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Document Details:

Title:	ERID-097054 1) PRELIMINARY DESIGN METHODS
ERID Number.StartPage:	ERID-097054
Office of Record:	ENV-ERSS
Date Received:	07/09/2007
Official Use Only:	N
Page Count:	20
Record Type:	Letter
Document Date:	01/01/2007
To:(Addressees - Organization) *(separate multiple values with semicolons)*	N/A
From:(Senders - Organization) *(separate multiple values with semicolons)*	CRAIG H. BENSON, GEO ENGINEERING PROGRAM-UNIVERSITY OF WISCONSIN MADISON
Other Document Number(s): *(separate multiple values with semicolons)*	N/A
TA: *separate multiple values with semicolons)*	N/A
PRS Number(s): *(separate multiple values with semicolons)*	N/A
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Preliminary Design Methods

by

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Preliminary Design Questions

1. How much water needs to be stored?

 - Identify critical meteorological years
 - Define precipitation to be stored

2. How much water can be stored?

- Define the storage capacity
- Relate to measurable soil properties

3. How much water can be removed?

- Assume cover has vegetation
- Relate to soil properties

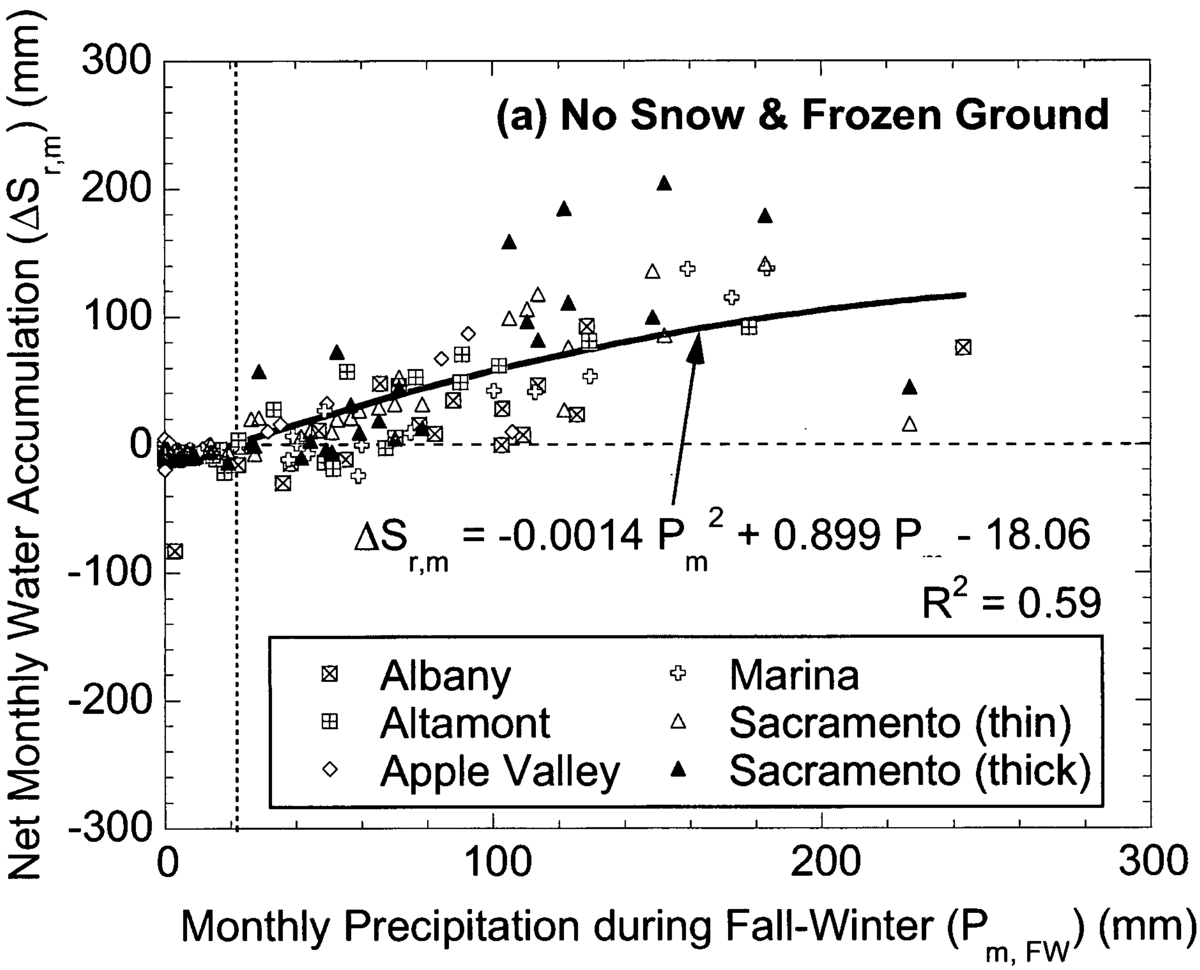
Required Storage:
Design Year

Typical Design Scenarios:

- Wettest year on record ★ - most common
- Year with highest P/PET
- Snowiest winter ★ - relevant to modeling
- Combinations
- Wettest 10 yr period ★ - relevant to modeling

Monthly Water Accumulation

Define climatic thresholds corresponding to water accumulation in the cover



Example: for Fall-Winter months at sites without snow, water accumulates in the cover when the monthly precipitation (P_m) exceeds 21 mm, on average.

Thresholds for Water Accumulation

Climate Type	Season	Monthly Climate Variable	Threshold
No Snow & Frozen Ground	Fall-Winter	P (mm)	21
		P/PET	0.34
		P-PET (mm)	-61
	Spring-Summer	P (mm)	113
		P/PET	0.97
		P-PET (mm)	19
Snow & Frozen Ground	Fall-Winter	P (mm)	23
		P/PET	0.51
		P-PET (mm)	-20
	Spring-Summer	P (mm)	46
		P/PET	0.32
		P-PET (mm)	-94

Water accumulates in the cover during months when the threshold is exceeded.

Data suggest that P/PET threshold works best.

Computing Required Storage

$$S_r = \sum_{m=1}^{6} \Delta S_{r,m}\Big|_{FW} + \sum_{m=1}^{6} \Delta S_{r,m}\Big|_{SS}$$

Fall-Winter Months | Spring-Summer Months

S_r = required storage

$\Delta S_{r,m}$ = monthly water accumulation in fall-winter or spring-summer

Computing Required Storage

$$S_r = \underbrace{\sum_{m=1}^{6}\left\{\left(P_m - \beta_{FW} PET_m\right) - \Delta_{FW}\right\}}_{\text{Fall-Winter Months}}$$

$$+ \underbrace{\sum_{m=1}^{6}\left\{\left(P_m - \beta_{SS} PET_m\right) - \Delta_{SS}\right\}}_{\text{Spring-Summer Months}}$$

P_m = monthly precipitation

PET_m = monthly PET

β_{FW} = ET/PET in fall-winter

β_{SS} = ET/PET in spring-summer

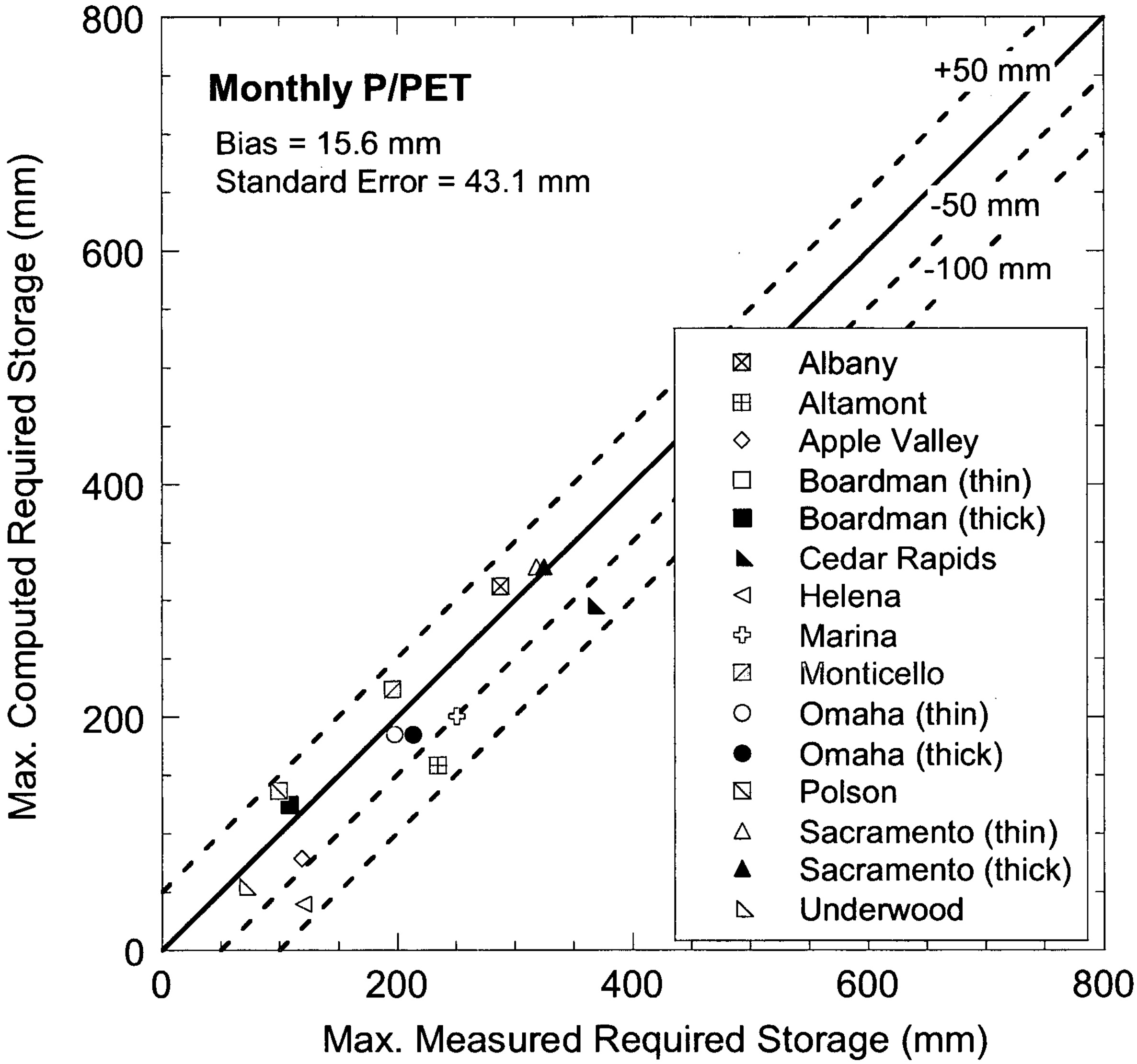
Δ_{FW} = runoff & other losses in fall-winter

