Near-Term Hydrological Performance Modeling of Covers

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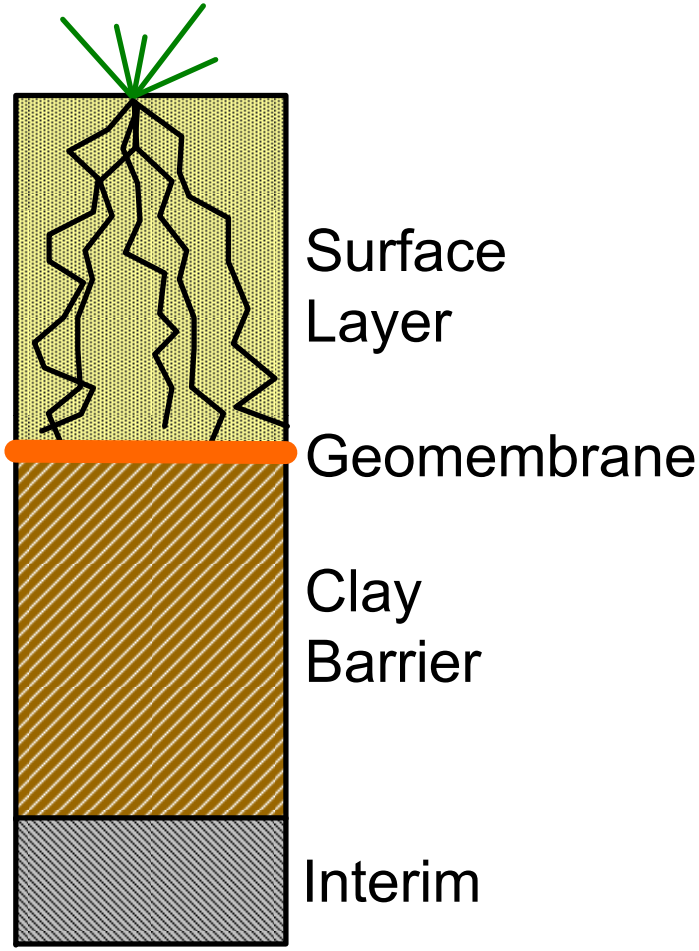
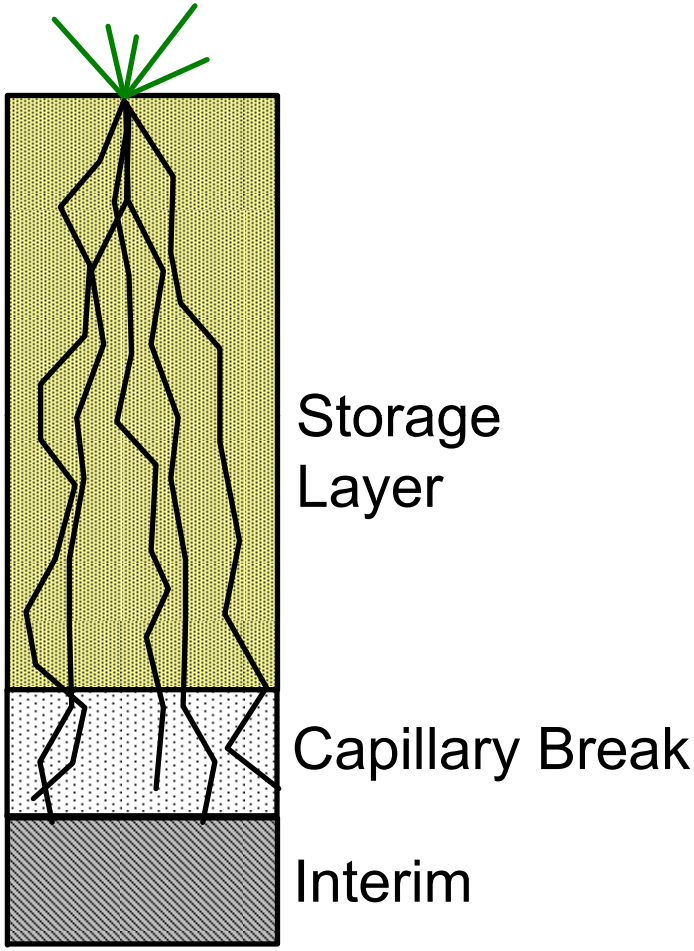
Covers for Waste Containment

