What kind of tree does soil data grow on?

NIBIO
NORSK INSTITUTT FOR BIOØKONOMI

A. Nemes and Cs. Farkas

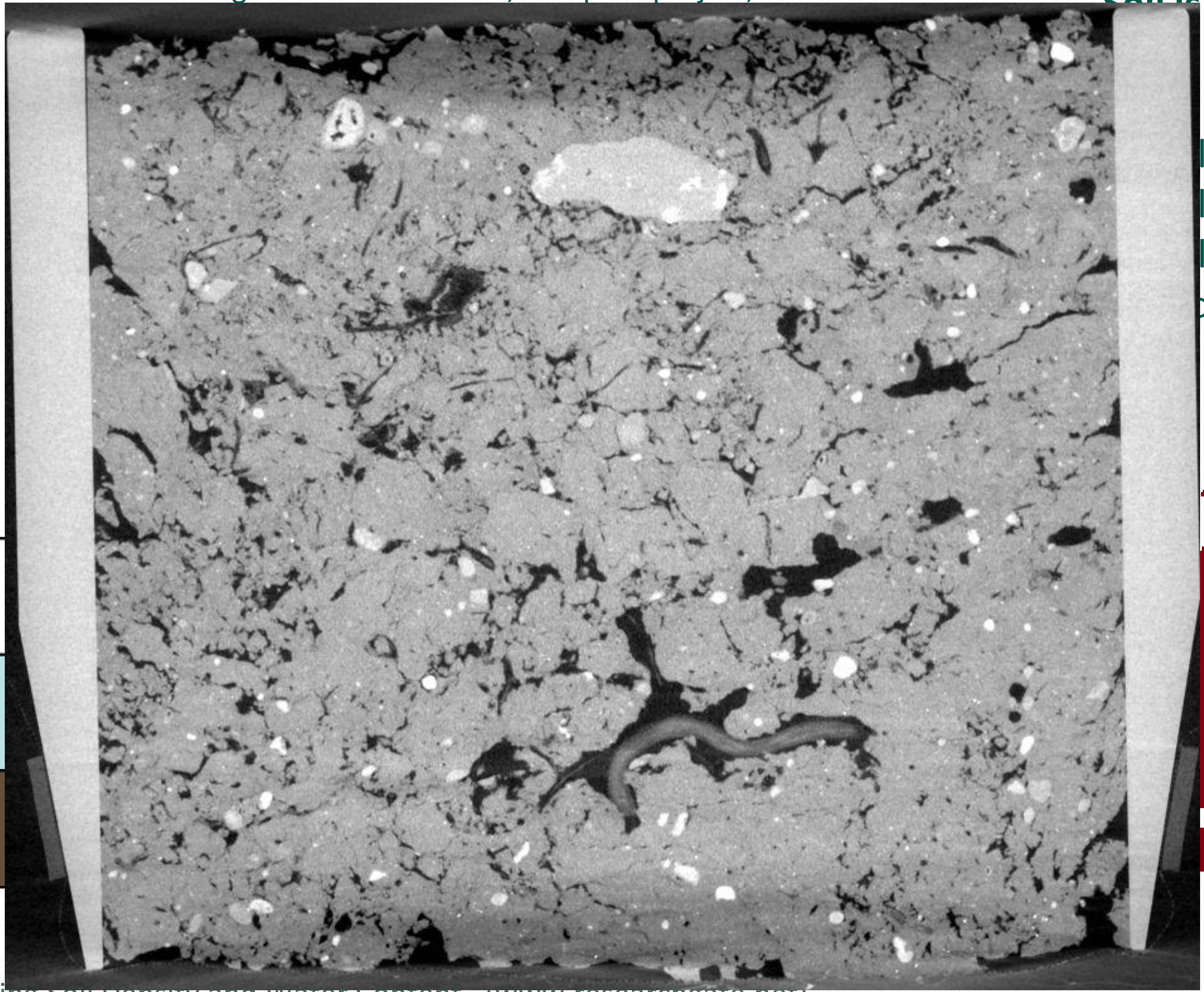
OPTAIN Soils workshop 6 April 2022 (online)

- Soil physics/hydrology 101
- Collection of field data
- Collection of laboratory data
- Sampling issues and the field-lab dichotomy
- Soil heterogeneity at the pedon and sub-field scale
- Soil heterogeneity at the field scale (and above)
- Upscaling options
- Temporal variability of soil hydraulic properties
- Conclusions

A soil monolith at the entrance of the 21st World Congress of Soil Science in Rio de Janeiro, Brazil (2018) @WorldSoilMuseum

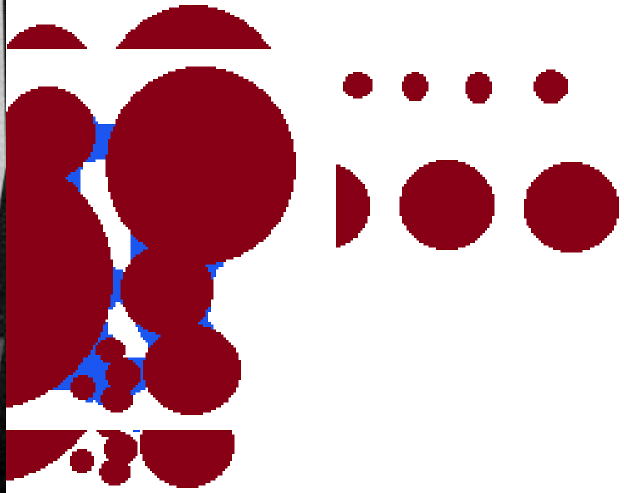
Soils 101

Image: Johannes Koestel, Soilspace project, 2016

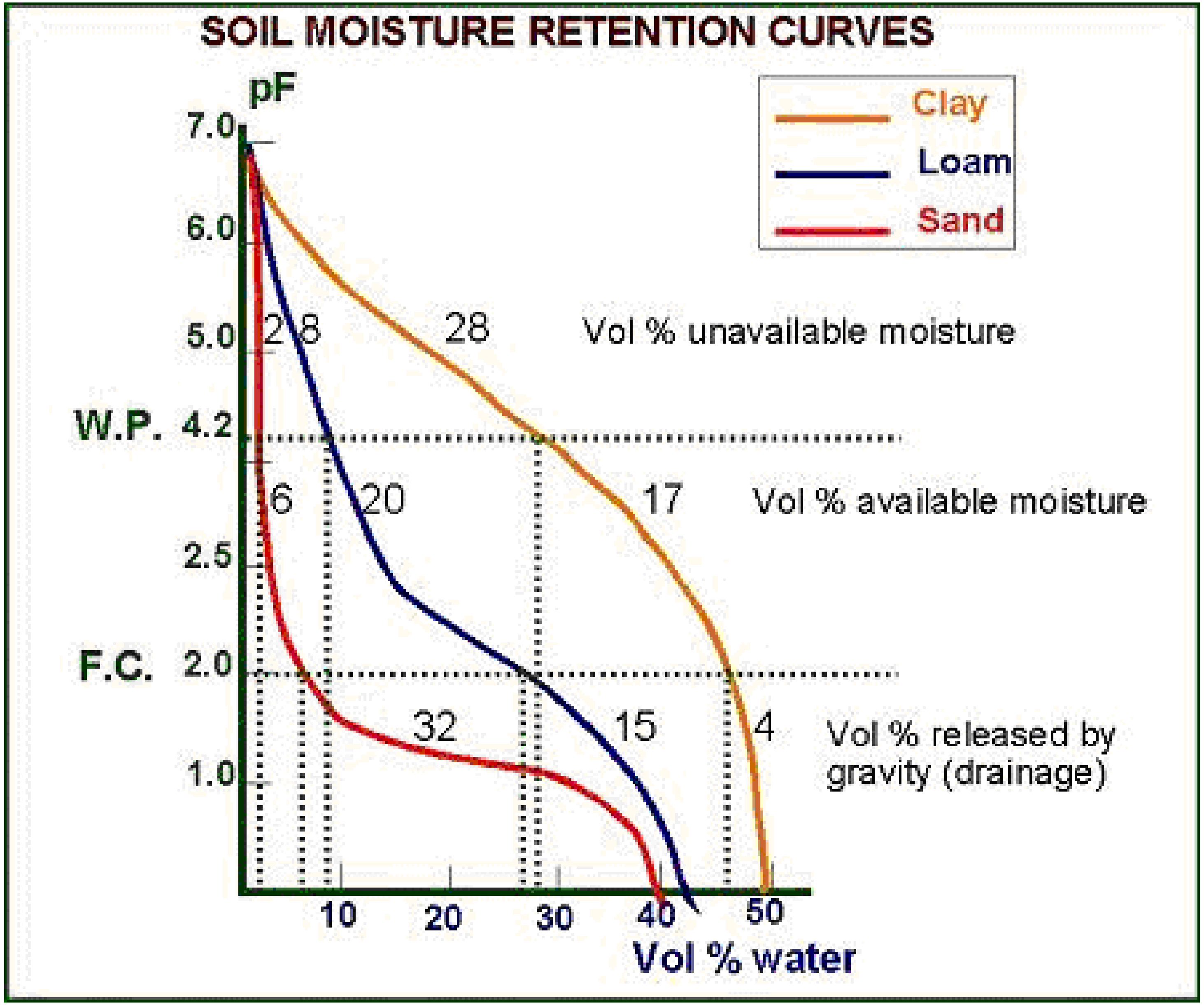


Soil is a dynamic, 3-phase system

- l texture
- l structure
- l water status
- draulic conductivity

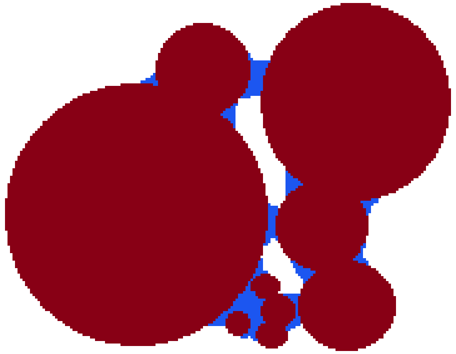


Veenstra, Matt & White,
Techniques for Determining Soil Density and Water Content. (www.researchgate.net)



pF: log10 (- matric potential in hPa)

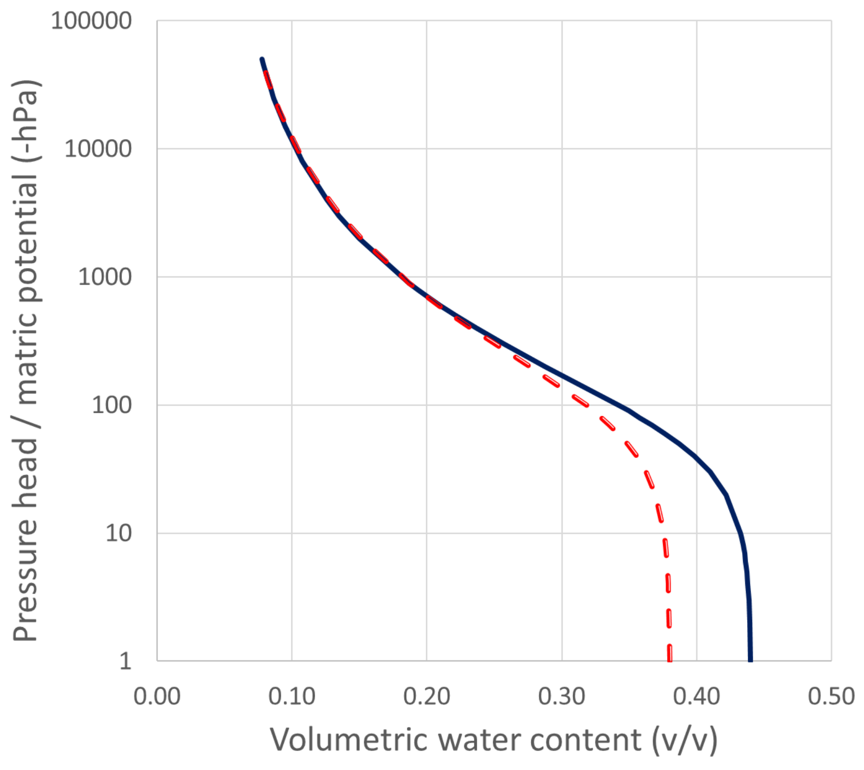
(hPa = ‘cm water column’)

