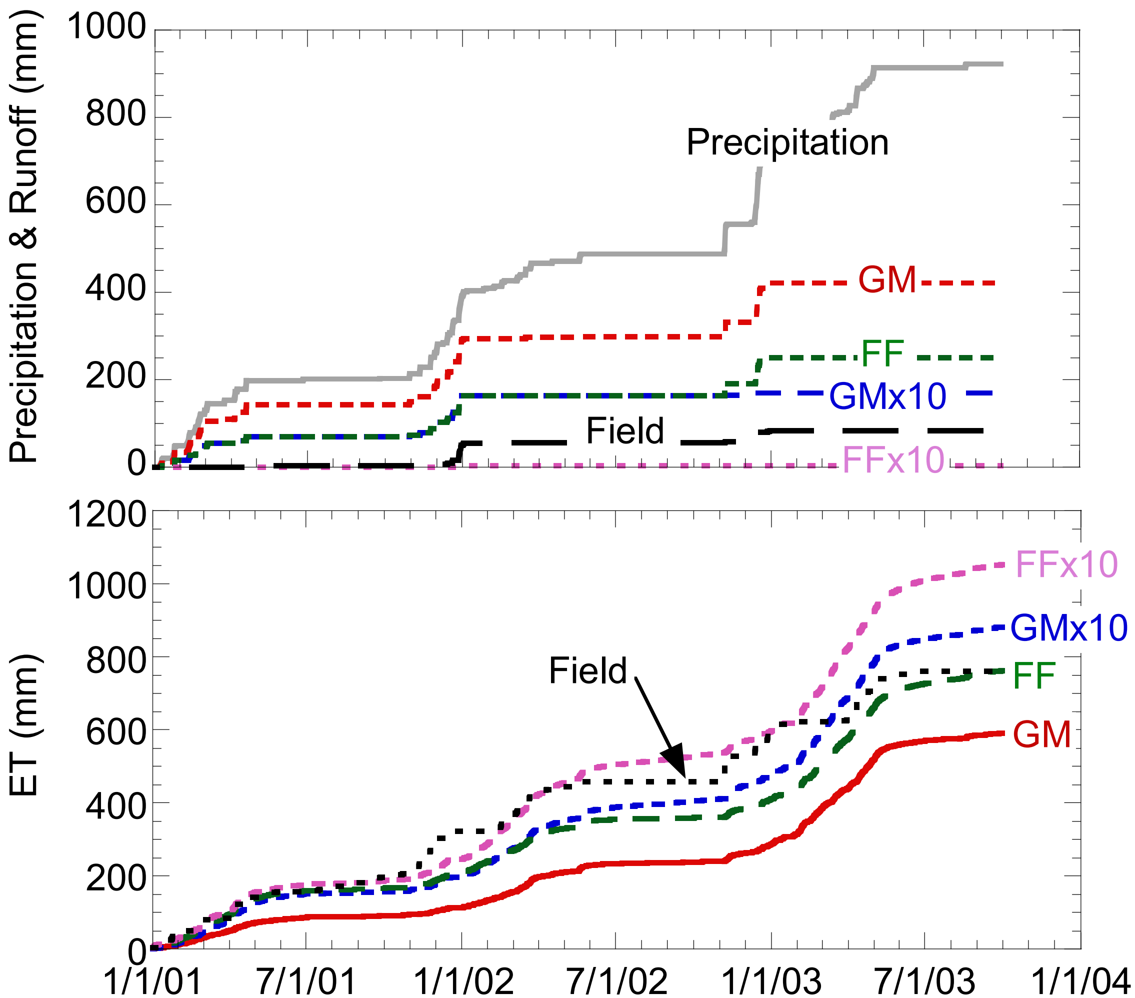


- Seasonal variation in SWS improves with LSC case, but too much drainage occurs (water retention under-estimated)