Δ_{SS} = runoff & other losses in spring-summer

Parameters for S_r Equation

Climate Type	Season	β (-)	Δ (mm)
No Snow & Frozen Ground	Fall-Winter	0.30	27.1
	Spring-Summer	1.00	167.8
Snow & Frozen Ground	Fall-Winter	0.37	-8.9
	Spring-Summer	1.00	167.8

Predicted and Measured S_r

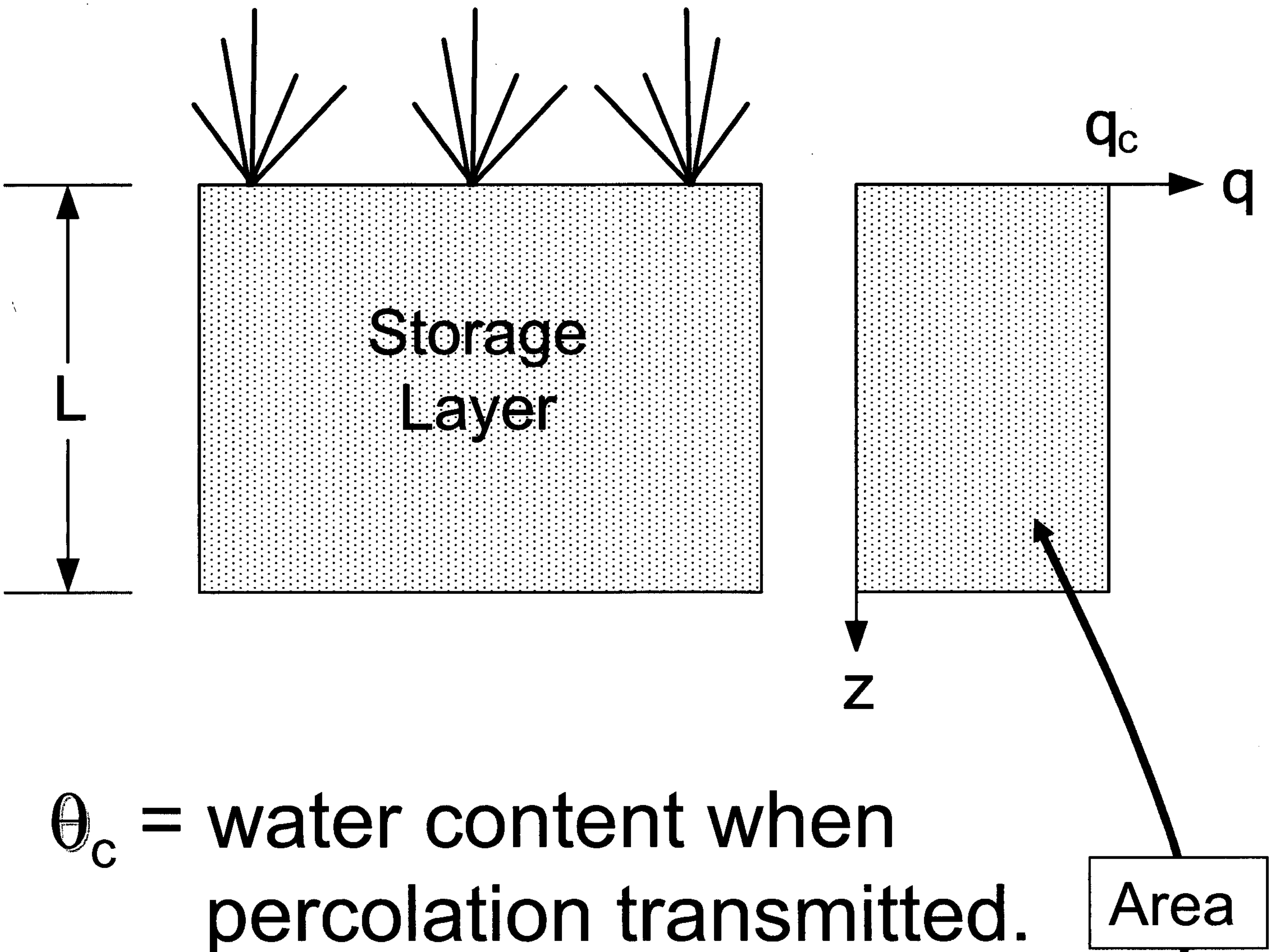


Good agreement between computed and measured required storage.

Add 50 mm for extra FS?

Monolithic Covers: Storage Capacity

What is the storage capacity (S_c)?

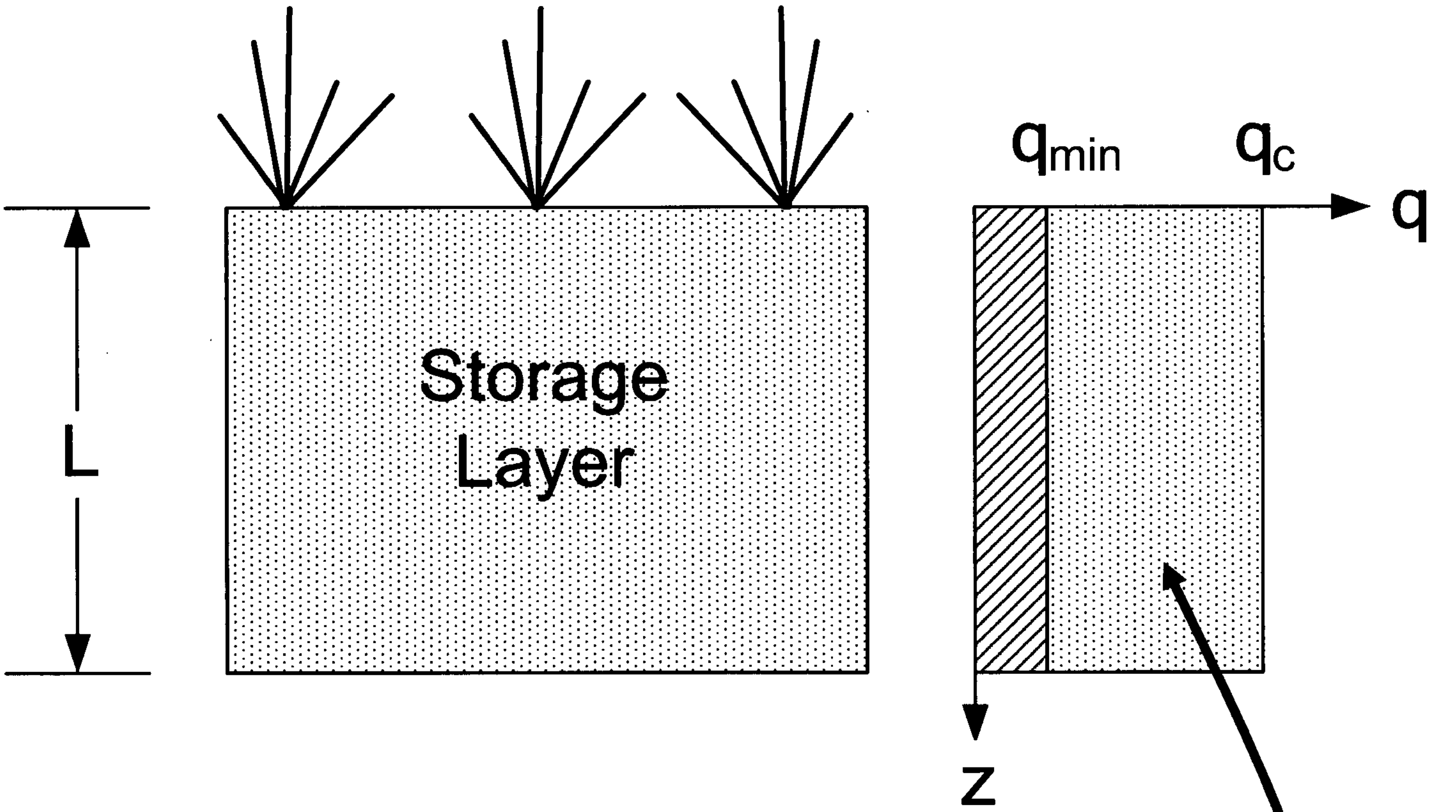


θ_c = water content when percolation transmitted.

$$S_c = \int_0^L \theta_c \, dz \approx \theta_c \, L$$

Monolithic Covers: Storage Capacity

What is the *available* storage (S_a)?

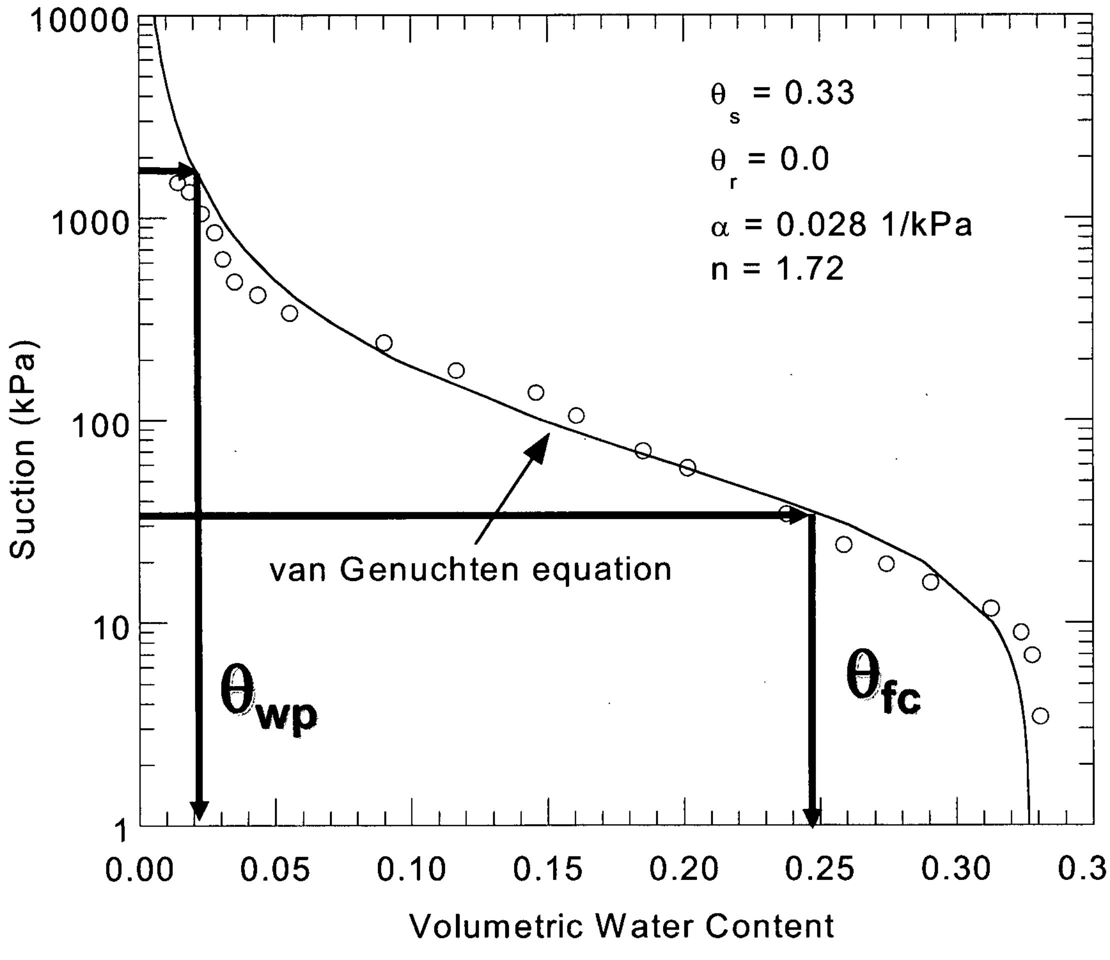


θ_{min} = lowest water content consistently achieved.

