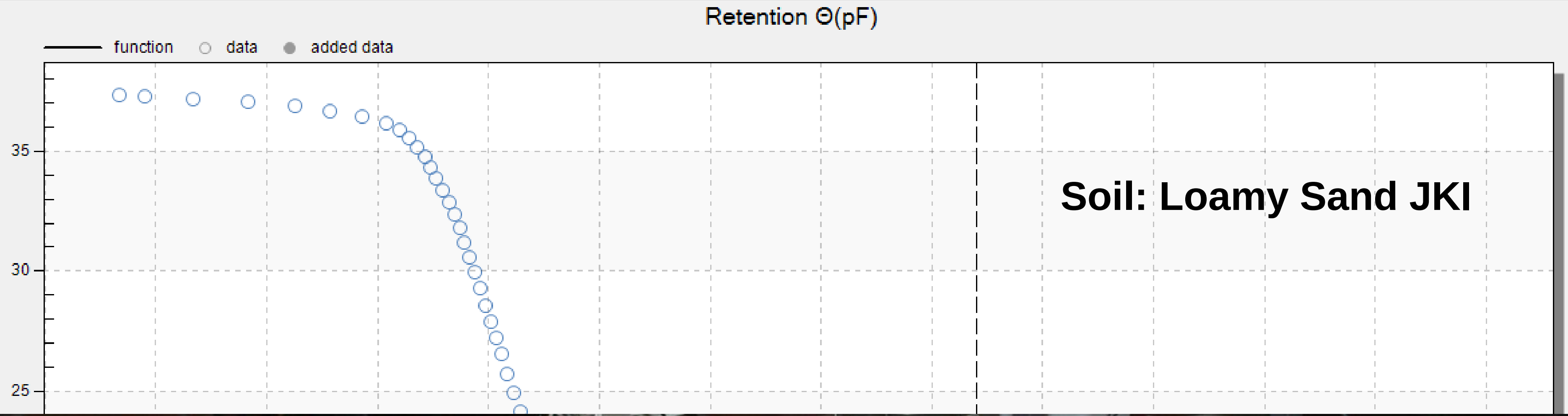
Technische Universität Braunschweig
Institut für Geoökologie
Bodenkunde und Bodenphysik

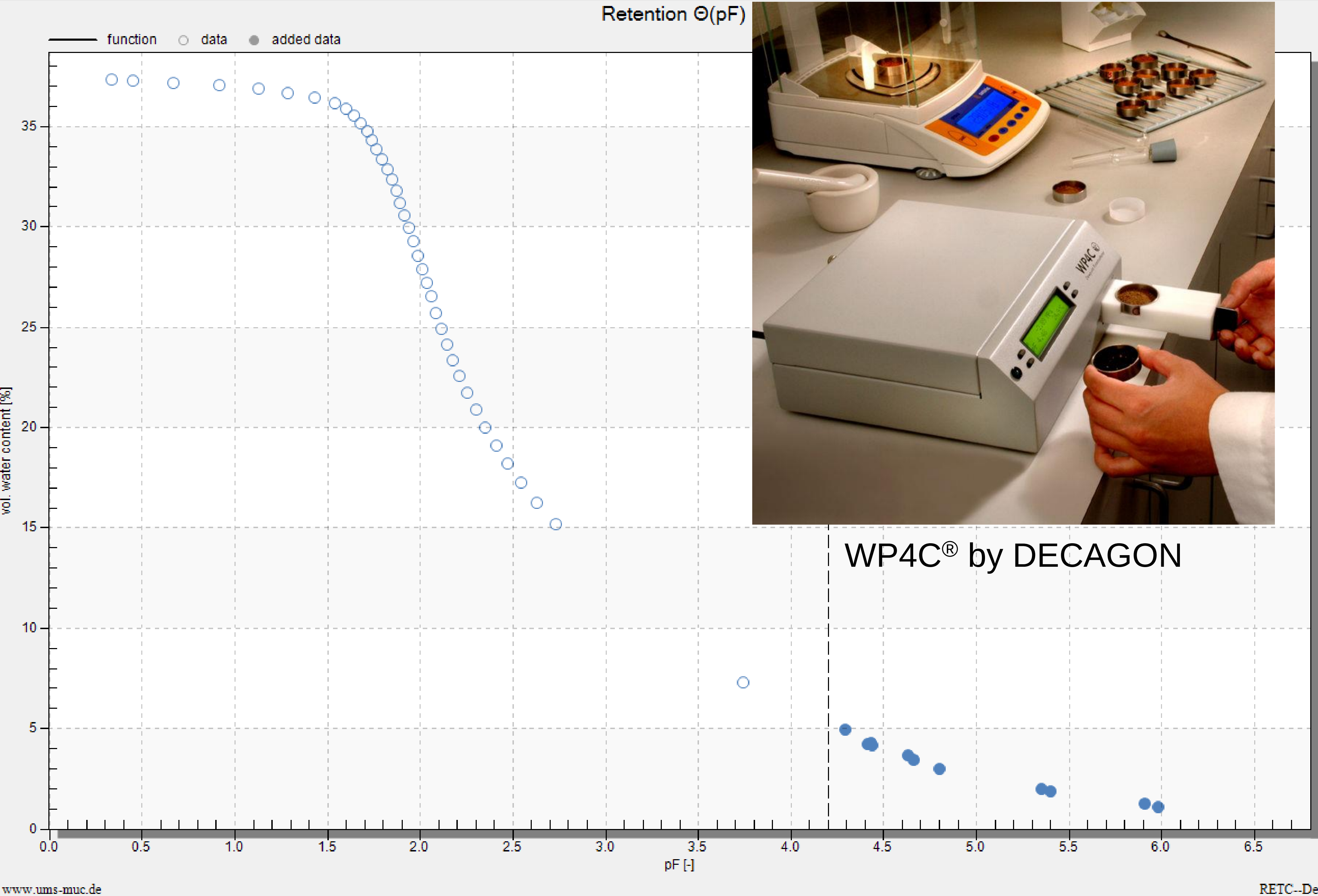
Parameterization of models for soil hydraulic properties: Challenges and recent advances

Wolfgang Durner

Sascha Iden, Andre Peters, Efstathios Diamantopoulos,
Kai Germer, Tobias Weber, Benedikt Scharnagl


Retention Θ(pF)
function
data
added data
35
30
25
Soil: Loamy Sand JKI


HYPROP by UMS



Retention Θ(pF)
function
data
added data
vol. water content [%]
pF [-]
0
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
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6.0
6.5
WP4C
WP4C® by DECAGON
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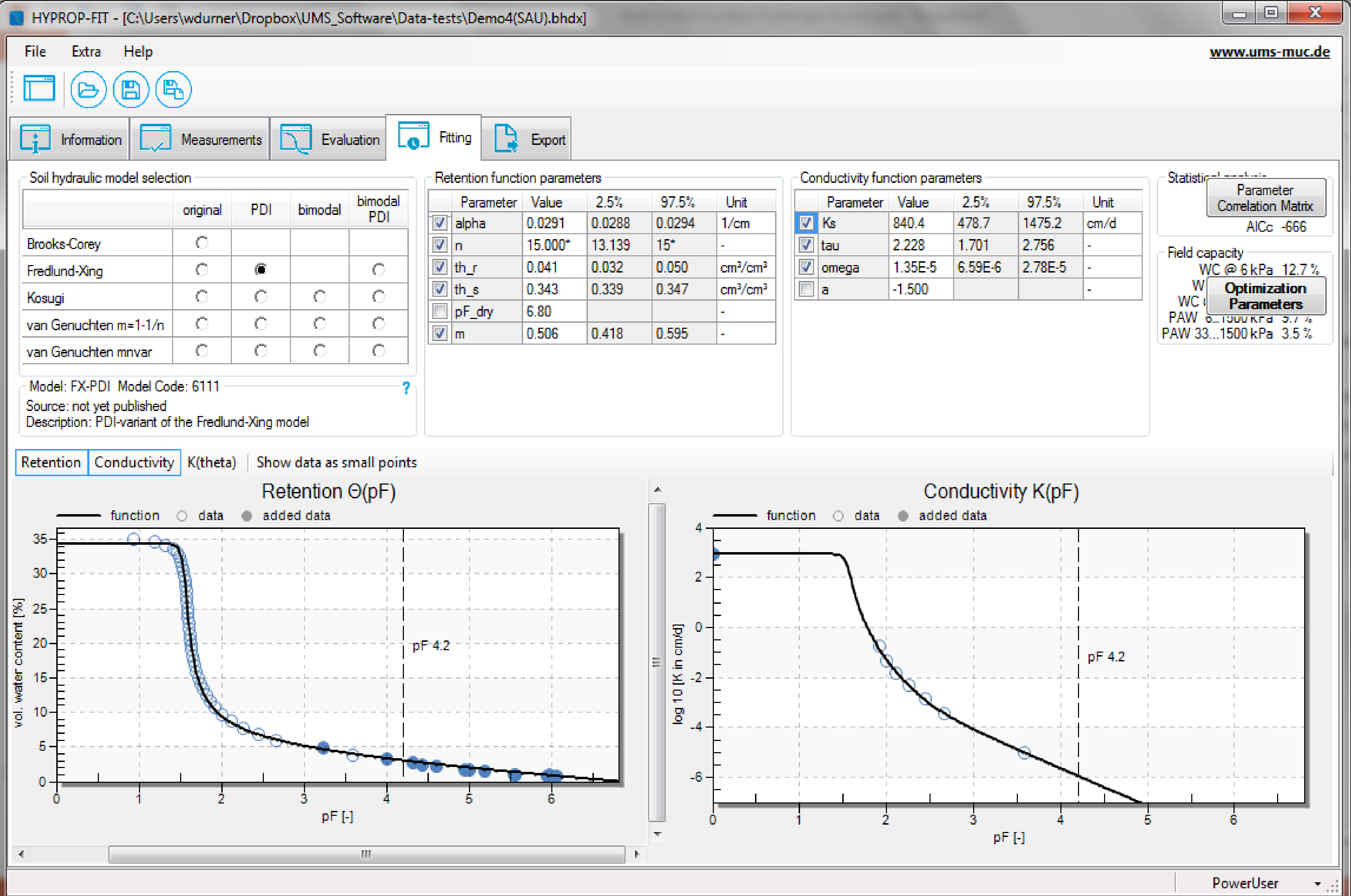
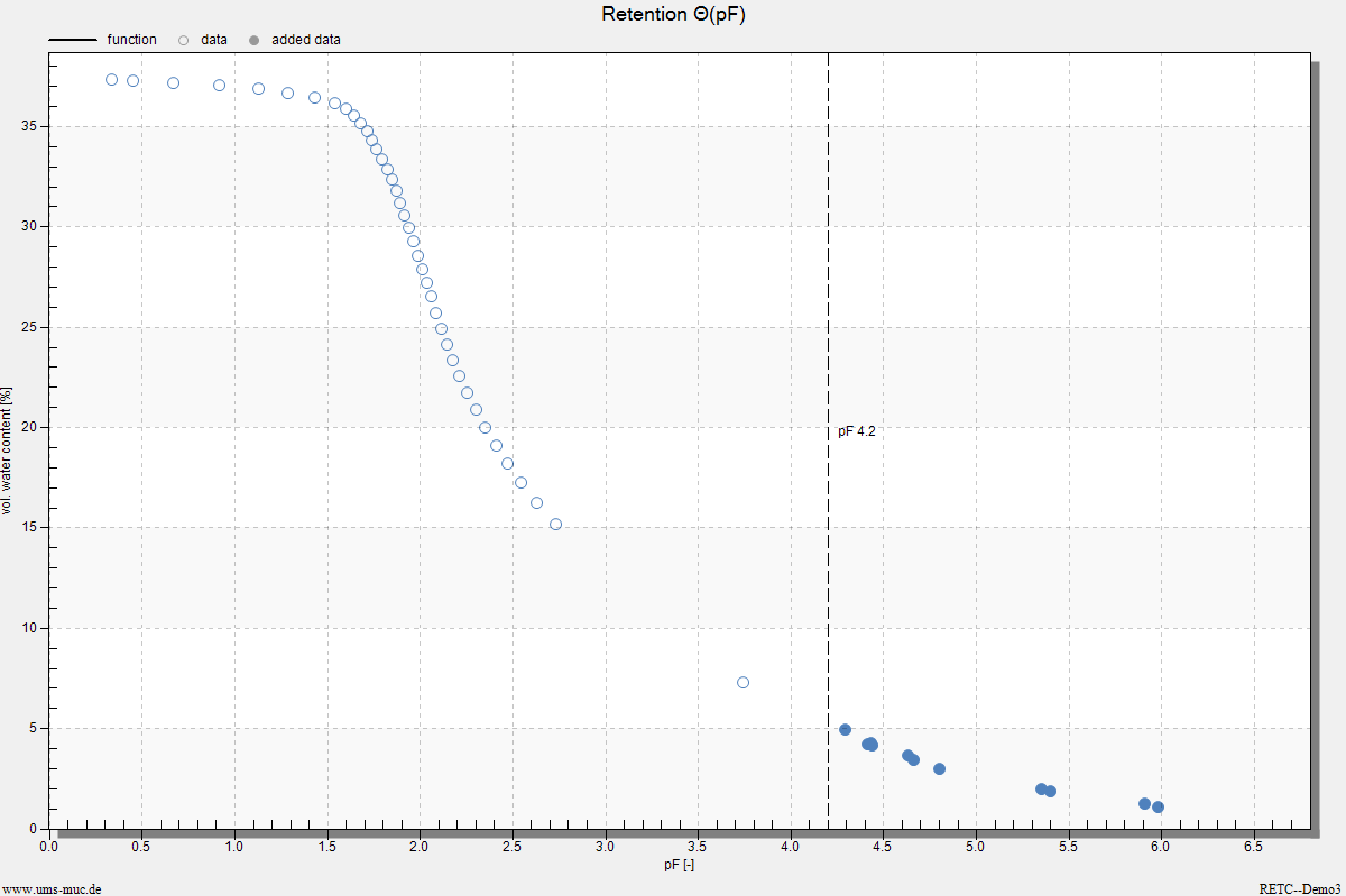
RETC--Demo3



3rd BRAZILIAN SOIL PHYSICS MEETING
III ENCONTRO BRASILEIRO DE FÍSICA DO SOLO
May 04 - 08, 2015

Technische Universität Braunschweig


Retention Θ(pF)
function
data
added data
35
30
25
20
15
10
5
0
vol. water content [%]
pF 4.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
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5.0
5.5
6.0
6.5
pF [-]
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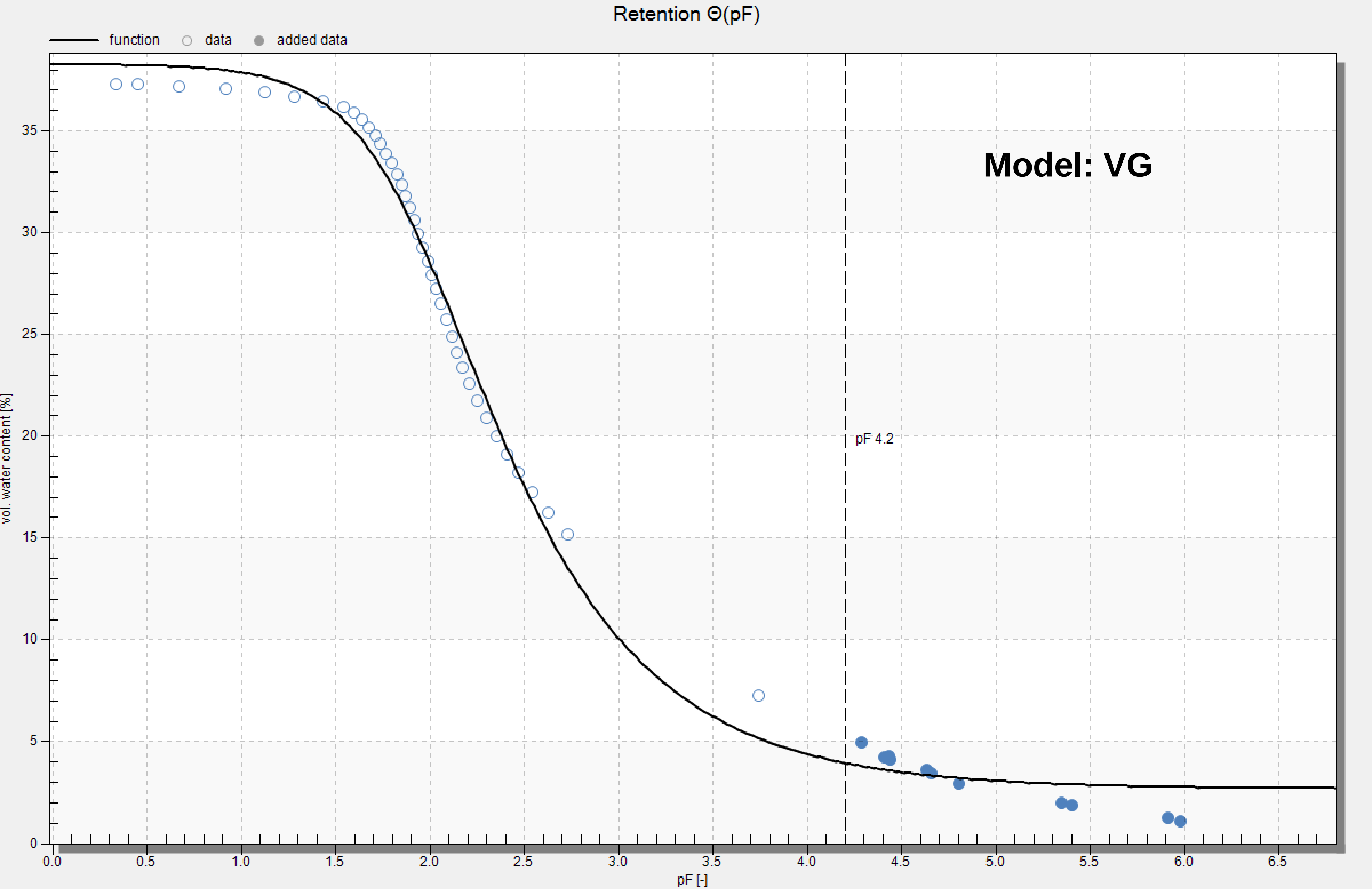
RETC--Demo3



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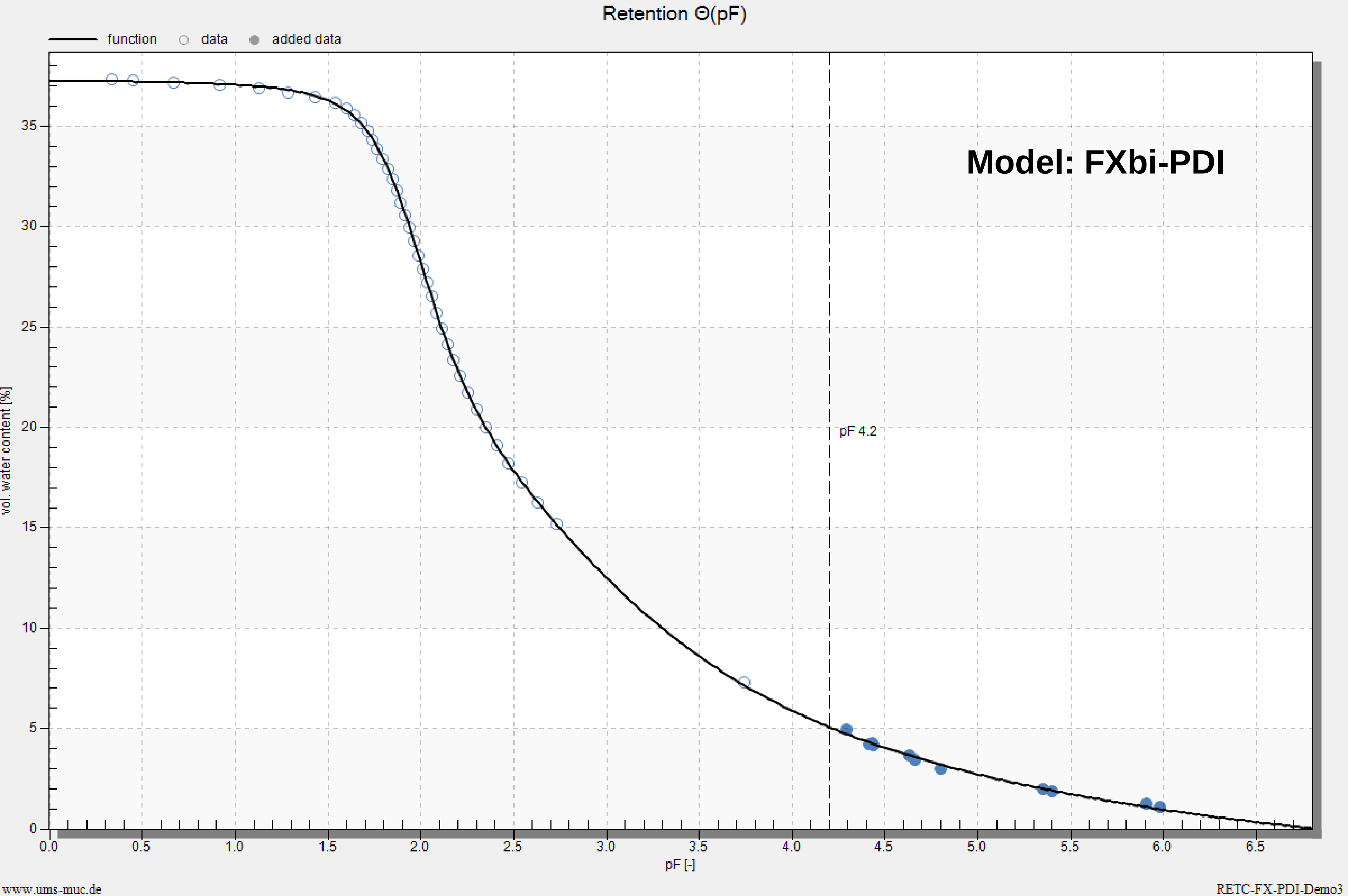
RETC-Demo3-VG