- Percolation grossly over-estimated using LSC parameters

- Predictions using range of as-built properties capture range of field data

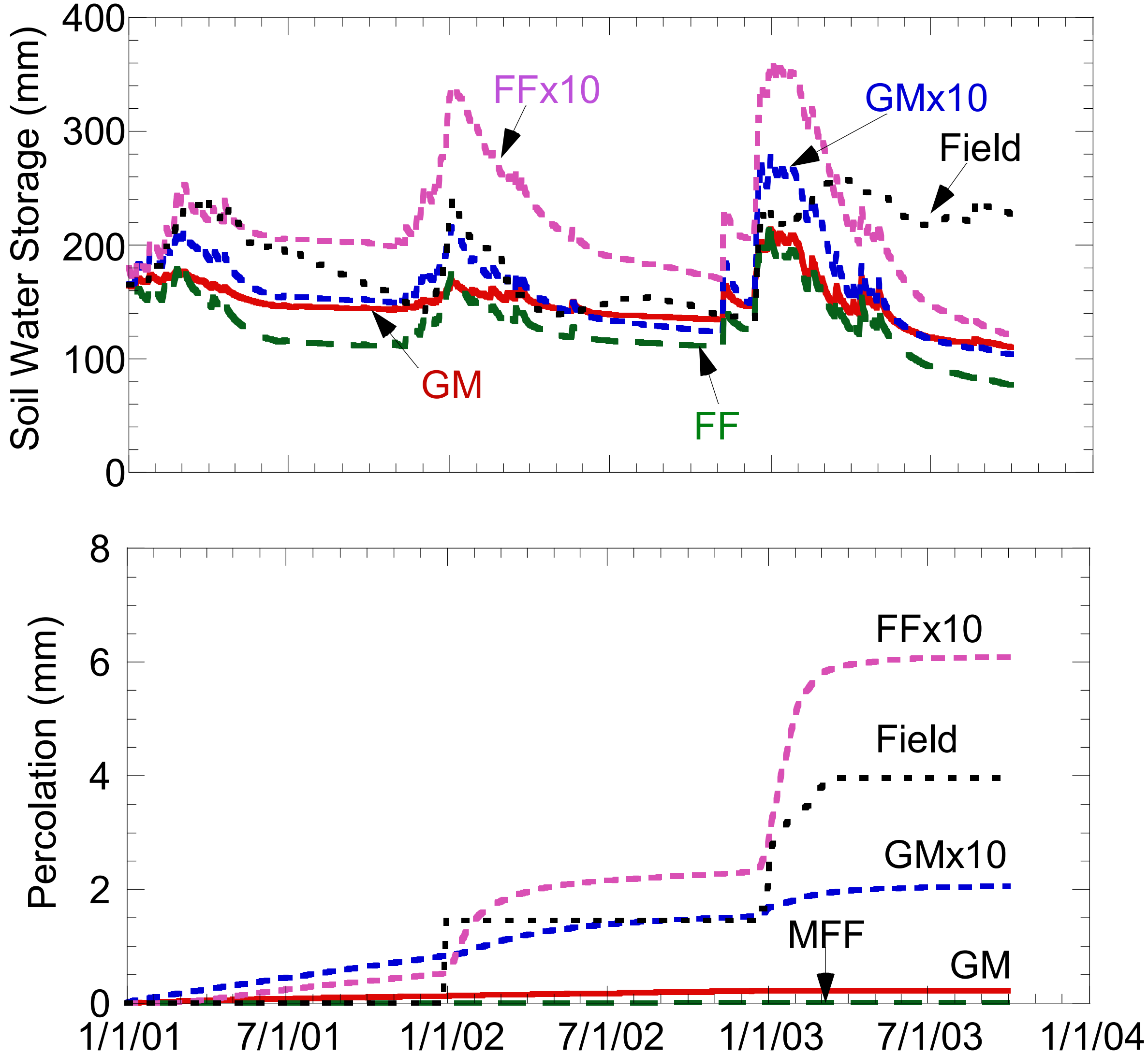
UNSAT-H Predictions: Field Fit Properties