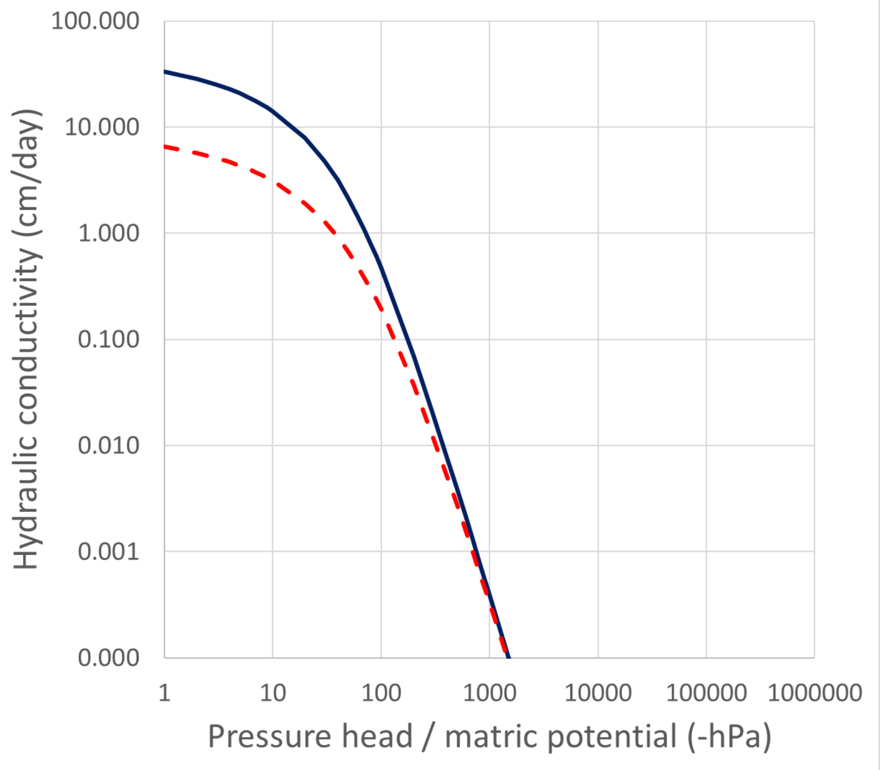


Source: www.tankonyvtar.hu – Prof. Lajos Blasko

There is a lot of focus recently on the effective porosity and hydraulic conductivity

- ‘Structural porosity’ -> major influence of the soil’s hydraulic functioning
- Volume of macroporosity: 1-2%   Share in infiltration: up to 70%!
- Large flash-storage potential
- Huge potential for human influence good/bad: e.g. bad management (e.g. compaction, physical damage, etc.) also by any land-use change, introduction/fallout of any management decisions, tillage choices…. etc.
- This is where we have a lot of potential for influence - short and long-term





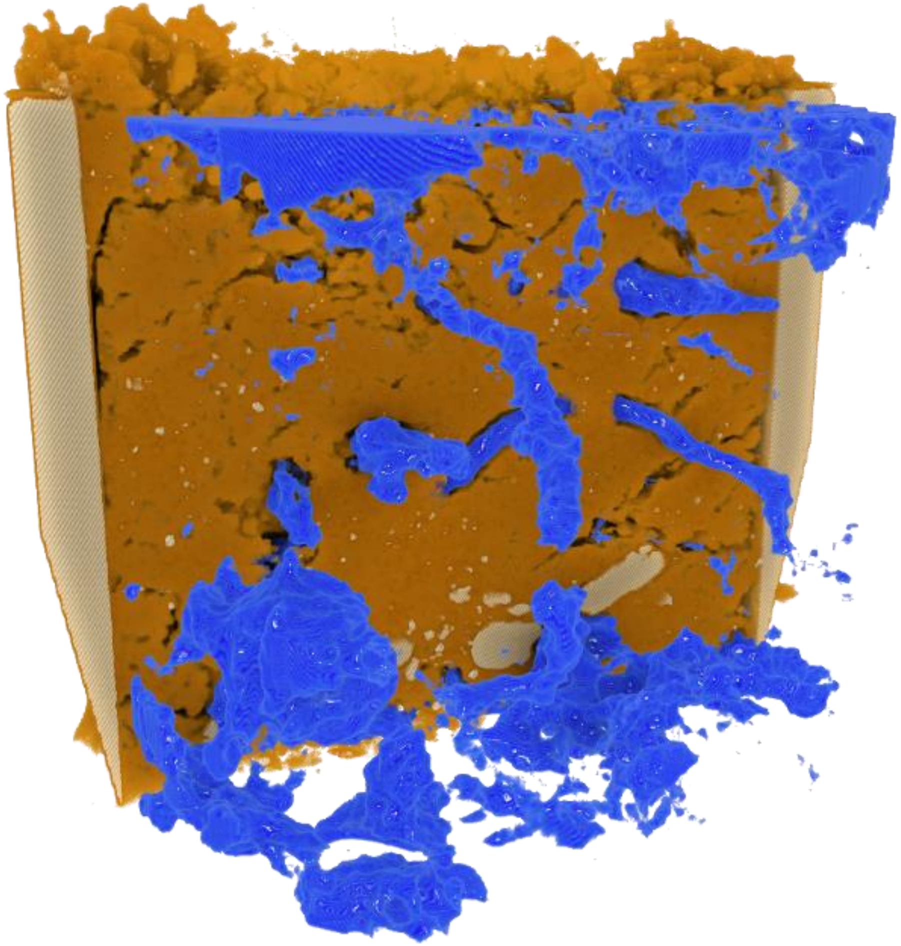
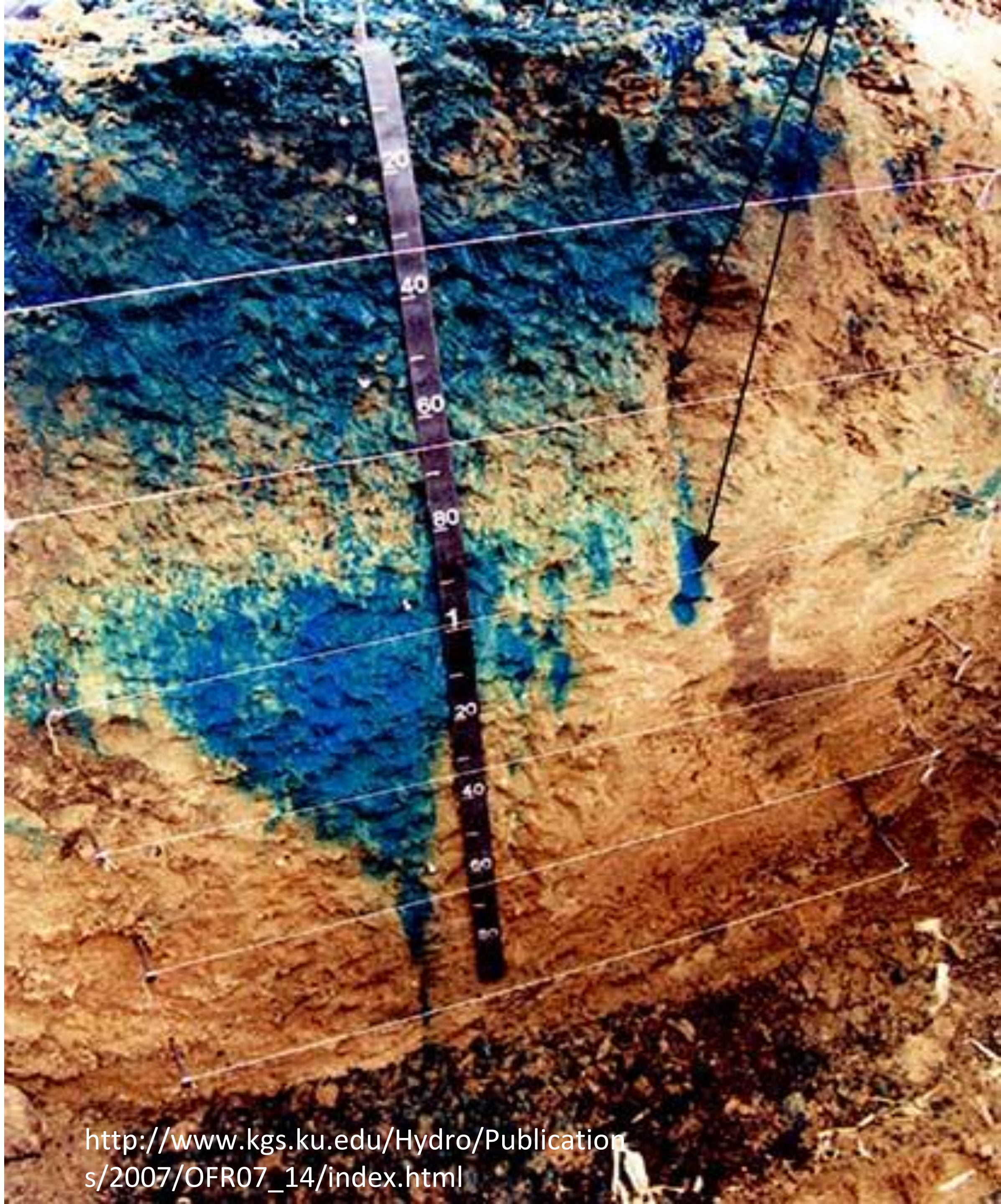


Image: Johannes Koestel, Soilspace project, 2016

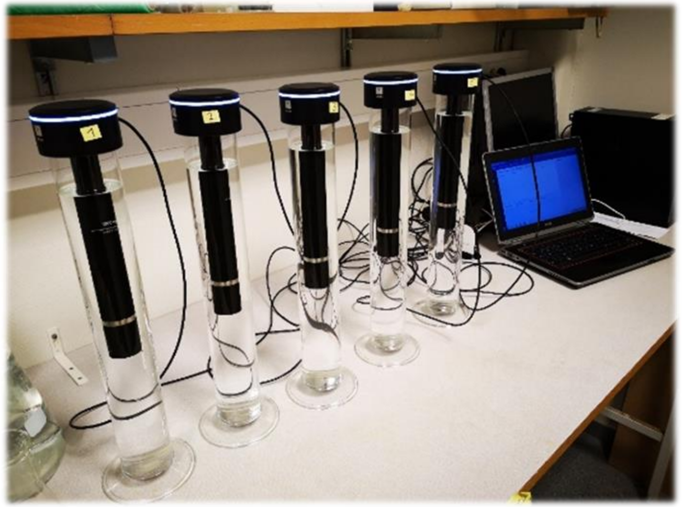


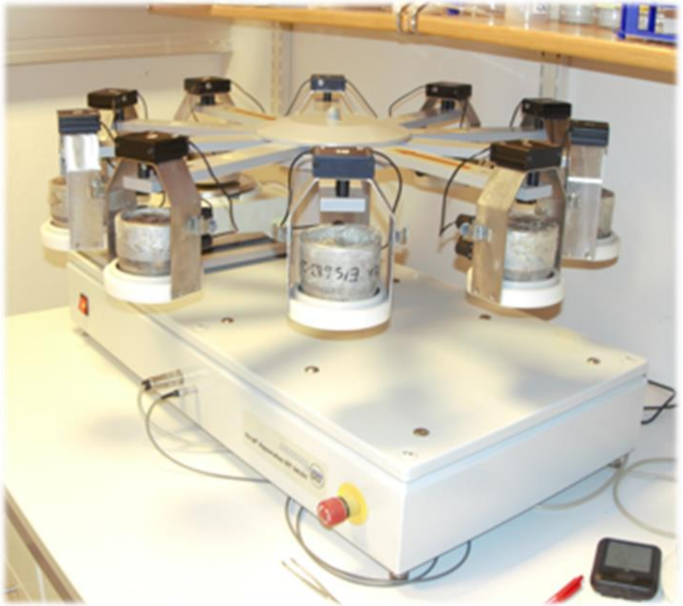
http://www.kgs.ku.edu/Hydro/Publications/2007/OFR07_14/index.html