Retention Θ(pF)
function
data
added data
Model: FXbi-PDI
pF 4.2
vol. water content [%]
pF [-]
0
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
2.0
2.5
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6.0
6.5
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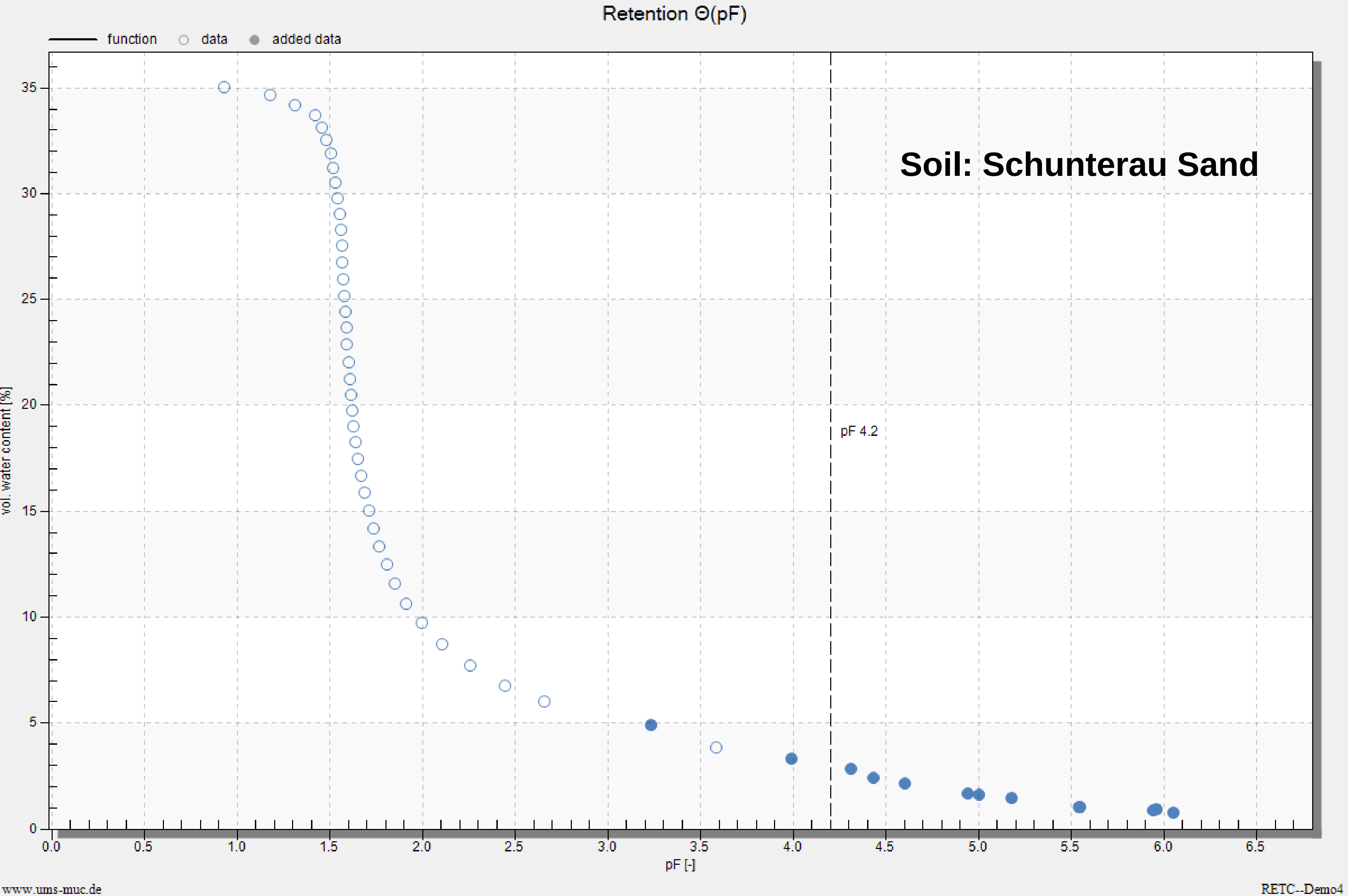
RETC-FX-PDI-Demo3



Retention Θ(pF)
function
data
added data
Soil: Schunterau Sand
pF 4.2
vol. water content [%]
pF [-]
0
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
2.0
2.5
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6.0
6.5
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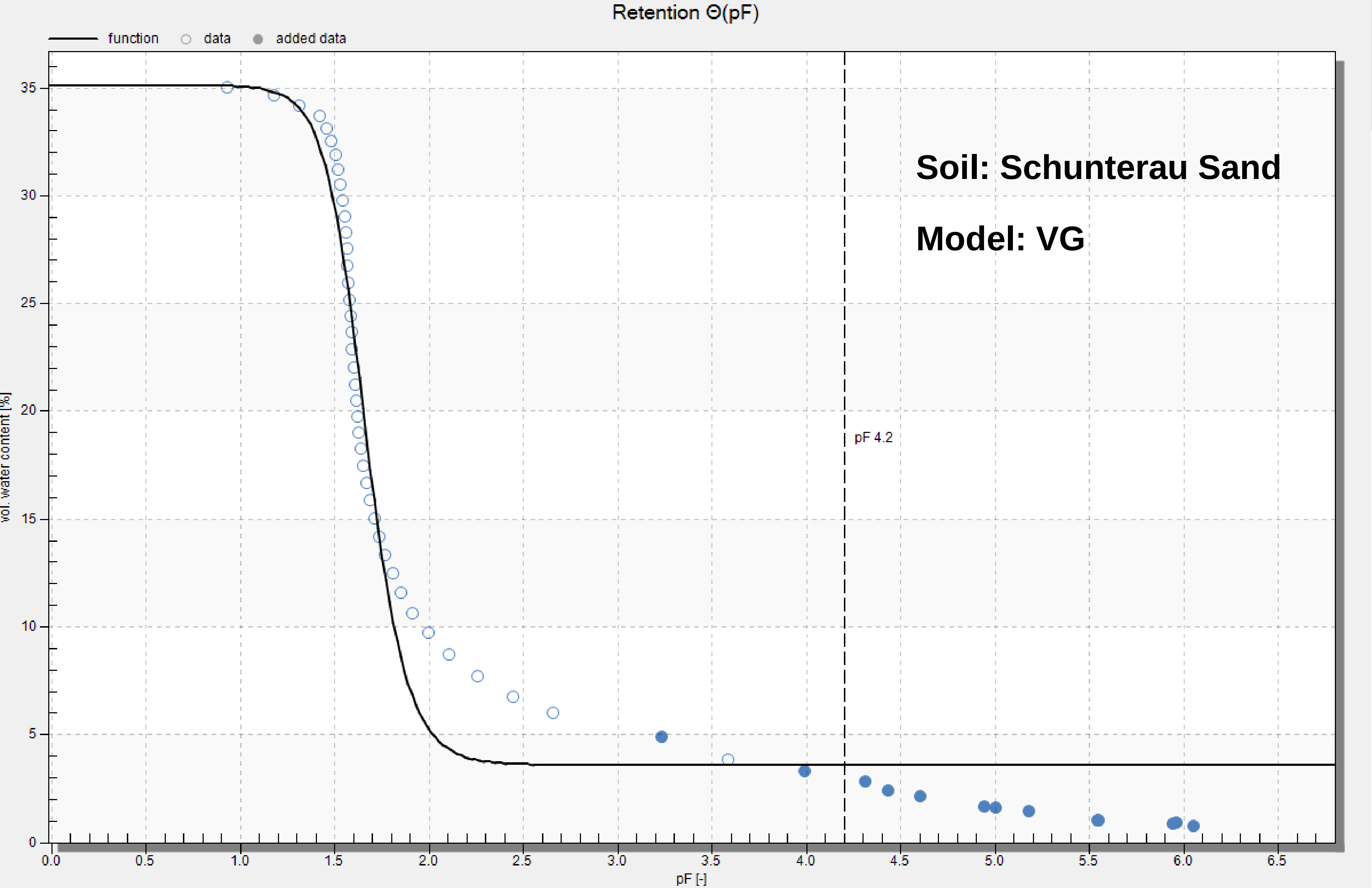
RETC--Demo4



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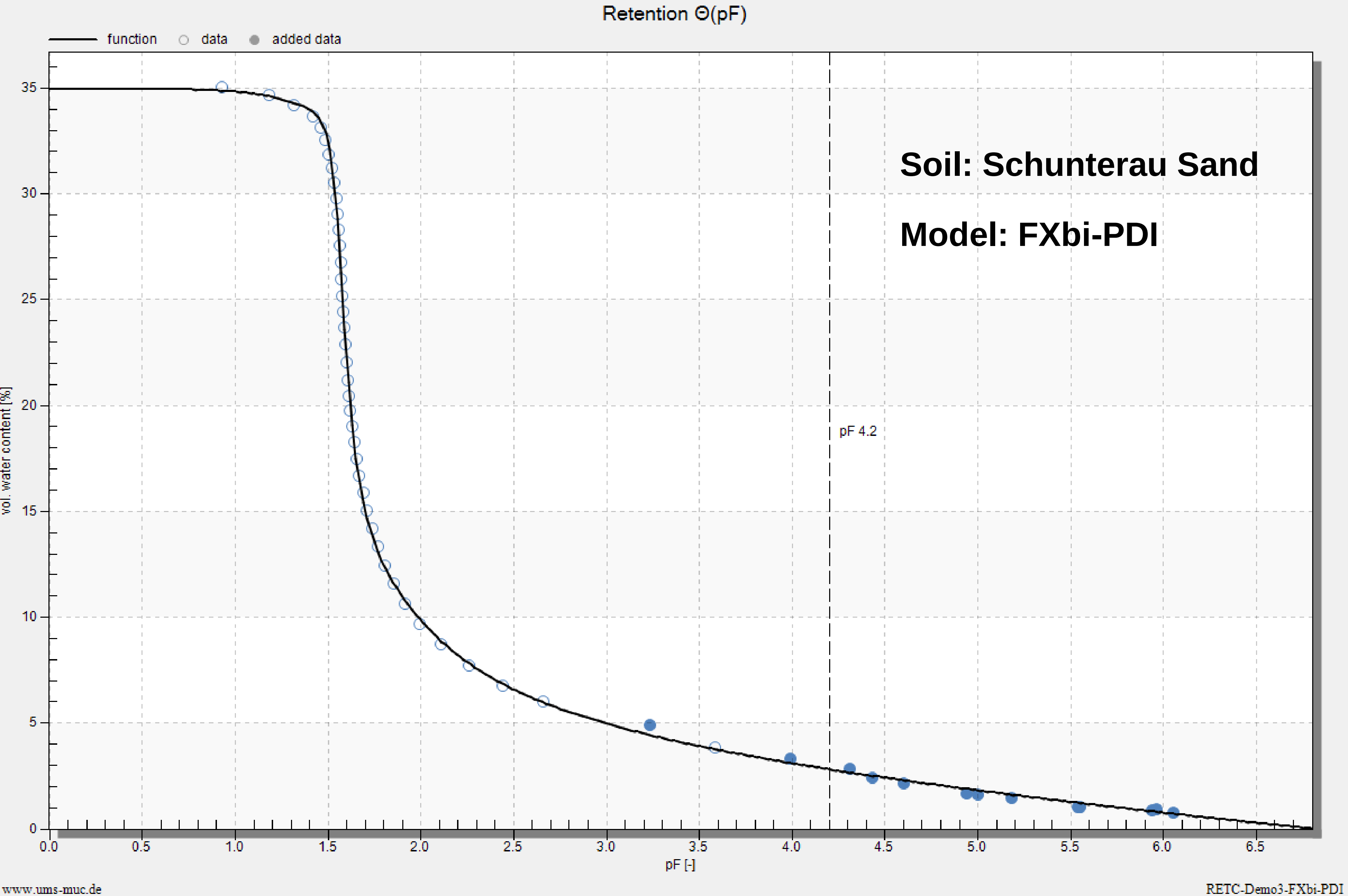
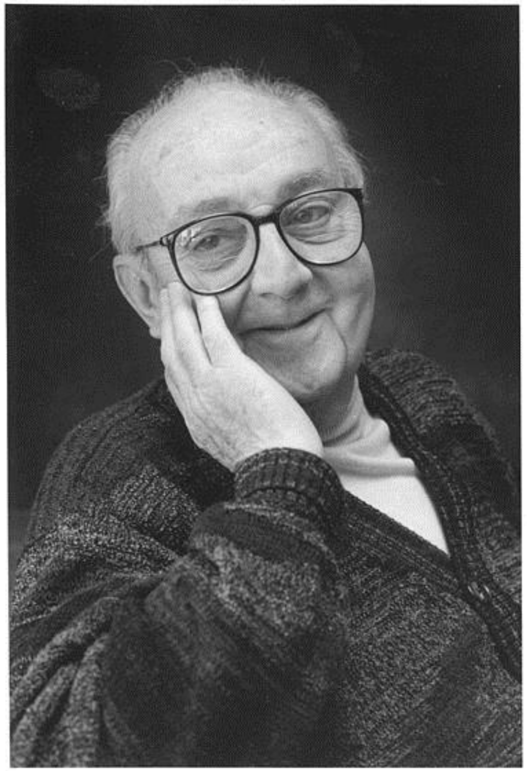
RETC-VG-Demo4



Retention Θ(pF)
function
data
added data
Soil: Schunterau Sand
Model: FXbi-PDI
pF 4.2
vol. water content [%]
pF [-]
0
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
www.ums-muc.de
RETC-Demo3-FXbi-PDI

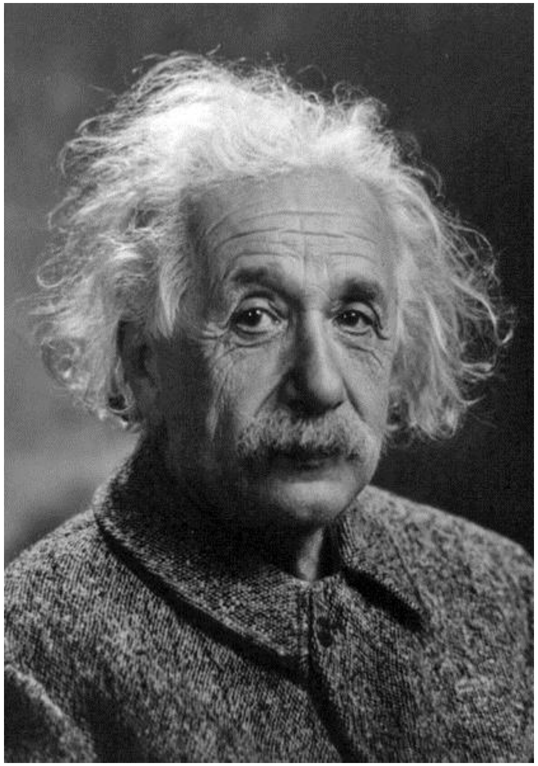
Parameterization

„All models are wrong …
… but some are useful“



G.E.P. Box 1919 –2013

„Models should be as simple as possible …
… but not simpler“



A. Einstein 1879 –1955

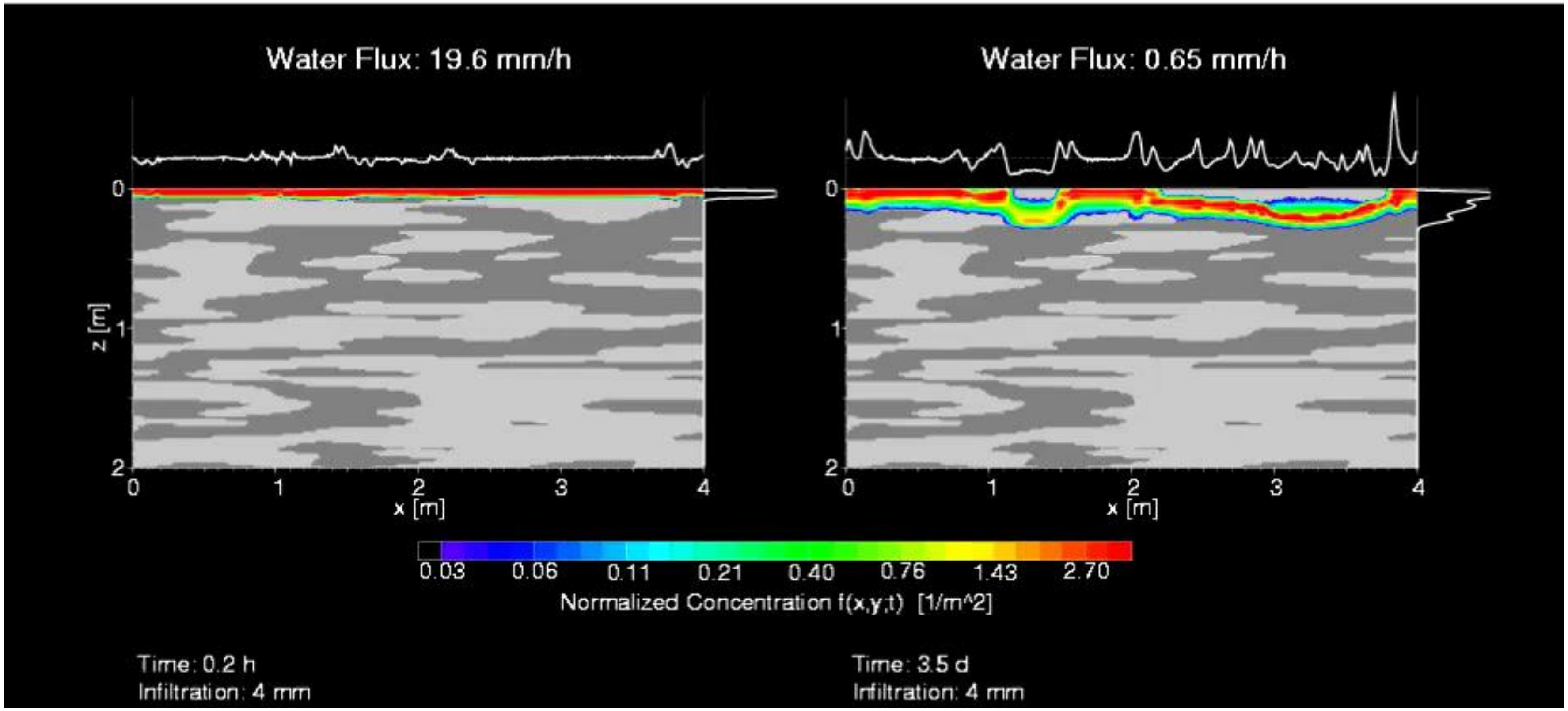
How good (accurate) should a model fit be?

… depends on the intended use of the model

- Field capacity
- Plant available water content
- Mapping of soil hydraulic properties
- RETC to derive secondary properties, e.g., predicting hydraulic conductivity
- Modeling soil water dynamics

Richards Equation is today's standard model for simulating soil water dynamics

(Infiltration, redistribution, evaporation, transpiration, drainage)



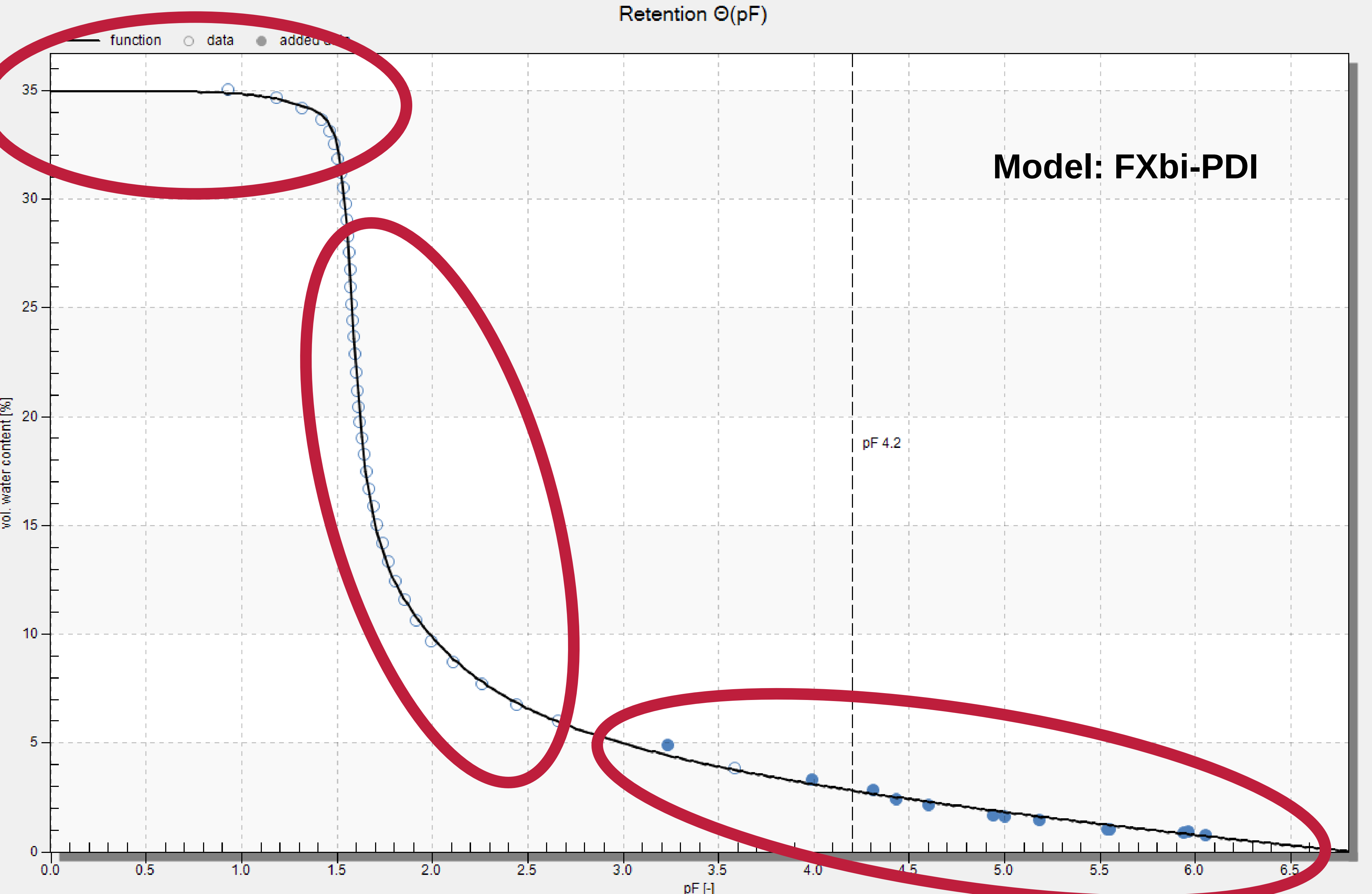
Courtesy Kurt Roth

- Extent of evaporation ?
- Water flow to roots ?

http://www.mrwallpaper.com/wallpapers/beau

- Erosion ?
- Solute transport ?

http://www.mrwallpaper.com/wallpapers/beau

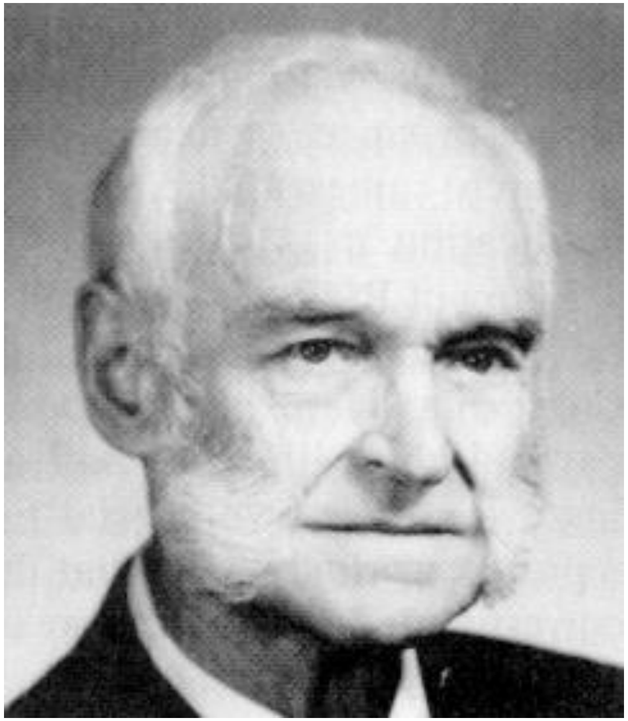


www.ums-muc.de

RETC-Demo3-FXbi-PDI

Part 2: A look on hydraulic properties

Lorenzo A. Richards (1931)



…combined Continuum equation with Darcy-Buckingham equation (here: 1D, vertical).