- Predictions using field fit parameters slightly better than GM parameters

- Increasing K_s by 10x for field fit and GM brackets field data

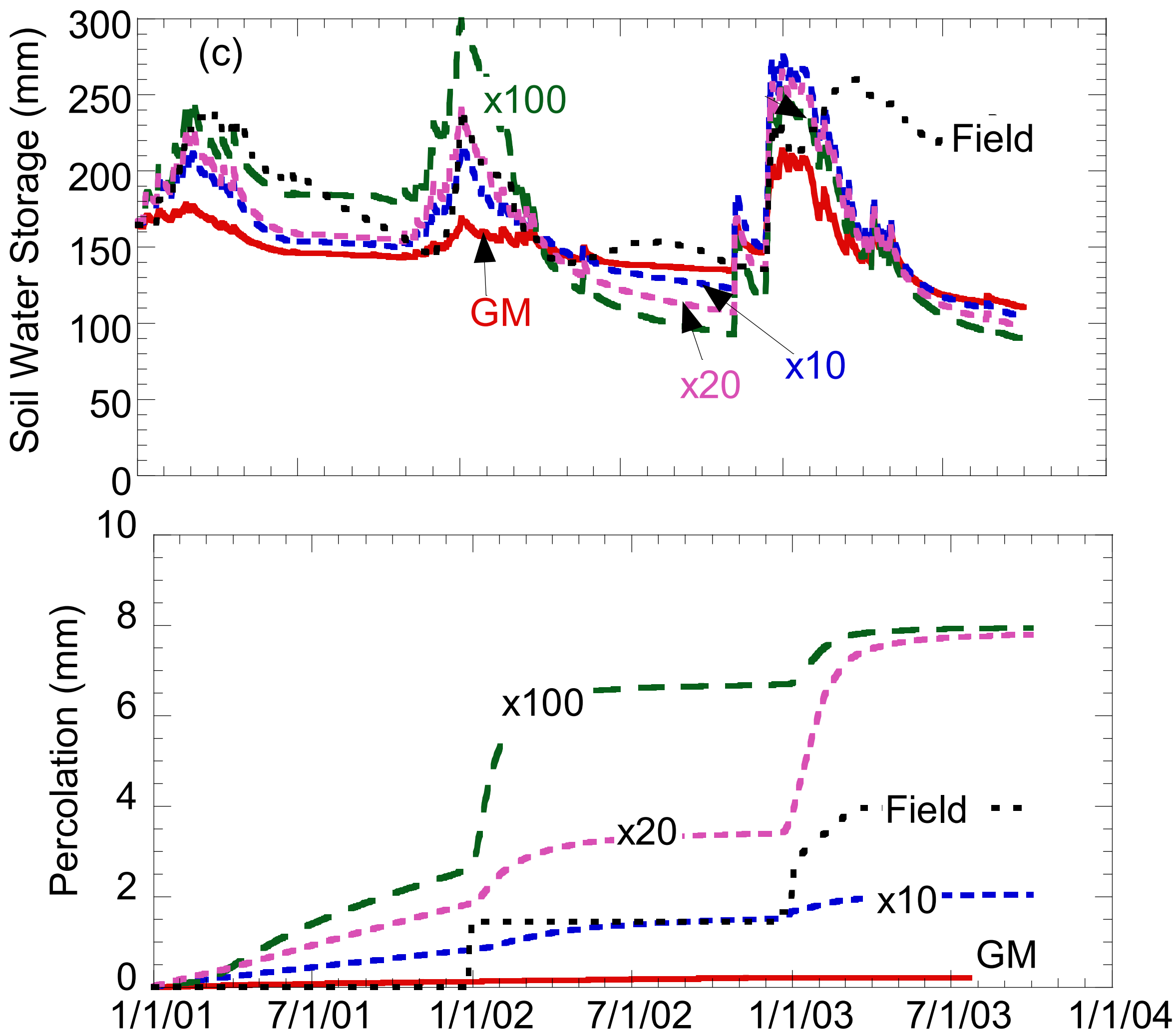
UNSAT-H Predictions: Field Fit Properties