$$S_a = \int_0^L \theta_c - \theta_{min} \, dz \approx \left[\theta_c - \theta_{min}\right] L$$

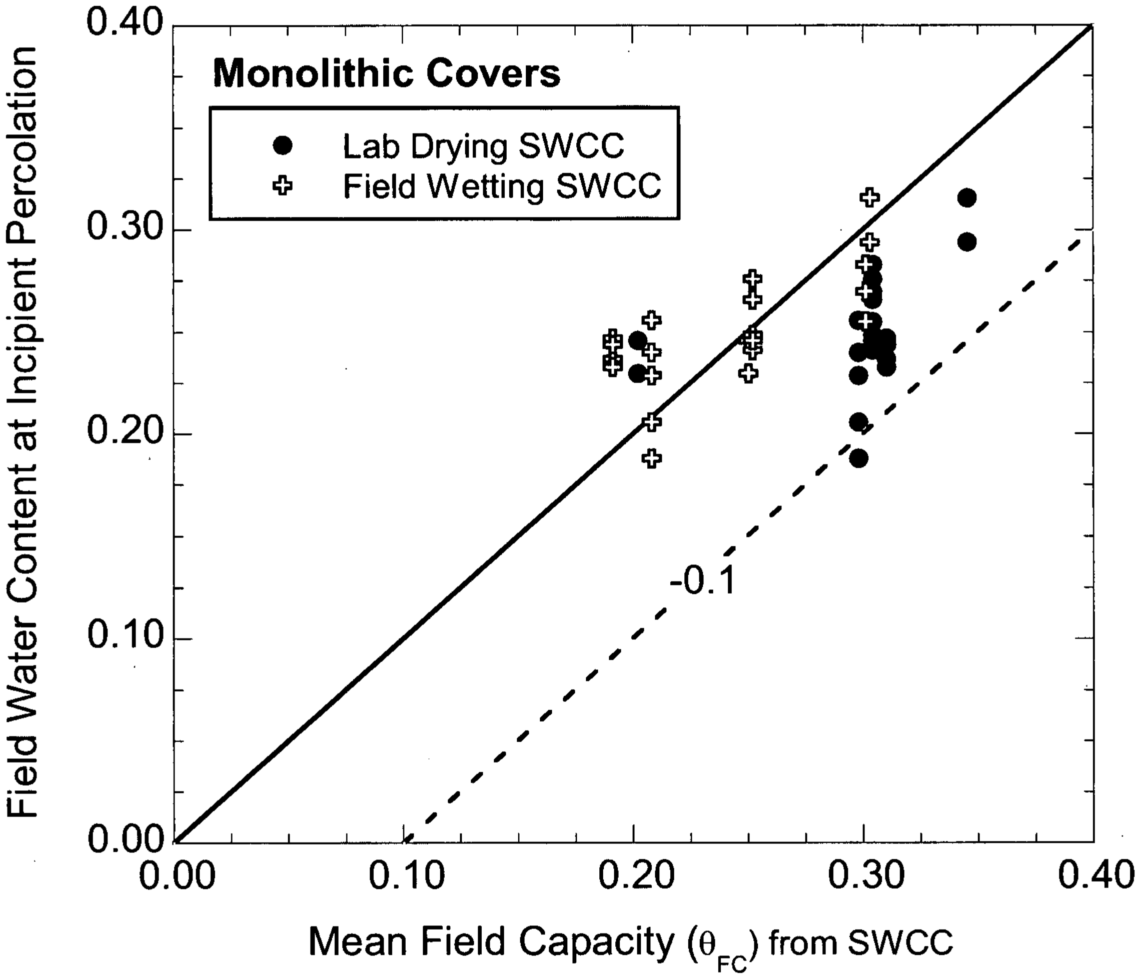
Storage Capacity & Soil Water Characteristic Curve (SWCC)

- Conventionally, θ_c has been defined as the field capacity water content (θ_{fc}) - the water content at 33 kPa suction.
- Conventionally, θ_{min} has been set at the wilting point water content (θ_{wp}) - the water content at 1500 kPa
- Defined using the SWCC, which relates suction and water content.



Lab-to-Field

ACAP data have shown that storage capacity based on laboratory SWCCs can over-estimate actual storage capacity in the field.

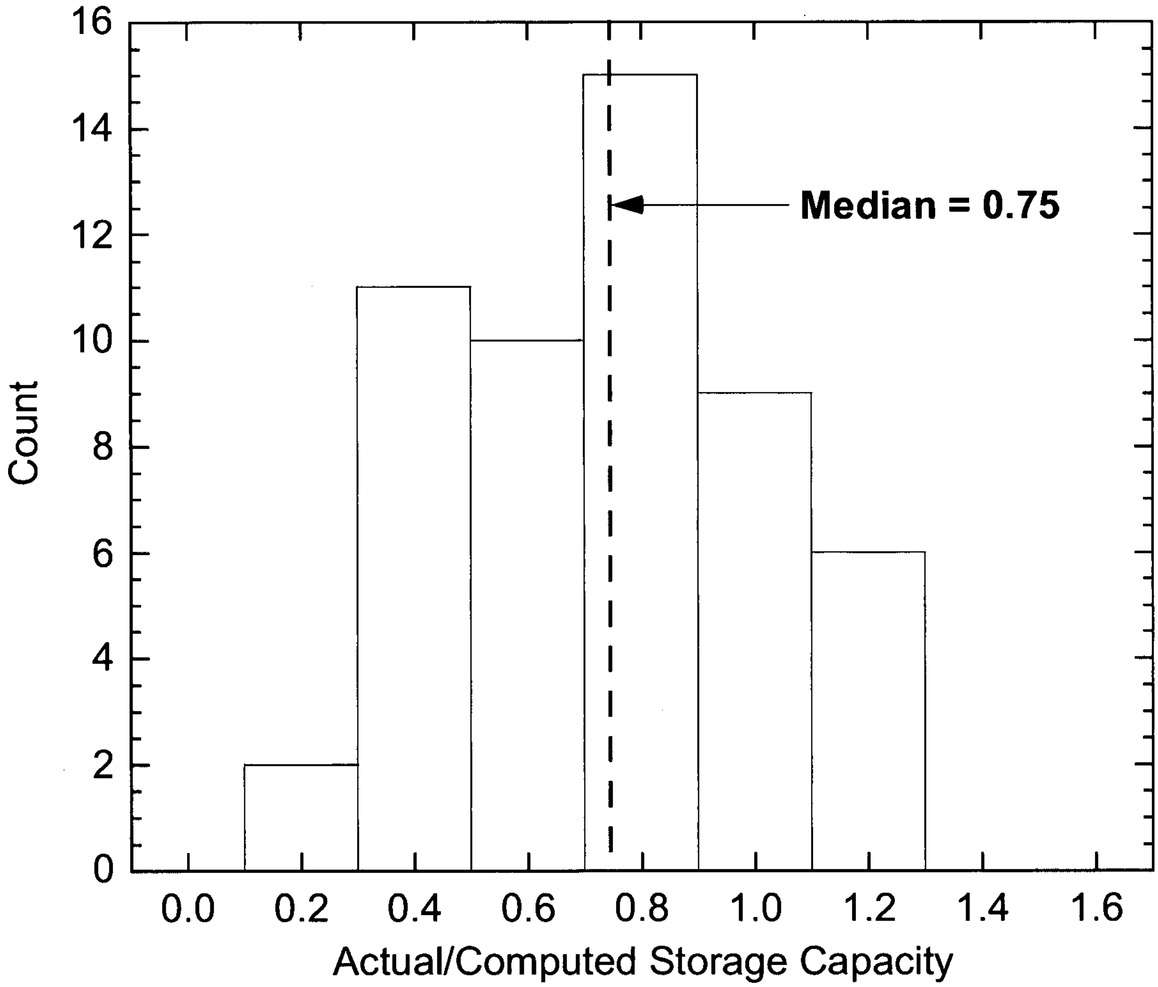


Field-measured SWCC provides better estimate of field capacity.

Simple correction method:

$$\theta_c = F\,\theta_{fc}$$

where θ_{fc} is from laboratory SWCC

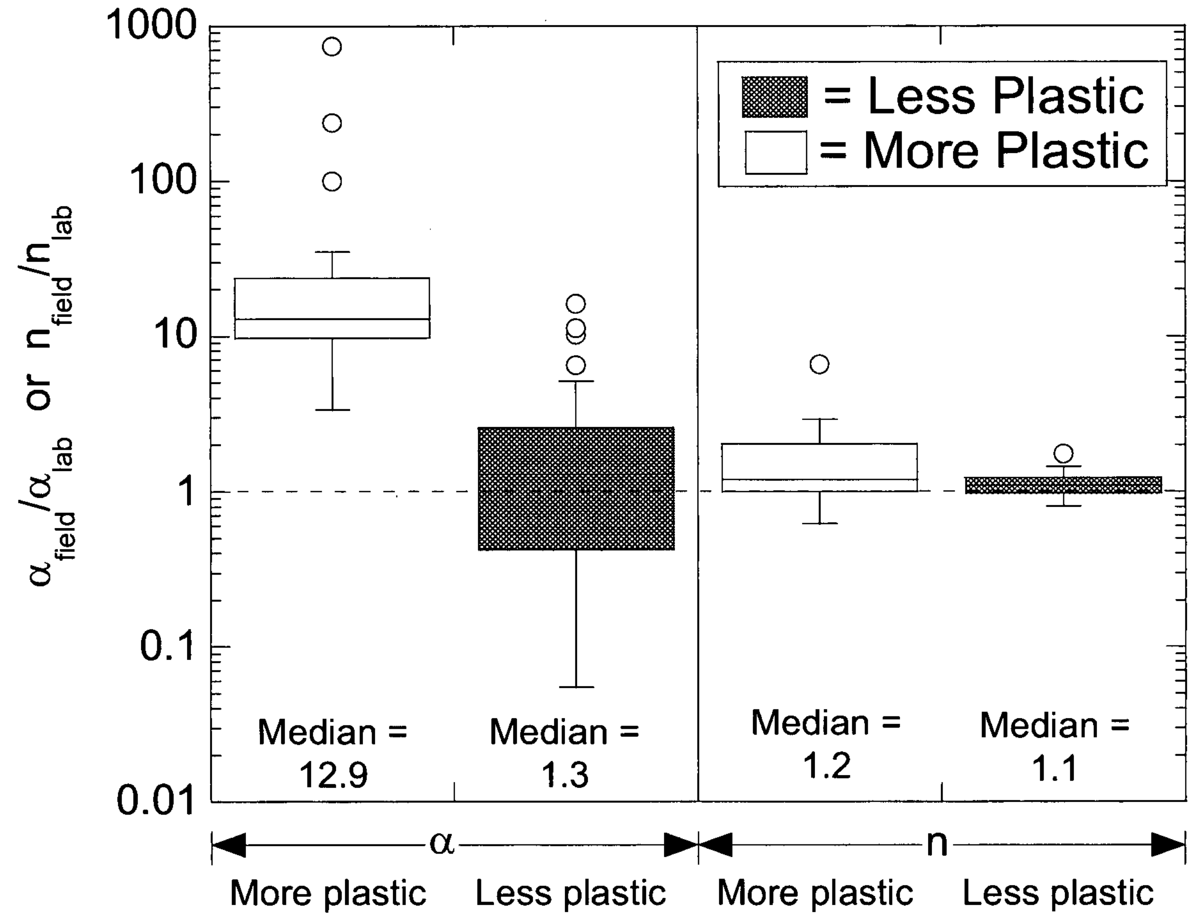


F = 0.75

Better correction method ties field and laboratory SWCCs:

$$\alpha_{field} = F_{\alpha}\, \alpha_{lab}$$

$$n_{field} = F_n\, n_{lab}$$



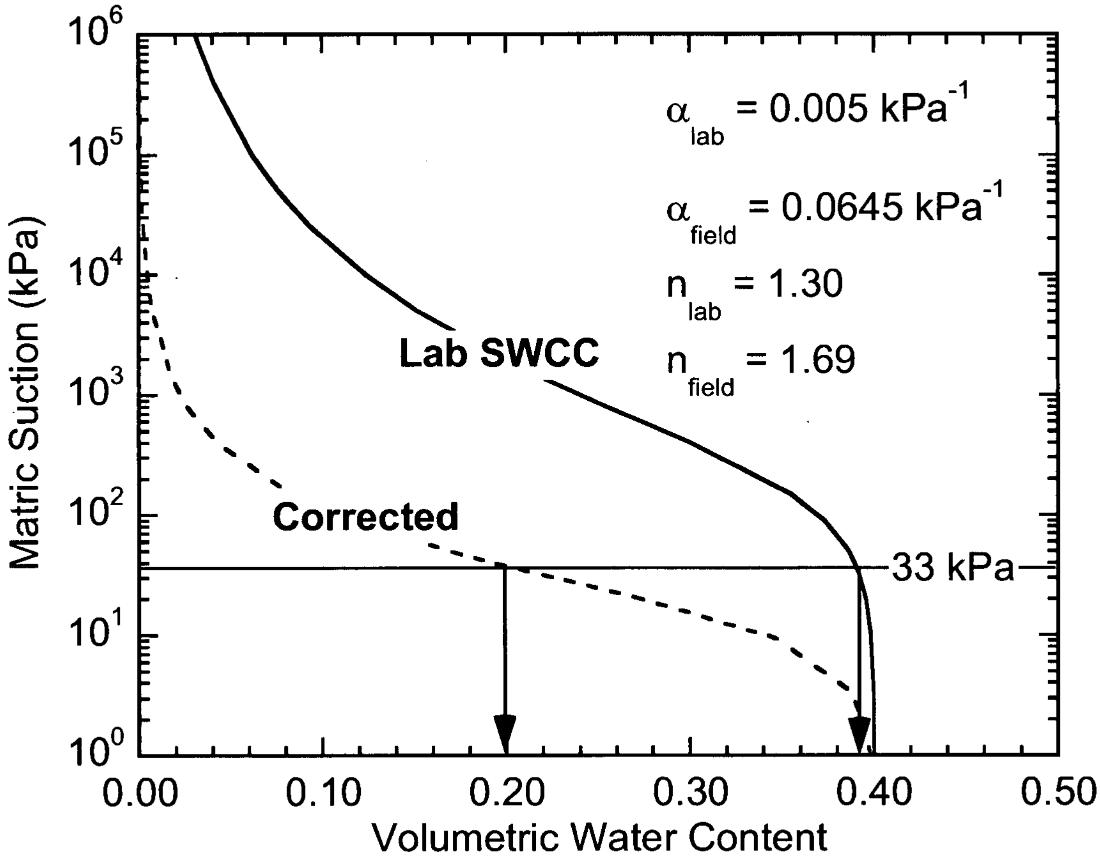
Recommended Correction Factors for α and n: Fine-Textured Soils

Soil Type	F_{α}	F_n
More Plastic	12.9	1.2
Less Plastic	1.3	1.1

More plastic soils – generally classify as clays (CL, CH, MH)

Less plastic soils – generally classify as sands and silts (SM, SC, ML, CL-ML)

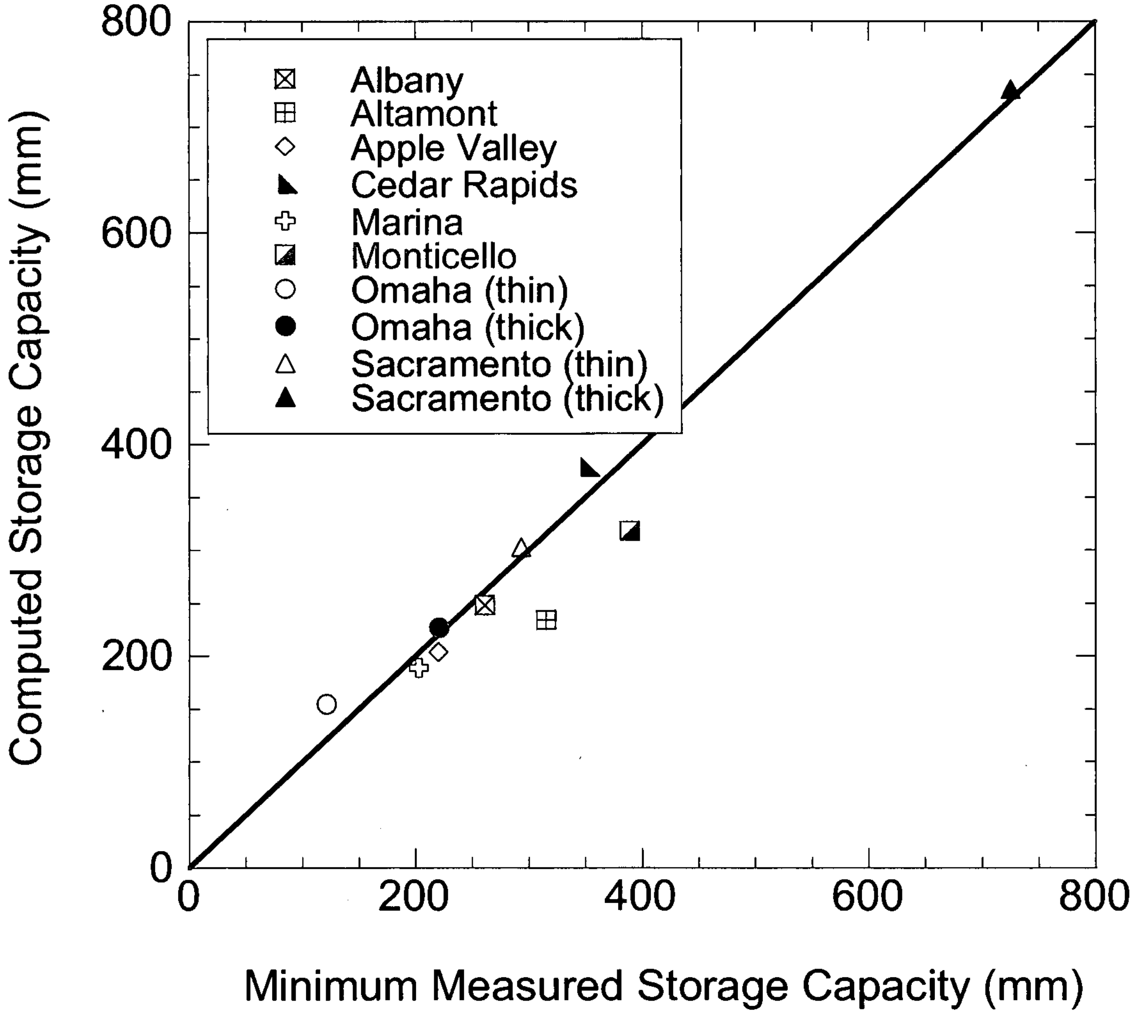
Example of Correction Procedure – More Plastic Soil



Apply F_α = 12.9 and F_n = 1.3

θ_{fc} revised from 0.39 to 0.20

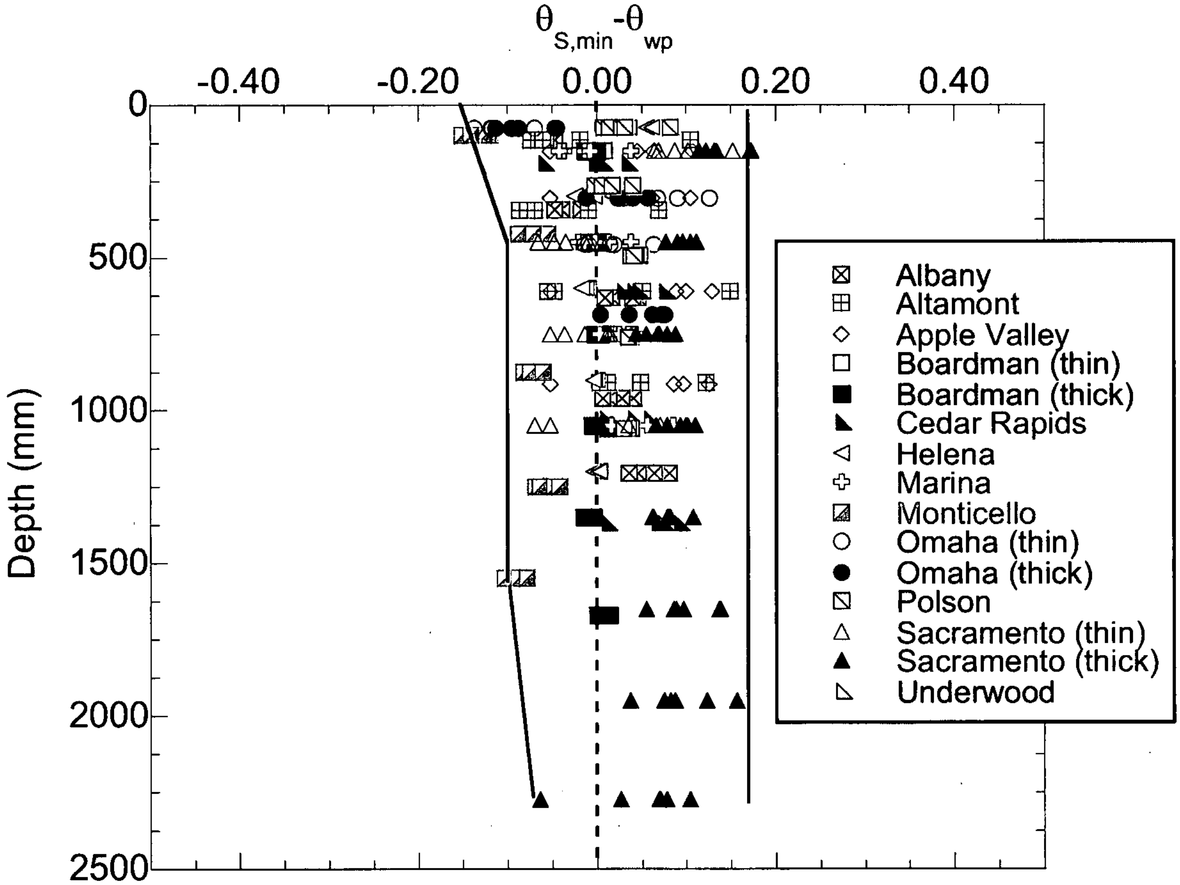
Comparison of Field-Measured and Computed Storage Capacities



Good agreement between computed and field-measured storage capacities when correction applied.