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]+s(z,t)$$

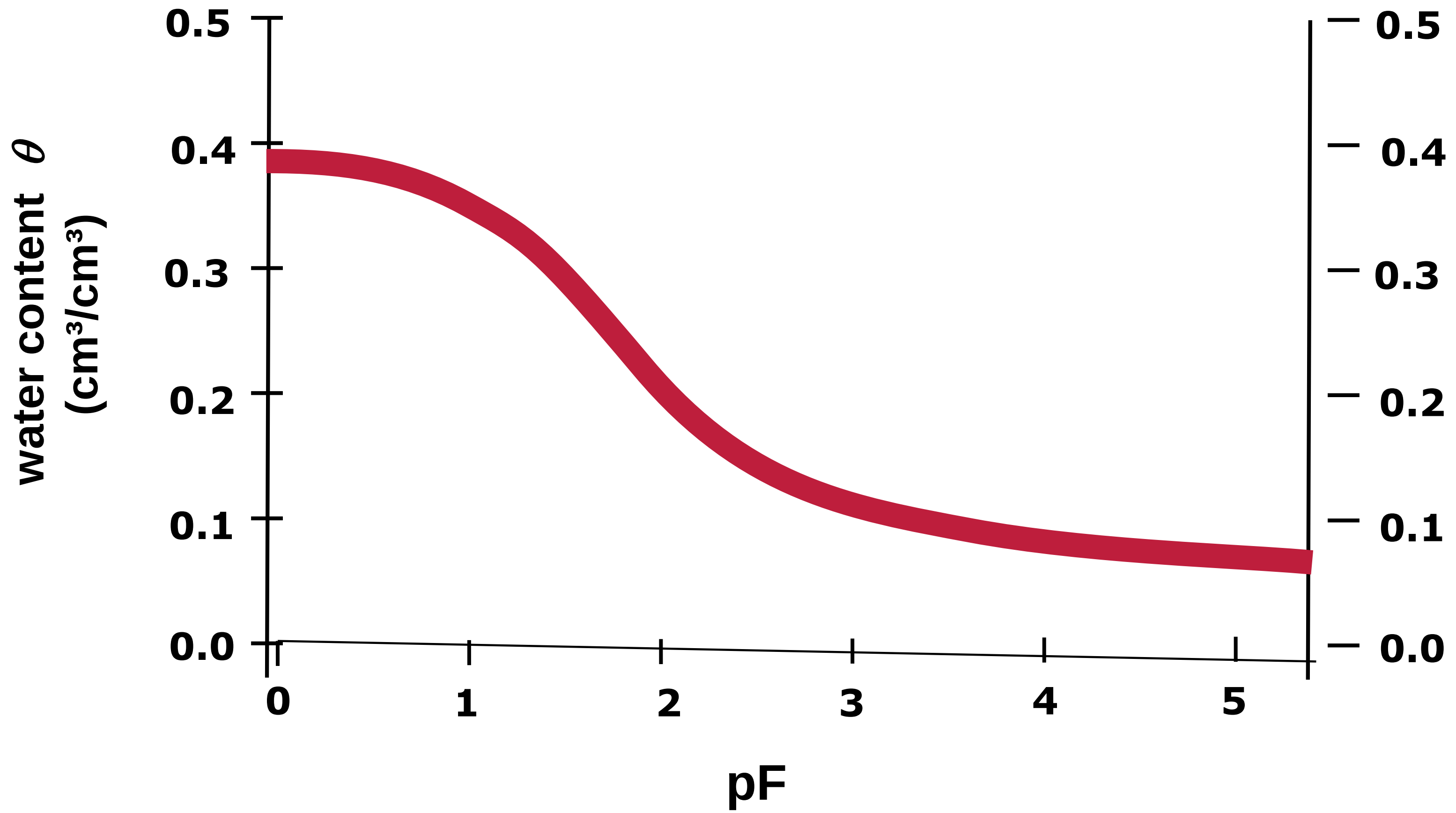
Constitutive relationships

1) Conductivity curve, $K(h)$

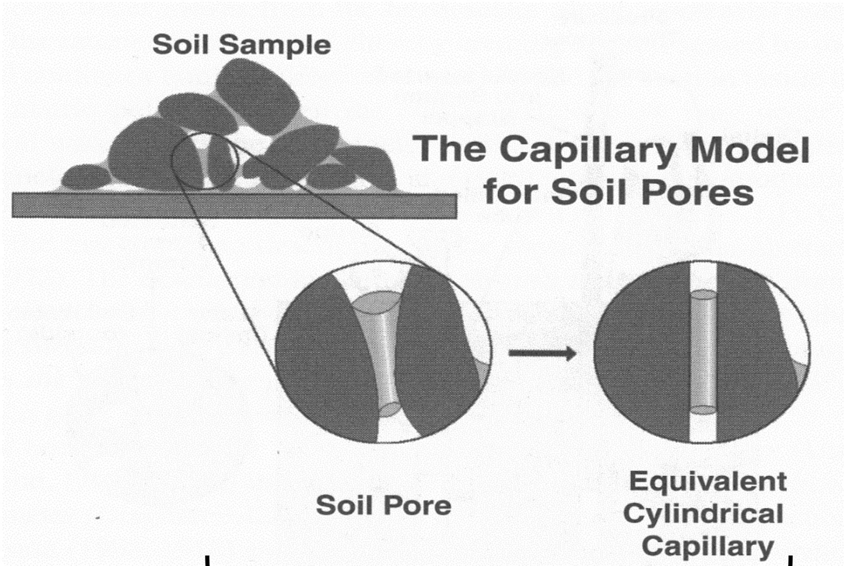
2) Retention curve, $\theta(h)$
   ("most important curve"
   in soil physics)

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z} + 1\right)\right]$$

Van Genuchten retention curve



Concept of equivalent pore sizes



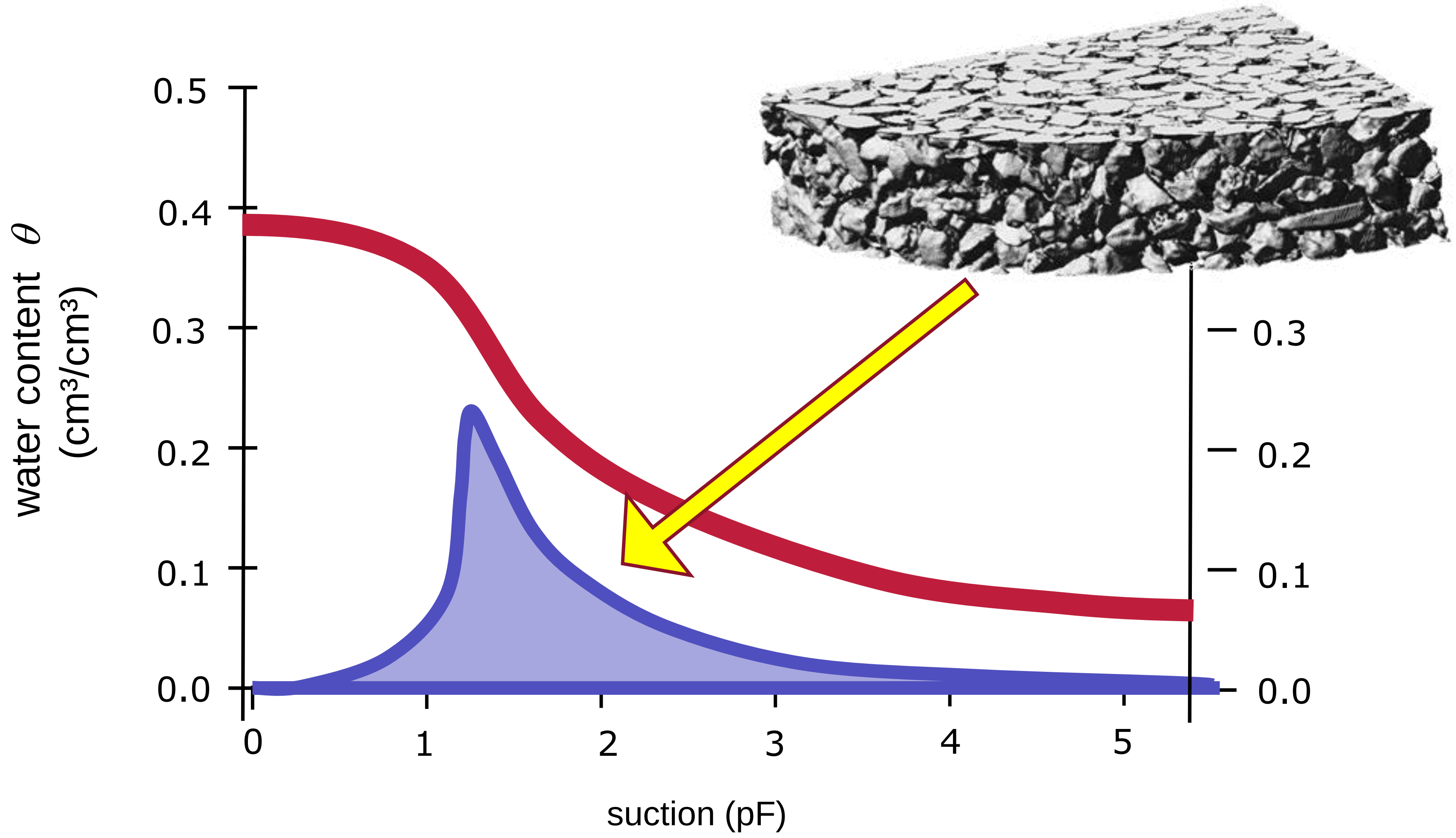
At equal capillary pressure identical water storage

Concept of cylindrical equivalent pores leads to a representation of the true pore space as a „capillary bundle“.

Allows to derive pore-size distribution, water holding capacity, and hydraulic conductivity

Or und Wraith, *Soil Physics Companion*, 2002

Equivalent pore-size distribution

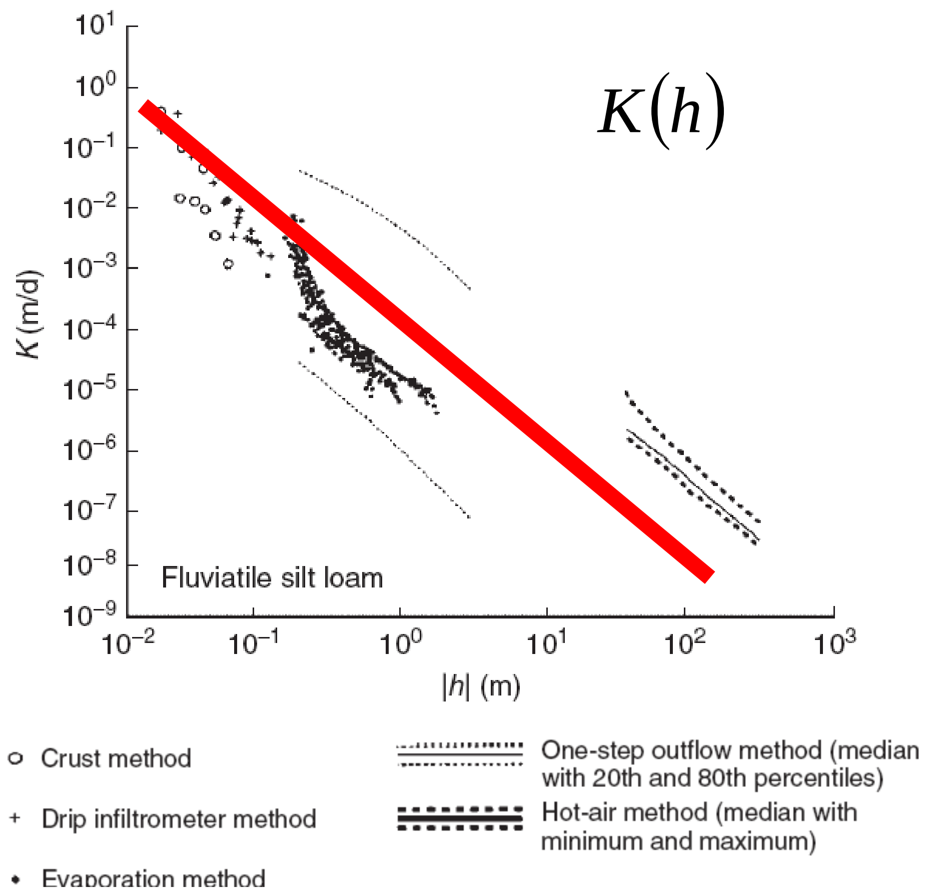


Constitutive relationships

1) Conductivity curve

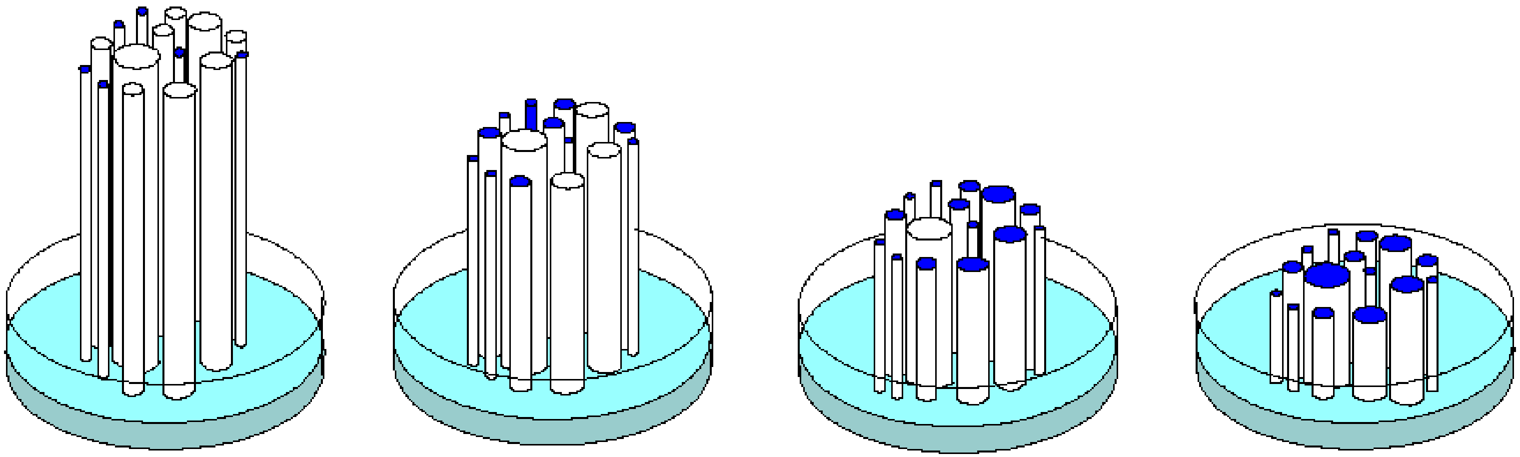
2) Retention curve (most important curve in soil physics ?)

„hydraulic properties“: Hydraulic conductivity function



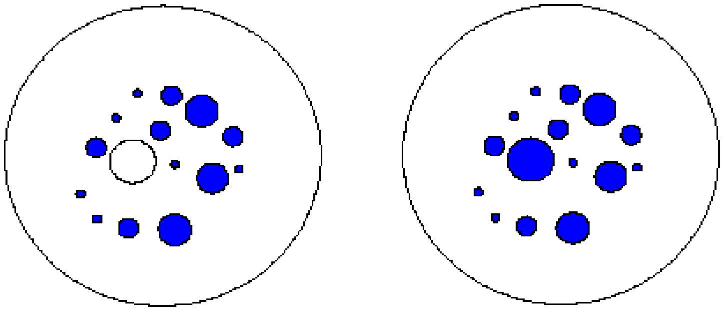
Stolte et al. (1994), SSSAJ

capillary tube model

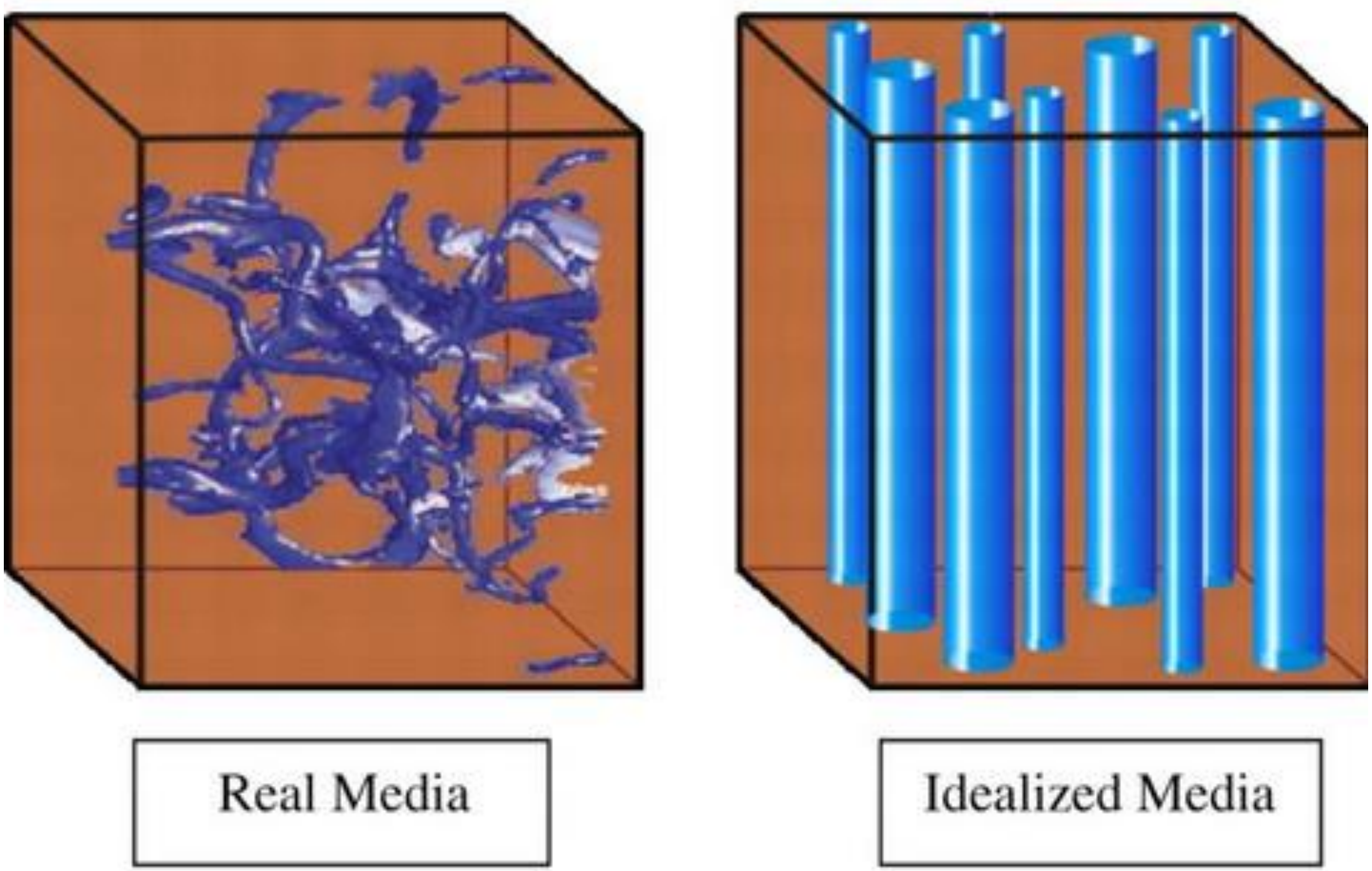


$$K(\theta) = a \cdot \int_0^\theta r^2 d\theta$$

$$= b \cdot \int_0^\theta \frac{1}{h^2} d\theta$$



Burdine, 1950



Khaleel and Saripalli, VZJ, 2006

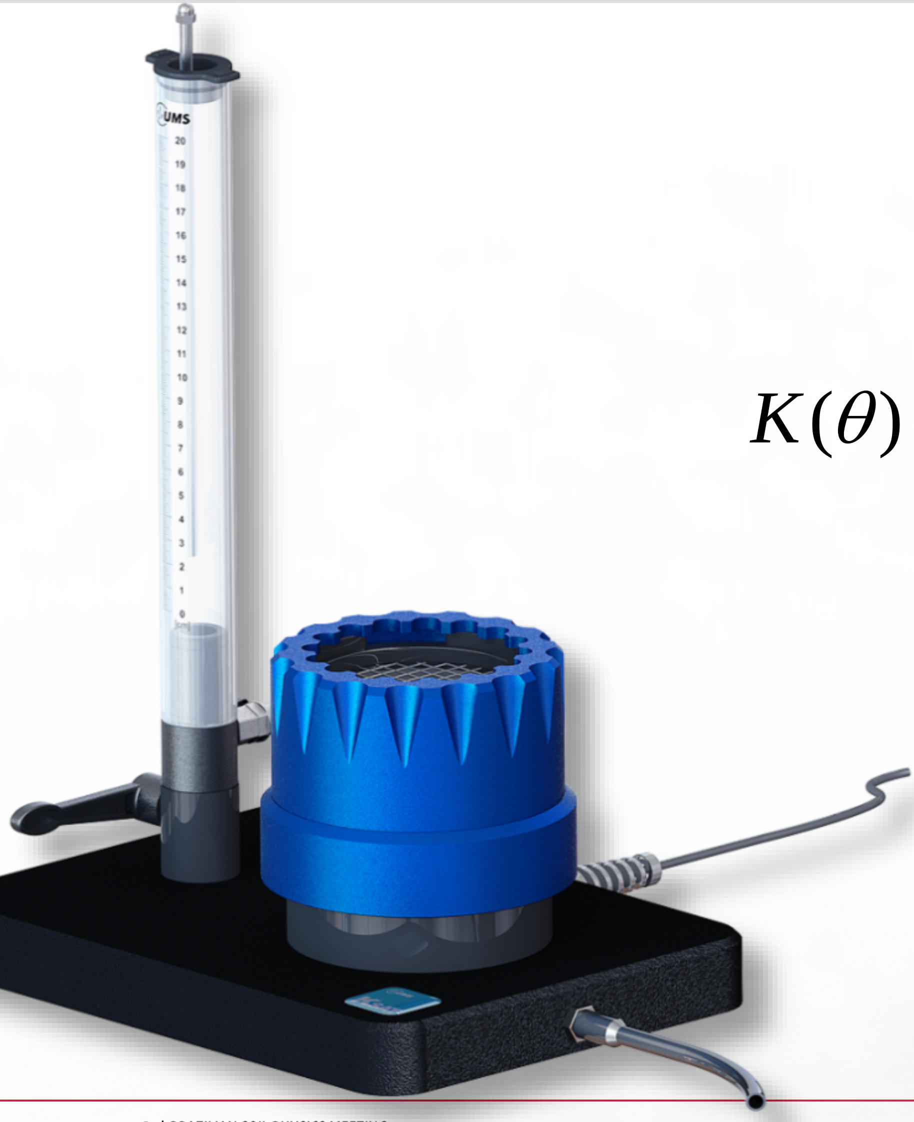
Relative conductivity function, $K_r(\theta)$