Direct measurements in the field

- Infiltration -> Saturated hydraulic conductivity

Soil hydrophysical measurements in the lab



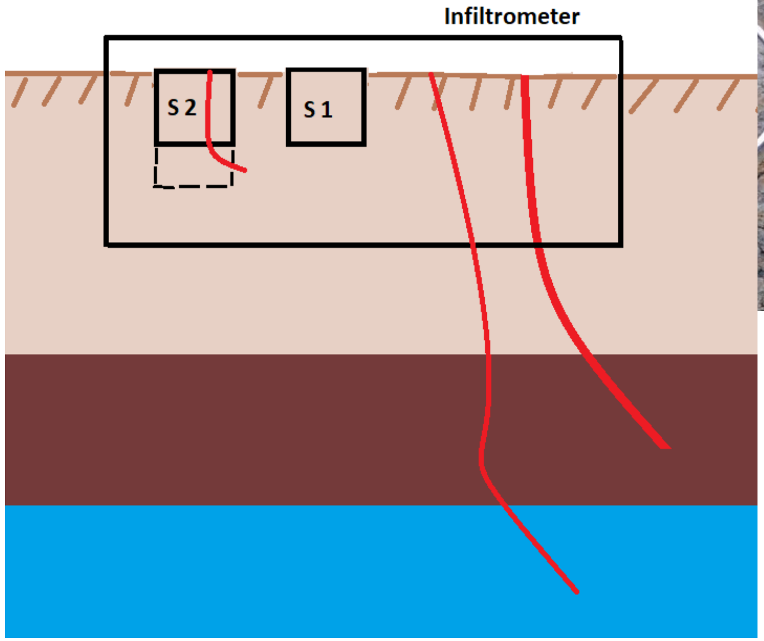


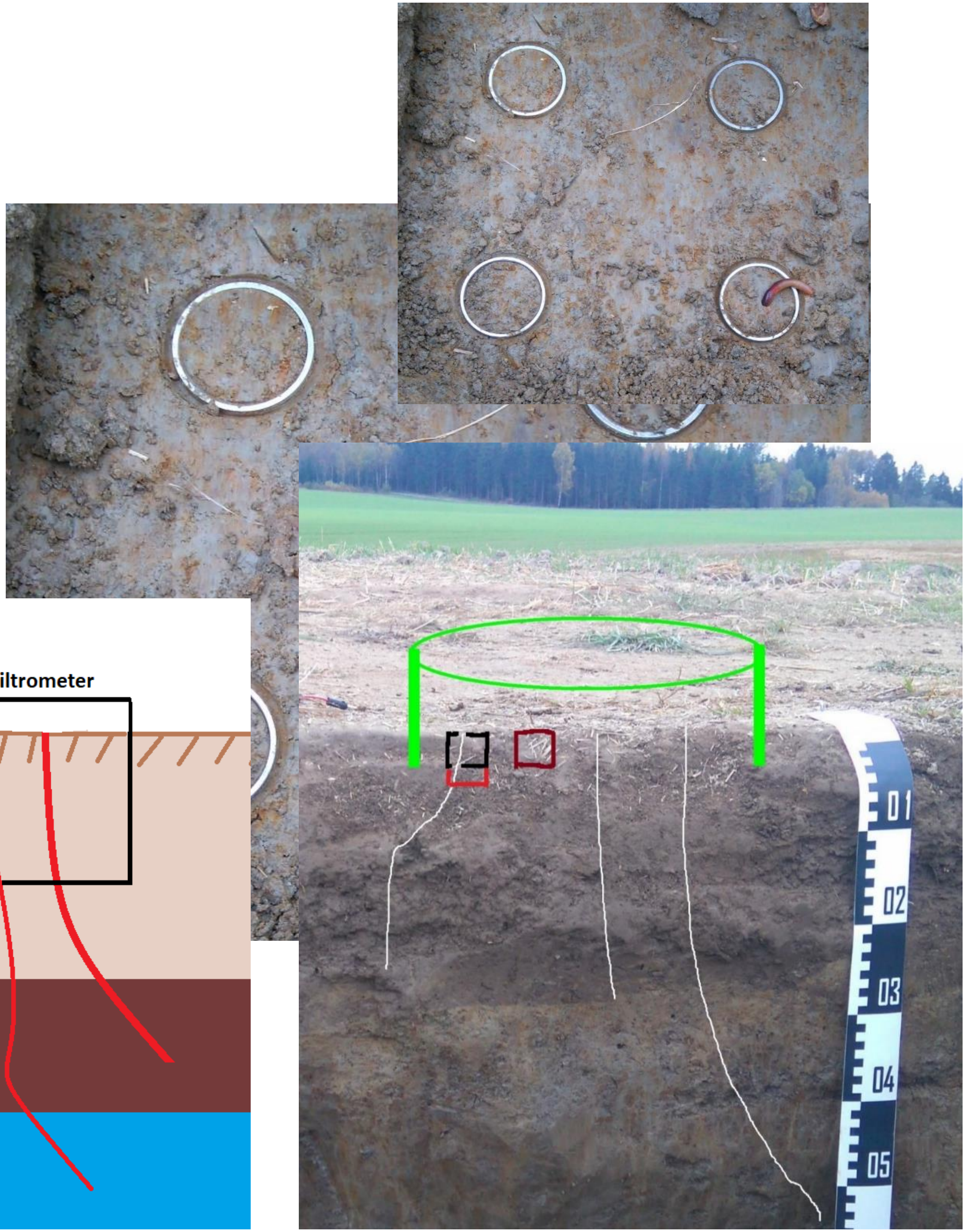
Soil hydrophysical measurements and our key dilemmas - III

- **Which sample(s) represent this soil?**

- Are the samples (and the measurement) representative of the real soil? (heterogeneity, sampling choices, field conditions, scale of the measurement)

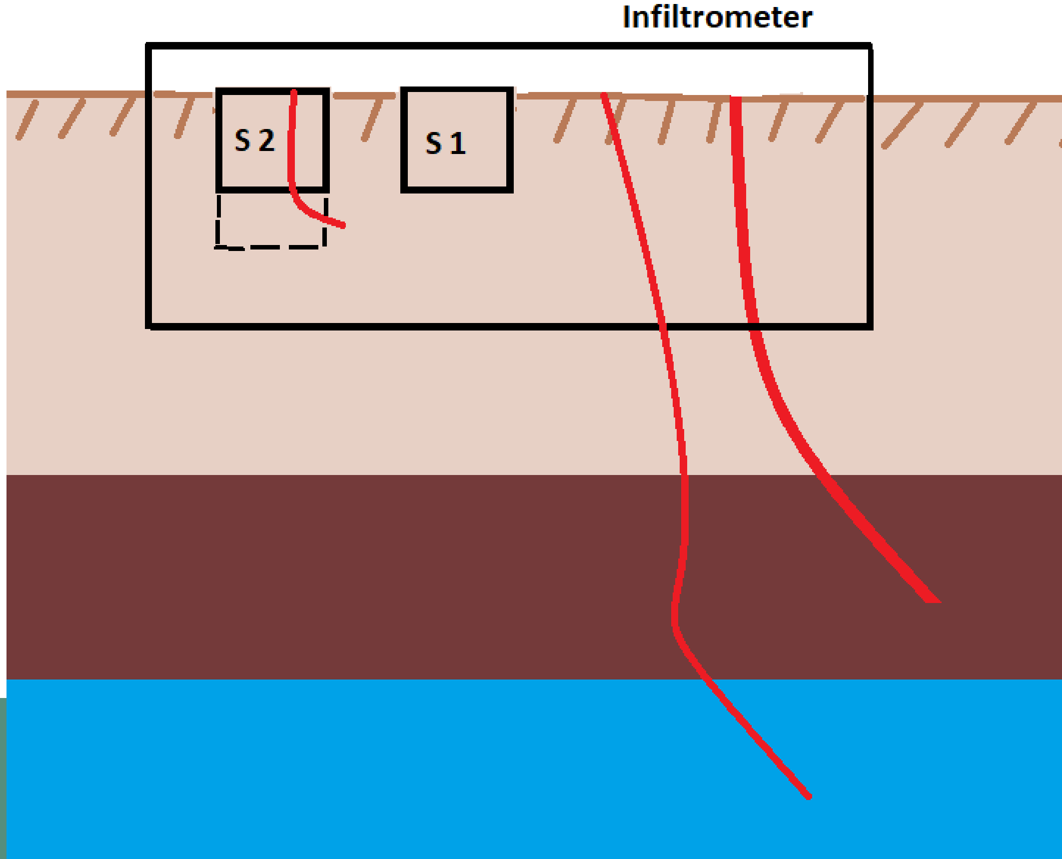
- Each sample is different – you cannot duplicate them!





Some notes about the validity of laboratory-based data for field conditions (dichotomy)

- The scale of measurement (vertical/horizontal) – connectivity, tortuosity, etc. (*Ghanbarian et al. 2016 CATENA, Scale-Dependent Pedotransfer Functions Reliability for Estimating Saturated Hydraulic Conductivity, 10.1016/j.catena.2016.10.015*)
- Representativeness? (REV?) (*Hirmas et al. (2013) GEODERMA: observed as much variation the distribution of fractal parameters that describe the hierarchical organization of soil structure of 6 large samples from a single soil horizon as there was across the entire continental-scale UNsaturated SOil hydraulic DAtabase (UNSODA) database!*
- Any confining layers present?
  (the unknown beneath)
- Dimensionality of the measurement? (1D? 3D?)
- Any lateral flow present (anisotropy)?
- Initial moisture conditions?
- Is the soil really saturated?
  (does it need to be???)



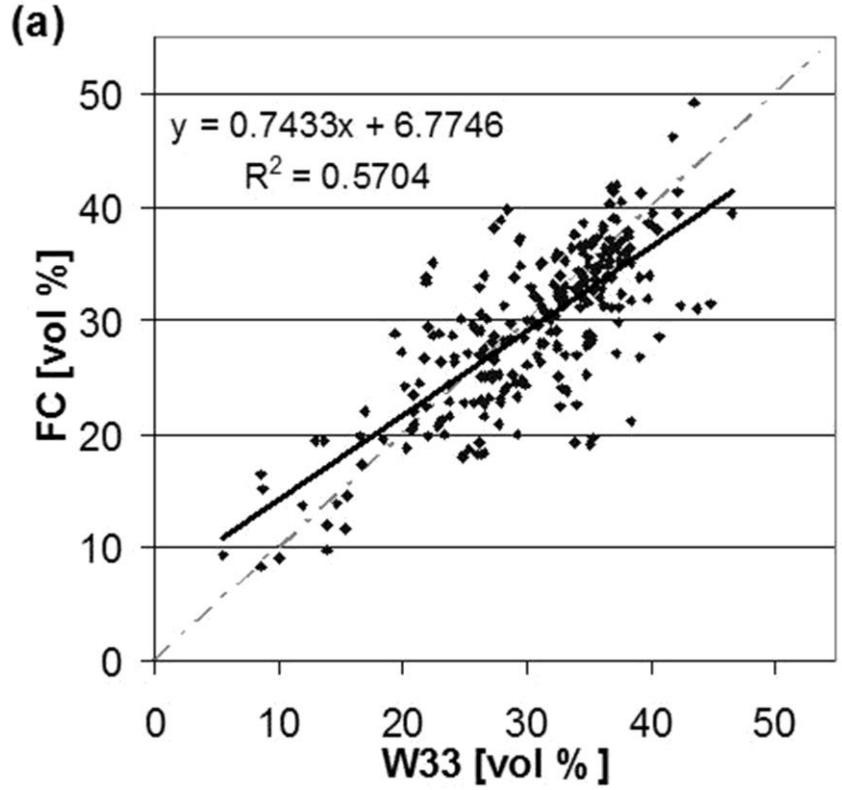
Field-relevance of laboratory measurements

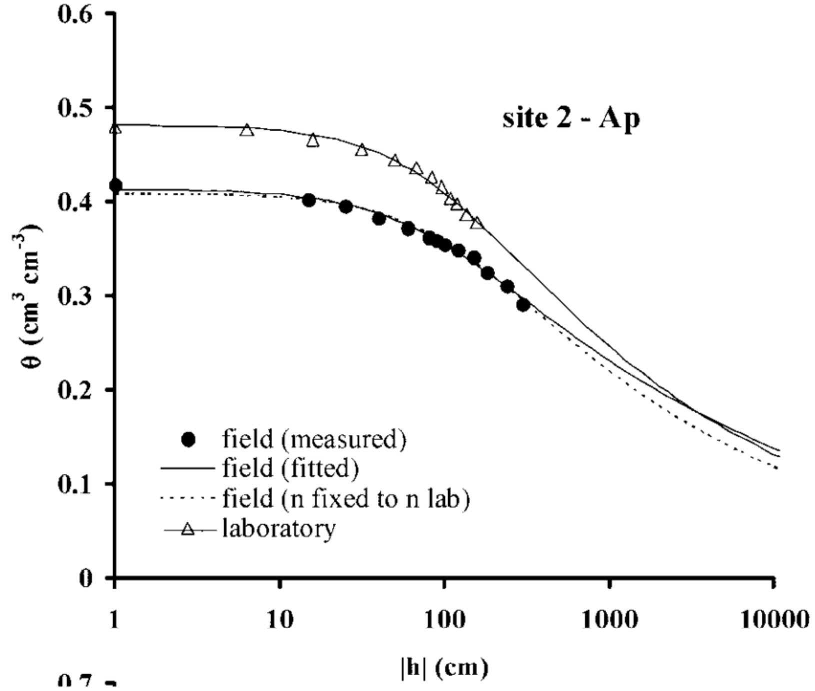
- “Field-capacity” (Nemes, Pachepsky, Timlin, 2011, SSSAJ 75:807-812)
- Water retention characteristics (Basile et al., 2003 WRR 39(15) 1355.)
- Saturated hydraulic conductivity (…extreme variability, next slide…)

Main reason for the discrepancy:

Unmatching initial and boundary conditions, being on different branches of the hysteresis-loop

What is the effective property then?

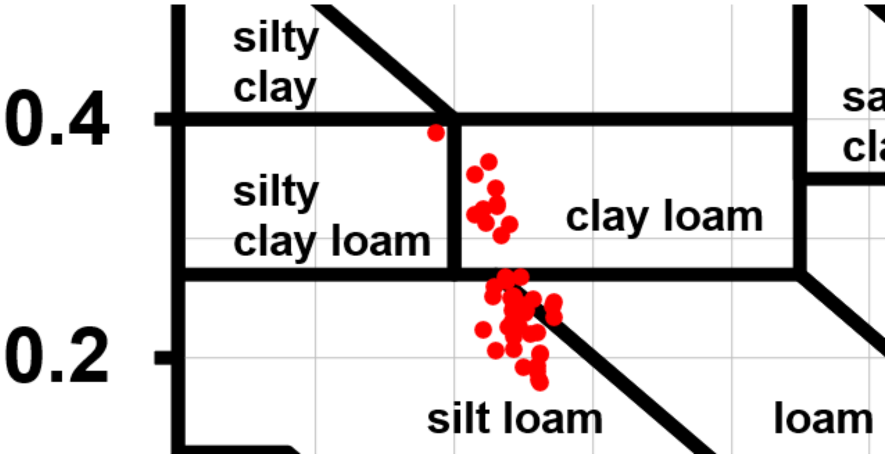




Basile et al., 2003 WRR 39(15) 1355. Figure 5a

Functional soil heterogeneity at the pedon scale.