Minimum Water Content

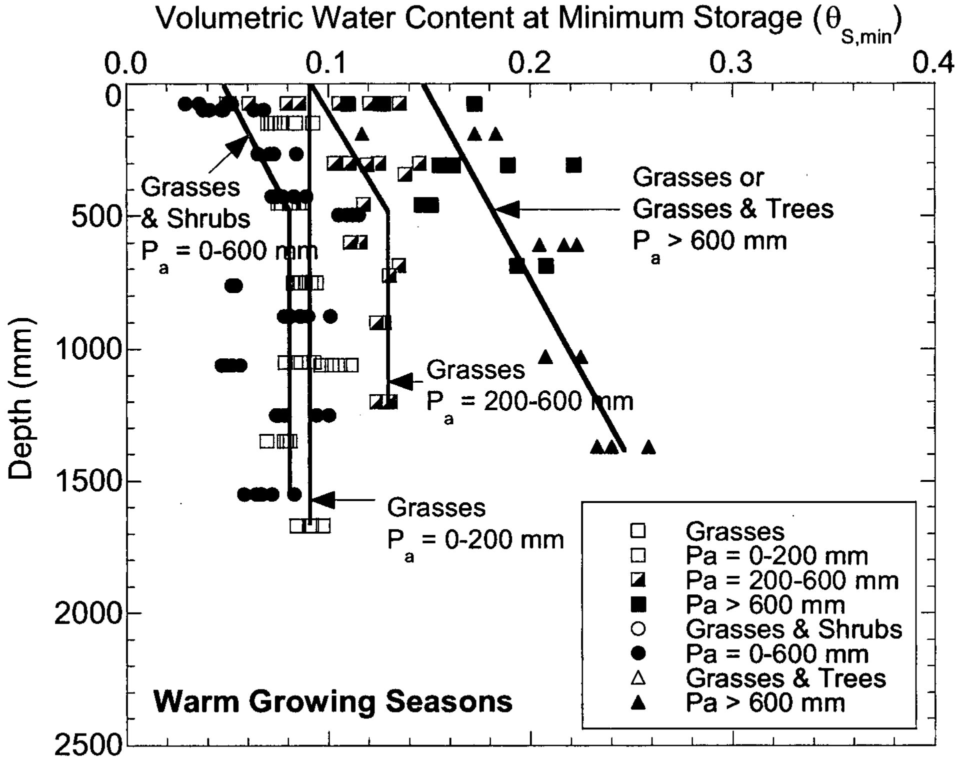
Wilting point water content can be higher or lower than wilting point obtained from lab SWCC.

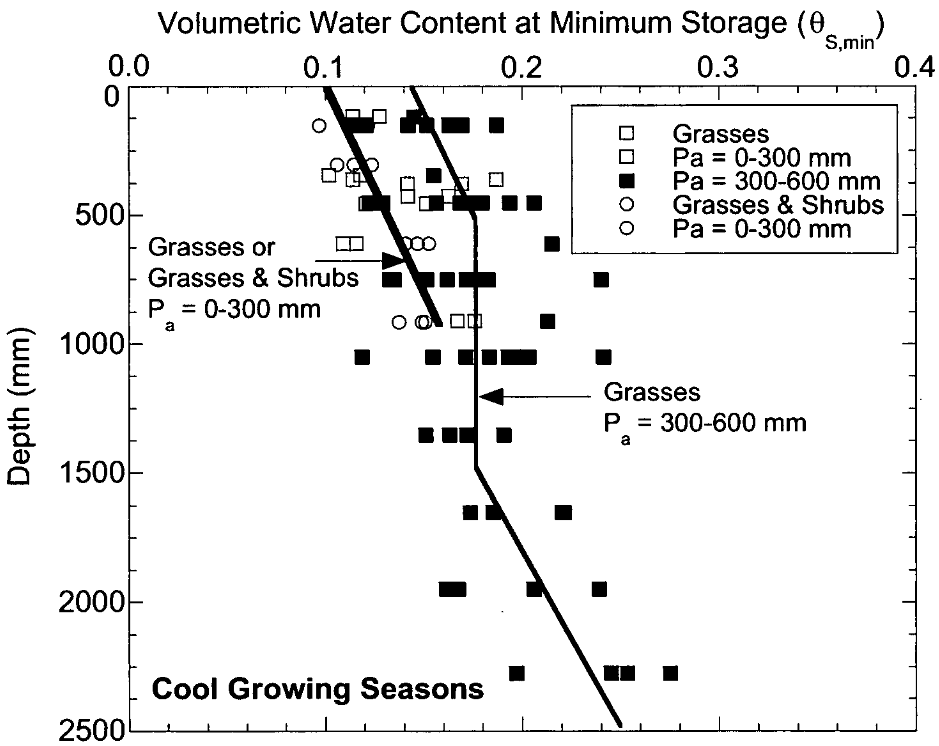


$\theta_{S,min}$ = field water content when storage is minimum.

θ_{wp} = wilting point from laboratory-measured SWCC.

θ_{min}, Climate, & Vegetation



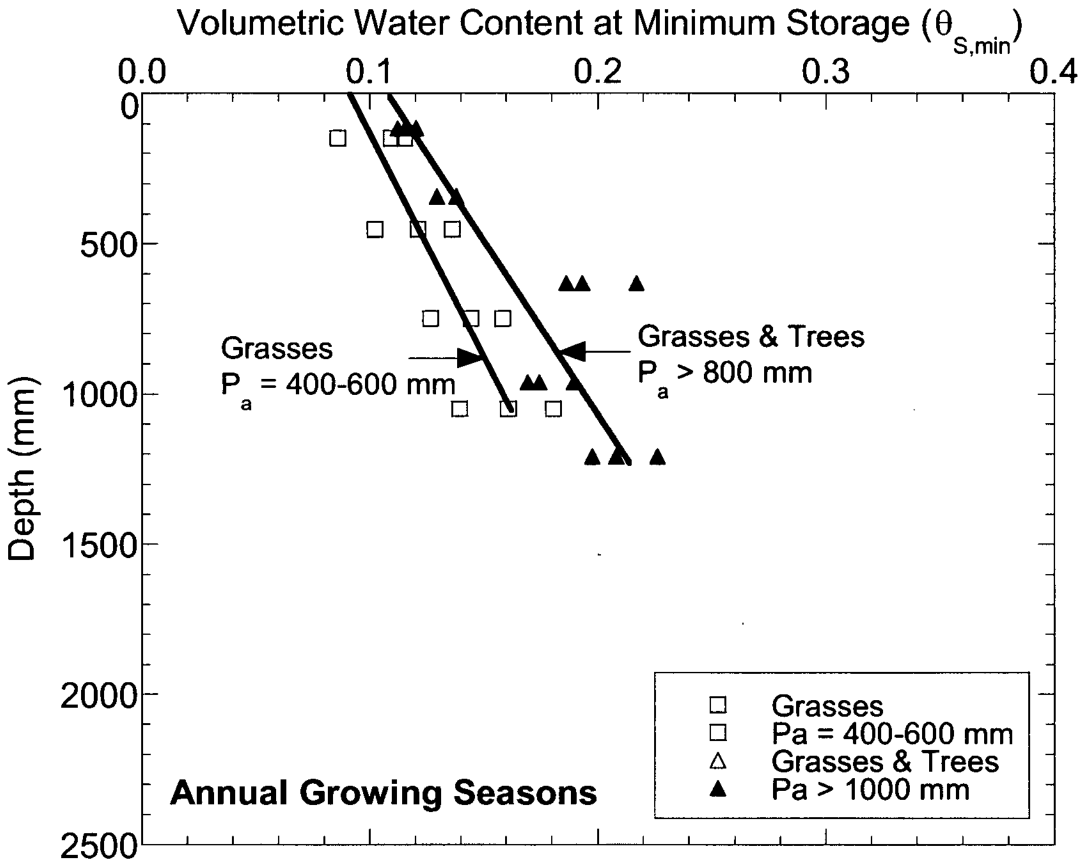


P_a = annual precipitation.

Lower water contents achieved in warm growing seasons and drier climates.

Greater extraction of water with grasses and shrubs.

θ_{min}, Climate, & Vegetation



Less efficient extraction with depth.