$$K_r(\theta) = S_e^{\,l}\left[\int_0^{\theta}\frac{1}{h^2}d\theta \bigg/ \int_0^{\theta_s}\frac{1}{h^2}d\theta\right]$$

Tortuosity coefficient *l*

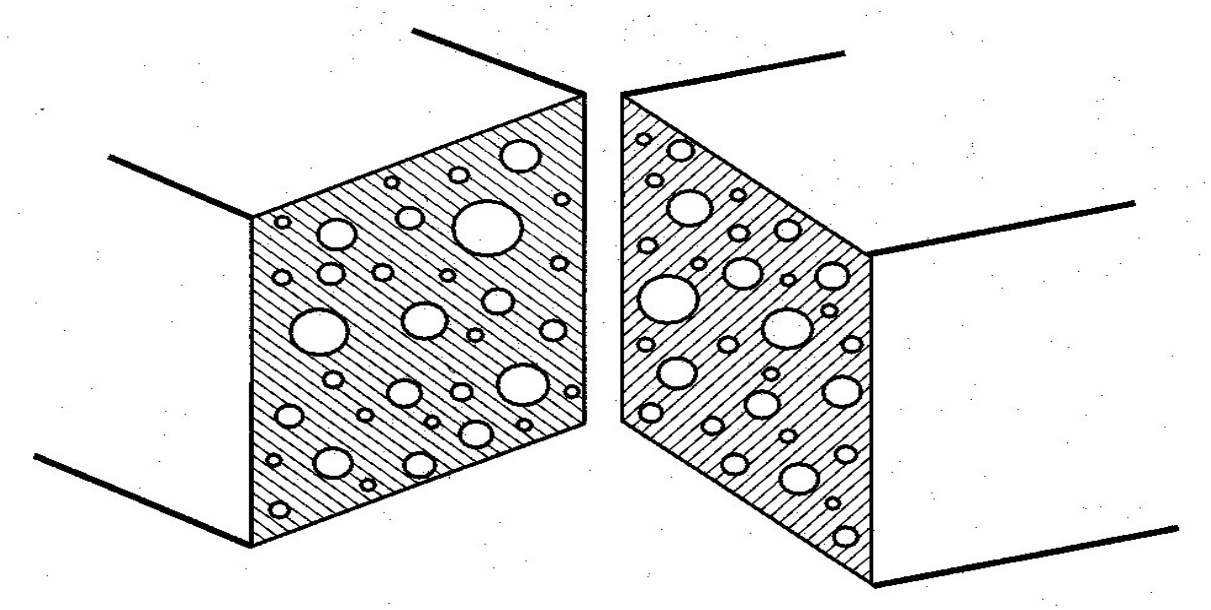
$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r)$$

UMS KSAT: Saturated hydraulic conductivity



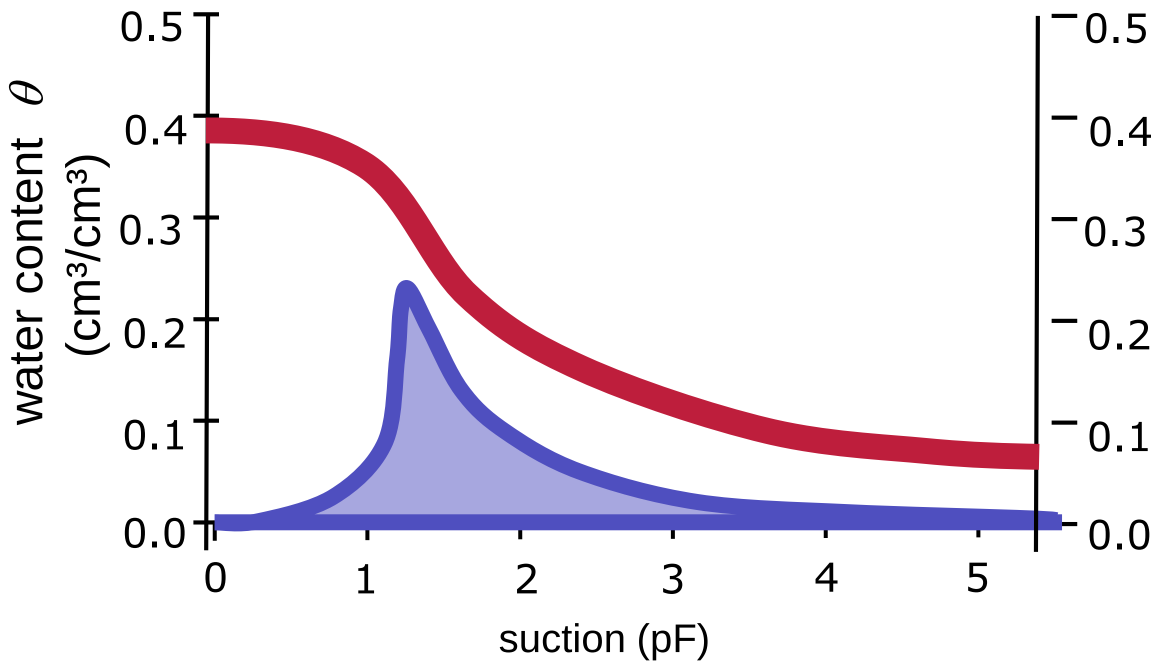
$$K(\theta) = K_r(\theta) \cdot K_s$$

capillary bundle models
cut-and-random-rejoin



Childs and Collis-George, 1950

Capillary bundle model: Mualem (1976)



$$K_r(\theta) = S_e^{0.5}\left[\int_0^{\theta}\frac{1}{h}\,d\theta \bigg/ \int_0^{\theta_s}\frac{1}{h}\,d\theta\right]^2$$

van Genuchten-Mualem model (1980)

retention function

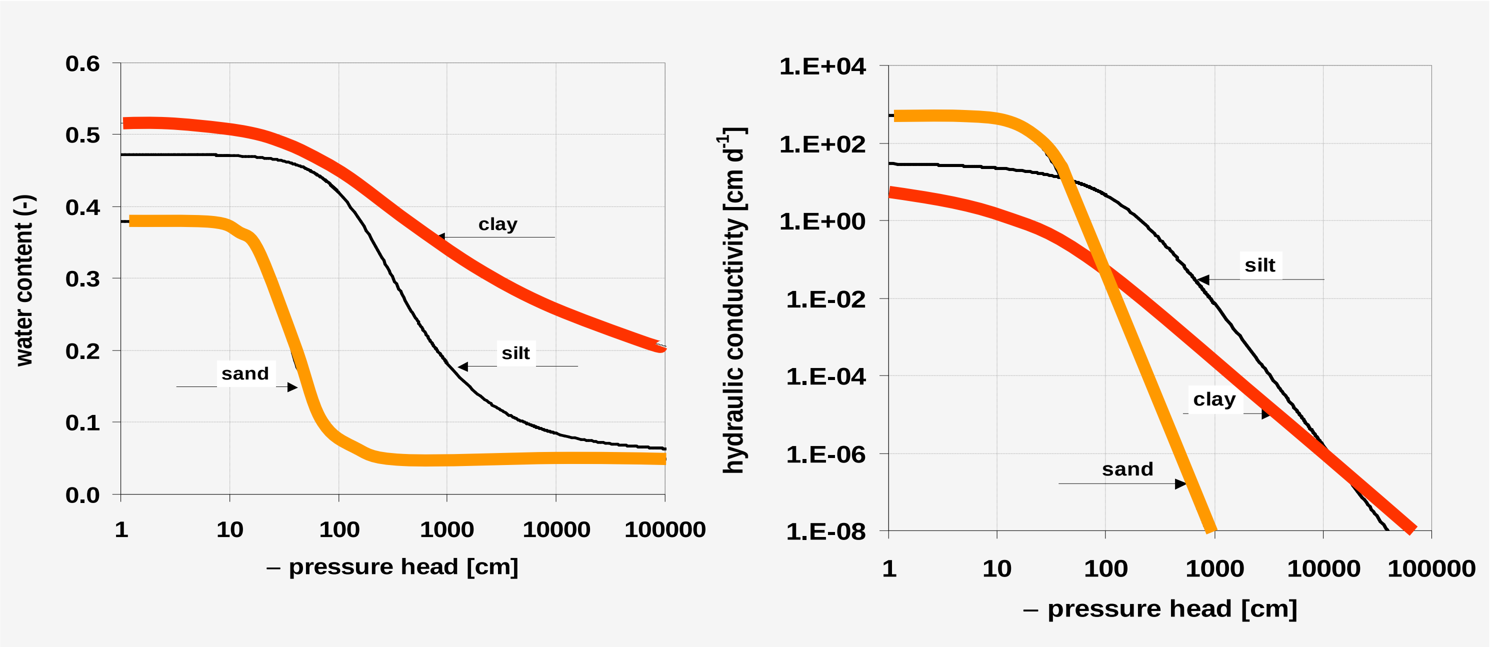
$$S_e = \left(\frac{1}{1 + |\alpha h|^n} \right)^m$$

conductivity function

$$K = K_s S_e^l \left[1 - \left(1 - S_e^{1/m} \right)^m \right]^2$$

α [m^{-1}], n [-], m [-]	van Genuchten parameters
$S_e(h)$ [-]	effective saturation
K_s [m s^{-1}]	saturated conductivity
l [-]	tortuosity coefficient

van Genuchten-Mualem parametrization



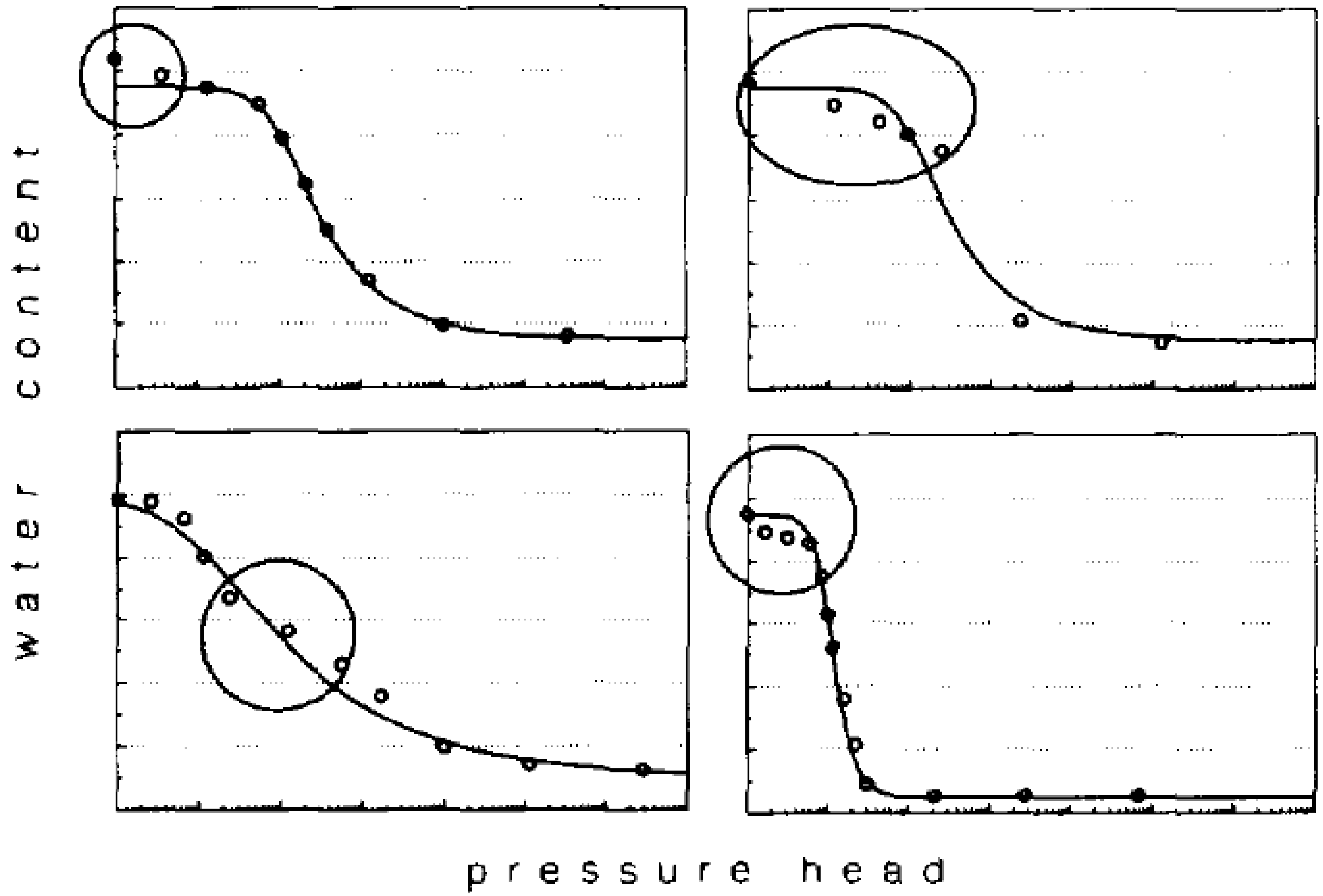
Typical hydraulic properties of differently textures soils Left: Water retention curves. Right: Unsaturated conductivity curves (Durner und Flühler, 2005).

So far: nothing new.