Select soil properties in the top 25cm of a $2m^2$ area in the Skuterud catchment near Ås, Viken



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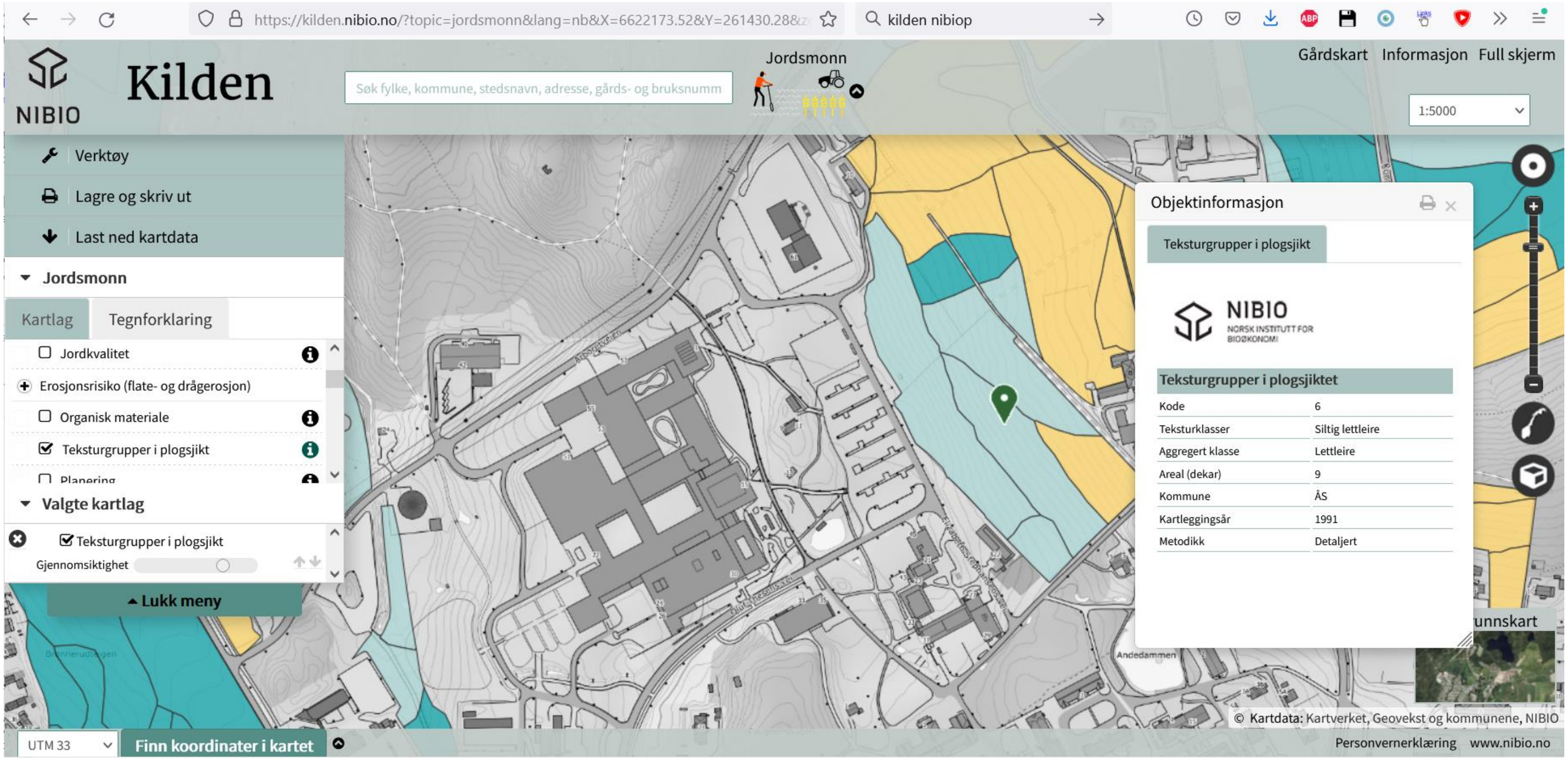
Functional soil heterogeneity at the (sub-)field scale (i.e. vs. what is in a soil map):

- NIBIO pesticide leaching project, lead by Roger Holten (Dominika, Attila, Mona involved)



Soil type (Epistagnic Albeluvisol (silty), silty loam) - a complex of sea deposits and beach deposits, EKo6 KSi3. The sea deposited EKo6 is dominating and contains more clay than KSi3 which is more sandy.

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Functional soil heterogeneity at the (sub-)field scale (i.e. vs. what is in a soil map) - II:

Photos: Erling Fløistad, NIBIO

Functional soil heterogeneity at the (sub-)field scale (i.e. vs. what is in a soil map) - II:

Photo: Line Tau Strand, NMBU (21 Oct 2021)

Profile 1:

General information on the soil:

Classification (WRB,2006) Umbric Epistagnic Albeluvisol (Siltic)

Classification (ST) Aquic Glossudalfs or a Mollic Glossaqualfs

Horizon	Depth (cm)	Org.C %	Org.N %	Fe_{ox} * %	Al_{ox} * %	Clay %	Silt %	Sand %
Ap	0-20	2.50	0.20	0.5	0.18	16.7	44.7	38.6
A/E	20 -30	0.75	0.08	0.42	0.12	16.5	61.3	22.2
Eg	30-40	0.36	0.06	0.43	0.11	21.3	57.0	21.7
Btg1	40 - 65	0.18	0.05	0.42	0.09	21.0	44.4	34.6
Btg2	65 -95	0.19	0.05	0.37	0.095	26.7	51.3	22.0
CB	95 -110+	0.21	0.05	0.33	0.075	25.6	59.1	15.3

(* Fe and Al extracted with acid oxalate, ** in volume %)

Profile 2:

General information on the soil:

Classification (WRB,2006/2015?) Haplic Cambisol (Dystric)

Classification (ST?) Humic Dystrudept

Horizon	Depth (cm)	Org.C %	Org.N %	Fe_{ox} * %	Al_{ox} * %	Clay %	Silt %	Sand %
Ap	0-25	2.50	0.19	0.55	0.17	11.2	41	47.9
Bw1	25 -55	0.34	0.05	0.45	0.075	8.5	28.1	63.4
Bw2	55-90	0.19	0.05	0.48	0.075	7.8	29.8	62.3
BC	90-110	0.07	0.03	0.18	0.043	5.8	27.1	67.1

(* Fe and Al extracted with acid oxalate. ** in volume %)

Spatio-temporal variability/heterogeneity at larger scales, upscaling

How do hydrological and LSM models typically represent soil?

- The representation of soil
  - map-based, dominant soil type or association per HRU or grid cell
  - layered (mostly…)

- Parameters they consider about soil hydrology
  ‘bucket’ models: field capacity, available water holding capacity, saturated hydraulic conductivity (Ks)
  Richards’-based models: the water retention (pF) curve, Ks

- Sources for those soil hydraulic parameters
  - texture-based estimations, + rarely other properties, such as bulk density, SOC
  - pedotransfer functions / lookup-tables (aka. class pedotransfers)

How about accounting for land-use effects?

- There is growing indication that land use is a significant modifier of soil hydraulic properties (…citing an ongoing meta-analysis.)
- None of the popularly used pedotransfers account for land use effects, neither do the models in the soil hydrological sense
- In most earlier soil hydraulic data collections land use has not been recorded
- The European Hydropedological Data Inventory (EU-HYDI) (*Weynants et al. 2013 doi:10.2788/5936*) and the Soil Water Infiltration Global (SWIG) database (*Rahmati et al. 2018 doi:10.5194/essd-10-1237-2018*) collected LU/LC information – that explains part of the problem.

EU-HYDI main LC categories	
Cropland	1708
Woodland	112
Grassland	292
ND	3822

SWIG database main LU categories	
Agriculture	2019
Forest	204
Grass/pasture	1050
ND	1195

The case of Norway…

- Land use in the Norwegian data contributed to EU-HYDI: arable/grassland: 71% forest: 9%
- Norway's true land use distribution: agriculture: ± 3.5% forest: ± 37%

Spatial extension / upscaling of measurements:

- Soil maps typically present dominant soil type or soil type-associations
- The dominant soil type is typically considered, or rarely some form of ‘weighted averaging’ of associations
- A pedotransfer function (PTF) is chosen from the literature
- Estimation of soil hydraulic properties are typically made using basic soil properties (soil texture, rarely other properties like SOC or BD)