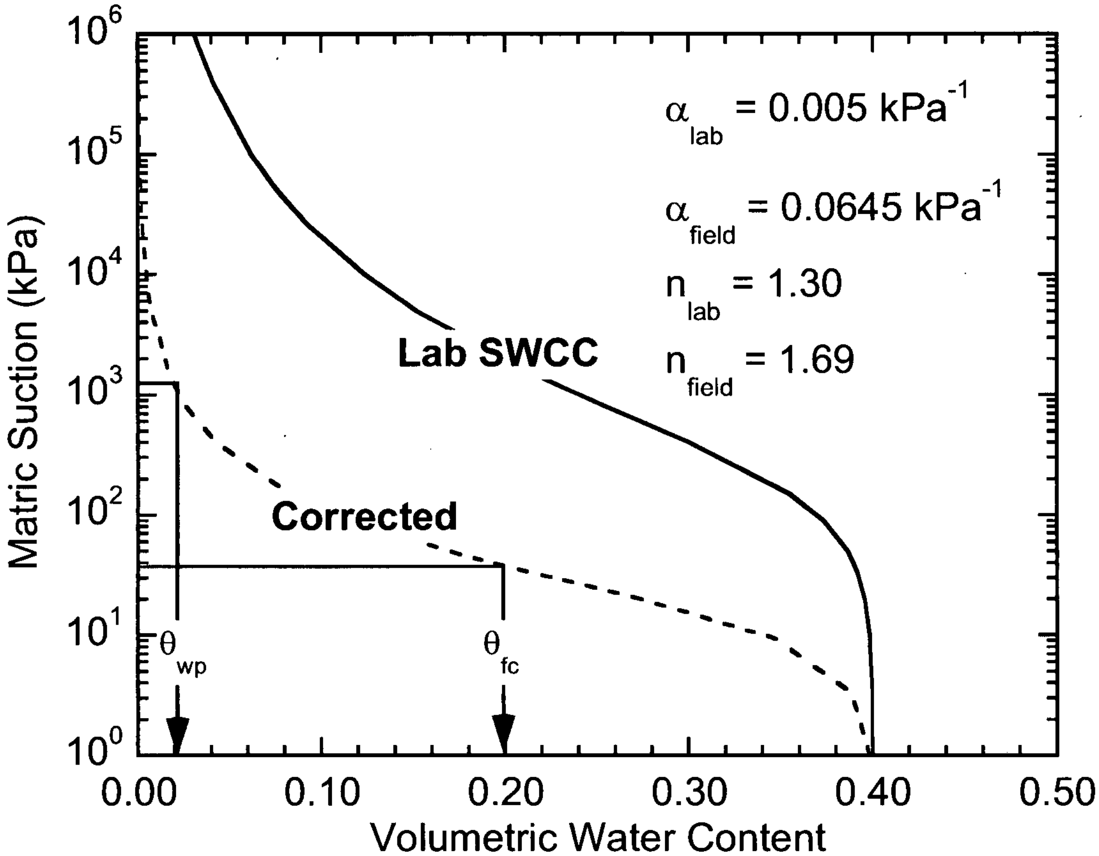
Profile for P_a > 800 mm comparable to profile for P_a > 600 mm for warm growing seasons.

Sample Design Calculation

Assume the following:

S_r = required storage = 200 mm

SWCCs from previous example



$\theta_{fc} = 0.20$, $\theta_{wp} = 0.02$

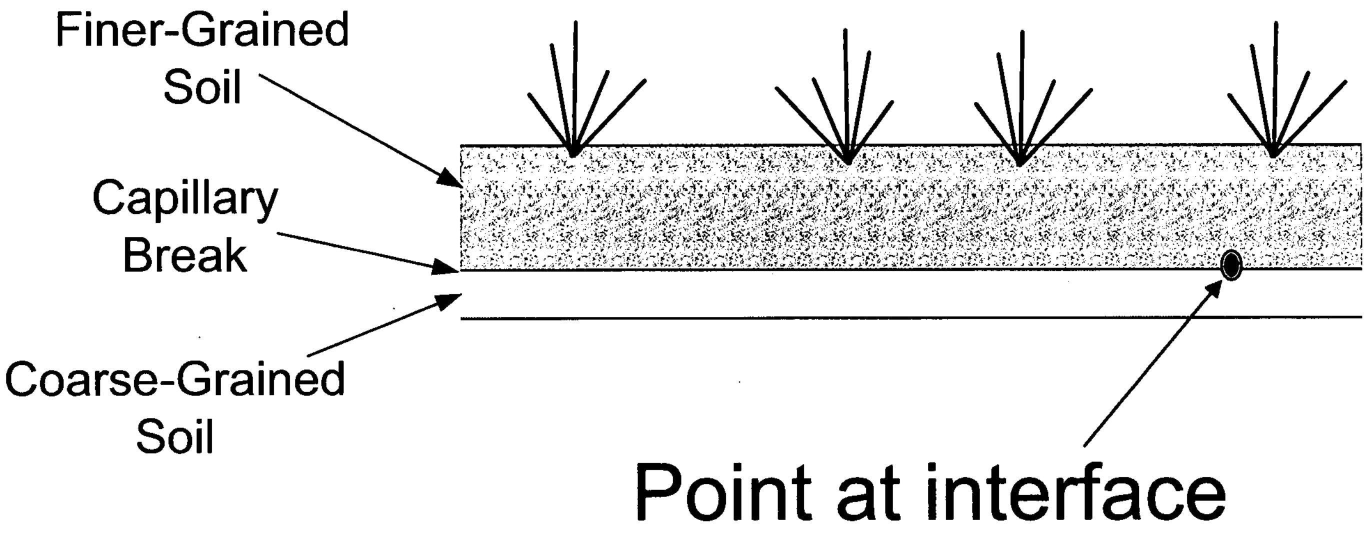
For simplicity, use $\theta_{min} = \theta_{wp}$ for example computations.

Example Continued

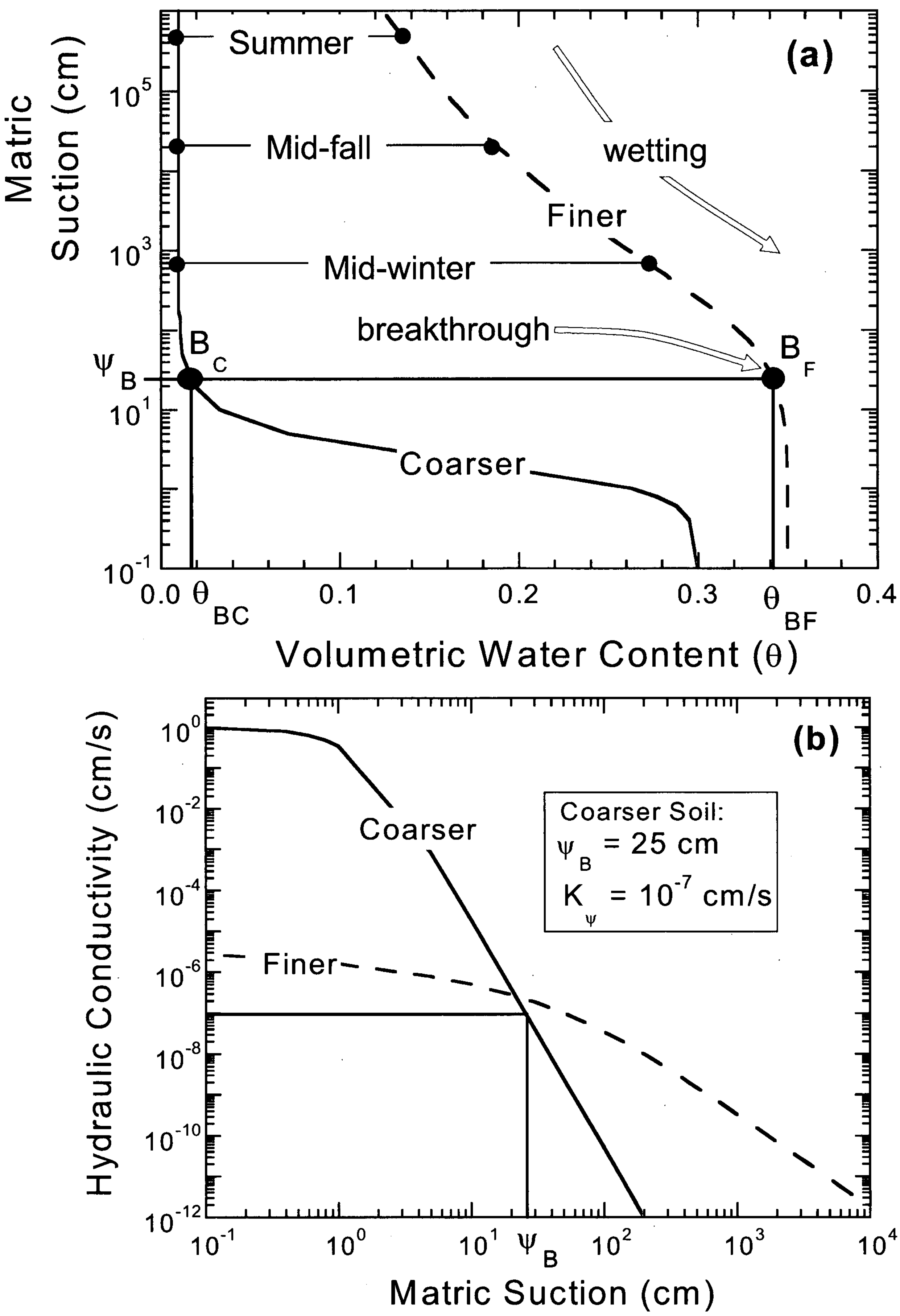
- $S_a \geq S_r$
- $S_a = L(\theta_c - \theta_{min})$
- $L \geq S_r / (\theta_c - \theta_{min})$
- $L \geq S_r /(\theta_{fc} - \theta_{wp})$
- $L \geq S_r /(0.20 - 0.02)$

$L \geq 1.1$ m

Capillary Barrier



- Coarser layer enhances water storage in the finer layer
- Quantitatively illustrated by considering continuity of pressure at the interface
- Break can also be used for lateral diversion



Khire, M., Benson, C., and Bosscher, P. (2000), Capillary Barriers: Design Variables and Water Balance, *J. of Geotech. and Geoenvironmental Eng.*, 126(8), 695-708.

Numerical Example

Finer: Silty clay loam

$\alpha = 0.010\ cm^{-1}$, $n = 1.23$, $\theta_r = 0.09$, $\theta_s = 0.43$
$K_s = 10^{-5}$ cm/s

Coarser: Uniform coarse clean sand

$\alpha = 0.050\ cm^{-1}$, $n = 9.7$, $\theta_r = 0.01$, $\theta_s = 0.36$
$K_s = 1$ cm/s