Part 3:
A closer look on hydraulic properties

The wet range

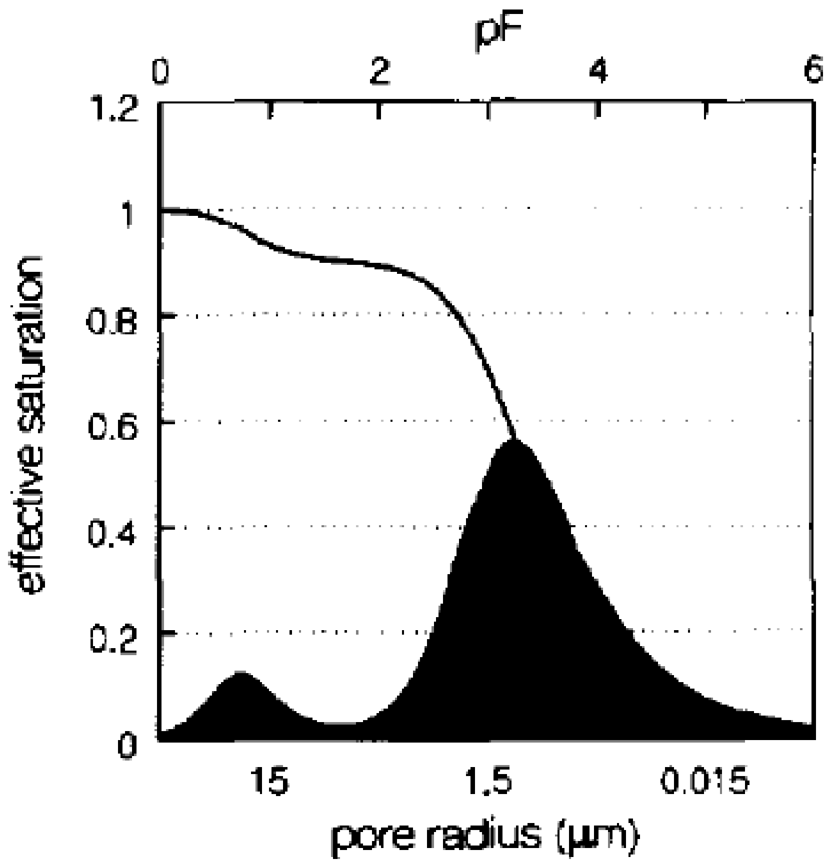
Wet range: small changes …



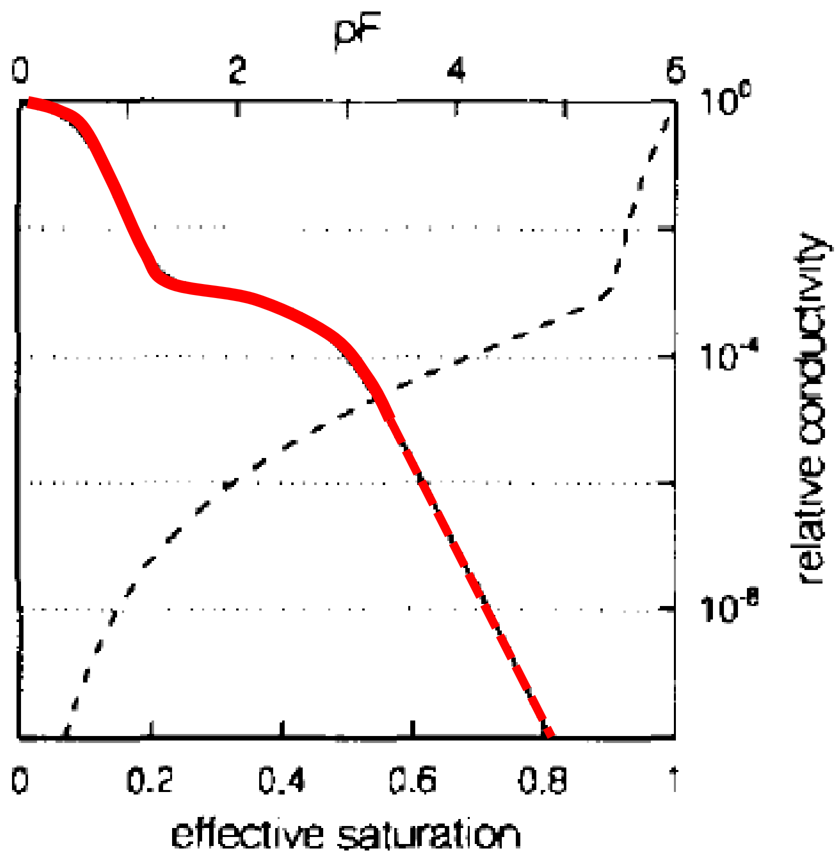
Durner (1994), WRR

Wet range: small changes …
…have big effects

Water retention function



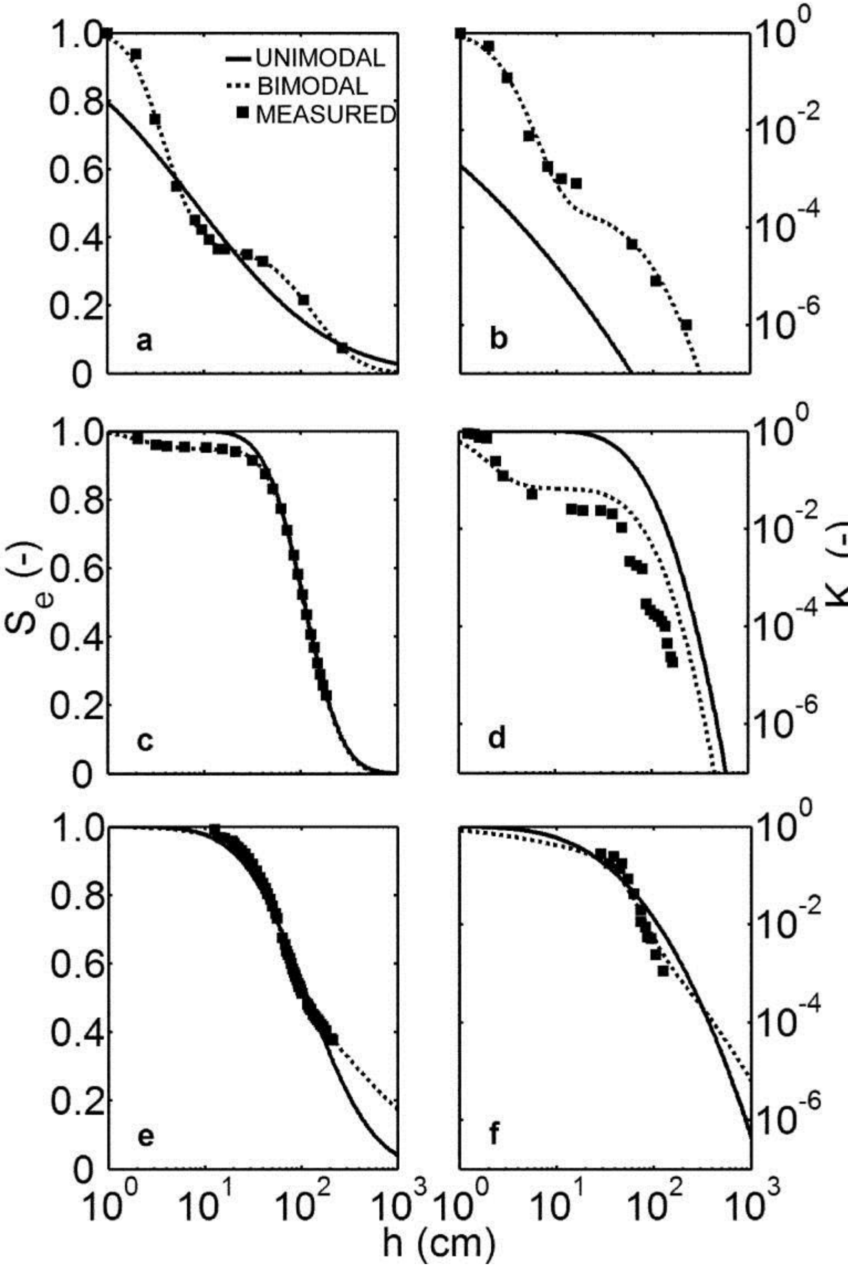
Hydraulic conductivity function



Durner (1994), WRR

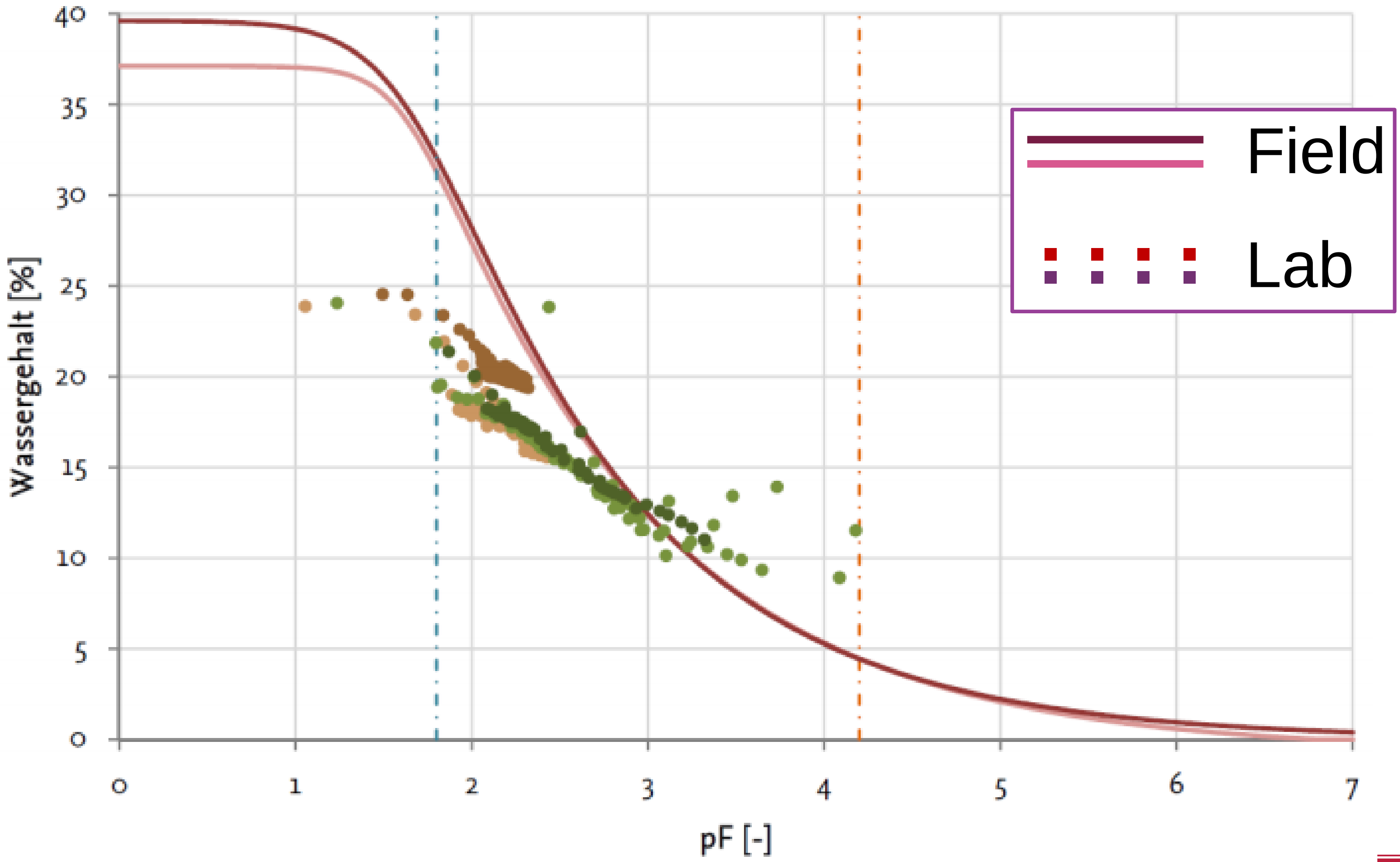
Using Bimodal Lognormal Functions to Describe Soil Hydraulic Properties

N. Romano et al., SSSAJ, 2010



The mid range

Mid range: fundamentally wrong perception?

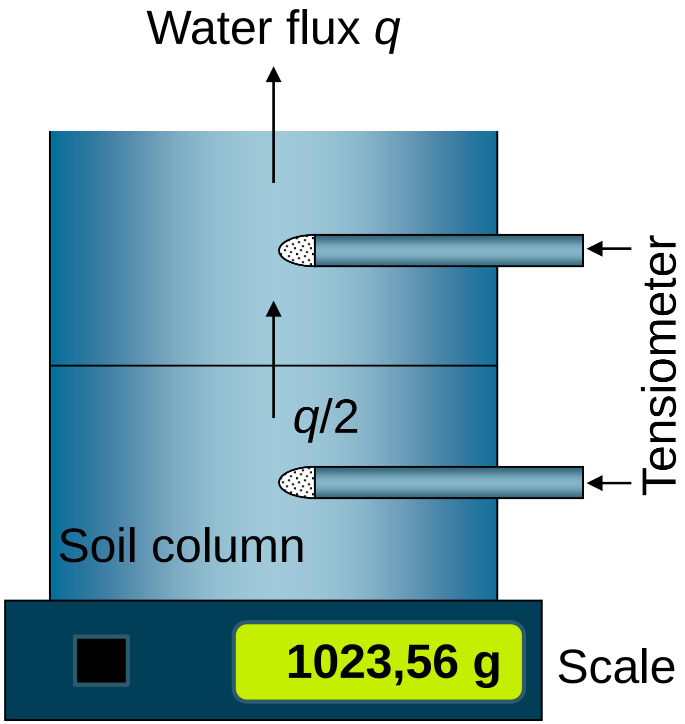


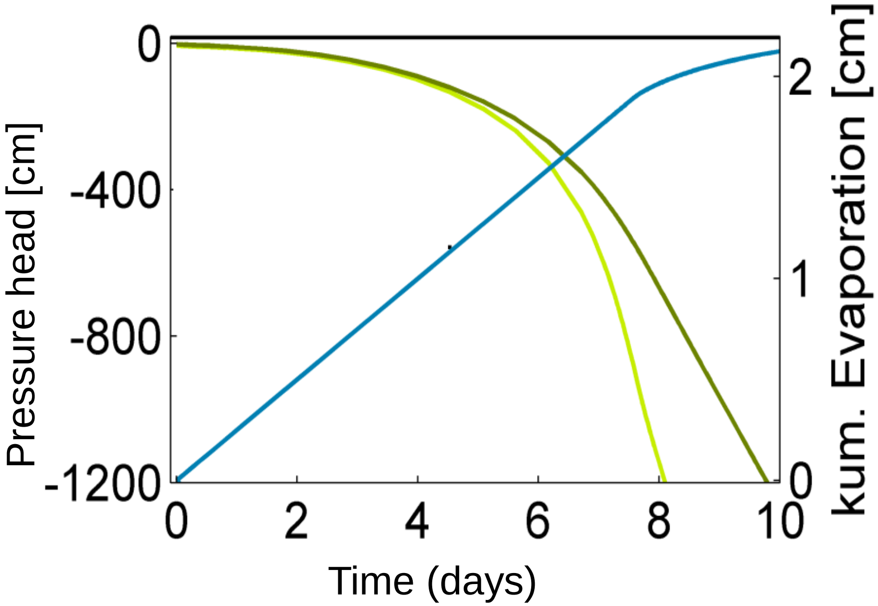
Hydraulic Properties: Challenges

- Hysteresis and dynamic effects
- Temporally varying hydrophobicity (mucilage, biofilms, OM)
- Shrinking and swelling porous media
- Heterogeneity and Upscaling
- Chemical and biological feedbacks
- T-dependence and thermohydraulic coupling

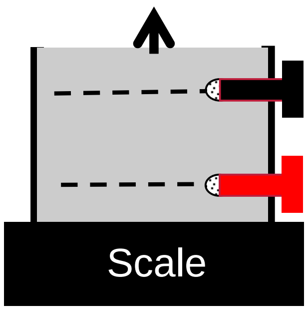
The dry range

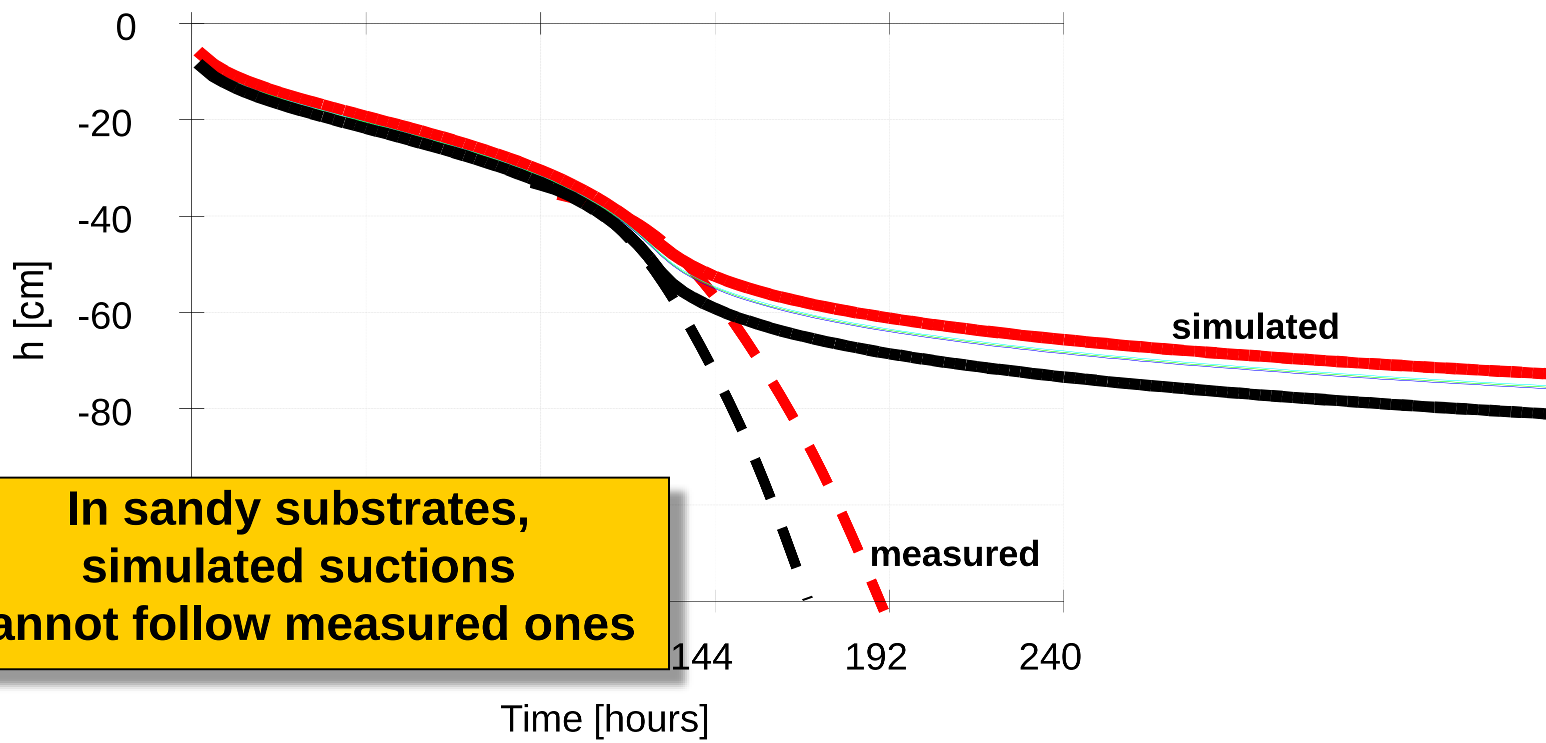
Dry end: Evaporation Experiments





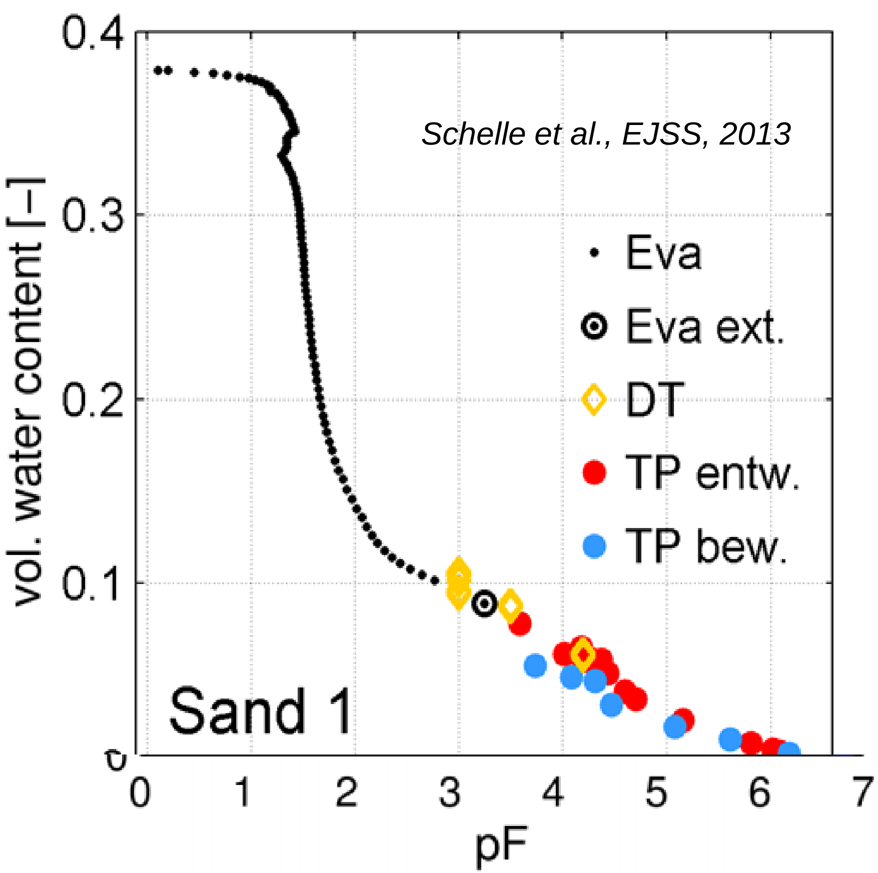
Observation (1)

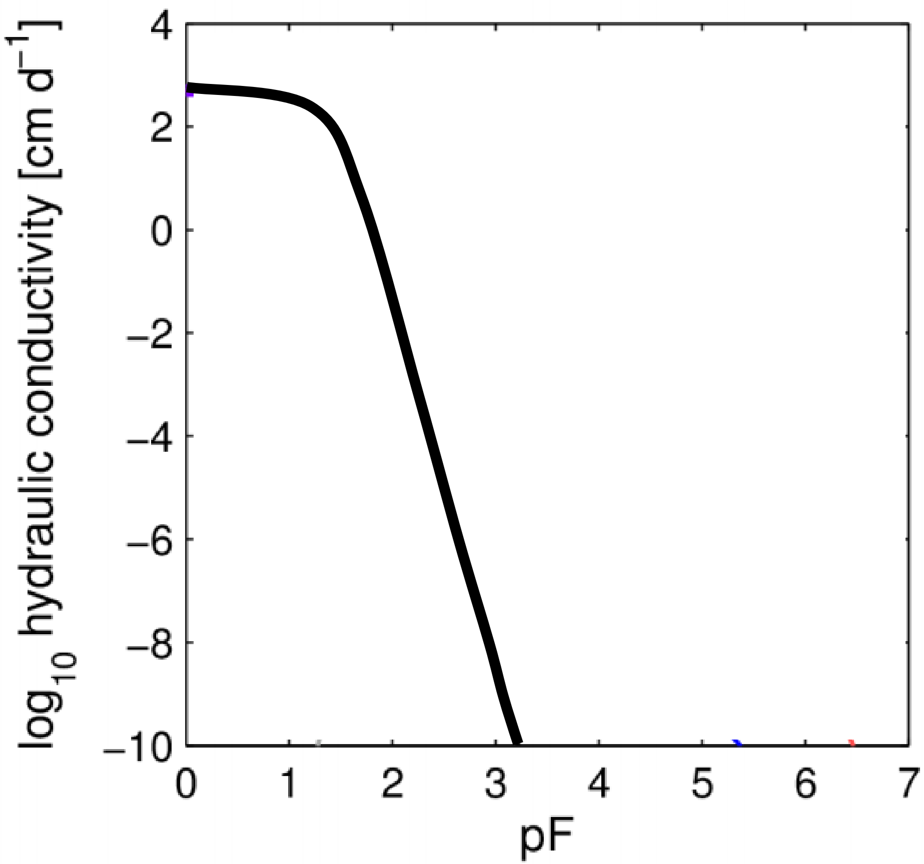




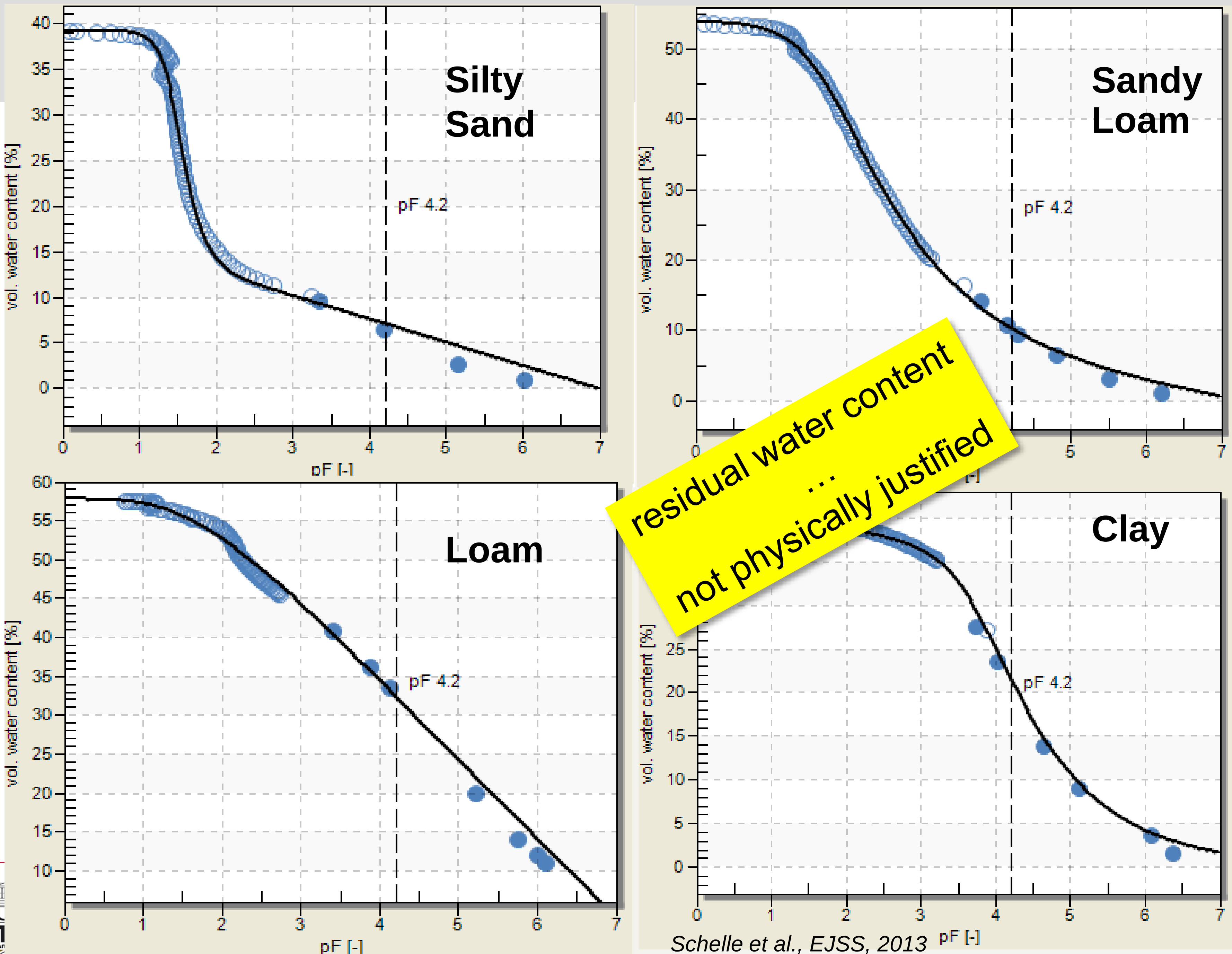
In sandy substrates, simulated suctions cannot follow measured ones