- Predictions using GM parameters slightly better than field fit parameters

- Increasing K_s by 10x for field fit and GM brackets field data

UNSAT-H Predictions: Scaling GM Properties



- Increasing K_s 10x – 20x brackets field water balance
- Use GM parameters to describe SWCC (or design parameters)
- Estimate K_s of surface as 10^{-4} cm/s

Summary of Case History

1. As-built water retention properties comparable to design properties and in situ measurements.

2. Saturated hydraulic conductivity higher than as-built

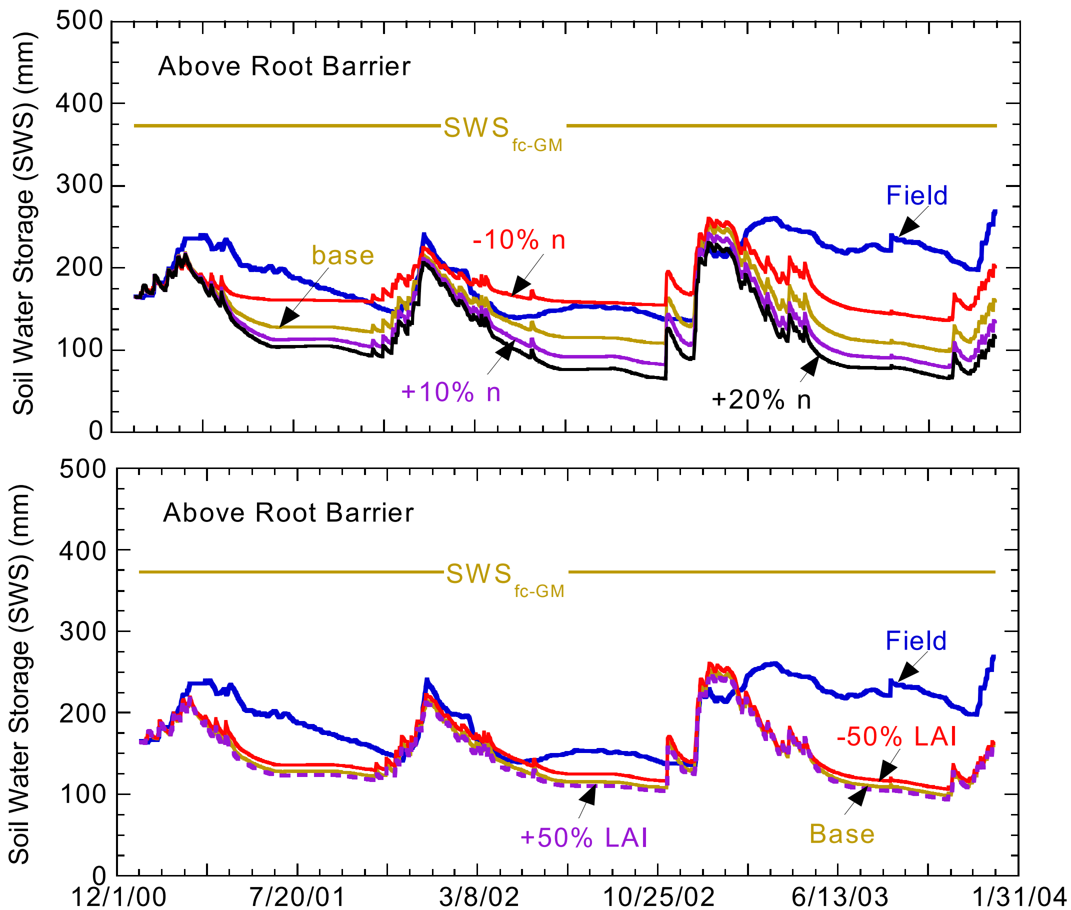
   - surface layer ~ 10^{-4} cm/s
   - storage layer ~ 10 to 20x GM K_s, or 10^{-5} cm/s

3. Hydraulic properties more variable than index properties. Proper characterization and sufficent testing is essential.

4. Assumed vegetation properties consistent with as-built condition. ET predicted with reasonable accuracy when runoff was not over-predicted.