Vereecken et al. 2019. Vadose Zone J. 18:180191. doi:10.2136/vzj2018.10.0191

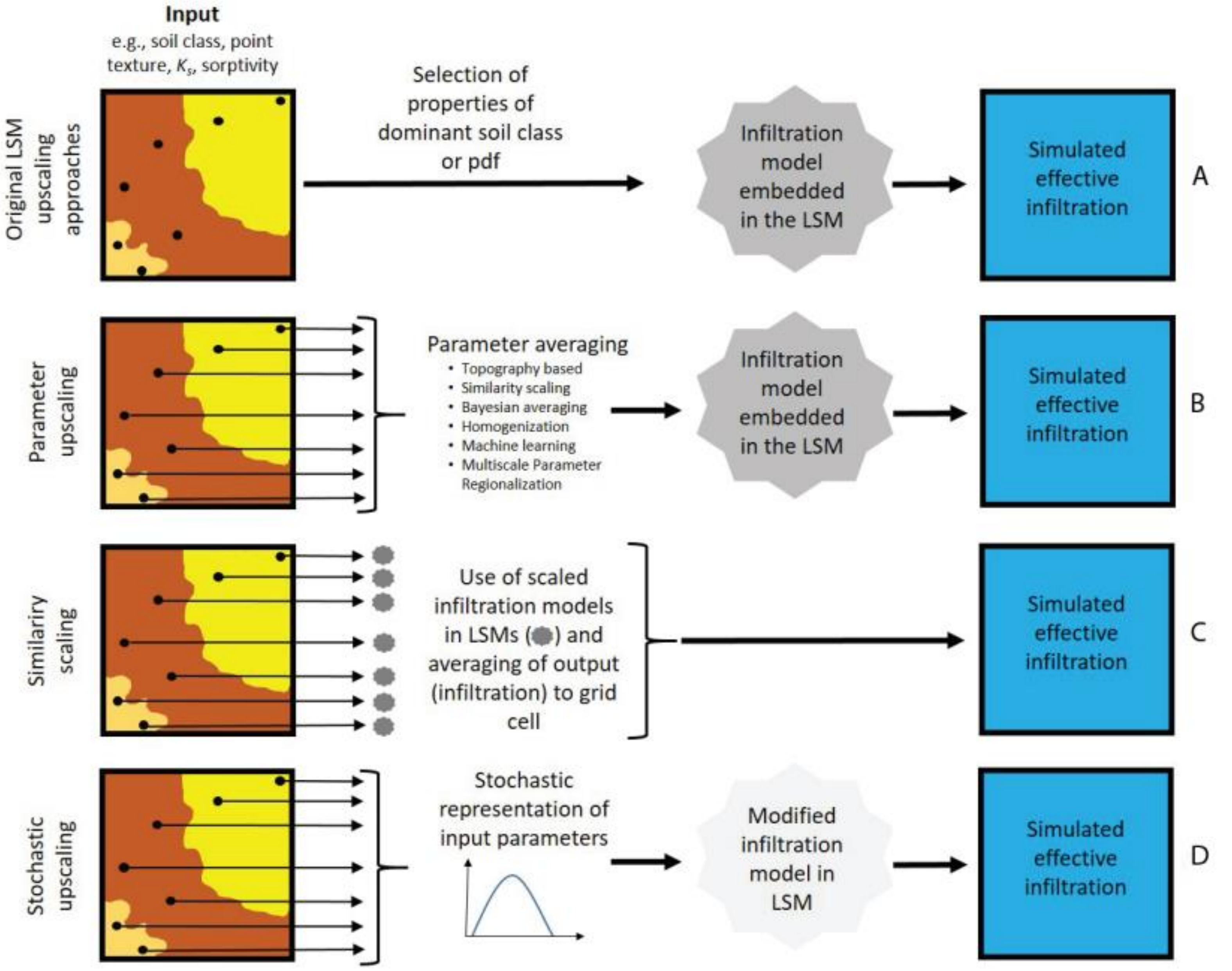


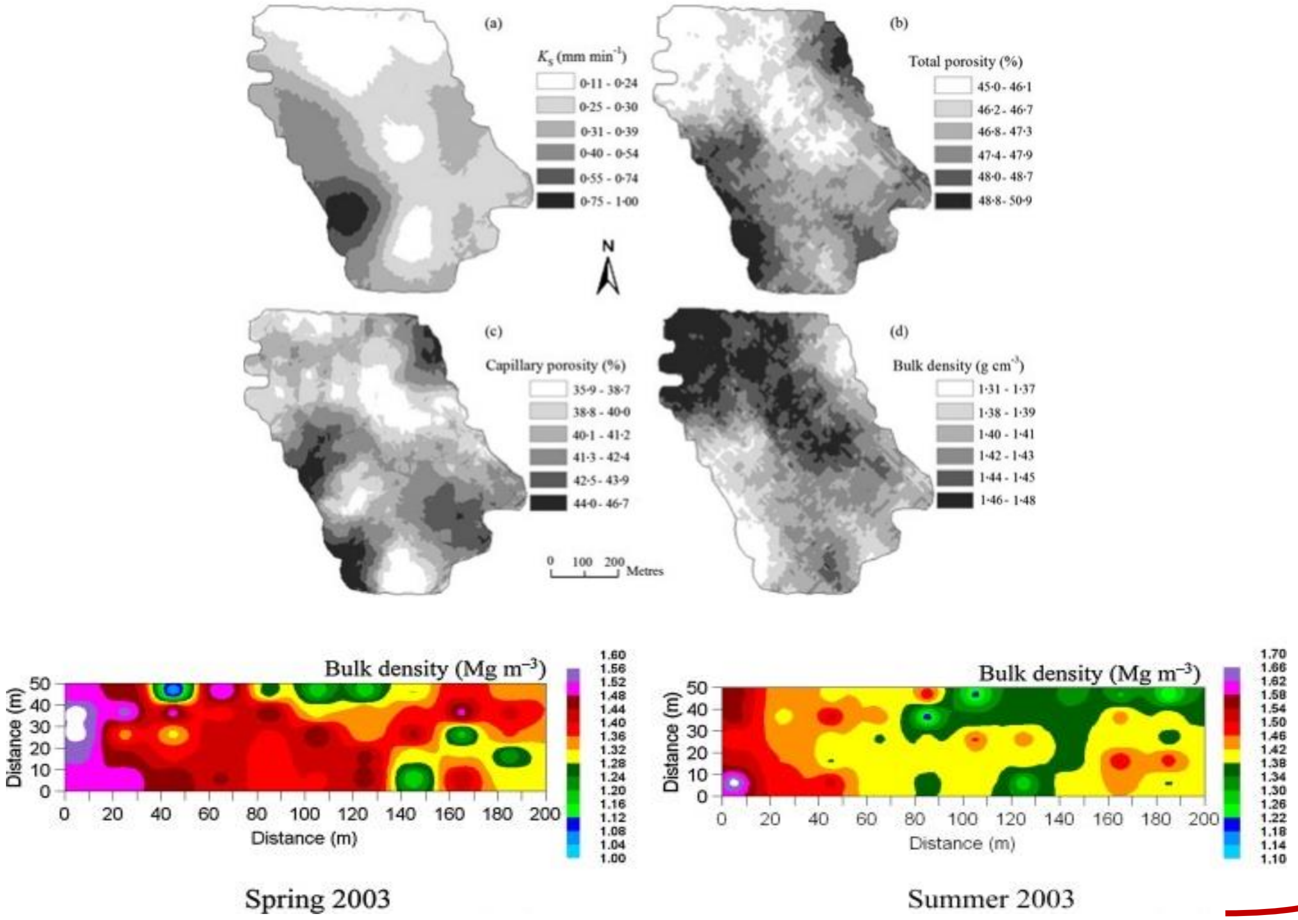
Fig. 6. Schematic overview of different upscaling methods of soil parameters (original land surface model [LSM] upscaling approach, parameter upscaling, similarity scaling, and stochastic upscaling) described in Infiltration Processes in Land Surface Models (A), Upscaling Spatially Heterogeneous Parameters Relevant for Infiltration (B), Similarity Scaling (C), and Stochastic Upscaling (D). Differences in the infiltration model used are indicated by different colors.

Some notes related to upscaling and the choice/use of PTFs:

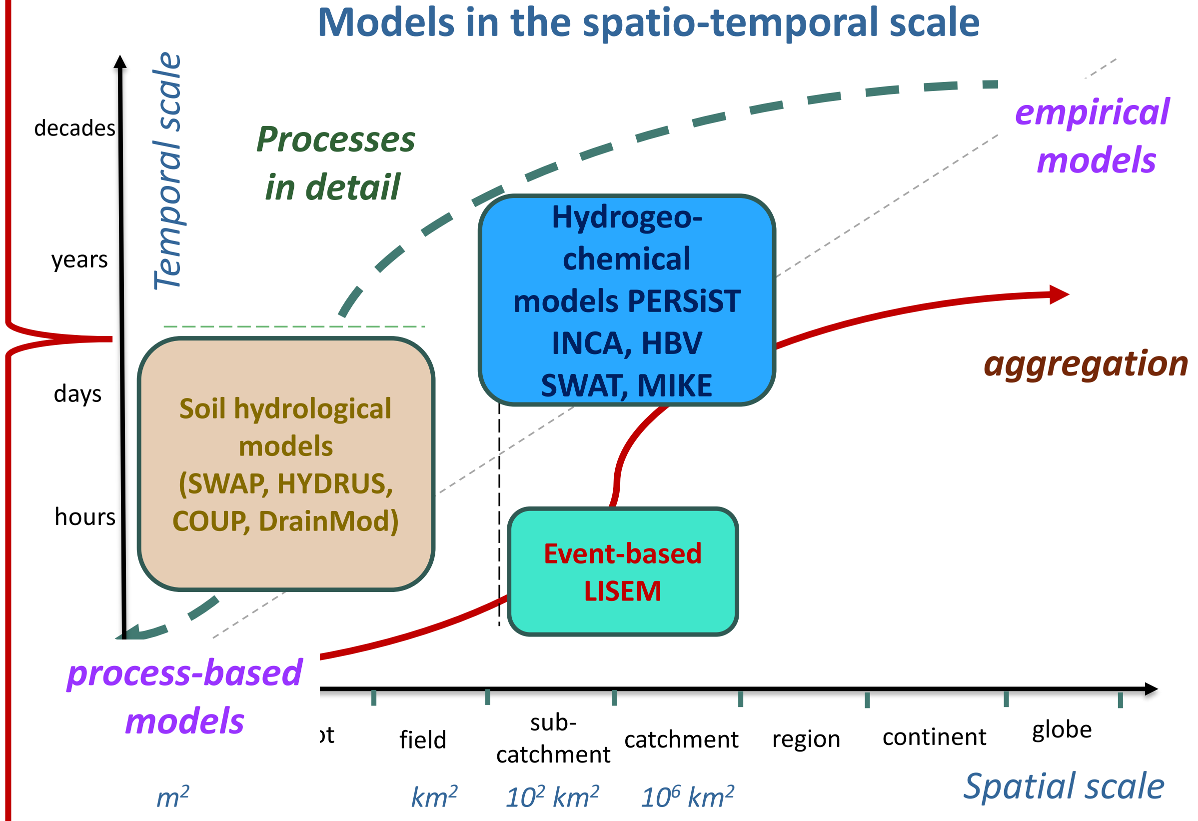
- There is no consensus ‘best approach’ to derive aerially representative soil hydraulic properties. At what step do you aggregate?
- The effect of soil structure is rarely represented in any ways
- Forest/urban soils are rarely represented in underlying databases
- More advanced PTF solutions exist, but one typically does not have the data to use those (e.g. hyperspectral info, 3D imaging, detailed particle-size data, etc.).
- Some soil hydraulic property maps already exist (e.g. SoilHydroGrids) and can be considered. *(upscaling is partially done in these cases)*
- Ks is typically the hardest to estimate, no matter what. At the catchment scale, it often ends up being a fitting parameter (‘effective Ks’).

HOW to represent

spatio-temporal variability of soil properties



In hydrological models at various scales?



Source_ Clement et al., 2007

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Spatial variability of soil properties at plot/field scale (Usowicz and Lipiec, 2017. Soil Tillage Res., 174:241-250)