Observation (2)



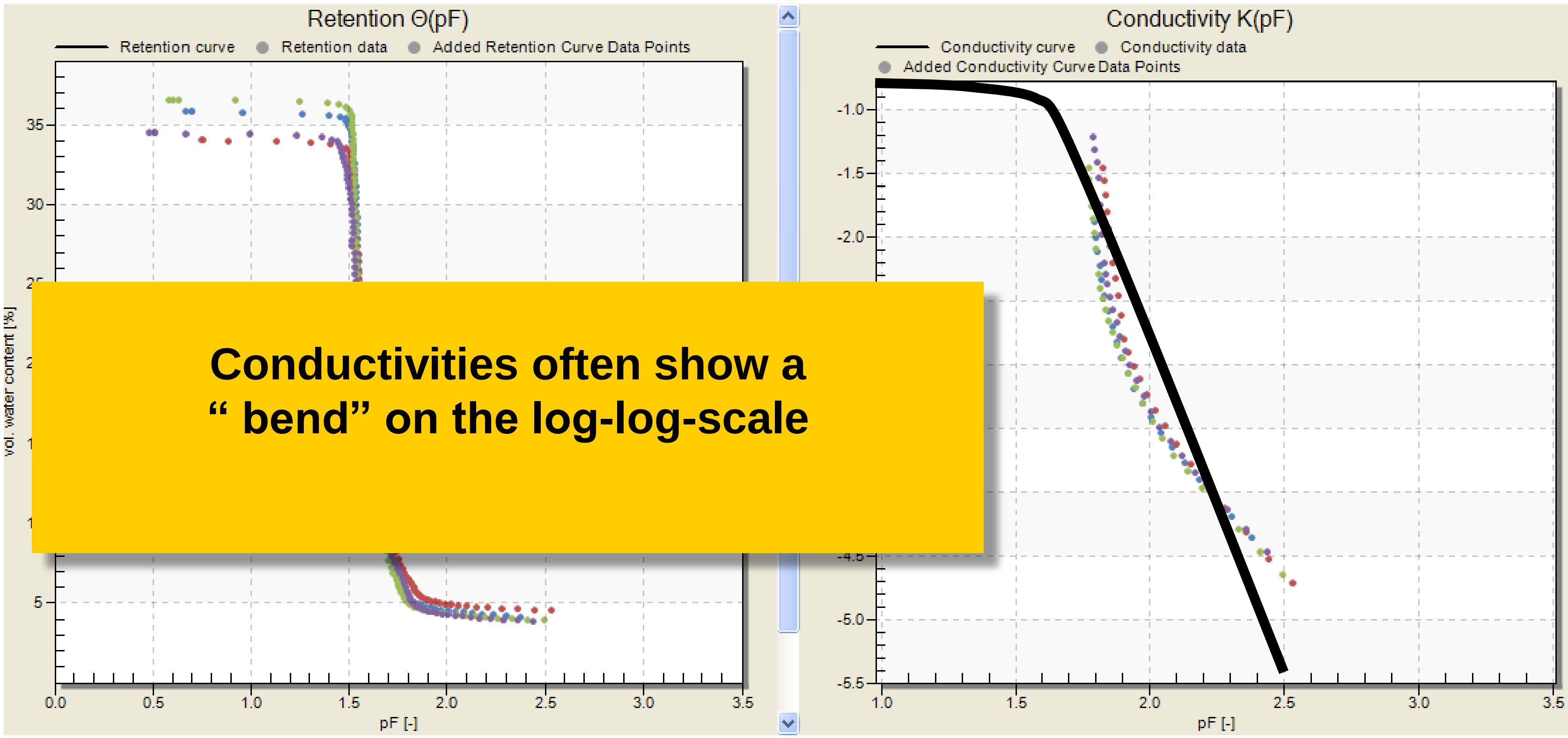


e.g. Nimo, 1991



Schelle et al., EJSS, 2013

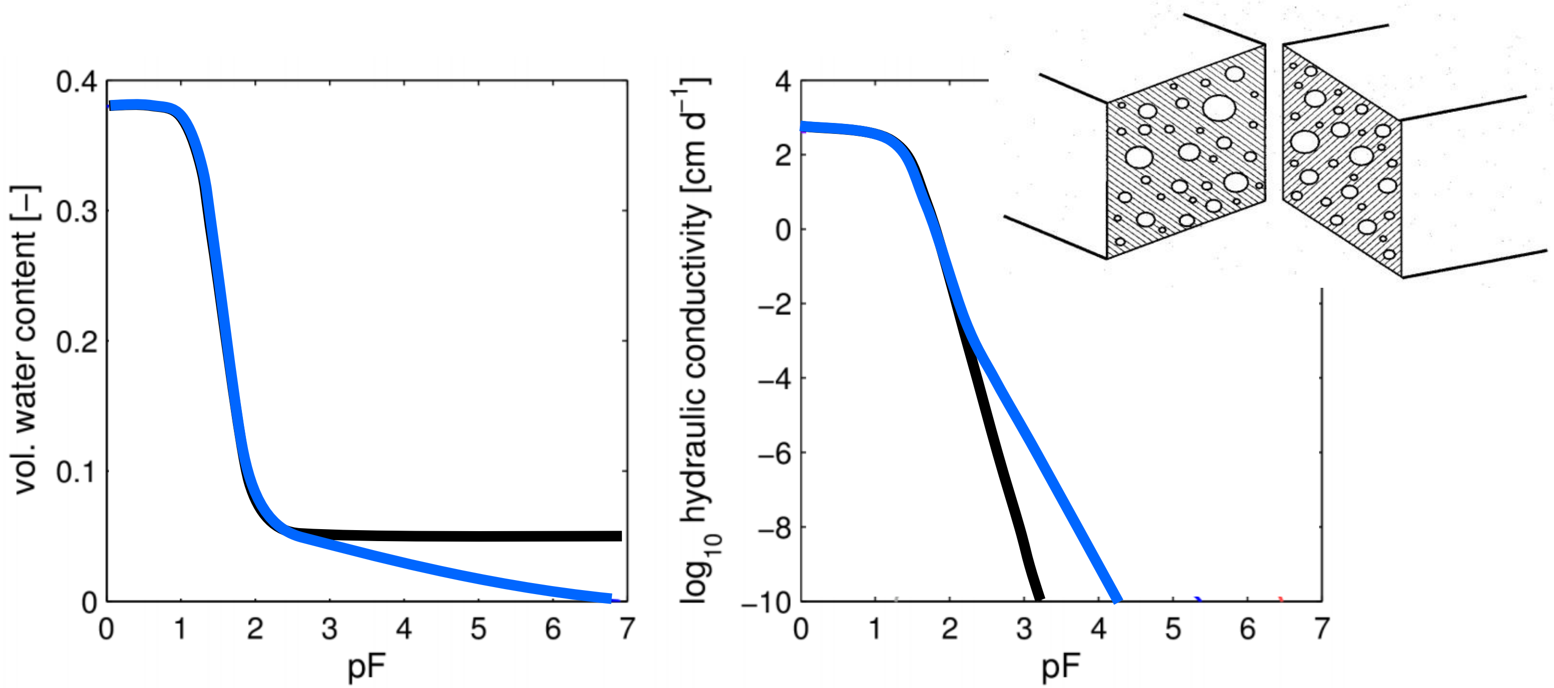
Observation (3)



Conductivities often show a “ bend” on the log-log-scale

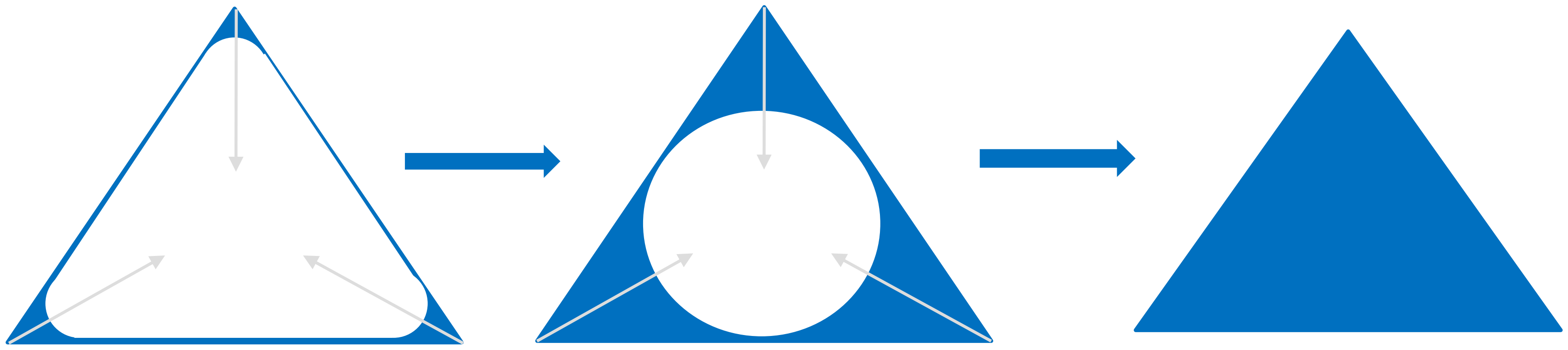
Part 4:
Better shaped hydraulic properties

Better SHP …



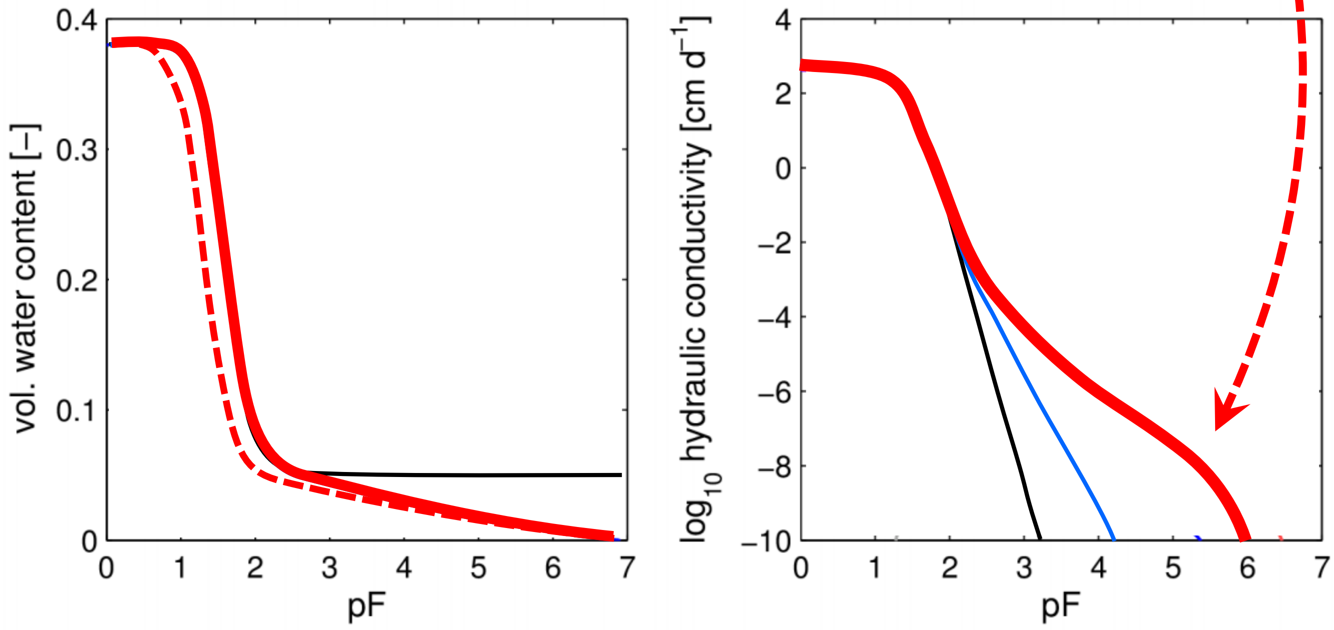
Ross et al. 1991 | Campbell-Shiozawa 1992 | Rossi and Nimmo 1994 | Fredlund-Xing 1994 | Fayer-Simmons 1995| Morel-Seytoux and Nimmo 1999 | Webb 2002 |Groenevelt and Grant 2004| Khlosi et al 2006 | …

Adding a film-flow + corner-flow component



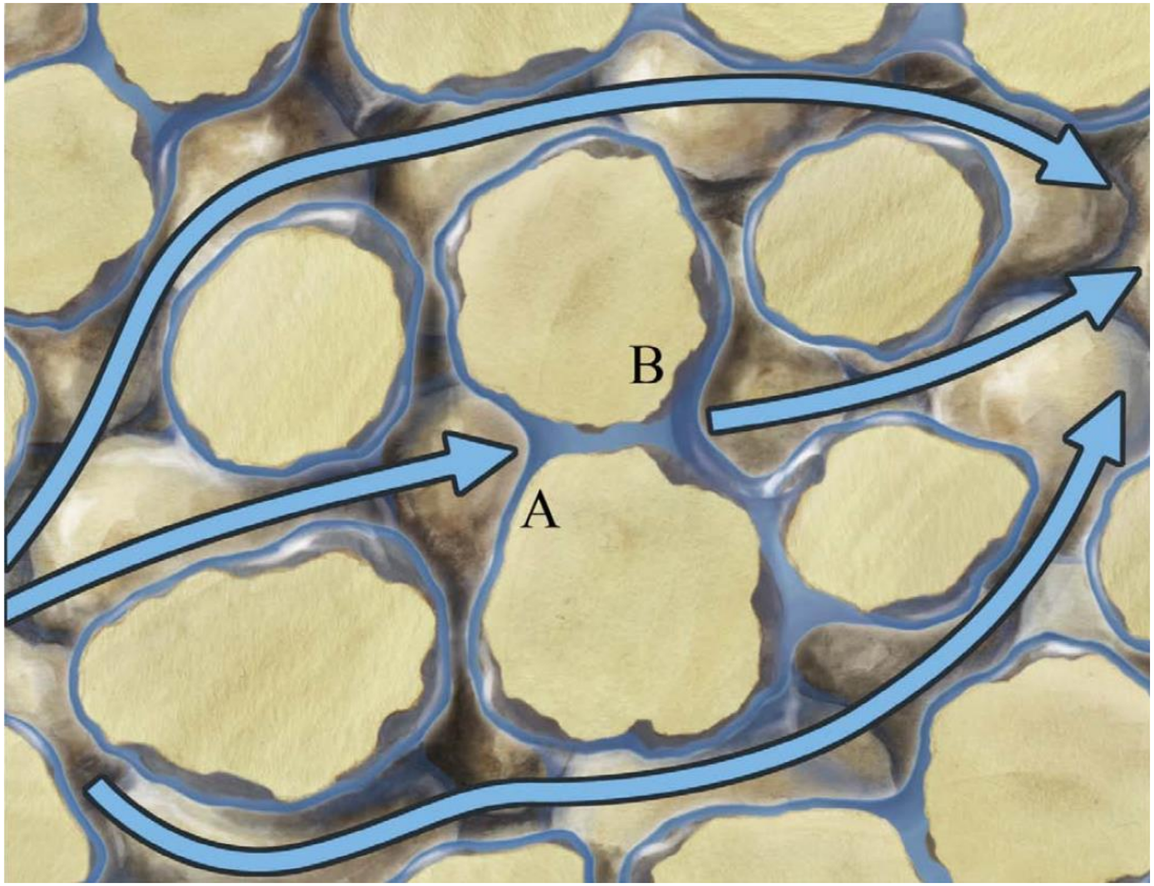
Tuller-Or 2001

… even better SHP …



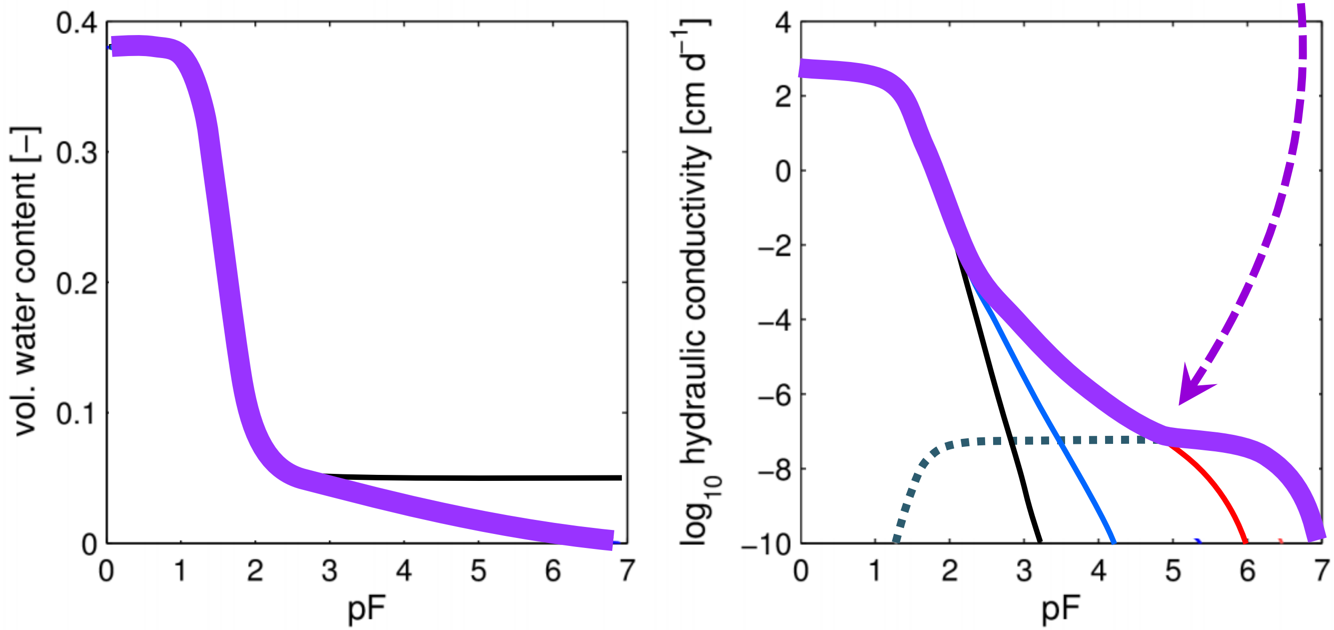
Tuller-Or 2001 |Peters-Durner 2008 | Tokunaga 2009 |Lebeau-Konrad 2010| Zhang 2011 | Diamantopoulos-Durner, 2013 | …

(Enhanced) diffusion of water vapor



(Enhanced) diffusion of water vapor by condensation and evaporation in presence of isolated liquid water
(Fig. by Shahraeeni und Or, 2012)

Really good SHP !