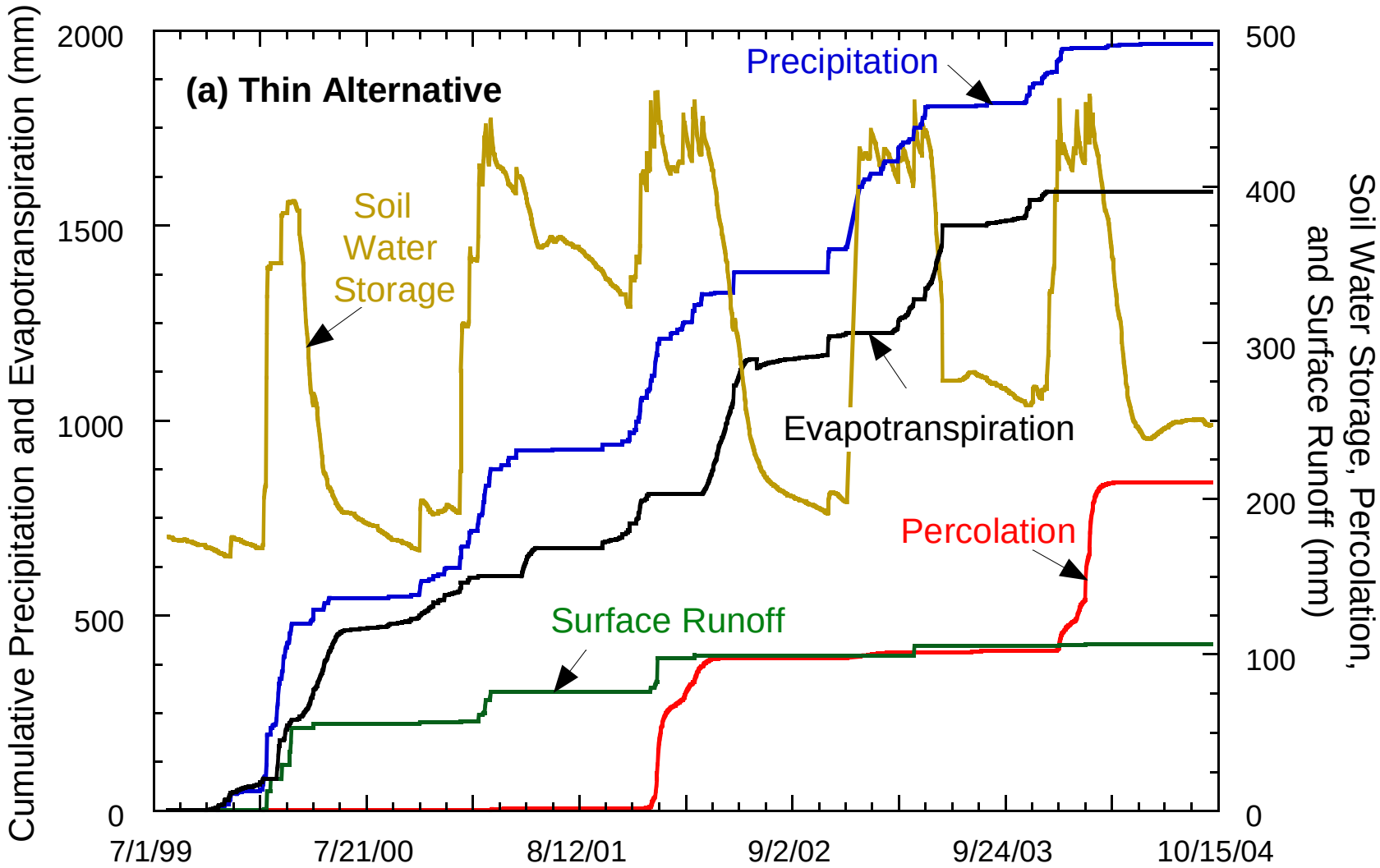


Earthen & Geosynthetic



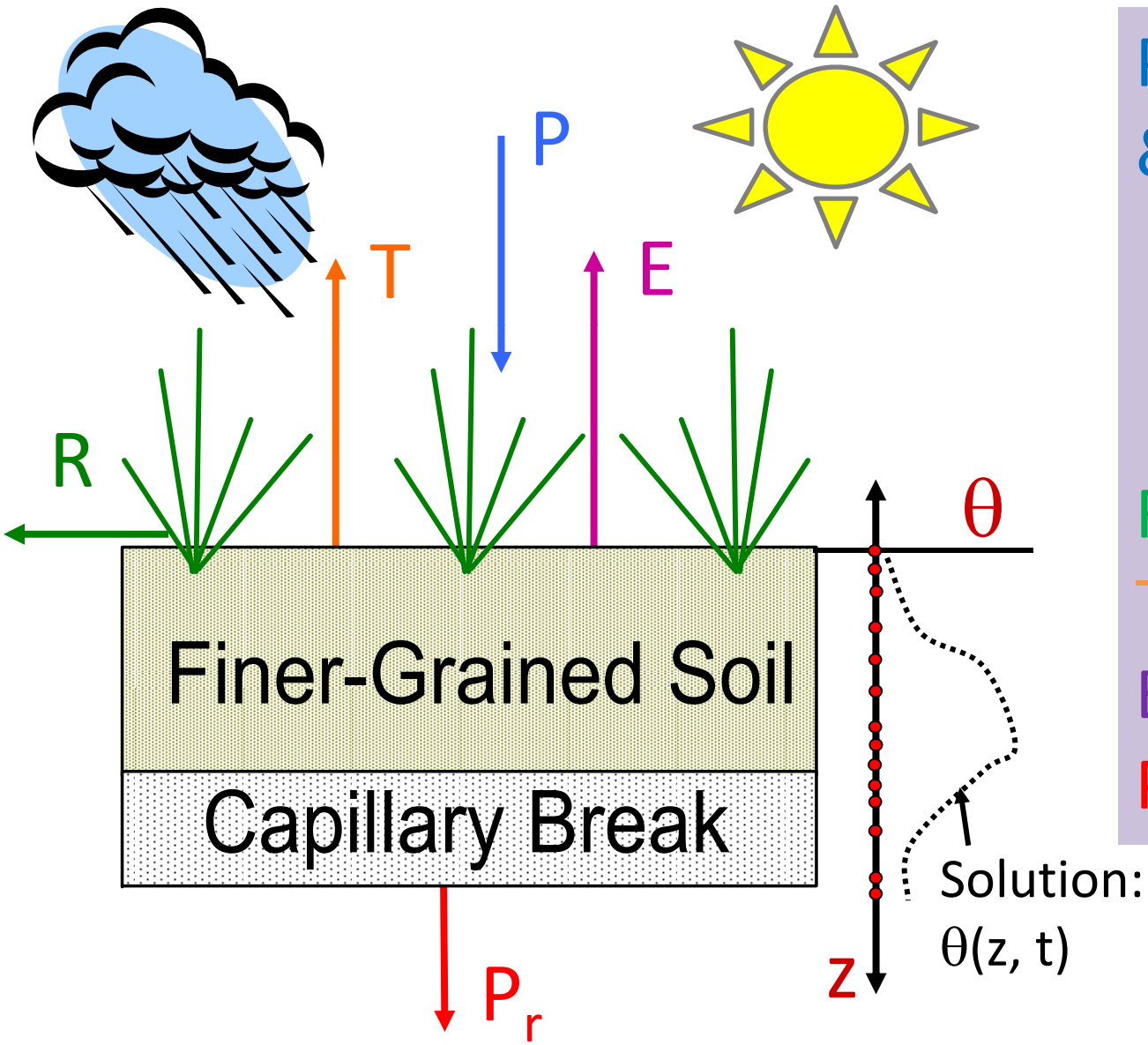
Earthen

Field Data from Water Balance Cover in Sacramento, CA



Can we predict this type of behavior a priori?

Conceptual Model



P = precipitation
& solar radiation

R = runoff
T = transpiration
E = evaporation
P_r = percolation

Modified Richards' Equation

$$\frac{\partial \theta}{\partial t} = \nabla \bullet \left[K_{\psi} \nabla \left(z - \psi \right) \right] - S$$

or

$$C_{\psi} \frac{\partial \psi}{\partial t} = \nabla \bullet \left[K_{\psi} \nabla \left(z - \psi \right) \right] - S$$

Terms: θ = volumetric water content, t = time, K_{ψ} = hydraulic conductivity, ψ = matric suction, z = vertical coordinate, C_{ψ} = specific water capacity, S = sink term for root water uptake.

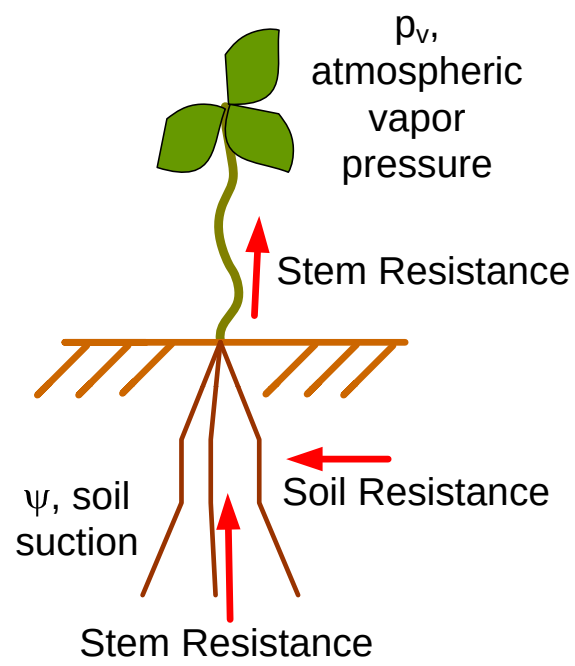
Key assumptions: isothermal, no volume change, liquid flow only

Atmospheric Interaction

- Flux boundary at surface (atmospheric boundary)
  - Infiltration during precipitation
  - Evaporation without precipitation
- Transpiration of water from root zone:
  - Constitutive model of hydraulics around roots
  - Empirical approach using plant limiting function

Transpiration

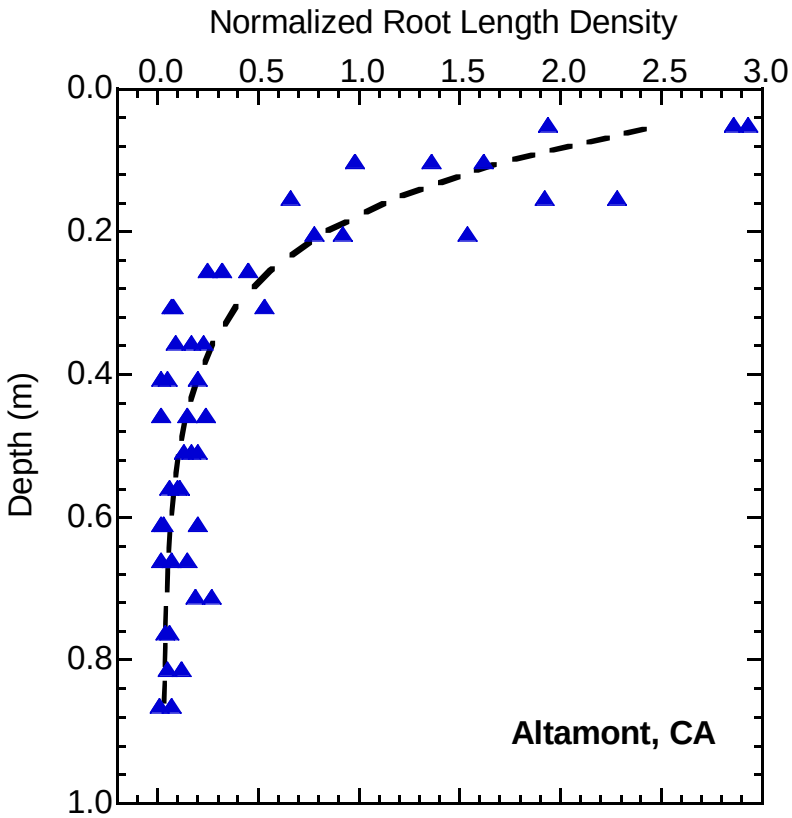
- Constitutive Approach
  - Simulate water uptake thru roots using flow laws in soil and plant
  - Difficult to parameterize