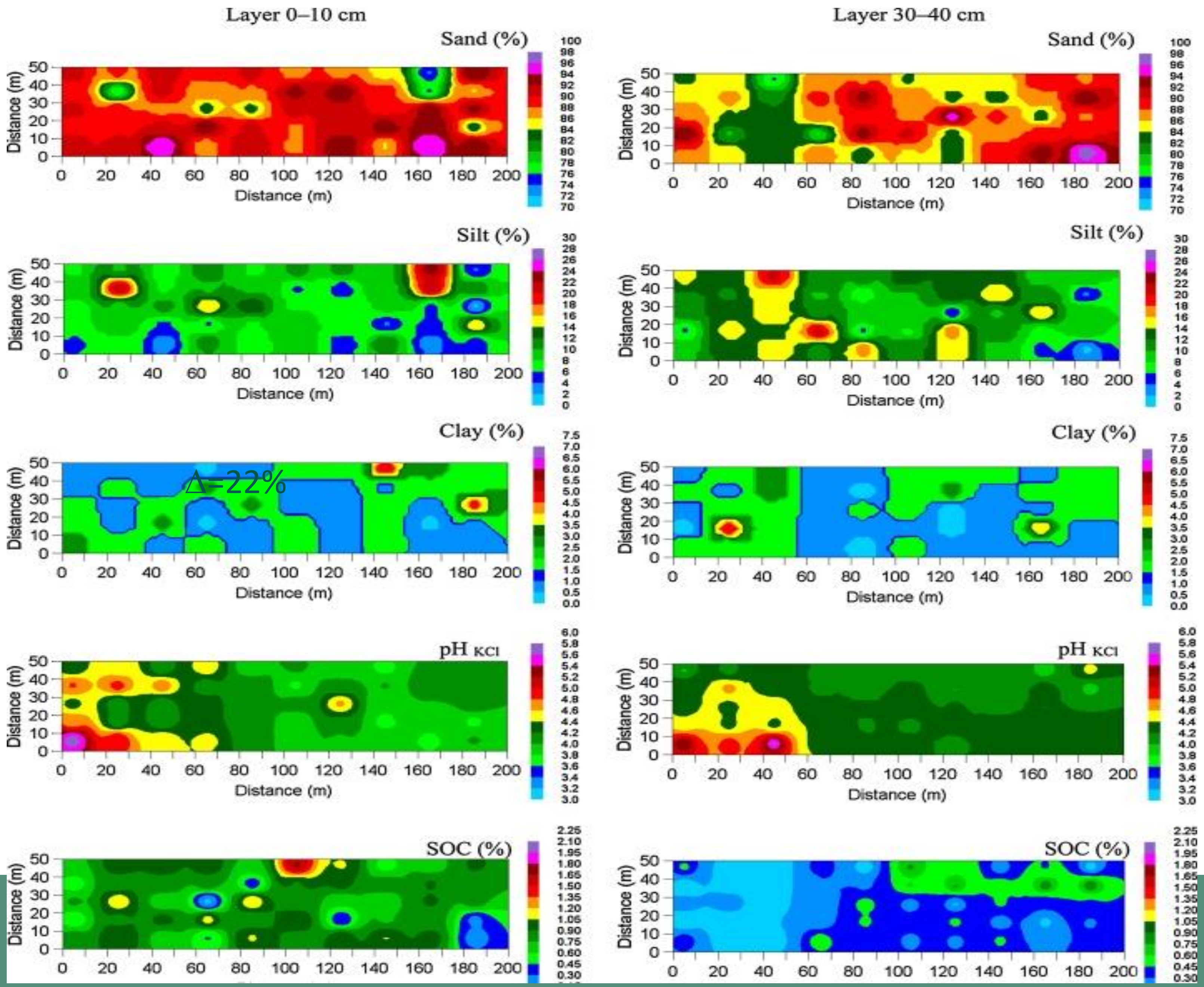
Sand
Δ=22%

Silt
Δ=22%

Clay
Δ=6.5%

pH $_{KCL}$

SOC



Δ=22%

Sand
Δ=26%

Silt
Δ=24%

Clay
Δ=6.5%

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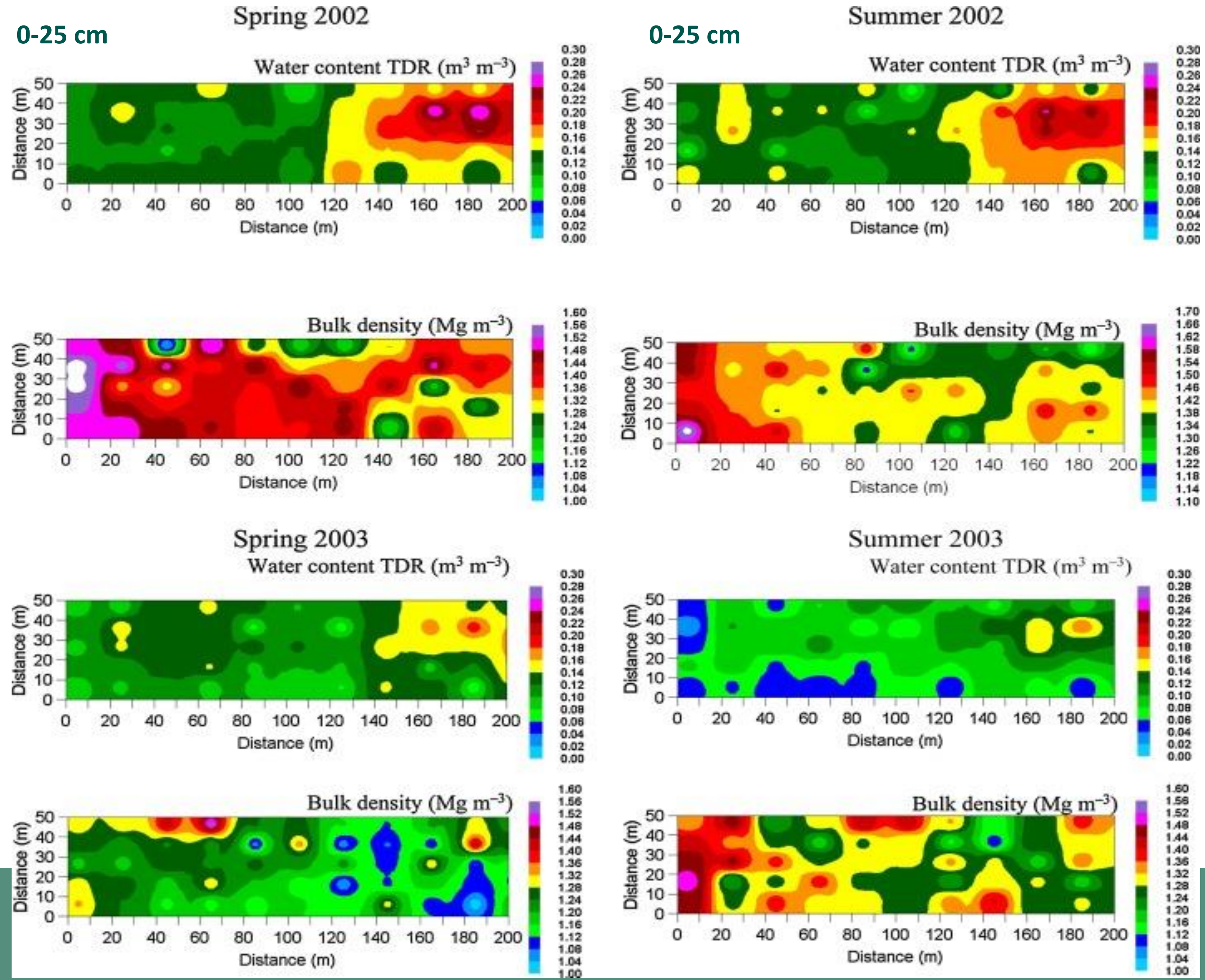
Spatial variability of soil water content at plot/field scale (Usowicz and Lipiec, 2017. Soil Tillage Res., 174:241-250)

Soil water content

Bulk density

Soil water content

Bulk density



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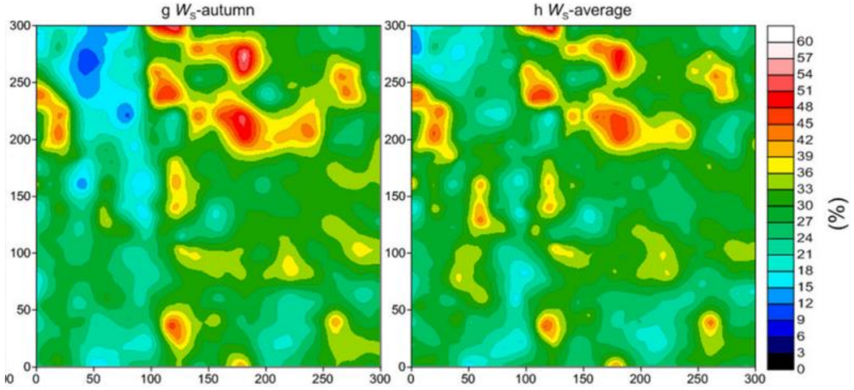
How to represent the spatial heterogeneity of soil properties in hydrological modelling?

➢ Focus on spatial variability of water balance elements at plot/field scale

- Soil hydrological models
- Spatial variability of soil properties should be transferred into spatial variability of
  - Soil water content
  - Surface runoff
  - Transpiration
  - Evaporation

Soil water content at 0-10 cm

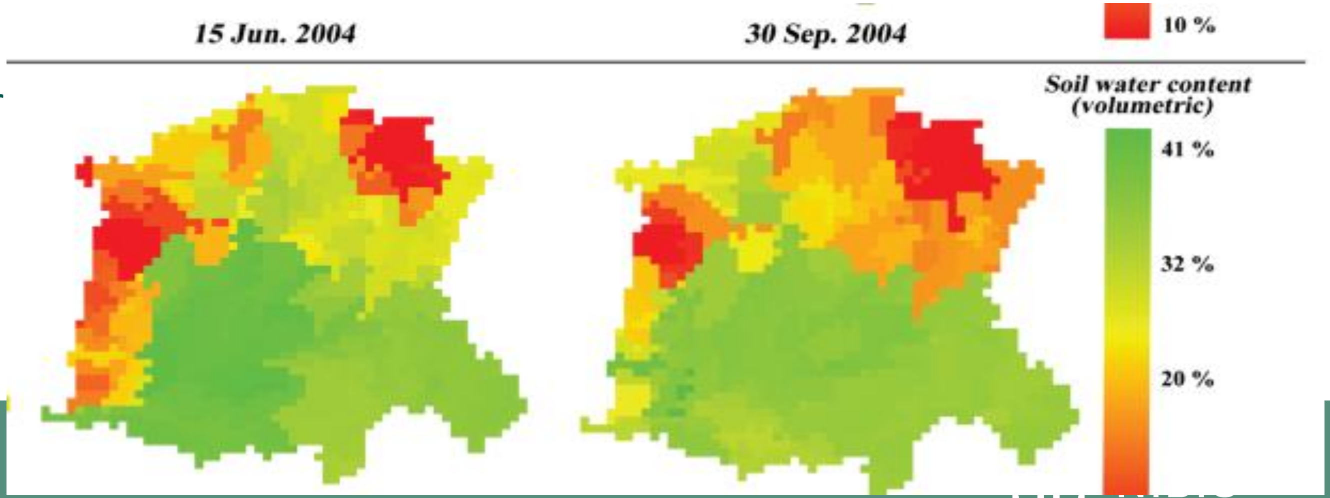


She et al., 2016. Plant&Soil, 400:263-274.

➢ Focus on the hydrological response of the inhomogeneous plot/field as a whole

- Effective soil hydraulic parameters
- Soil water balance elements calculated for each soil patter

-



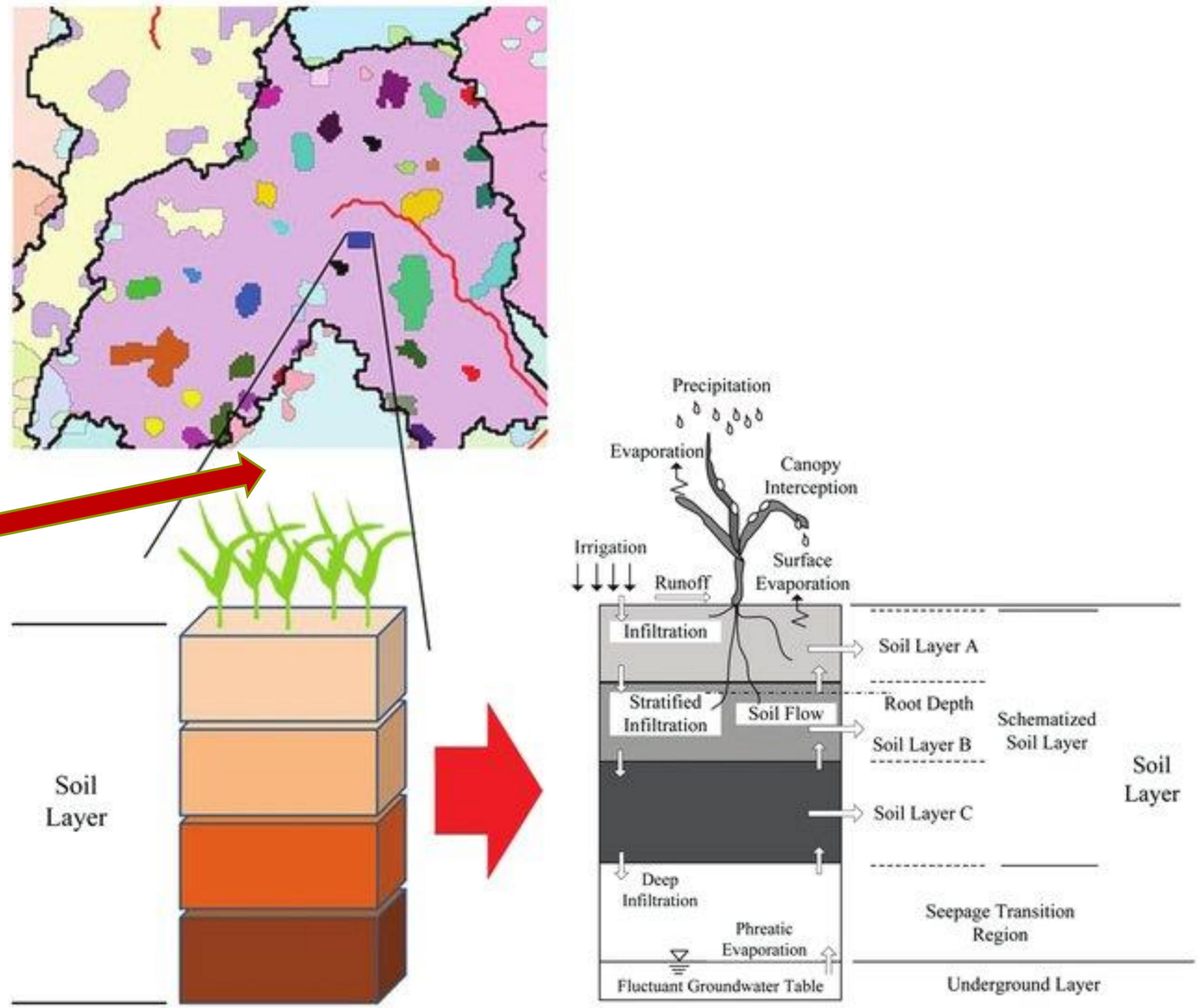
Gao et al., 2016. J. of Irrigation and Drainage Engineering, 142(9):04016029

How to represent the spatial heterogeneity of soil properties in hydrological modelling?

Uniform soil water content for the modelled soil type

Represented with one set of soil parameters in the hydrological model

Soil profile representative for the individual soil type



Spatial variability of soil water balance elements as influenced by the spatial heterogeneity of soil hydraulic properties

Spatial variability of soil hydraulic properties: geostatistical approach

- Preliminary (reconnaissance) sampling
- Representative sampling
- **448 points;** texture, OM, BD, water retention curve, Ksat

Photo: József Szabó, MTA ATK

Monitoring and modelling the soil water regime

Photo: Zsófia Bakacsi, MTA ATK

Spatial variability of soil water balance elements as influenced by the spatial heterogeneity of soil hydraulic properties

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Photo: Zsófia Bakacsi, MTA ATK

Monitoring and modelling the soil water regime

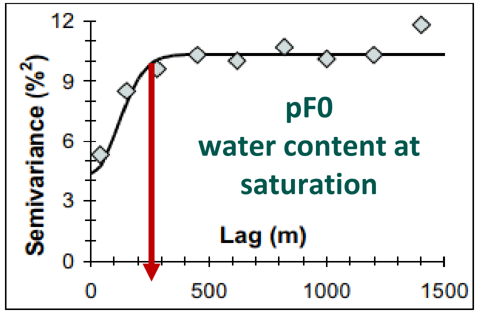
- Soil profile sampling + measurements
- Soil water content dynamic measurements
- In situ hydraulic conductivity measurements

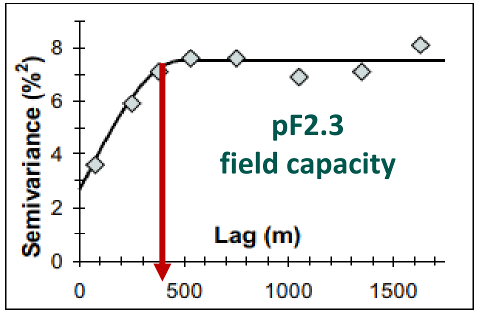
Photo: Andrea Hagyó, MTA ATK

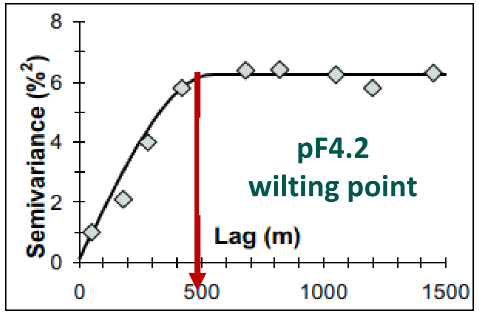
Spatial variability of soil water balance elements as influenced by the spatial heterogeneity of soil hydraulic properties