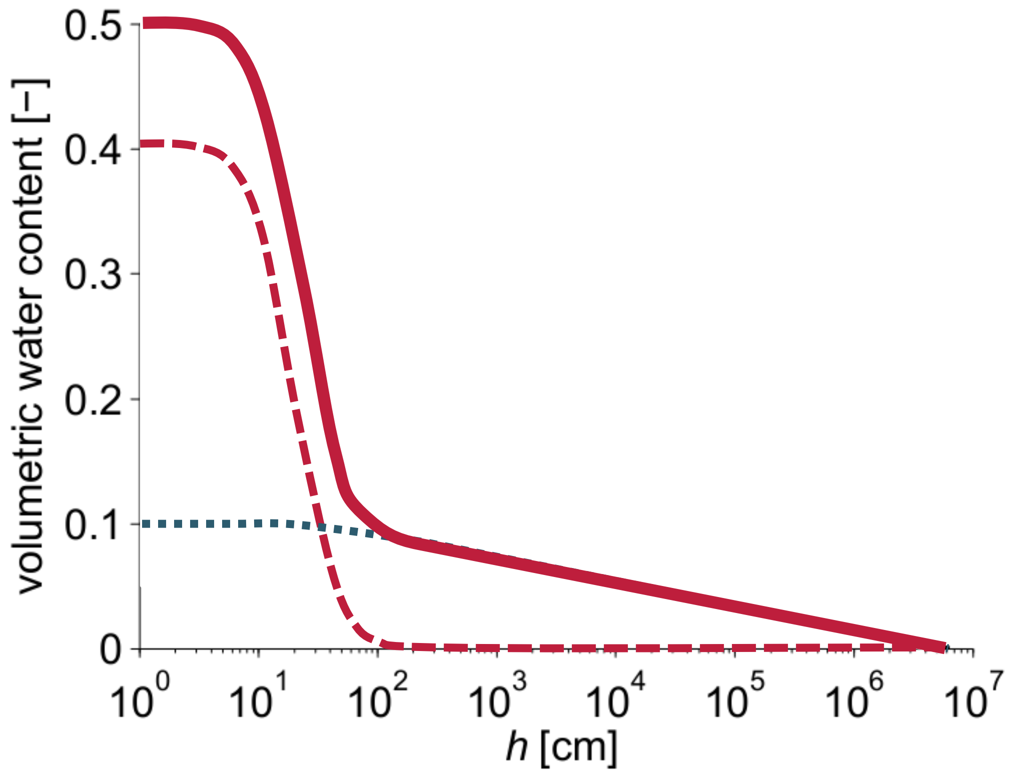


Philip and de Vries 1957 | Saito et al. 2006

A parsimonious parameterization: The PDI model

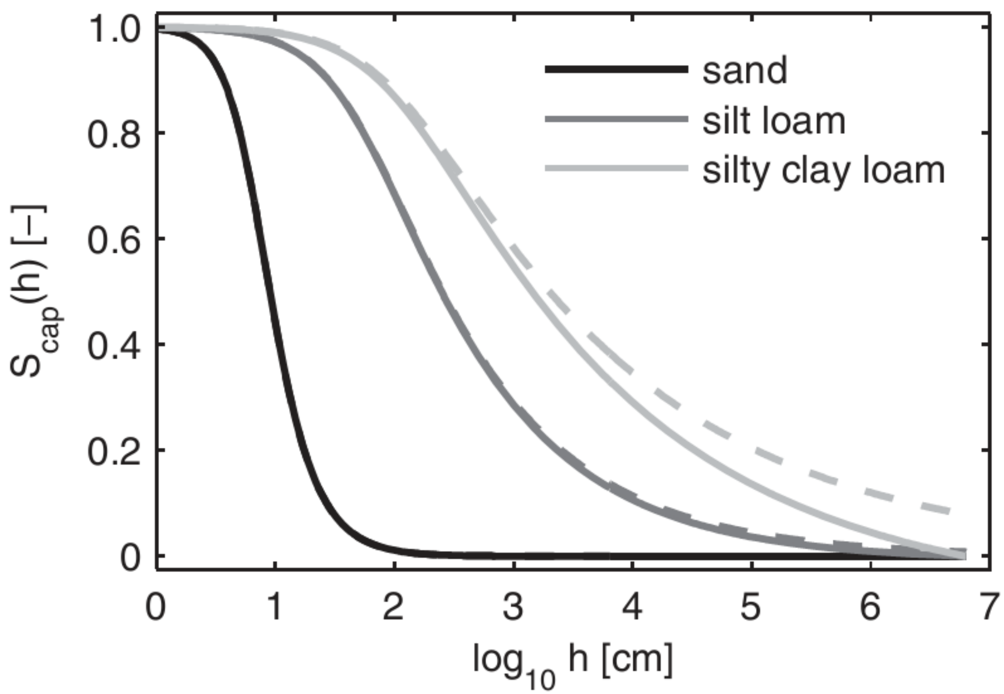
PDI model: retention curve (Peters 2013 | Iden and Durner 2014 | Peters 2014)

$$\theta(h) = (\theta_s - \theta_r)\, S_{cap}(h) + \theta_r\, S_{ad}(h)$$



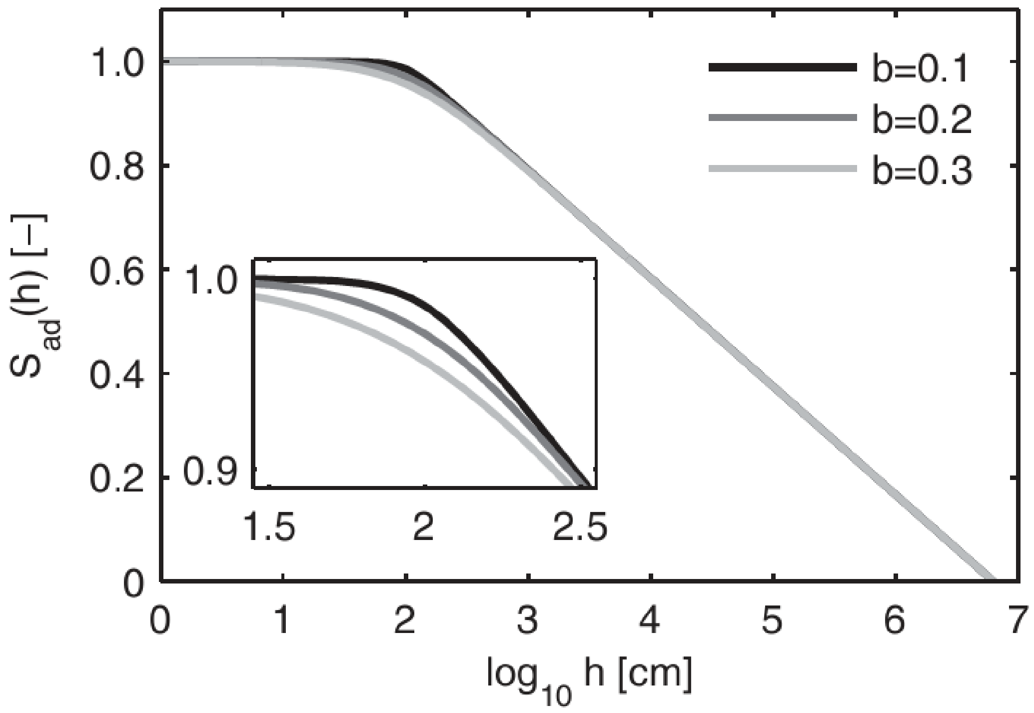
PDI model: capillary part

$$S_{\mathrm{cap}}(h) = \frac{\Gamma(h) - \Gamma(h_0)}{1 - \Gamma(h_0)}$$



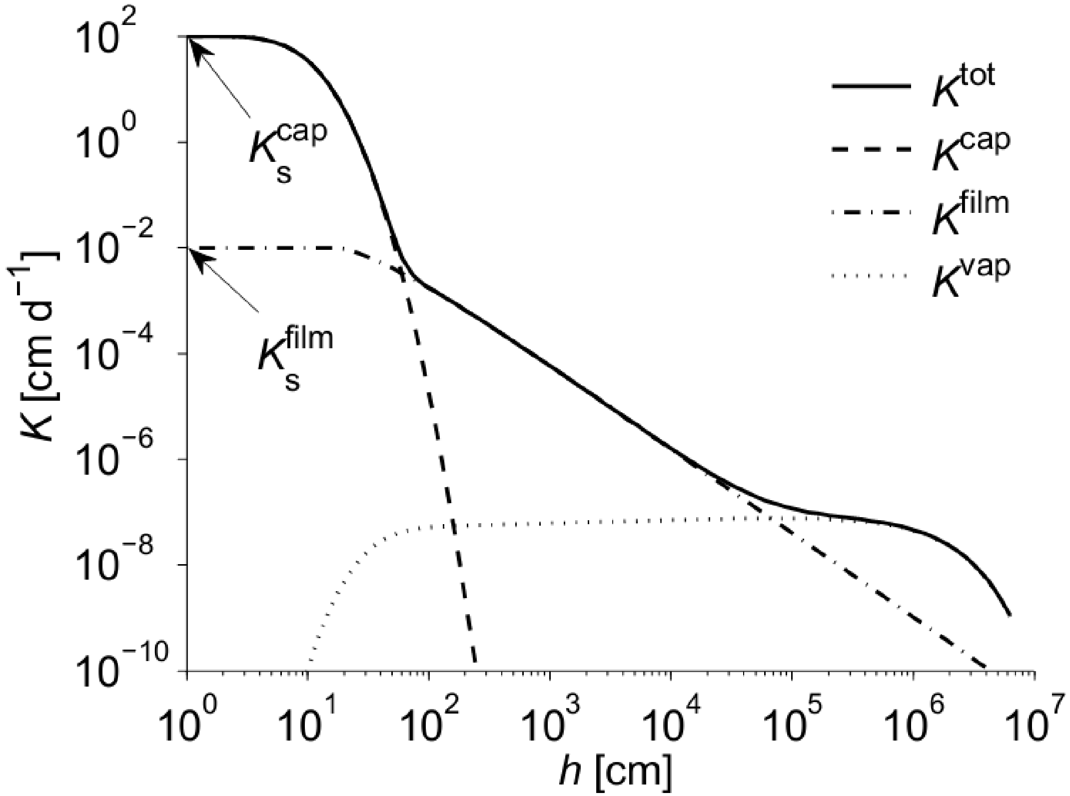
PDI model: non-capillary part

$$S_{\mathrm{ad}}(x) = 1 + \frac{1}{x_a - x_0}\left\{x - x_a + b\,\ln\left[1 + \exp\left(\frac{x_a - x}{b}\right)\right]\right\}$$

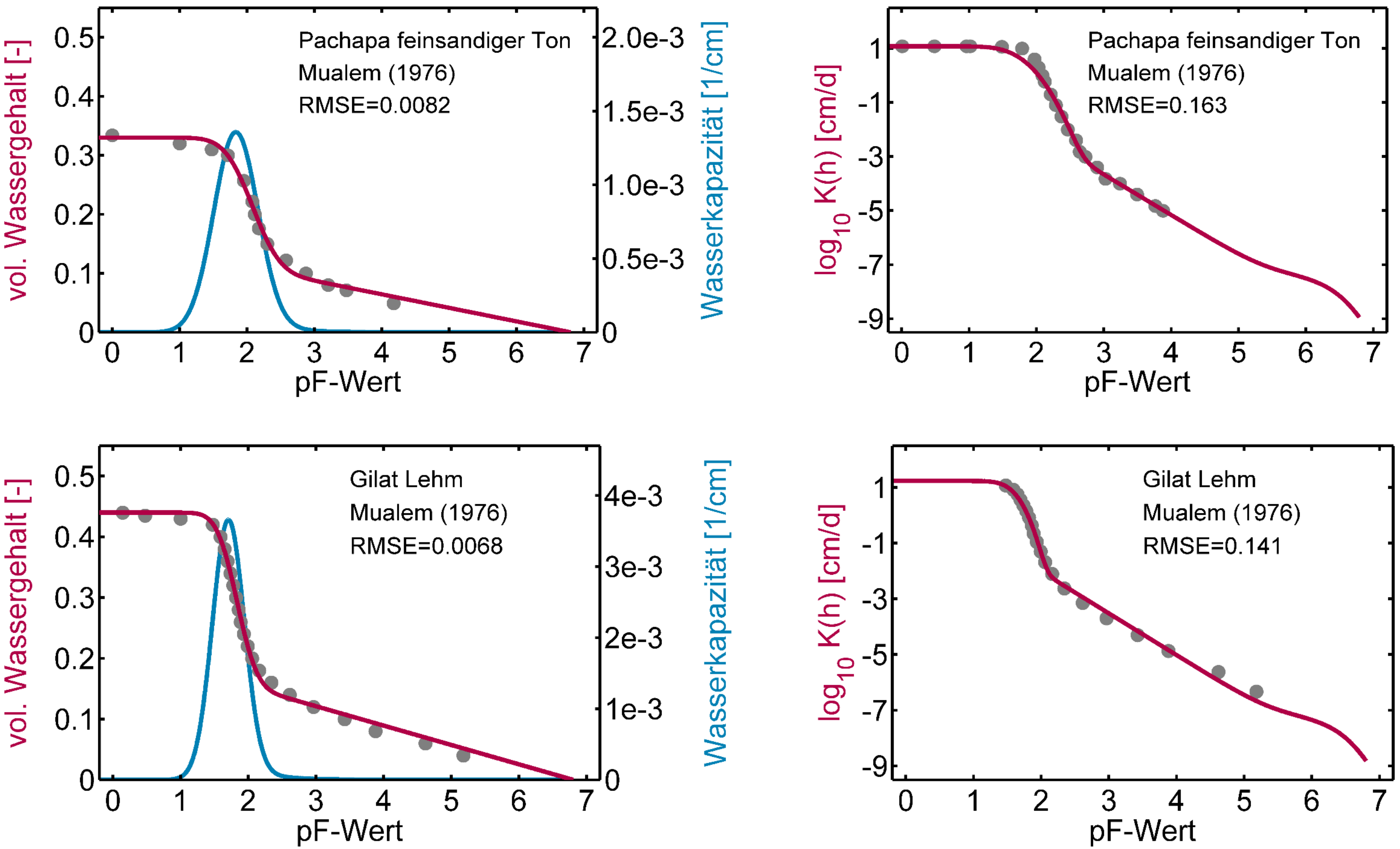


PDI model: conductivity curve

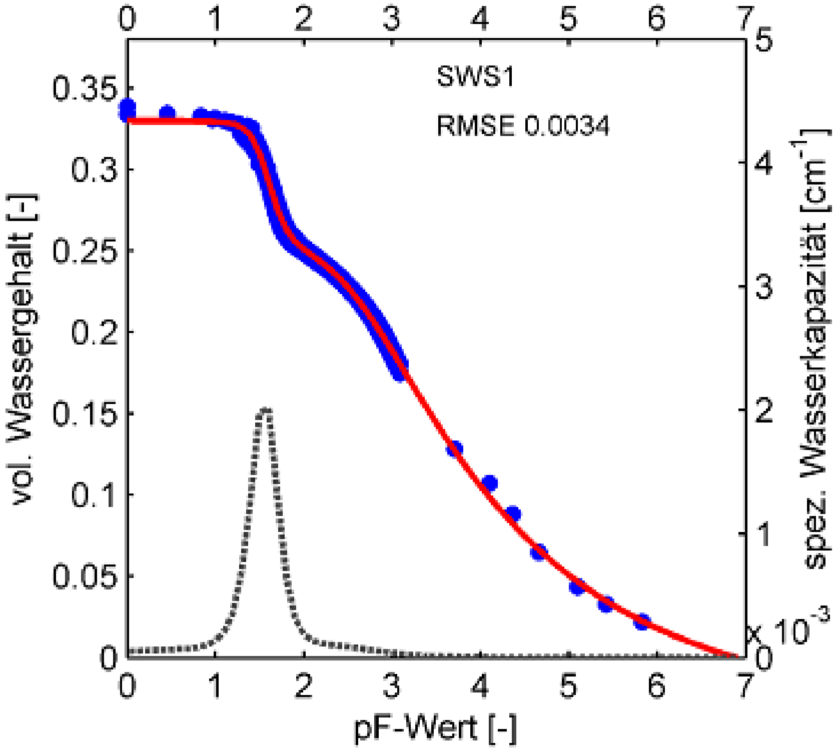
$$K^{\mathrm{lv}} = K^{\mathrm{liq}} + K^{\mathrm{vap}} = K^{\mathrm{cap}} + K^{\mathrm{film}} + K^{\mathrm{vap}}$$

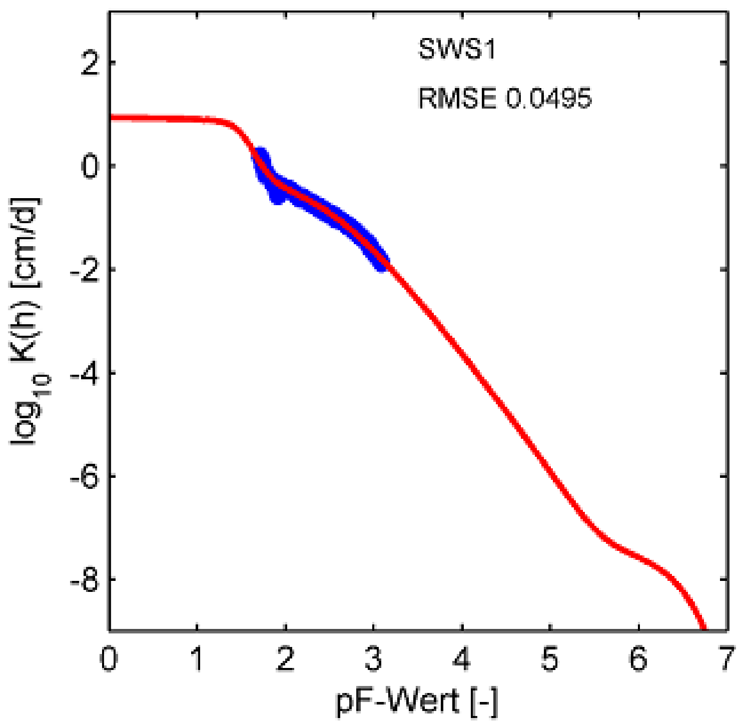


PDI model fitted to data



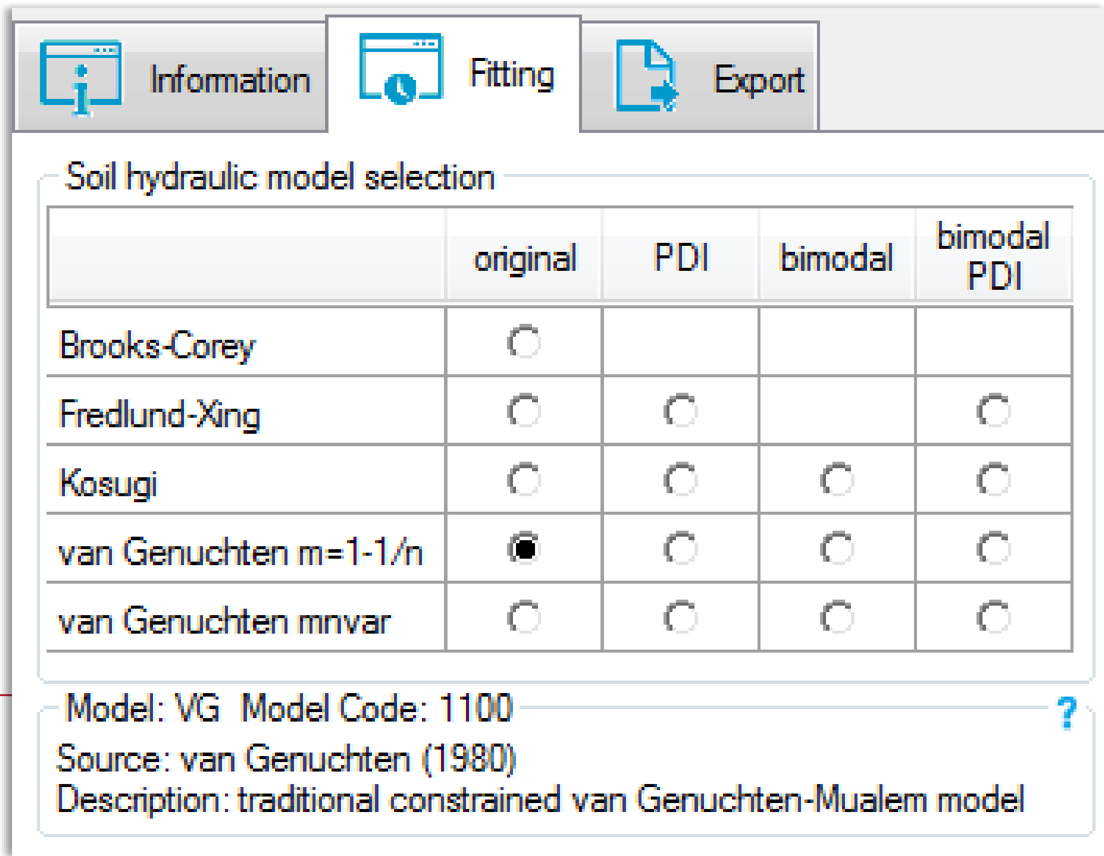
PDI model fitted to data

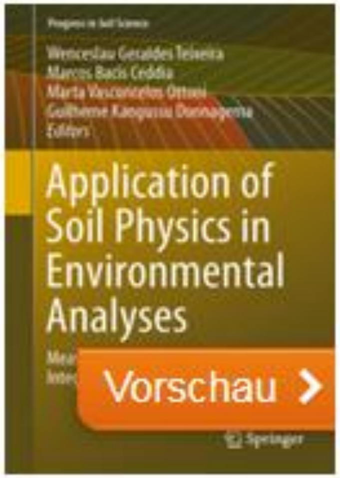




Summary: Properties of the PDI model

- Always reaches zero water content at oven dryness
- Continuous water capacity function
- RETC: no more parameters than traditional models, e.g., $\alpha, n, \theta_s, \theta_r$
- Very robust
- Implemented in the free HYPROP-FIT software



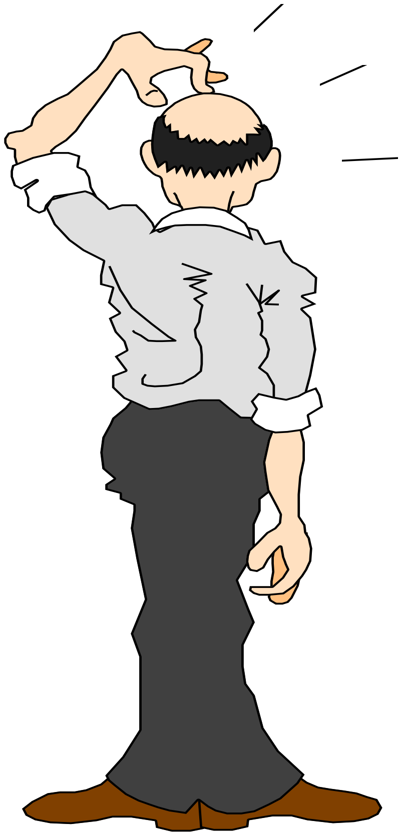


Chapter 17
Hydraulic Properties and Non-equilibrium Water Flow in Soils

Wolfgang Durner, Efstathios Diamantopoulos, Sascha C. Iden, and Benedikt Scharnagl

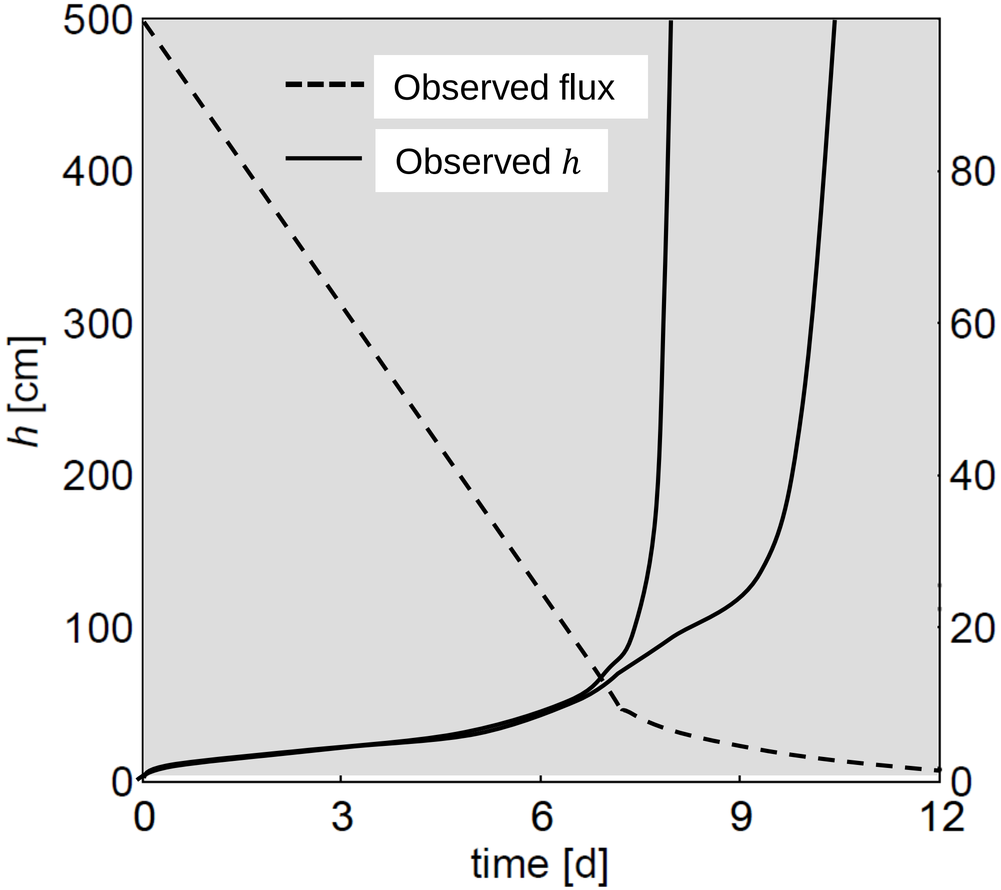
Abstract Accurate knowledge of hydraulic properties for unsaturated soils is critical in the estimation of soil water fluxes by simulation models that are based on the Richards equation. The purpose of this chapter is to review the characteri-

Does that matter ?