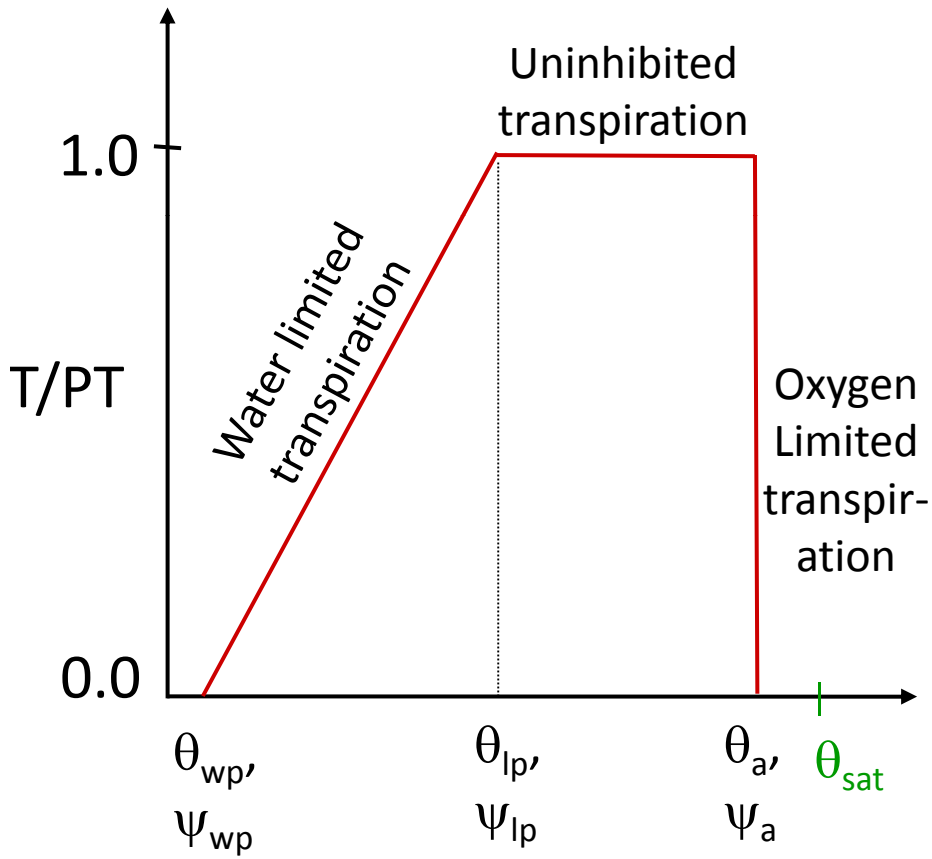
- Semi-Empirical Approach
  - Determine potential transpiration (PT) from PET
  - Distribute PT in root zone by relative root density
  - Account for water stress using plant limiting function

Semi-Empirical Approach

Root Density Function



Plant Limiting Function

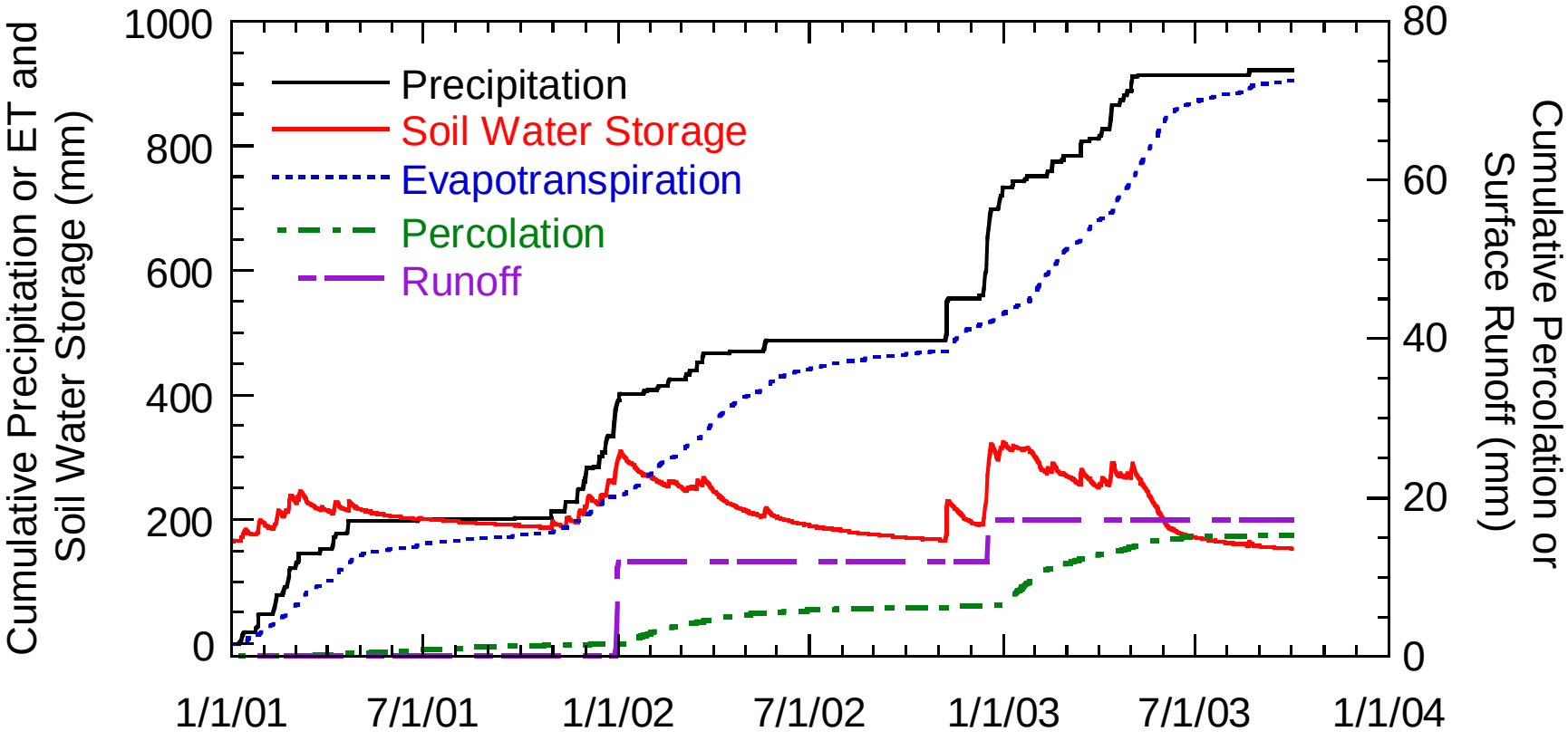


Difficult to Parameterize.

Models Being Used in Practice

Code	Developer	Dimensionality	Interaction Characteristics
HYDRUS	J. Šimůnek	1, 2, or 3D	Evaporation: mechanistic Transpiration: semi-empirical
LEACHM	J. Hutson	1D	Evaporation: mechanistic Transpiration: mechanistic
SVFLUX	M. Fredlund	1, 2, or 3D	Evaporation: suction function Transpiration: semi-empirical
UNSAT-H	M. Fayer	1D	Evaporation: PE approach Transpiration: semi-empirical
VADOSE/W	G. Newman	1D or 2D	Evaporation: suction function Transpiration: semi-empirical

Model Prediction or Reality?



Predictions look real, but are they accurate?

Model predictions are mathematical abstractions! Not facts!

Model Accuracy

- Performance assessment is prediction a priori, which requires a model sufficiently accurate *or conservative* for the design goal (typically 1-10 mm/yr percolation).
- Validation of existing models has been limited.
- Validation requires comparing model predictions to field data, with measured properties used as input.
- Validation is significantly different from calibration. Calibrated models not transferable from site-to-site, or even into the future at a given site.