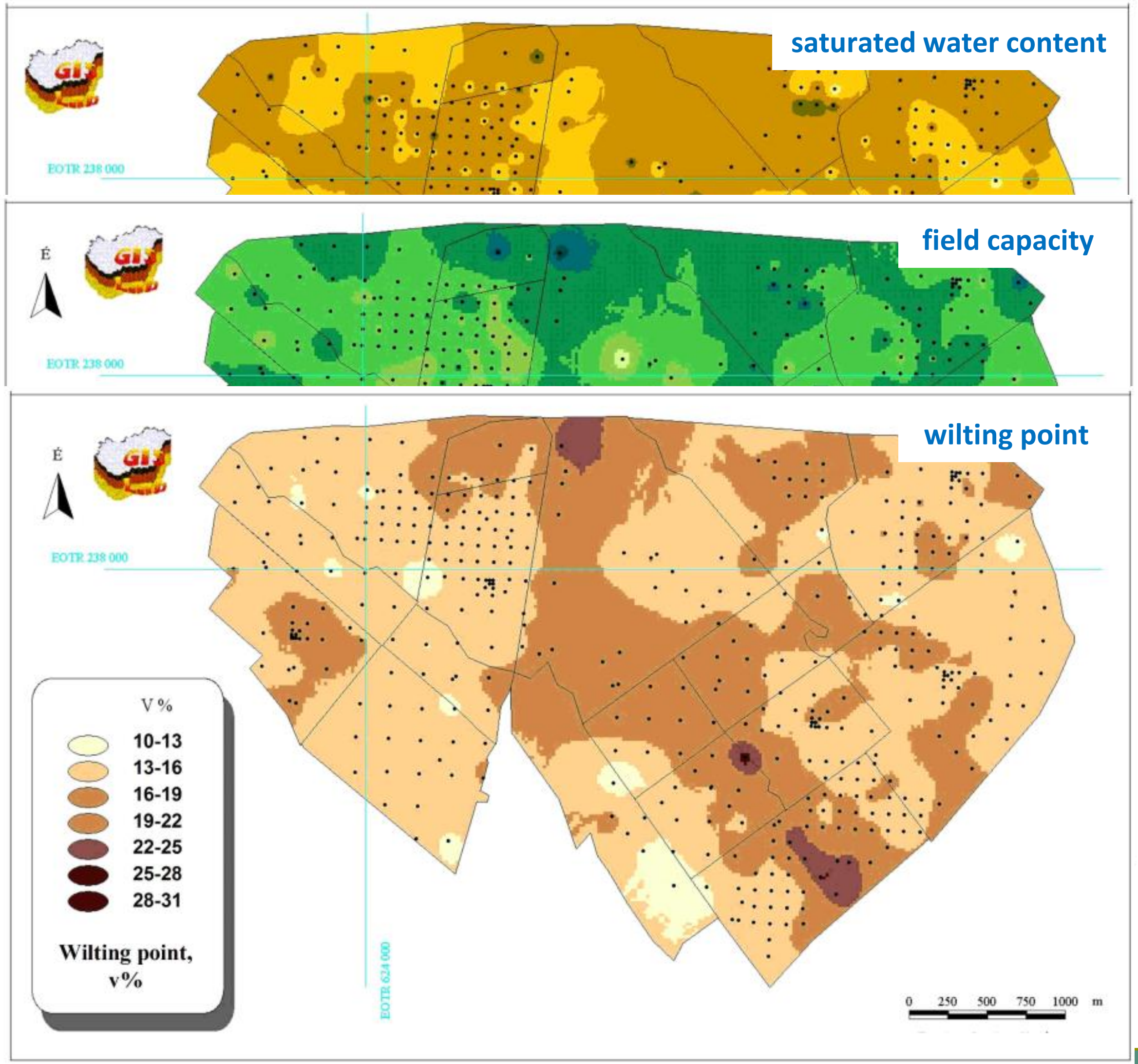
Spatial variability of soil hydraulic properties: geostatistical approach

- Preliminary (reconnaissance) sampling
- Representative sampling
- **448 points;** texture, OM, BD, water retention curve, Ksat
- Semi-variograms describing the spatial structure
- Ordinary Kriging – visualizing spatial distribution









Case study 1.

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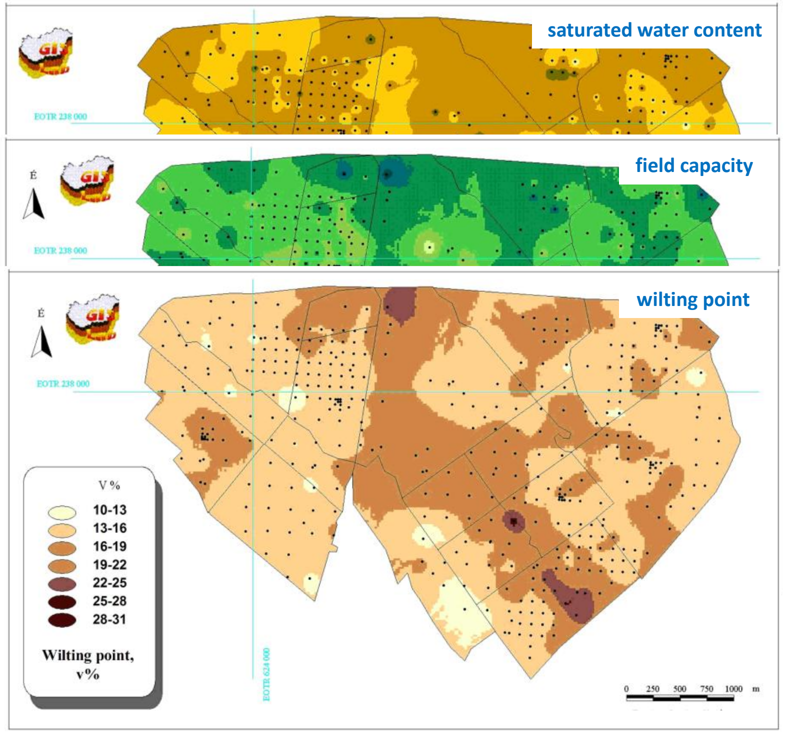
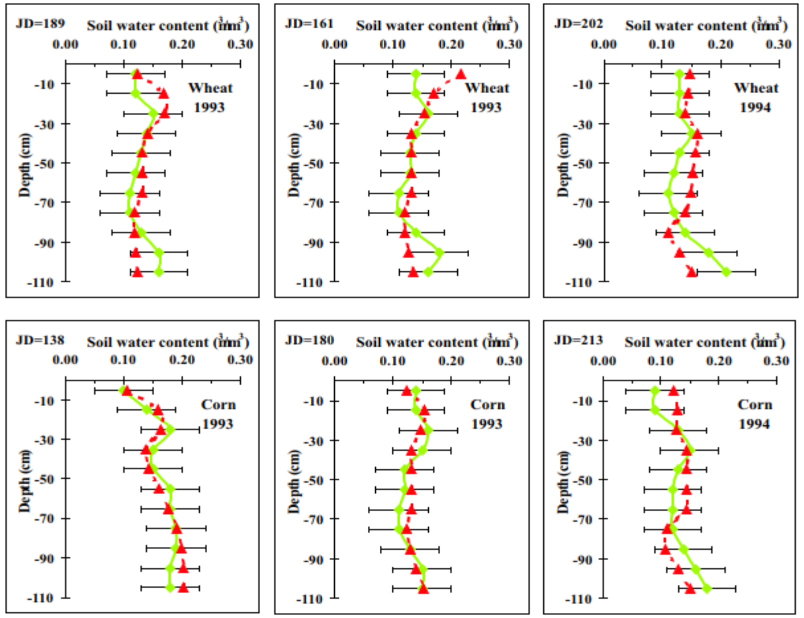
Data analyses and evaluation

Spatial variability of soil hydraulic properties



Modelling the soil water regime



Measured and simulated soil water content

Knowledge about the

spatial structure of soil (hydraulic) properties

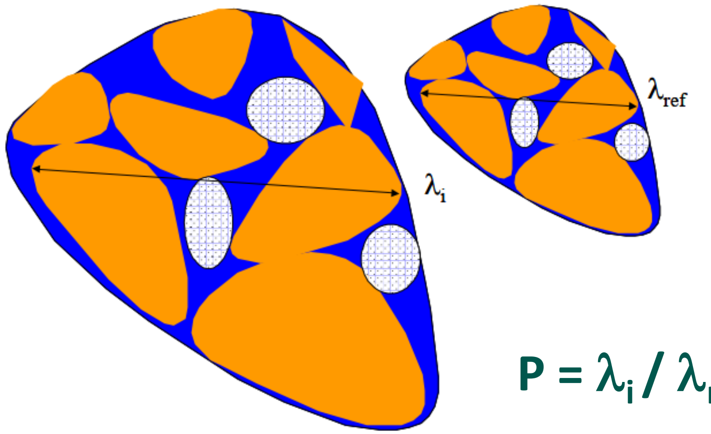
Precise prediction of soil water balance elements

at profile scale

How to combine these for modelling the spatial structure of soil water balance elements ?

Spatial variability of water balance elements

SIMILAR MEDIA SCALING – theory
(Miller&Miller, 1956)



$$P = \lambda_i / \lambda_{ref}$$

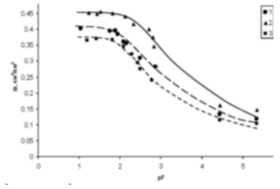
Characteristic lengths λ in geometrically similar media

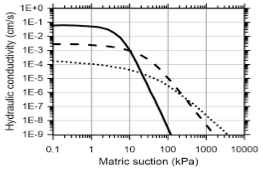
$$h_i = h_{ref}/p_i$$

$$K_i = K_{ref} * p^2_i$$

P_i scaling factor
h water potential (cm)
K hydr. cond (cm/day)

Practical application of similar media scaling for spatial extension of the SWAP model





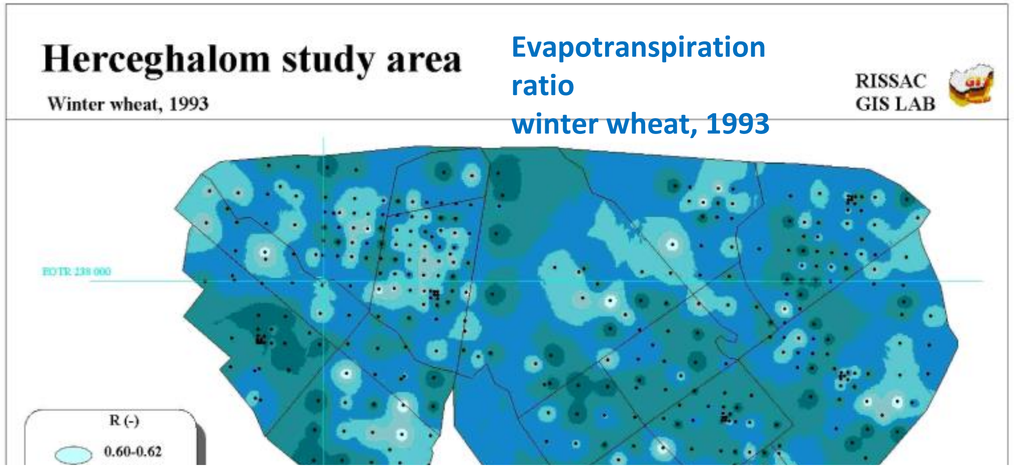
1. Scaling the 448 pF- and K(h) curves
2. 1-1 reference pF and K-curve and 448 scaling factors
3. Running SWAP for the reference and 448 scaling factors

Each pair of pF and K(h) curve was represented by one **p_i** number, instead of 7 or more parameters