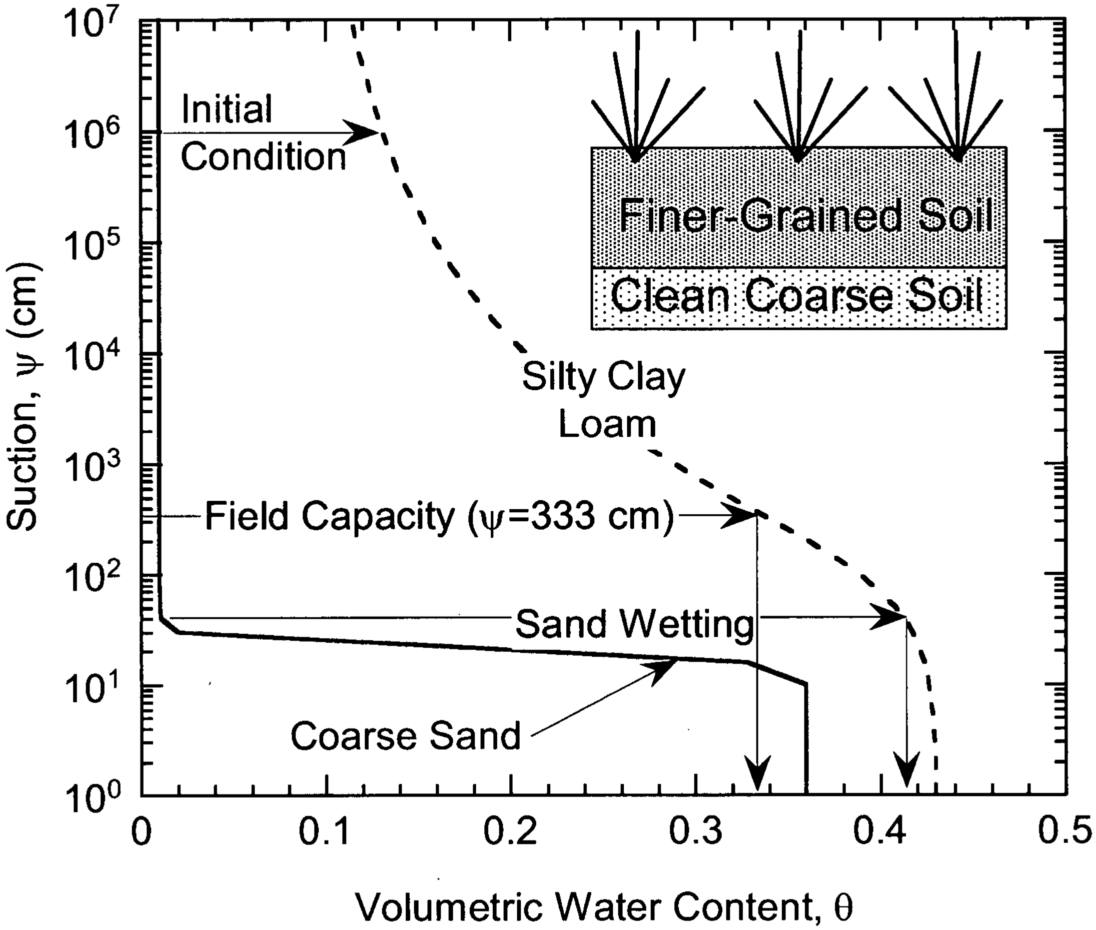
Initial Condition:

$\psi = 1{,}000{,}000$ cm

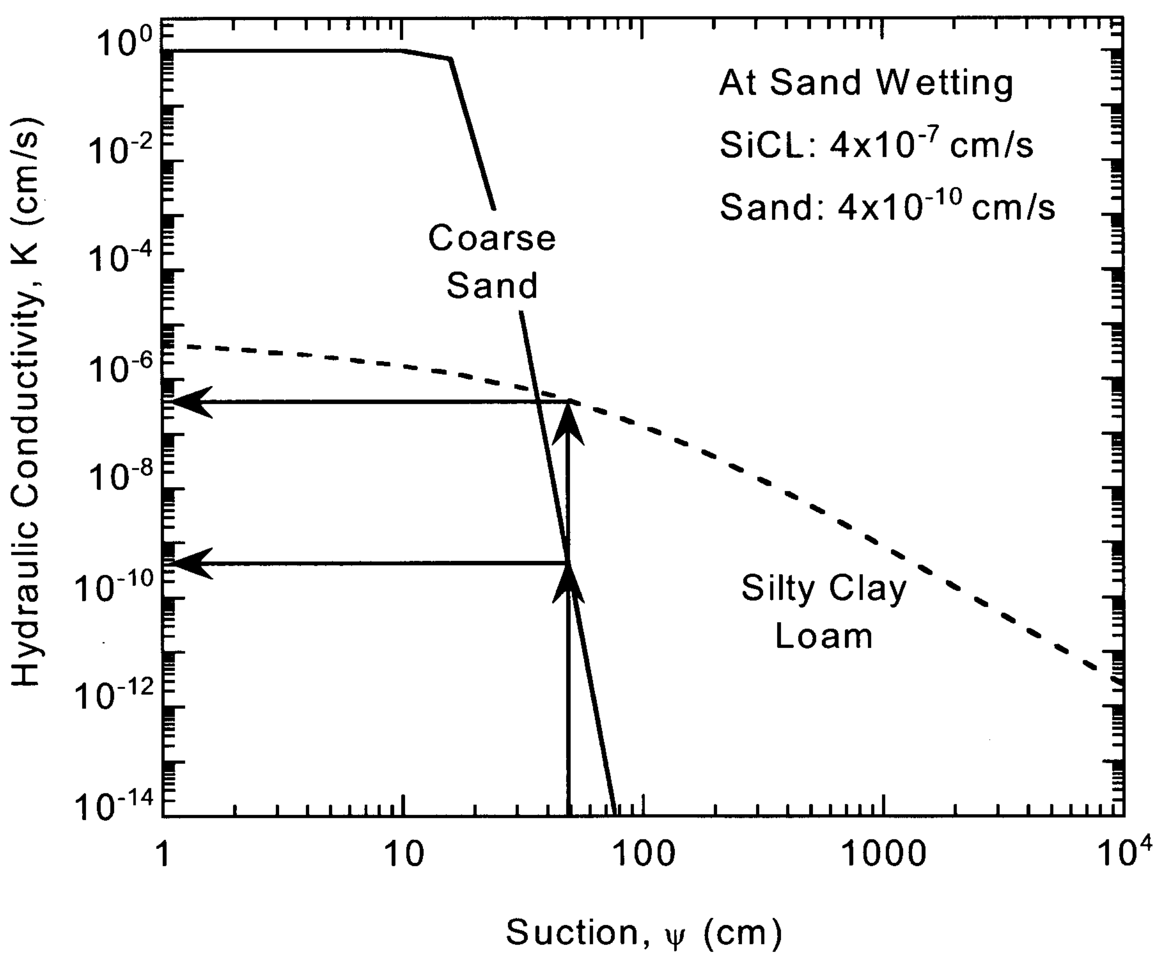
Equations:

$$\frac{K_\psi}{K_s} = \frac{\left\{1-(\alpha\psi)^{n-1}\left[1+(\alpha\psi)^n\right]^{-m}\right\}^2}{\left[1+(\alpha\psi)^n\right]^{m/2}}$$

$$\frac{\theta-\theta_r}{\theta_s-\theta_r} = \left\{\frac{1}{1+(\alpha\psi)^n}\right\}^m$$

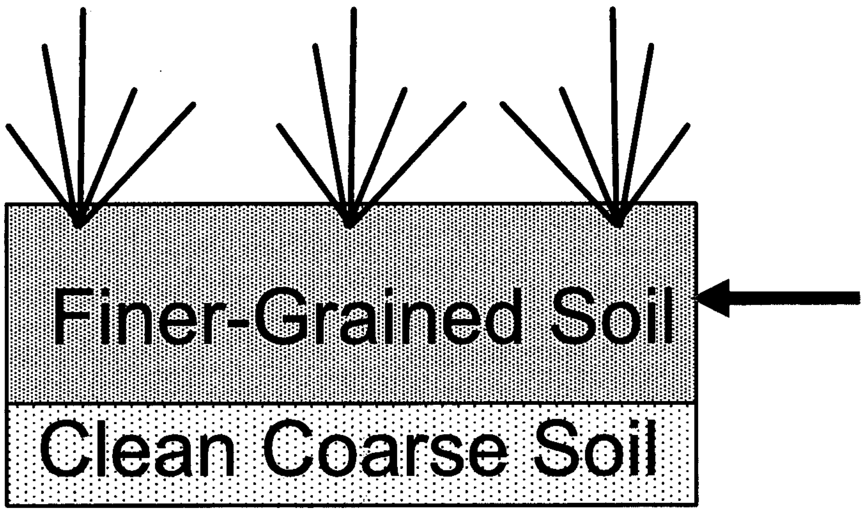


Finer-Grained Soil
Clean Coarse Soil
Initial Condition
Silty Clay Loam
Field Capacity (ψ=333 cm)
Sand Wetting
Coarse Sand
Suction, ψ (cm)
Volumetric Water Content, θ



At Sand Wetting
SiCL: 4x10^-7 cm/s
Sand: 4x10^-10 cm/s
Coarse Sand
Silty Clay Loam
Hydraulic Conductivity, K (cm/s)
Suction, ψ (cm)

Capillary Barrier – Storage Capacity



At incipient breakthrough, suction at the interface = ψ_b and the hydraulic gradient (i) = 0.

For i = 0, the suction at the top of the profile is $\psi_T = L + \psi_b$

θ_T = water content at top of finer-grained layer when breakthrough occurs, i.e., θ at $\psi_T = \psi_b + L$

$$S_C = \int_0^L \theta(z + \psi_b)dz \approx \frac{(\theta_T + \theta_{bf})L}{2}$$

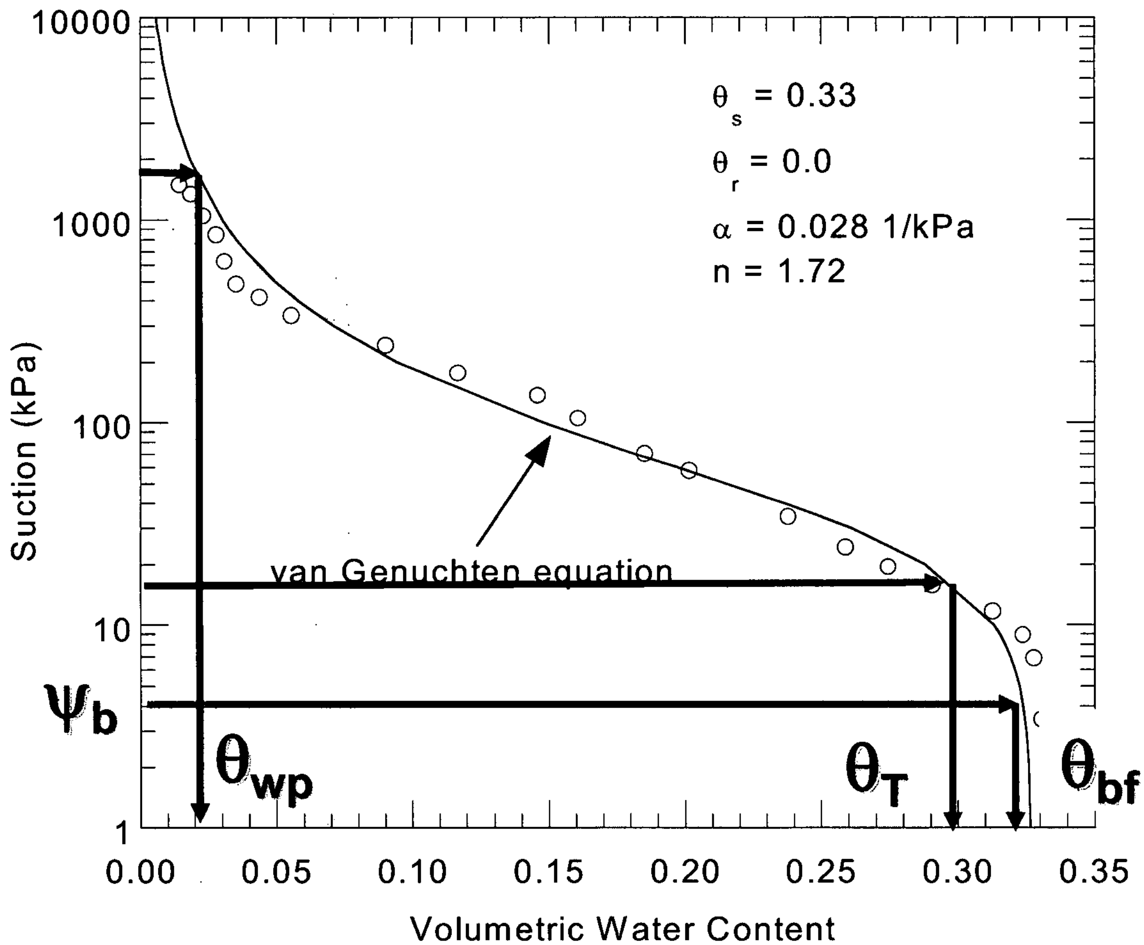
Sample Design Calculation

Assume the following:

S_r = required storage = 200 mm

Sand from previous capillary barrier example, with ψ_b = 40 cm = 4 kPa.