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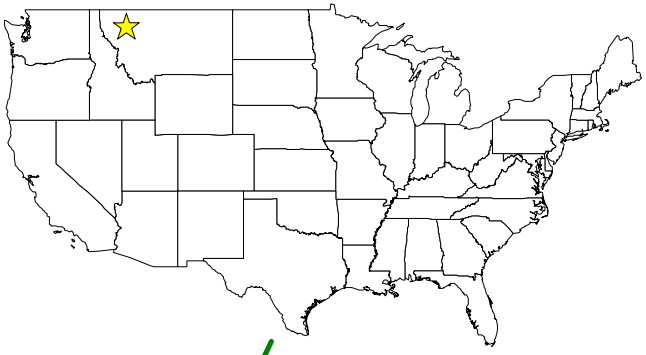
Source of Field Data: Polson, MT

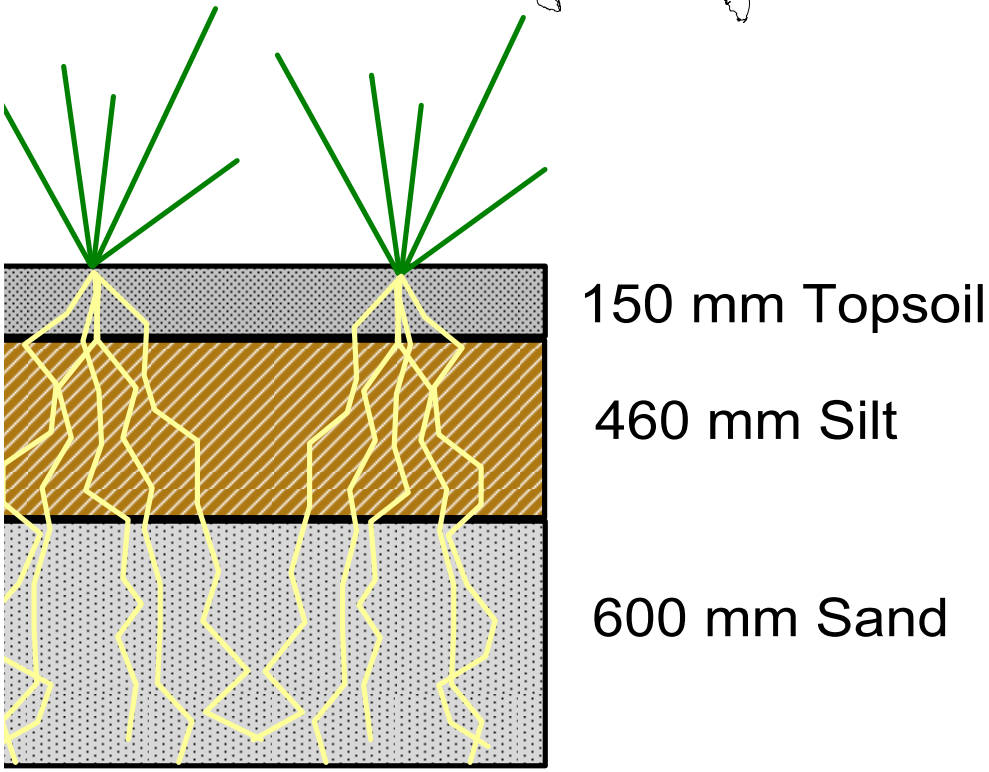
Cool and Seasonal Semi-Humid Climate

Capillary Barrier

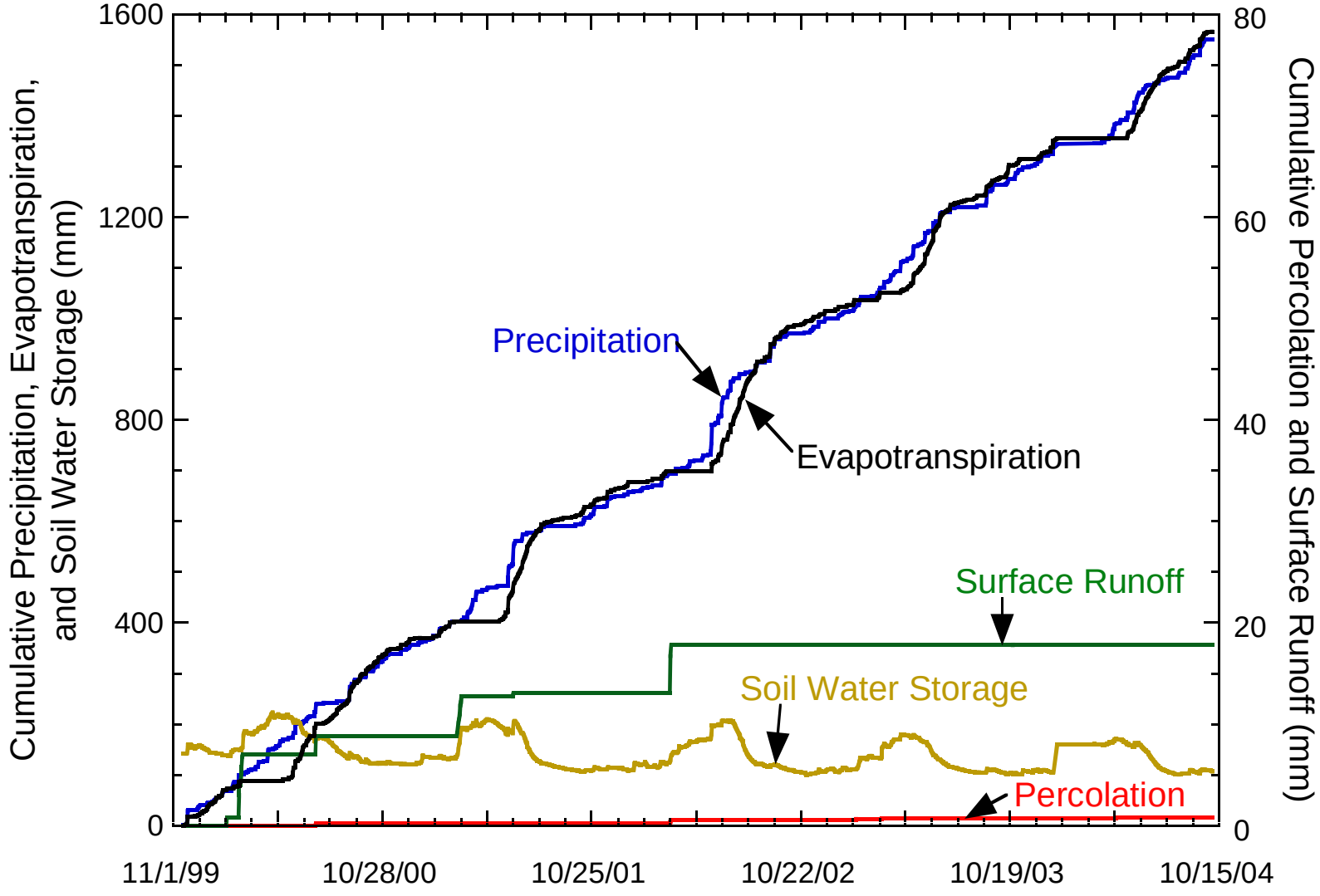
Precipitation ~ 380 mm/yr)