Sensitivity Analysis

Conducted systematic evaluation of input parameters using UNSAT-H and HYDRUS to assess relative impact on water balance predictions: high, modest, or low



van Genuchten's n parameter: HIGH (n = 1.15-1.45, 1.3)

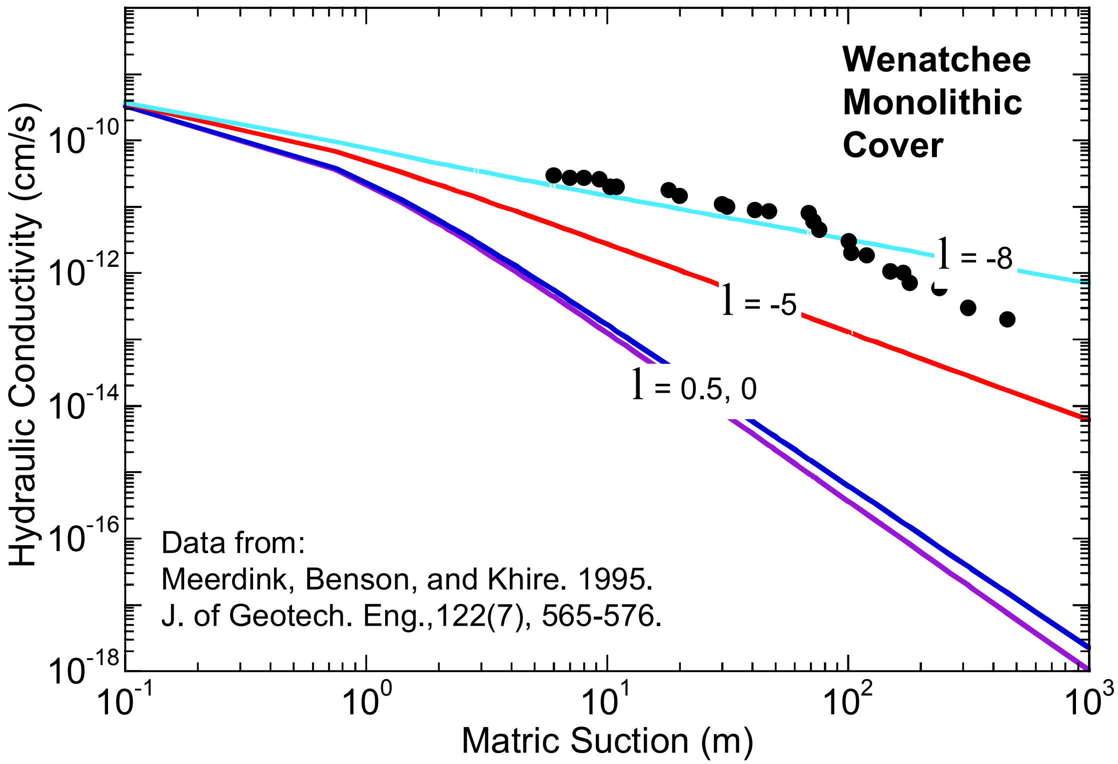
LAI: LOW (for LAI > 1)

Sensitivity Analysis & Design Recommendations

Hydraulic Properties:

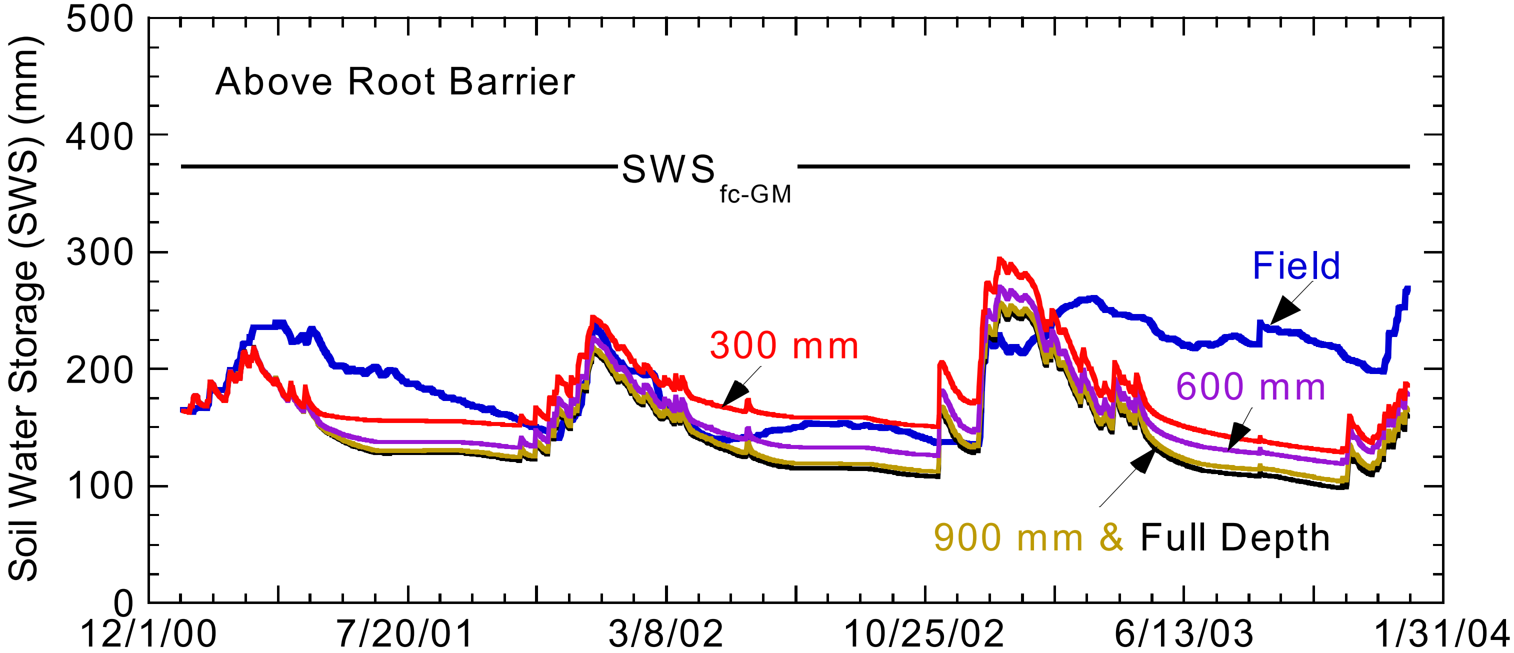
K_s – HIGH (10x – 20x GM value), ≥10^{-4} cm/s for surface layer
α – HIGH (use design α or GM field α)
n – HIGH (increase design n or GM field n by 10%)

Use $\ell < 0$ in van Genuchten-Mualem function describing unsaturated hydraulic conductivity (ℓ = -1 to -5 reasonable)



Vegetation Properties:

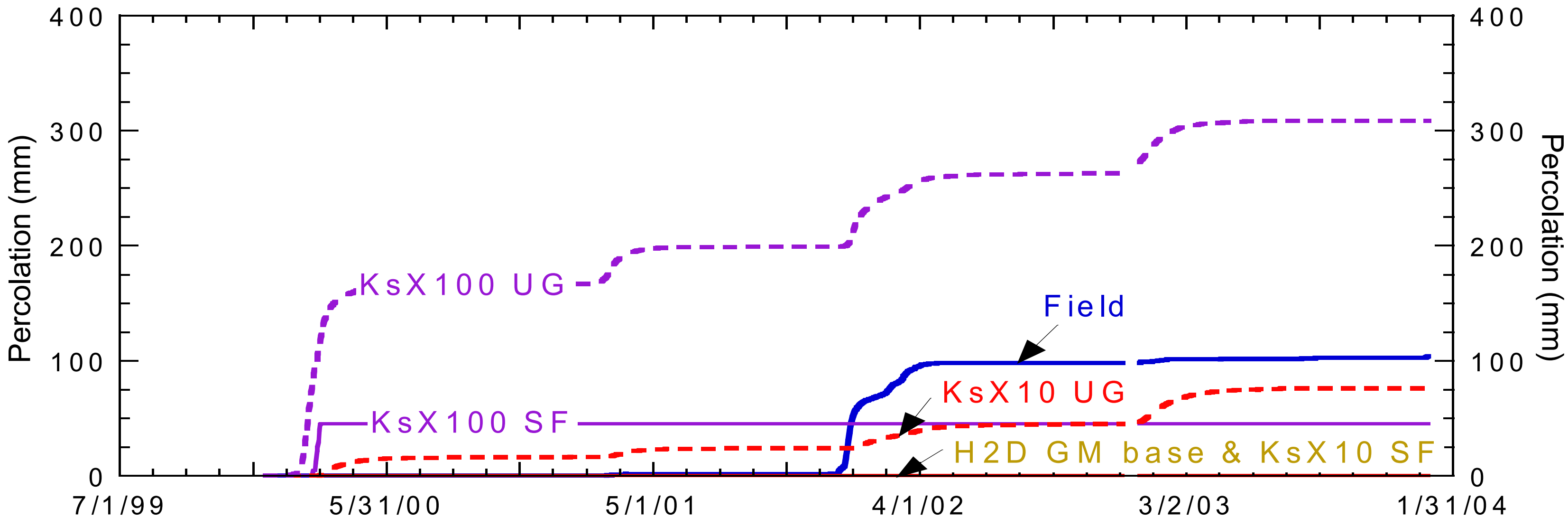
LAI – LOW (LAI > 1) <u>*or*</u> MODEST (LAI < 1)
RLD – LOW (use design value or GM field value)
Root Depth – MODEST (roots penetrate entire cover)
Growing Season – HIGH (local specialist & literature)



Sensitivity Analysis

Lower Boundary:

HIGH - use unit gradient boundary for design



UG = unit gradient

SF = seepage face

Sensitivity Analysis & Design Recommendations

Meteorological Conditions:

Precipitation ±10%: LOW

Design: (i) wettest year on record 5x, (ii) snowiest year on record 5x, (iii) wettest 10 yr period on record

Summary of Sensitivity Analysis

1. Model predictions are very sensitive to hydraulic properties (K_s, α, n). See case history discussion for recommendations.

2. The n parameter is strong influence but is difficult to define with accuracy. Increase n by 10% from lab measurement to be conservative.

3. Use ℓ = -1 to -5 in the VG-M model for unsaturated hydraulic conductivity.

4. LAI and root density shape not particulary important (if LAI > 1). Extend roots to depth of cover. Define growing season using local expertise.

Summary of Sensitivity Analysis

5. Prediction very sensitive to lower boundary. Use unit gradient boundary for most design simulations.

6. Local NWS data usually is sufficent. Spend time picking design data for simulations.

Question: Can we predict the water balance of alternative covers using numerical models?

Answer: Yes. Conservative predictions can be made using carefully selected input parameters. Conduct sensitivity analyses to identify the critical conditions affecting design.

Acknowledgements

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