Corrected SWCC for Finer Layer:



Sample Design Calculation – Con't.

$$S_C \approx \frac{(\theta_T + \theta_{bf})\,L}{2}$$

Assume: $L = 1.0$ m

Compute: $\psi_T = \psi_b + 1$ m $= 0.4 + 1 = 1.4$ m $=$ 14 kPa

From SWCC: $\theta_{bf} = 0.32$ and $\theta_T = 0.30$

$$S_C \approx \frac{(0.30 + 0.32)1}{2} = 0.31 \text{ m} = 310 \text{ mm}$$

Discount the water that can be removed by plants (below wilting point)

$$S_a = S_C - S_{WP} \approx 310 - (0.02 \text{ x } 1000)$$

$$S_a = 310 - 20 = 290 \text{ mm}$$

$S_a > S_r = 200$ mm. Therefore, cover is too thick. Reduce L (say 800 mm). Try again.

Sample Design Calculation – Con't.

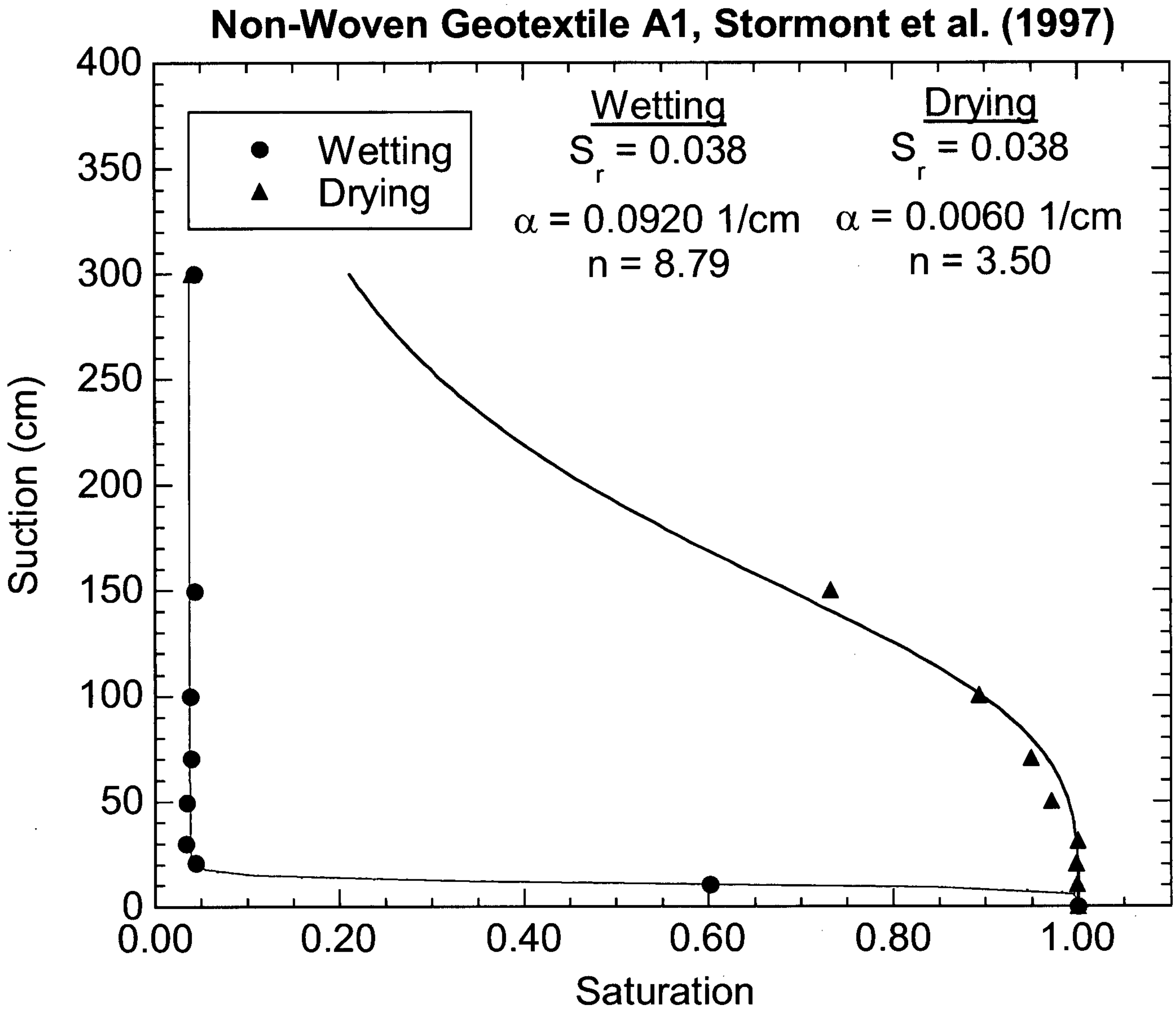
Question: How thick does the coarse layer need to be?

Answer: Only need enough sand to from a continuous capillary break. 150 - 300 mm is sufficient.

Question: Can a non-woven geotextile or geocomposite drain be used instead of sand?

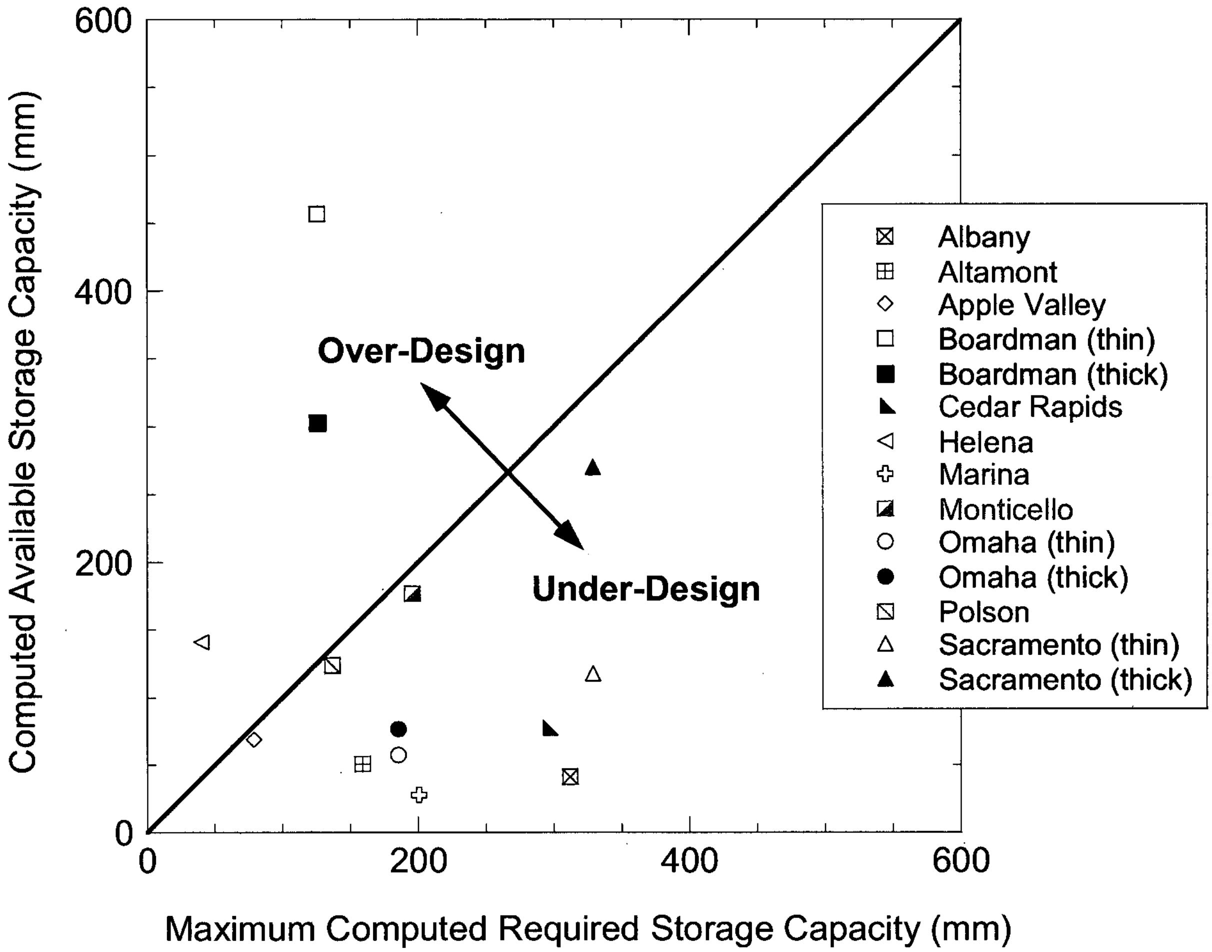
Answer: Data indicate yes. Needs field evaluation.

Sample SWCC for Non-Woven Geotextile



Stormont, J., Henry, K., and Evans, T., (1997), Water retention functions of four nonwoven polypropylene geotextiles, *Geosynthetics International*. 4(6), 661-672.

Comparison of Actual and Computed Storage Capacities – ACAP Sites



Consistent with field observations:

No percolation - Boardman (thin & thick covers), Helena

Little percolation - Apple Valley, Polson, Monticello, Sacramento (thick)

Considerable percolation - Altamont, Omaha (thin & thick), Marina, Sacramento (thin), Cedar Rapids, Albany

Storage Layer Properties

- Water retention characteristics (high, finer textured) ★
- Saturated hydraulic conductivity (low, finer textured soil) ★
- Shrink-swell potential (low, modest clay fines, well graded, appreciable coarse fraction) ★
- Erosivity (low, well graded, blend of clay and silt fines) ★
- Shear strength (high, well graded)
- Sufficient volume and close proximity
- Agronomic properties

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Engineering Standards Manual	pdf	10/06	LANL	ISD 341-2.0 ~~ISD 341-2~~	14	097065

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