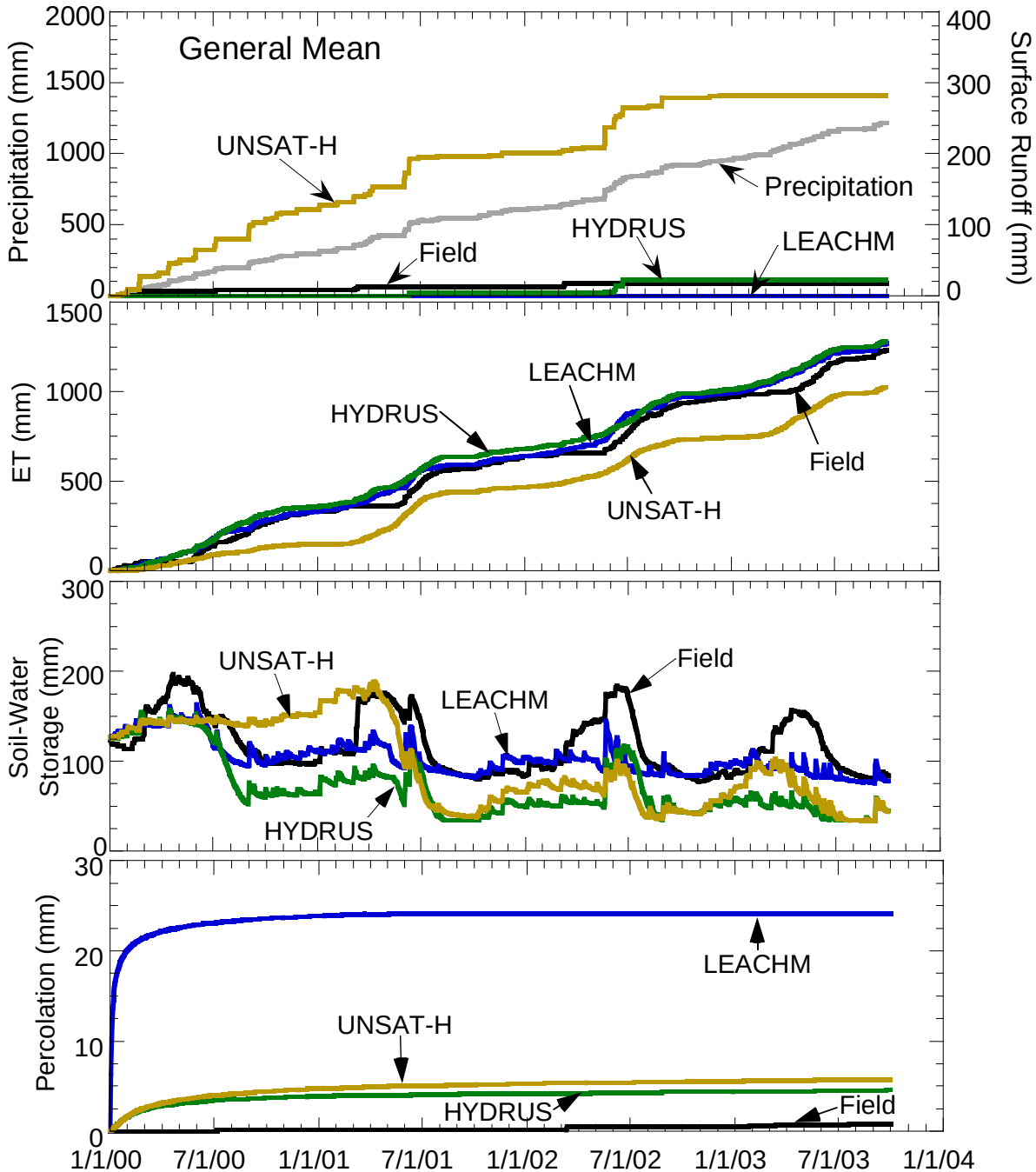
P/PET = 0.58





Capillary Barrier: Polson, MT

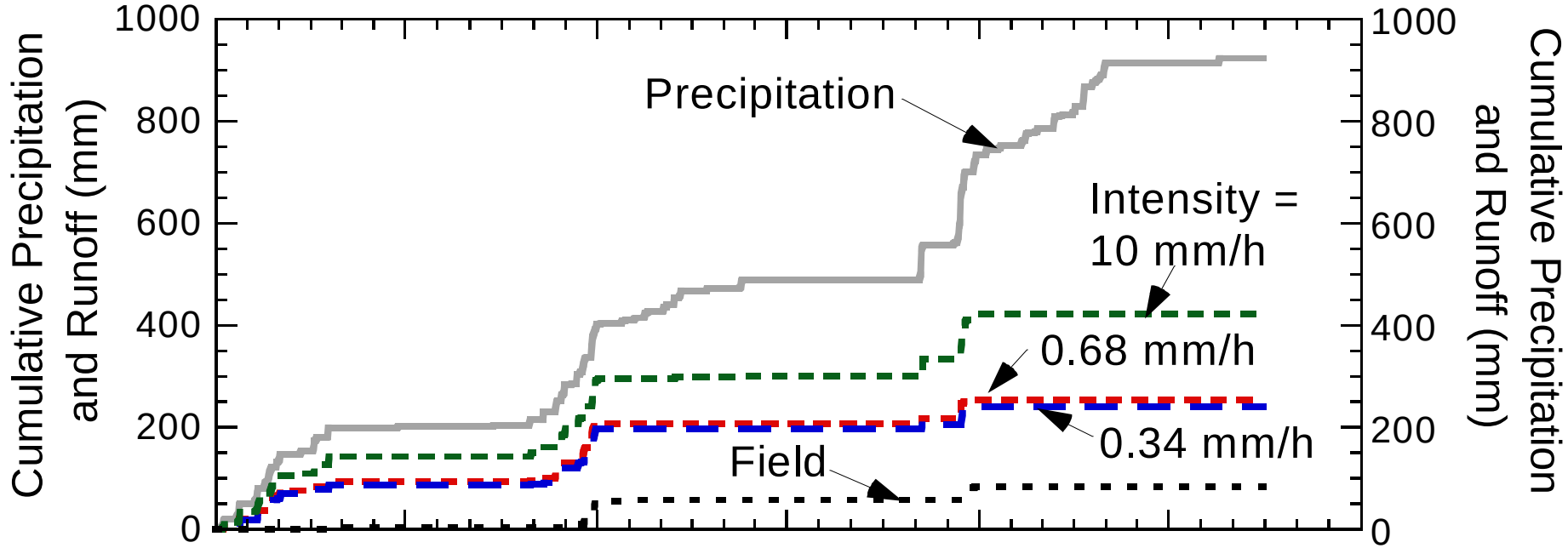




Observations:

- UNSAT-H over-predicts runoff appreciably, LEACHM under-predicts
- ET under-predicted by UNSAT-H, over-predicted by HYDRUS & LEACHM
- None of models capture soil water storage
- Percolation over-estimated by all models
- Seasonal variations captured by all models

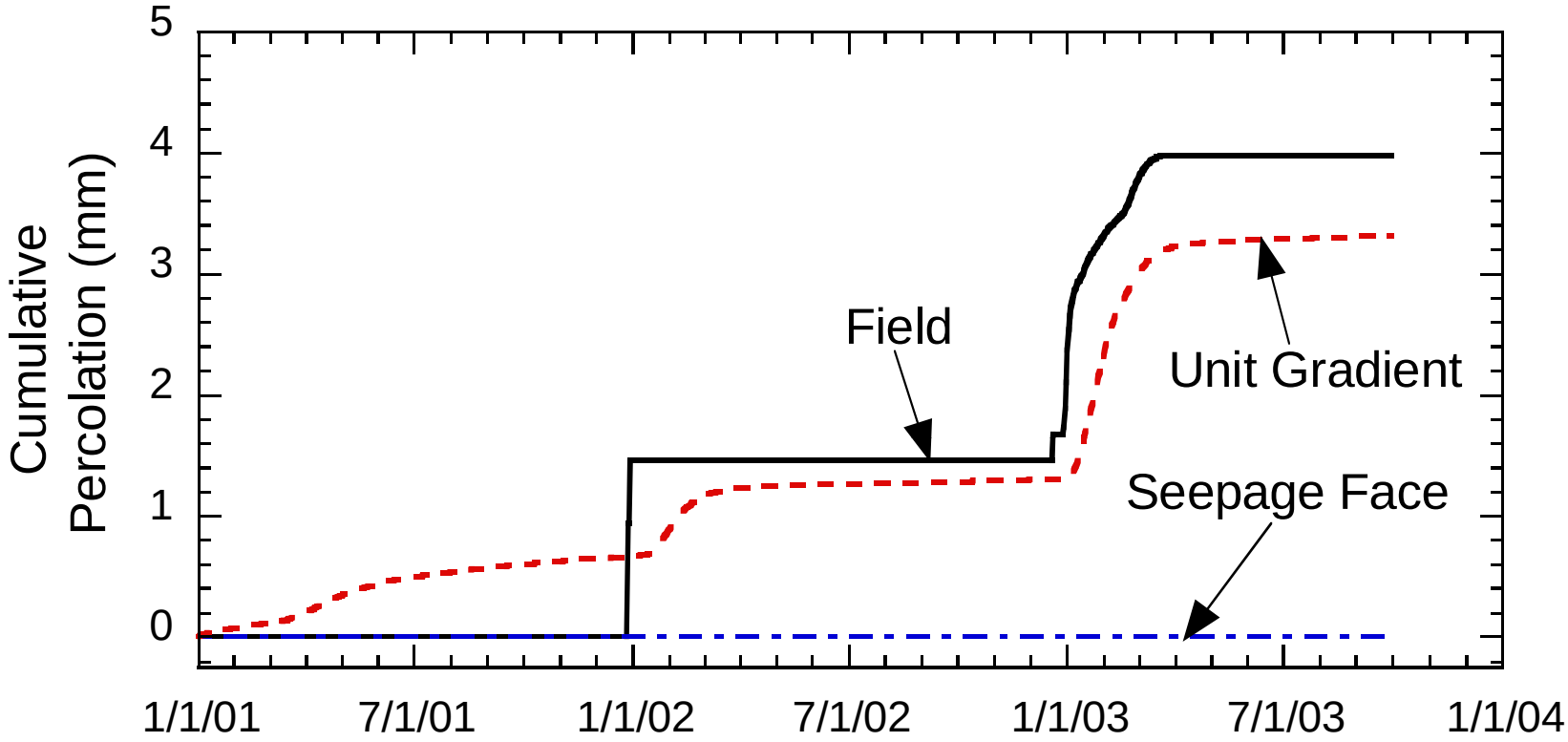
Runoff Intensity – UNSAT-H



Default precipitation intensity = 10 mm/h; field = 0.68 mm/h, on average.