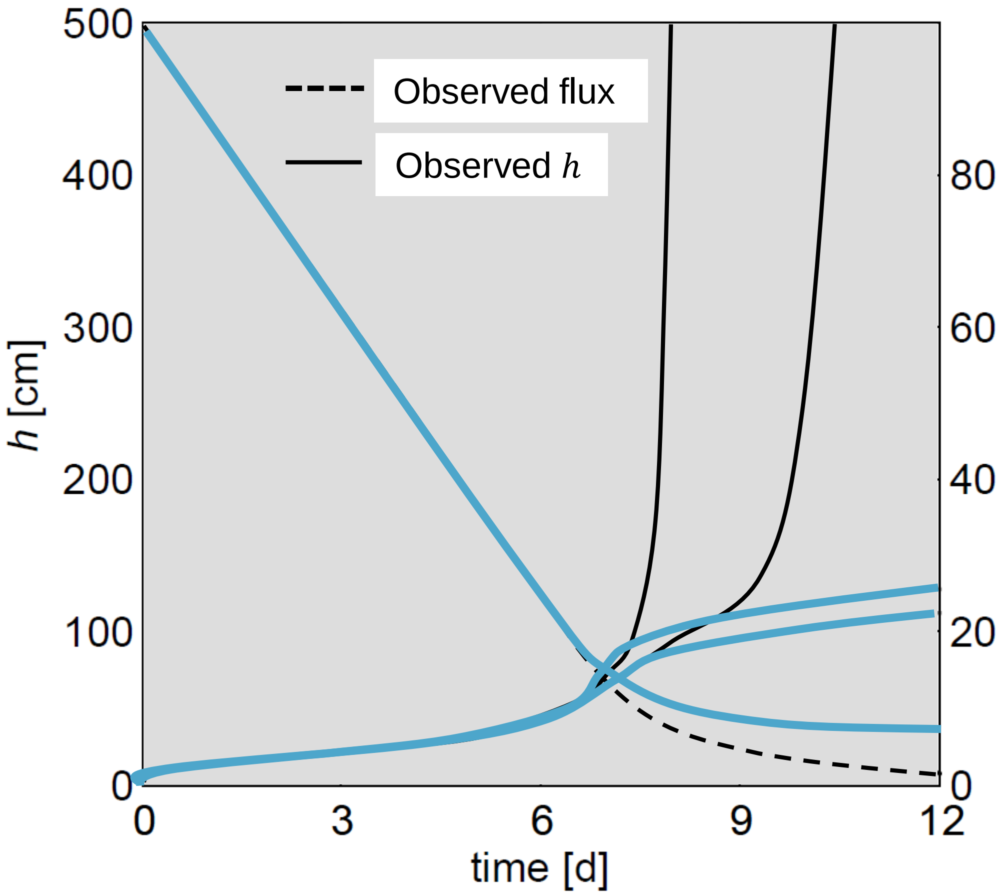


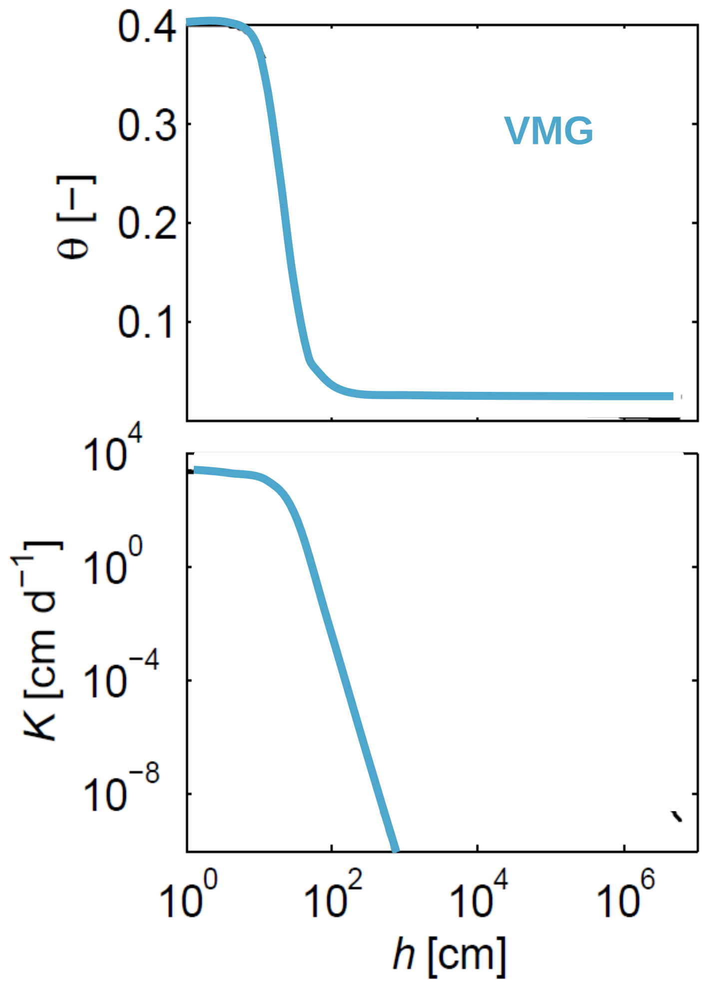
Part 5:
Application Example

Does that matter (1)?

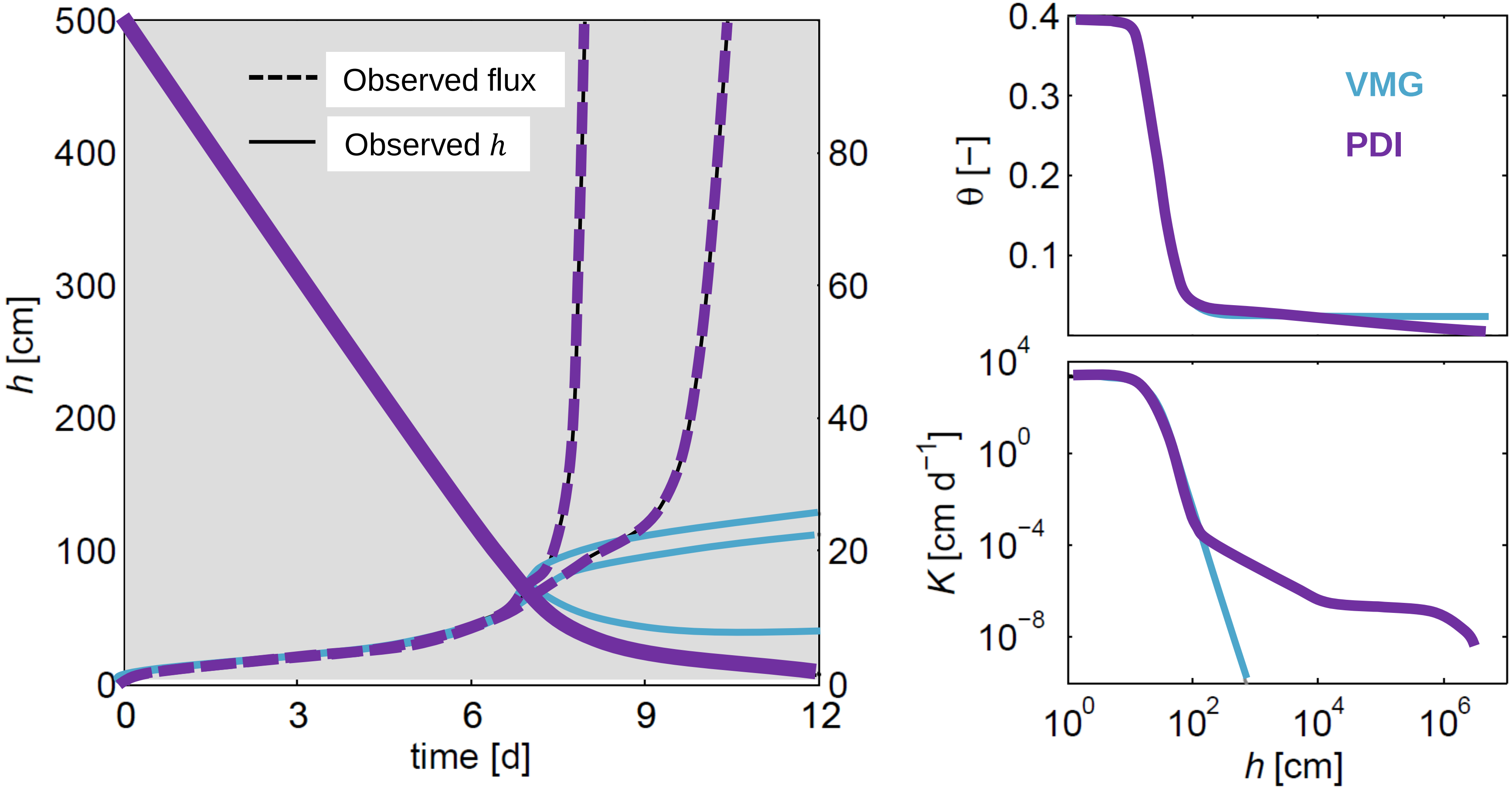


Does that matter (1)?

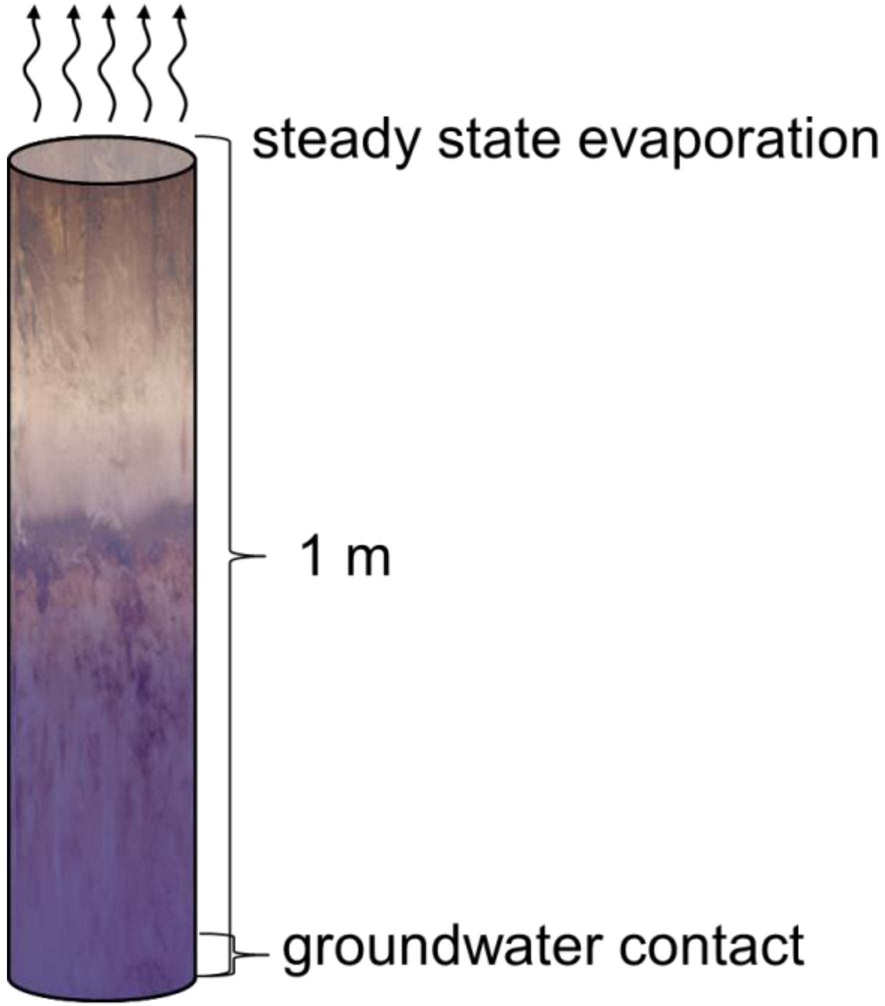




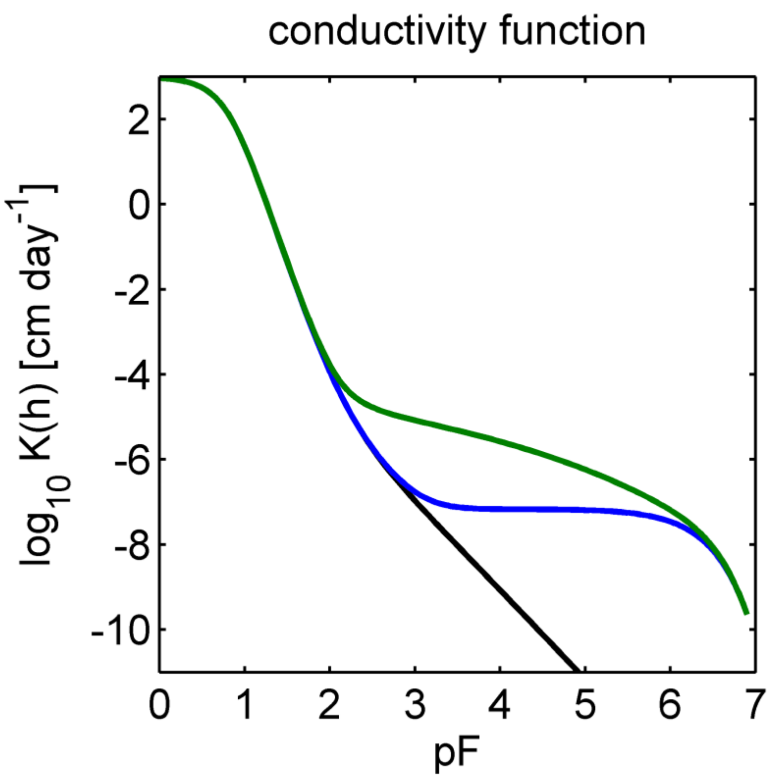
Does that matter (1)?

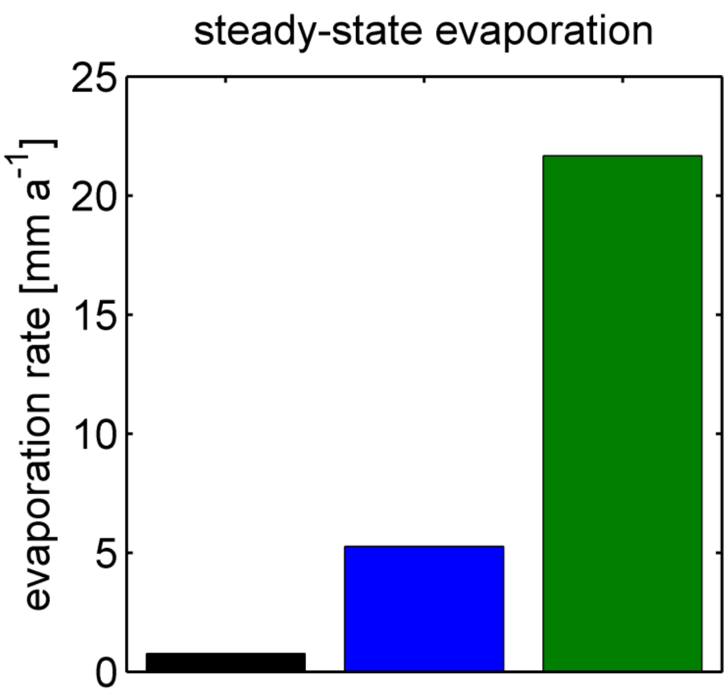


Does that matter (2)?



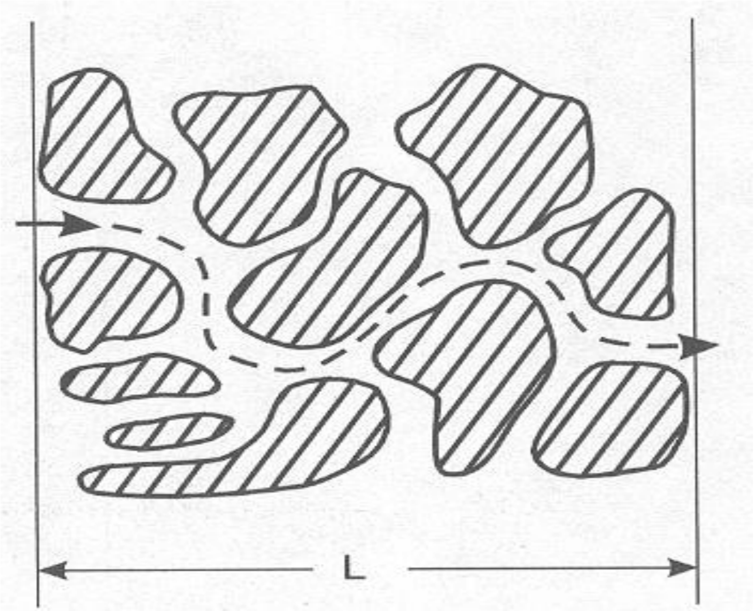
Does that matter (2)?





Final Excursus: The tortuosity coefficient

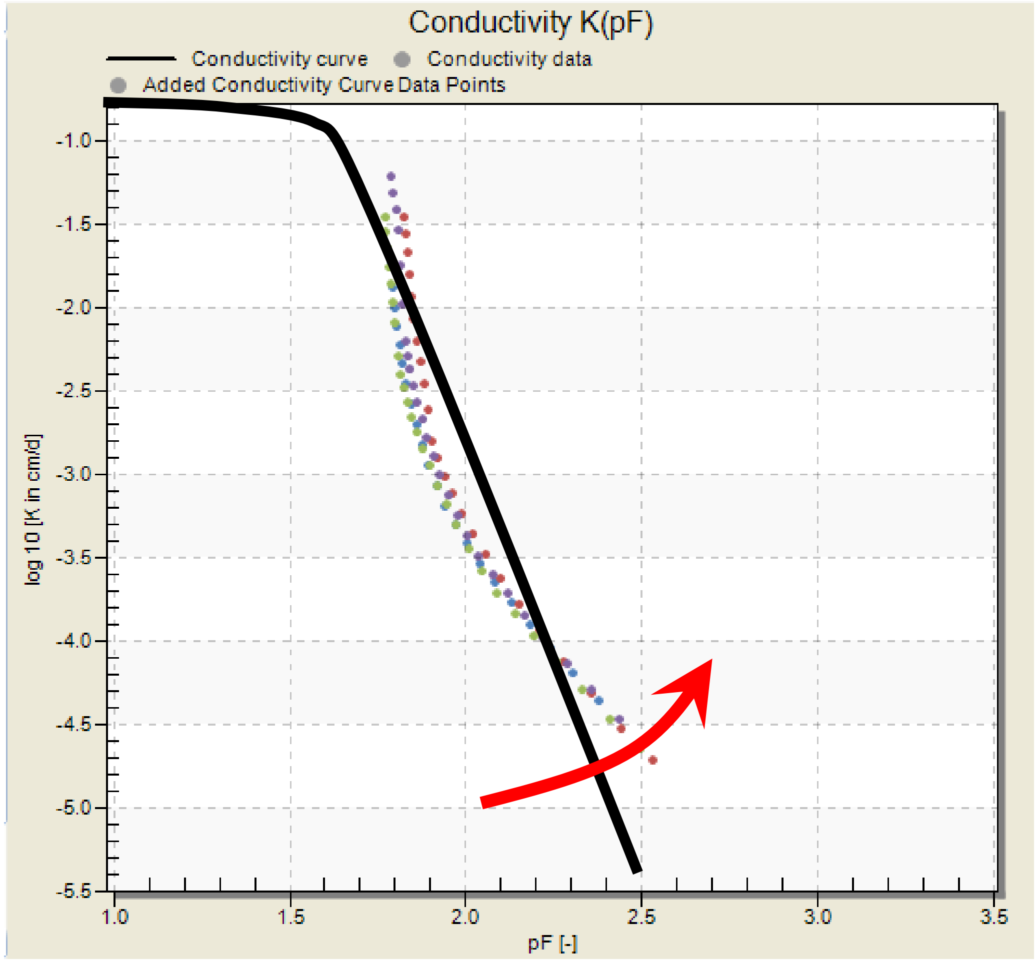
Theoretically: inverse of tortuosity!



$$0 < l < 1$$

De facto: empirical fitting parameter

Excursus 2: The tortuosity coefficient



Excursus 2: The tortuosity coefficient

Negative tortuosity coefficients are
an artefact of an inadequate model structure

Conclusions

Conclusions (1): Where do we go?

- The limits of the usability(!) of Richards' equation are not yet explored.
- Many limitations can be overcome by adapting hydraulic functions.
- No replacement of the current standard, rather identifying situations where specific adaptations are needed.
- Limitations are not given by the modeling ability but by the inability to derive appropriate parameters.
- More and better experiments are needed.

Conclusion (2): SHP parametrizations

- Parameterizations of SHP should be a simple as possible – but not simpler
- Traditional SHP have structural deficits
- Conductivity function in the medium moist range is dominated by film/corner flow which can [under certain conditions] strongly affect the water flow
- Avoiding structural errors is of great importance in development of pedotransfer functions

Technische Universität Braunschweig

Institut für Geoökologie
Bodenkunde und Bodenphysik

Parameterization of models for soil hydraulic properties: Challenges and recent advances

Wolfgang Durner

Sascha Iden, Andre Peters, Efstathios Diamantopoulos,
Kai Germer, Tobias Weber, Benedikt Scharnagl