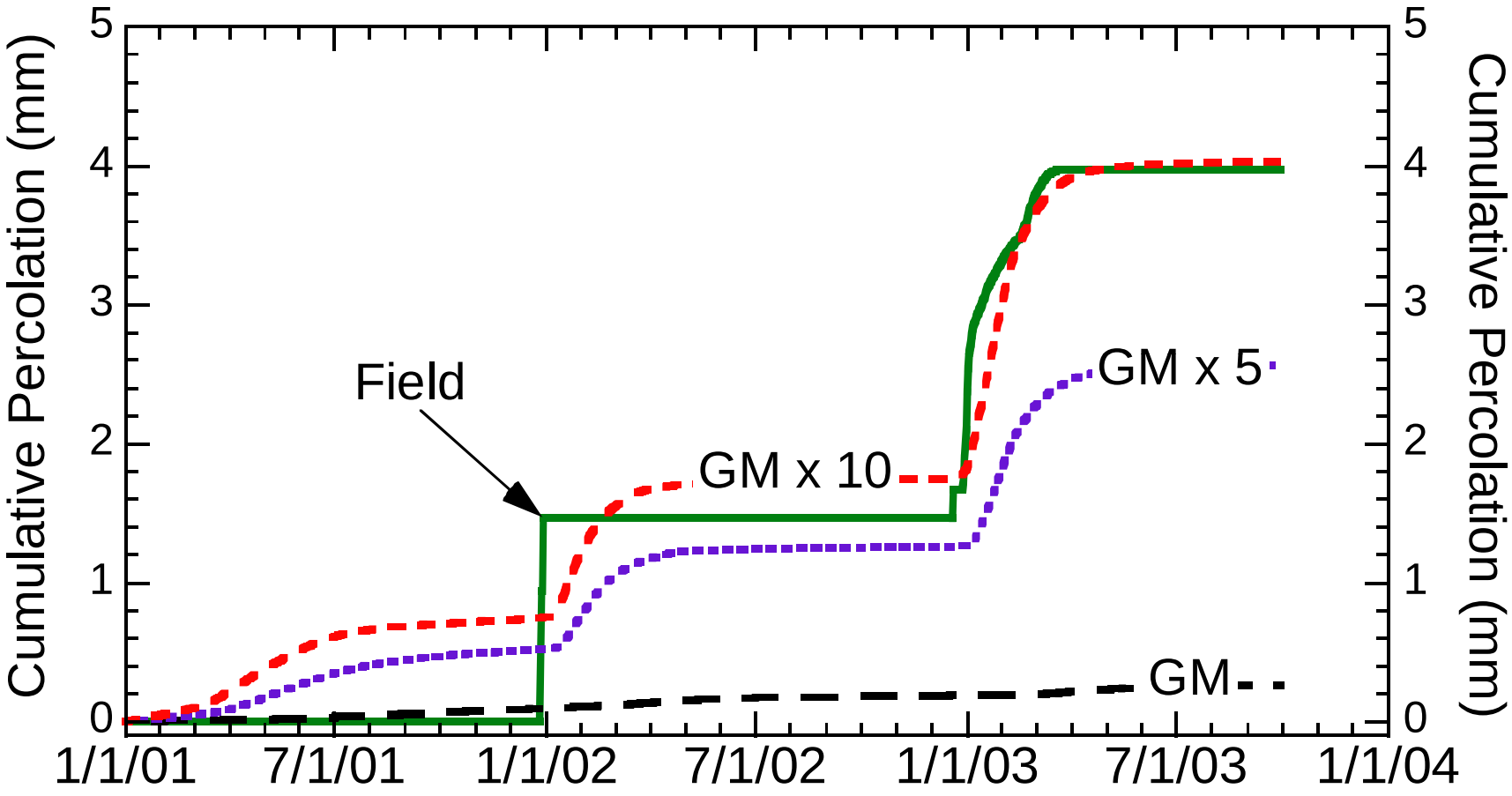
Using average field intensity reduces, but does not eliminate runoff error.

Lower Boundary



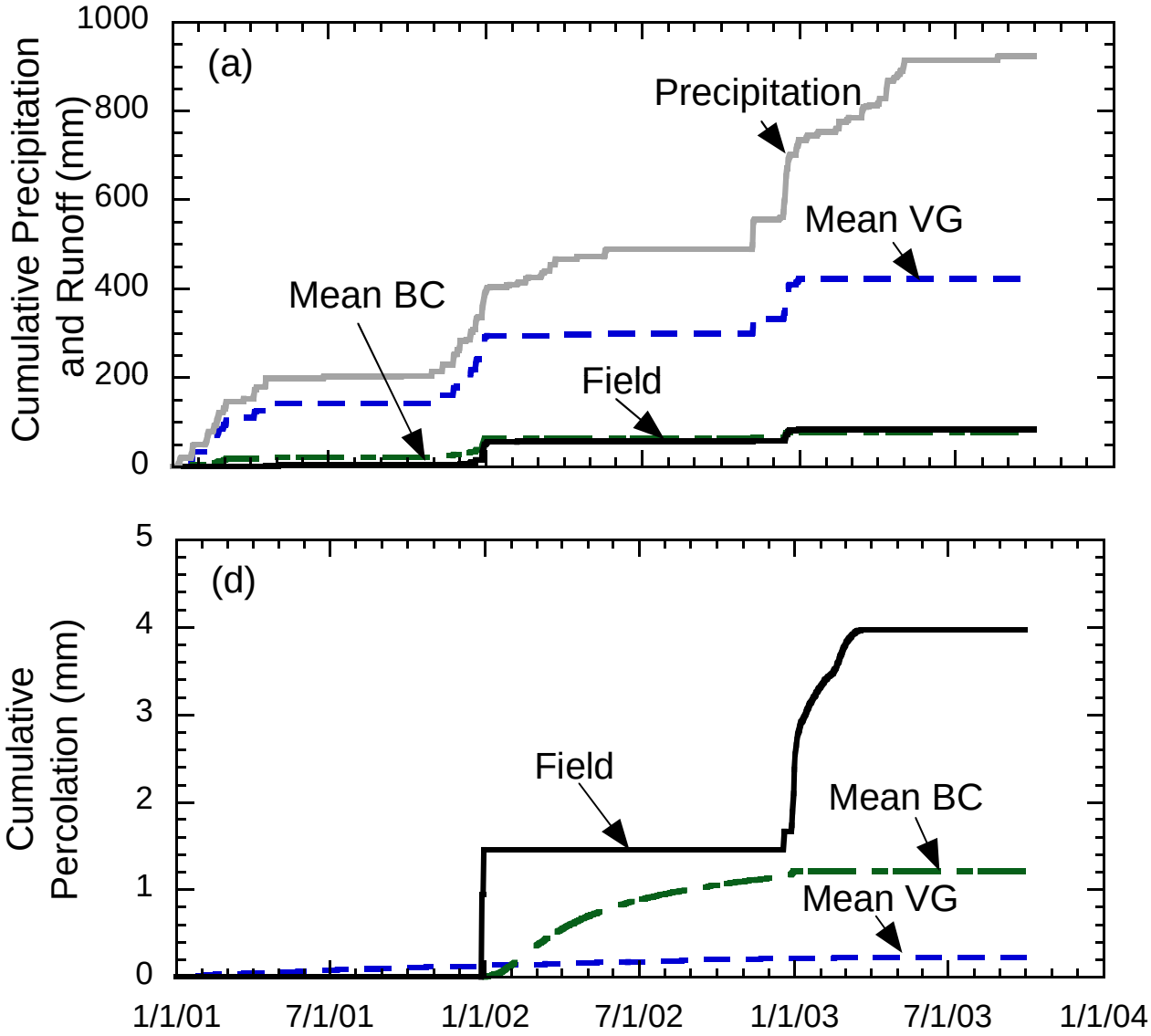
- Unit gradient assumes $q = K_{\psi}$ at lower boundary.
- Seepage face sets $q = 0$ (unsaturated boundary) or $q = K_s$ (saturated boundary).
- Difference is subtle compare to other factors. Unit gradient usually appropriate when modeling cover.

Saturated Hydraulic Conductivity



Model predictions are most sensitive to saturated hydraulic conductivity. Changing saturated hydraulic conductivity over time will affect predictions.

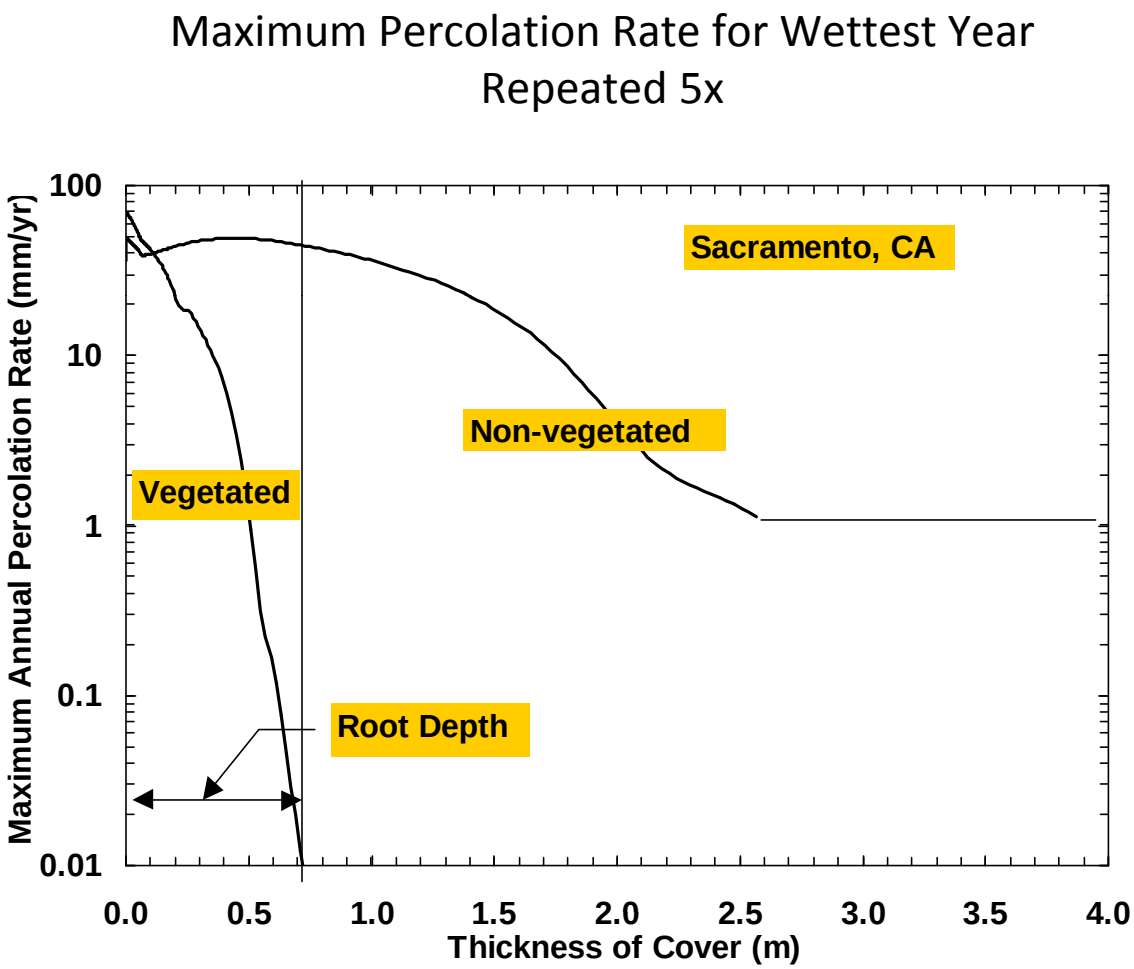
Unsaturated Hydraulic Conductivity Model



Changing unsaturated hydraulic conductivity model results in different runoff.

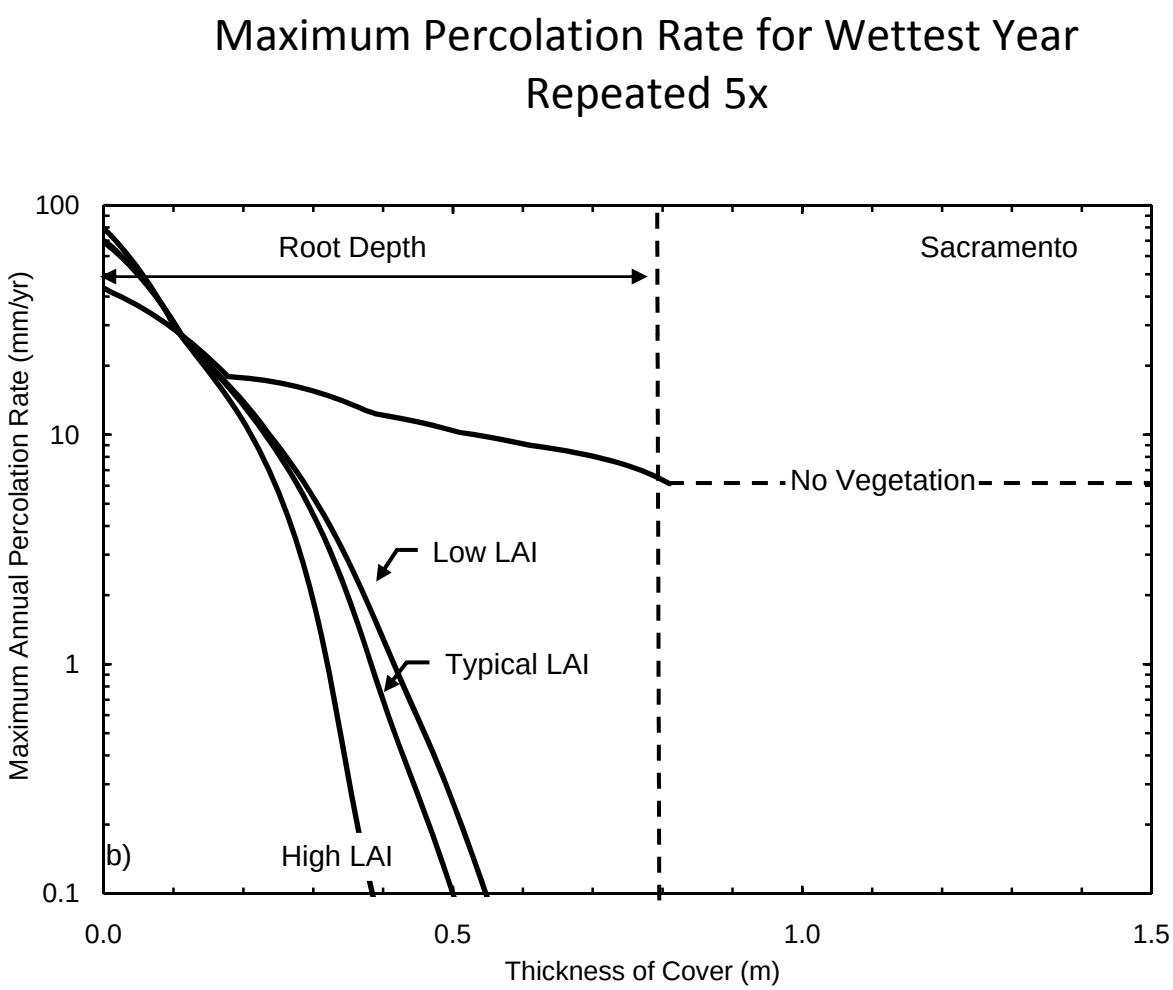
Unsaturated hydraulic conductivity model affects percolation too.

Influence of Vegetation on Percolation



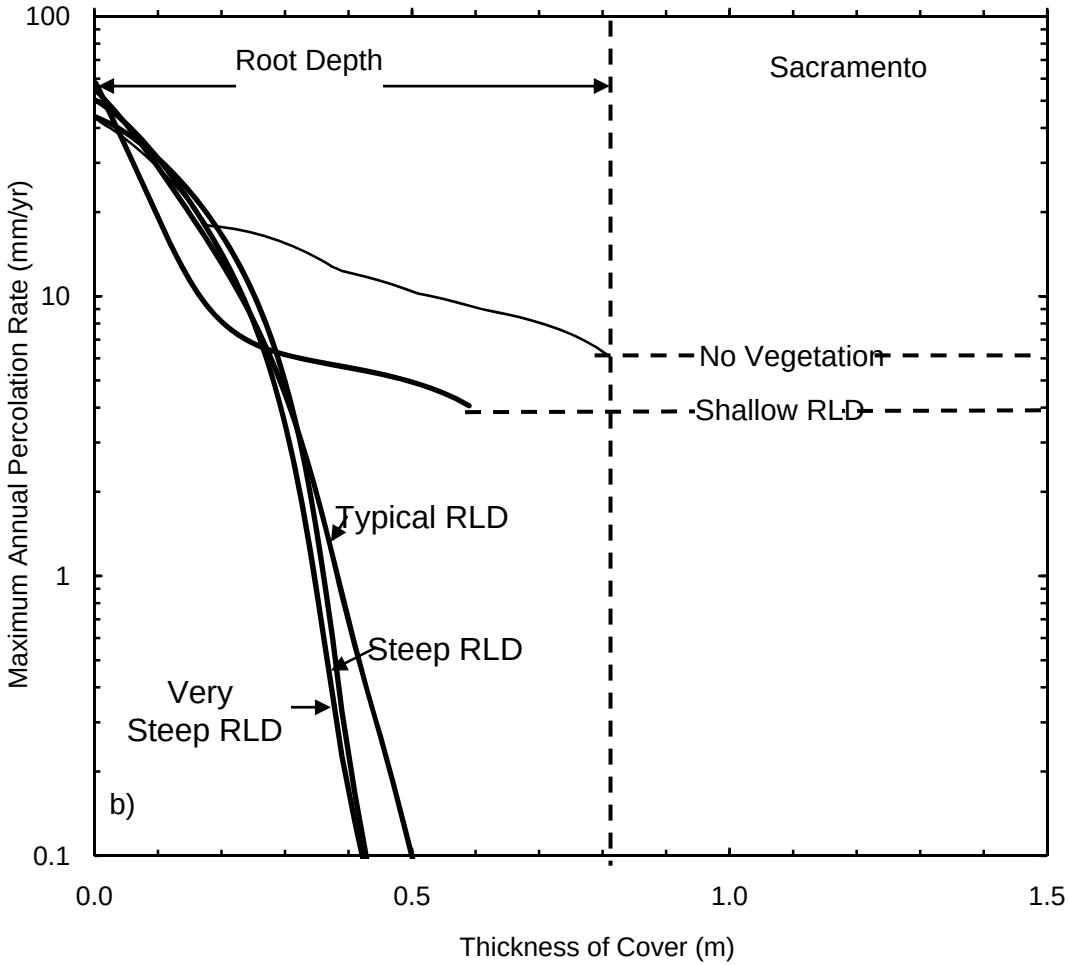
- Parametric simulations conducted by Winkler (1999)
- Illustrates how vegetation pumps water stored within profile.

Sensitivity to Leaf Area Index

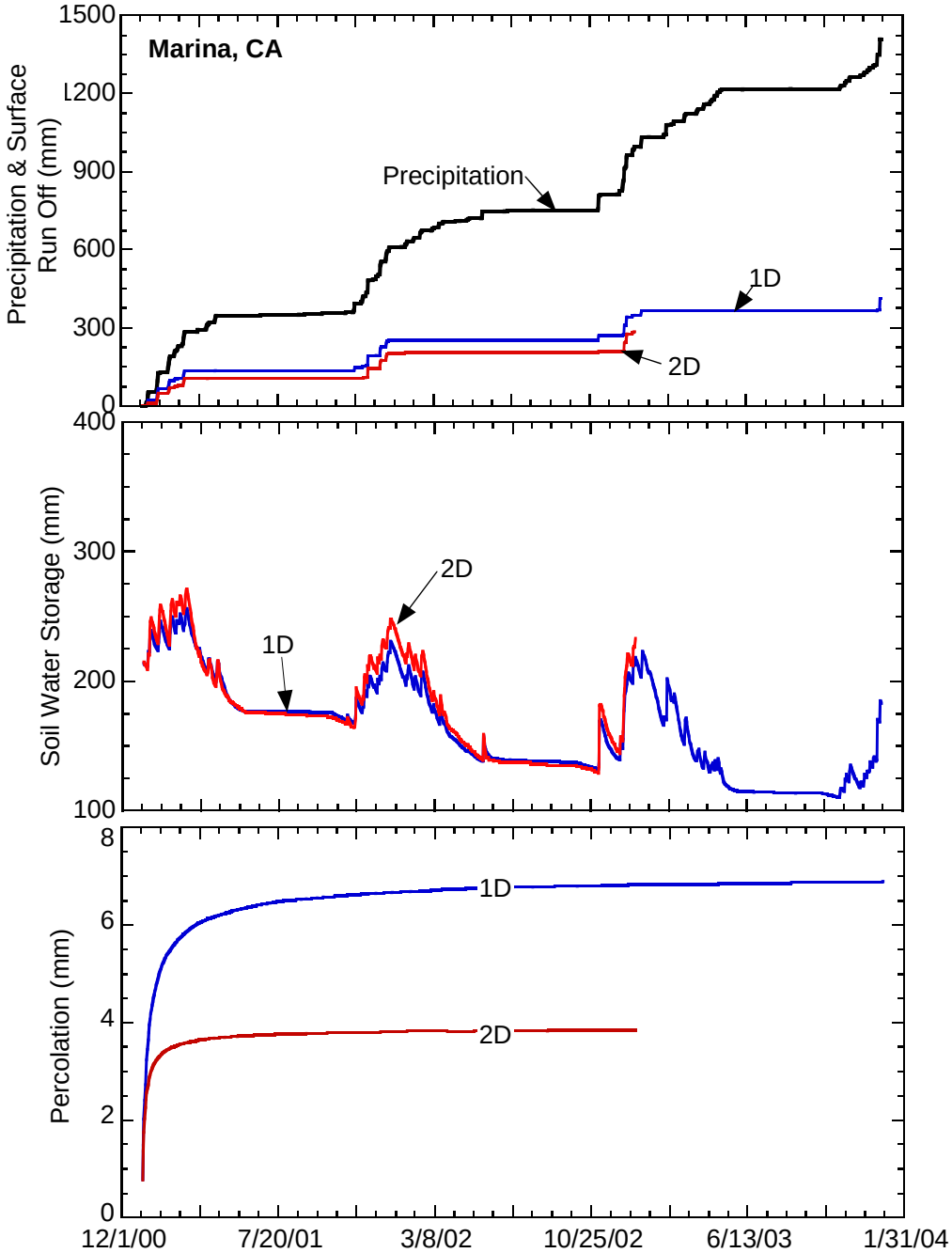


- LAI Used
  - Low = 0.7
  - Med = 1.4
  - High = 5.2
- Not particularly sensitive for reasonable LAI.

Sensitivity to Root Depth & Density Function



- Not very sensitive to RLD provided roots extend through depth of cover.
- Using typical RLD from Winkler acceptable.



Dimensionality:

- Comparison of 1D and 2D predictions for a site with a 4:1 slope.

- Differences between 1D and 2D are relatively small. Generally can use a 1D model for performance assessments.

Take Away Messages

- Hydrology of final covers is driven by seasonality rather than annual quantities or discrete events. Account for seasonal behavior in models.
- Predictions are sensitive to assumed boundary conditions. Ensure conditions replicate field with reasonable realism.
- Models are very sensitive to hydraulic properties used as input (magnitude and constitutive model). Select hydraulic properties that are as realistic as practical.
- Models are not particularly sensitive to vegetation characteristics, even though vegetation has a major role in managing water. This can be done better.

Take Away Messages

- Monte Carlo simulation cannot address model inaccuracy and bias. Monte Carlo simulation is useful for understanding how uncertainty in inputs affects predictions, but only in context of model formulation.
- Model predictions are not reality. Monitoring by engineering function is essential to ensure objectives are being achieved.