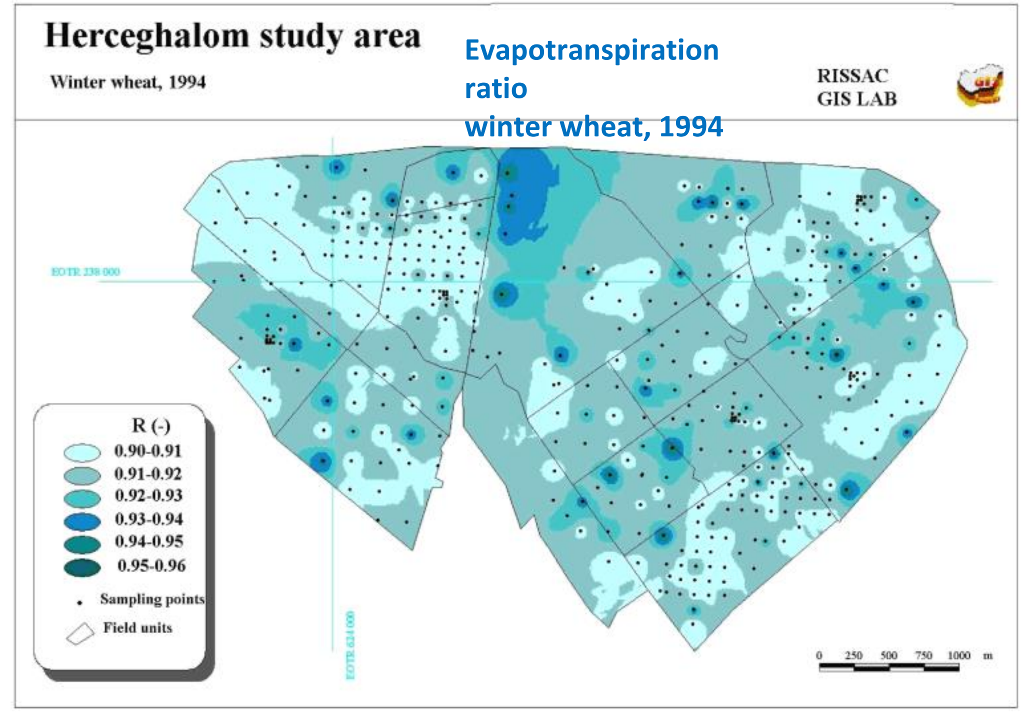
SWAP

448 sets of water balance elements

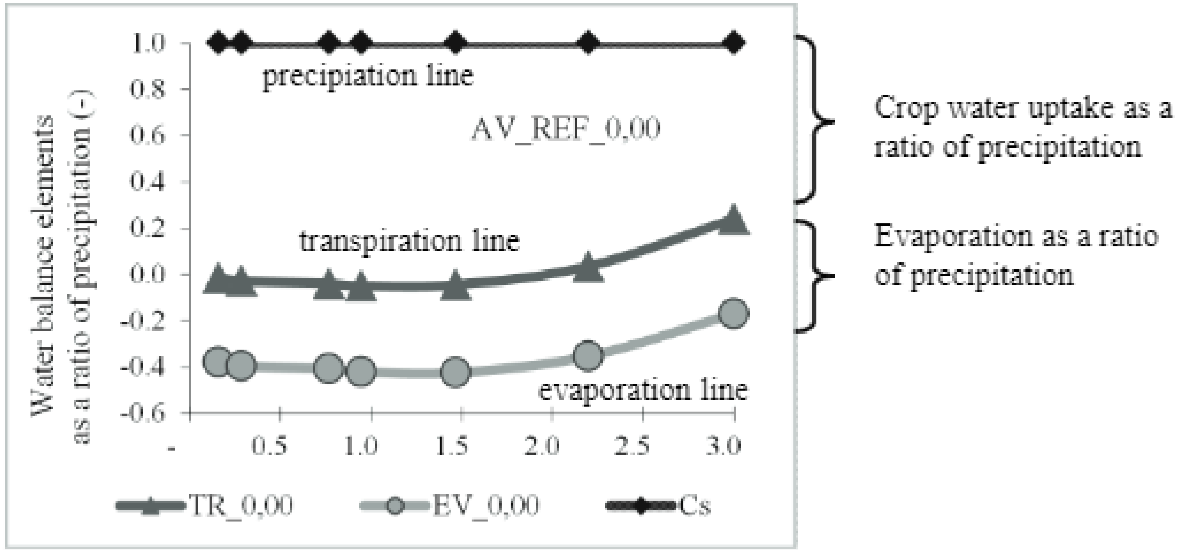
Spatial variability of water balance elements



Evapotranspiration ratio
winter wheat, 1993



Evapotranspiration ratio
winter wheat, 1994



Relationship between the scaling factor and water balance elements

Case study 1.

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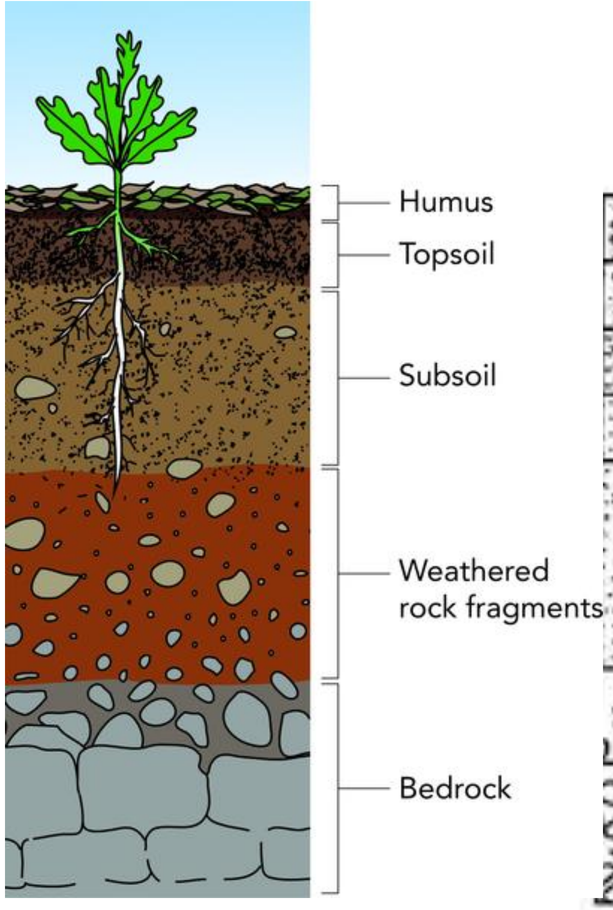
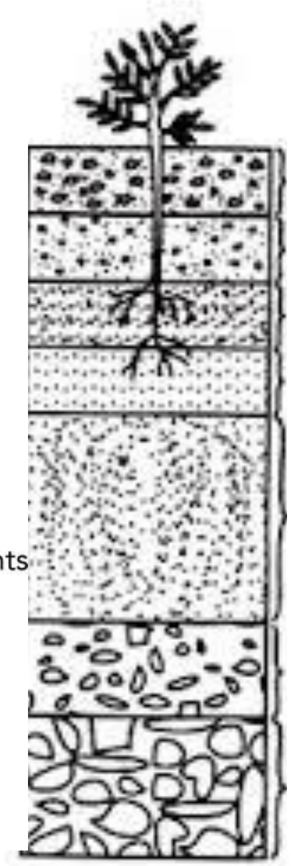
Representation of the SOIL in the hydrological models

Photo: Jim Turenne



After: Melony Smith



Total porosity
Bulk density
Field capacity
Saturated hydr. cond.

Pore-size distribution

Water retention curve

Hydraulic conductivity function

http://nesoil.com/images/haven.htm;
https://no.pinterest.com/pin/292171094567322865/?lp=true

Representation of the SOIL in the hydrological models

MODEL	CODE	MODEL PARAMETER
HBV	SM	soil moisture content
	FC	maximum amount of water stored in the layer
	INFMAX	maximum infiltration rate
	DRAW	capillary rise parameter
SWAT	SM	soil moisture content
	SOL_CRK	crack volume
	TEXTURE	texture (gravel; sand; silt; clay)
	SOL_BD	bulk density
	SOL_AWC	available water capacity
	SOL_K	hydraulic conductivity
PERSIST	SM	soil moisture content
	K	maximum infiltration rate
	POR	porosity
	WAT_MAX	maximum amount of water stored in the layer
INCA	TEXTURE	texture (gravel; sand; silt; clay)
	K	maximum infiltration rate
	TOT/AV	Ratio of total to available water
	DEF	Maximum soil moisture deficit

ALL THE BLUE PARAMETERS ARE STATIC

SOIL COVER

3-phase sytem ⟷ **4-phase system**

Solid, liquid, gaseous

living phase composed of organisms

lifeless, static body ⟷ **dynamic system**

Flood-induced changes of an alluvial soil profile

Source: Martinov A.V., https://www.science-education.ru/ru/article/view?id=24747

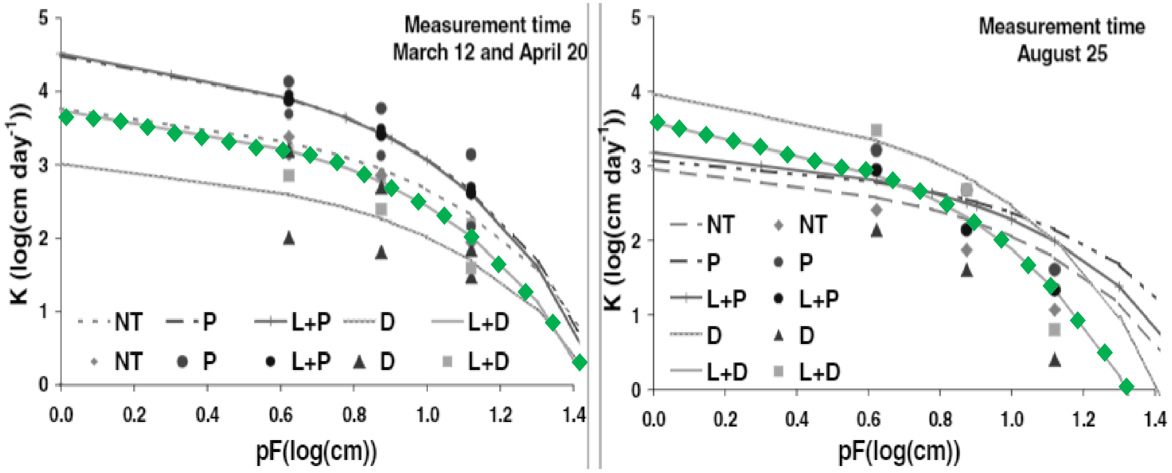
Temporal variability of soil hydraulic properties

- Long-term **tillage experiment** in Hungary
- NT (no tillage); P (ploughing); D (disking), L+P (loosening + P); L+D
- Chromic Luvisol (brown forest soil)

- Soil sampling (100 cm^3 cores) – March, June, August
  - Texture
  - Bulk density
  - Soil water retention curve
  - Ksat
- Tension disk infiltrometer measurements in situ - March, June, August

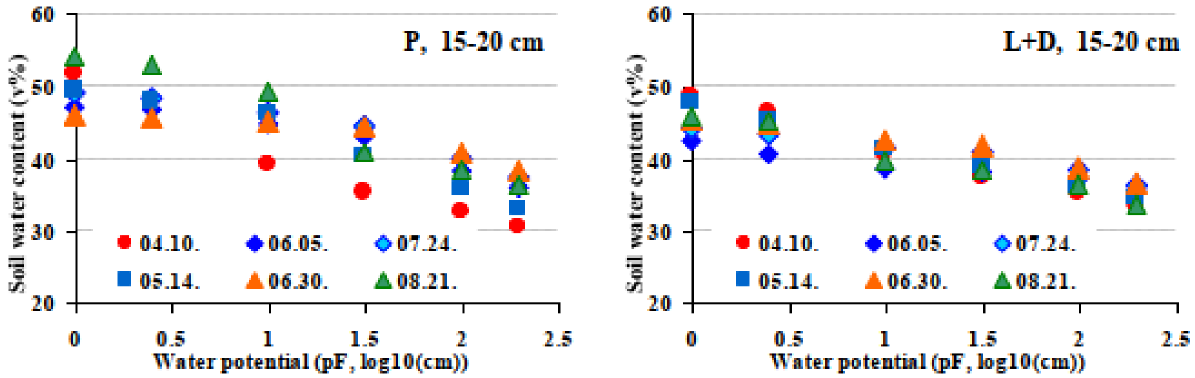
Temporal variability within a growing season (Farkas et al., (2004). Adv. Geoecol. 32., Catena Verlag, pp. 251-257.)

Seasonal changes of hydraulic conductivity
(tension disk infiltrometer, field measurements)

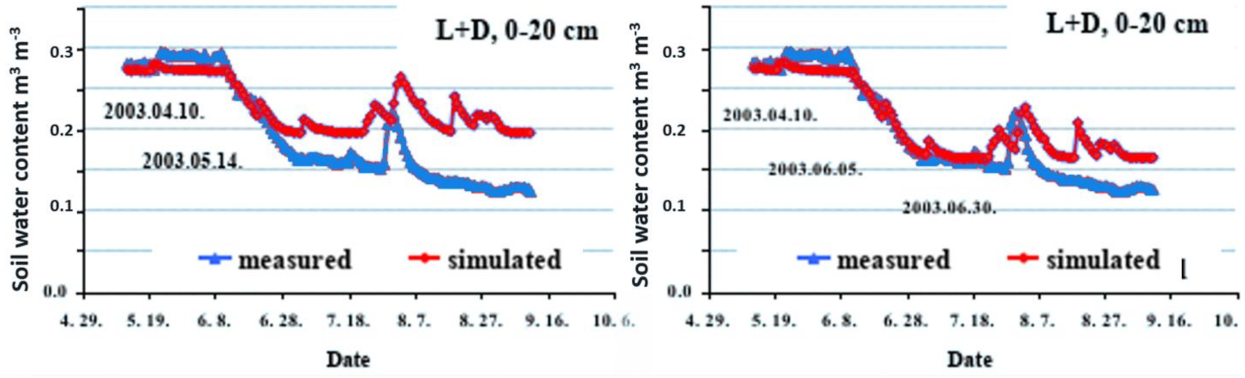


NT (no tillage)
P (ploughing)
D (disking)
L+P (loosening + ploughing)
L+D (loosening + disking)

Seasonal changes to soil water retention



Soil moisture dynamics simulated with/without temporally variable soil hydraulic properties



Approaches to handle the spatio-temporal variability of soil hydraulic properties in hydrological models

There are no standard methods to introducing the soil hydraulic functions in hydrological models

- Measured – at profile level - values: fixed
- Estimated – at profile level – values: fixed
- Measured or estimated (at profile level) values: calibrated (inverse modelling; autocalibration)
- „Areal representative values” derived from measurements or estimates - fixed
- „Areal representative values” derived from measurements or estimates - calibrated
- Applying the scaling theorey based on similar media concept

➢ Measuring and mapping the **spatial inhomogeneity of soil hydraulic properties** and modelling their effect on spatial variability of soil water balance elements

➢ **Seasonal variability of soil hydraulic properties** in cultivated soils

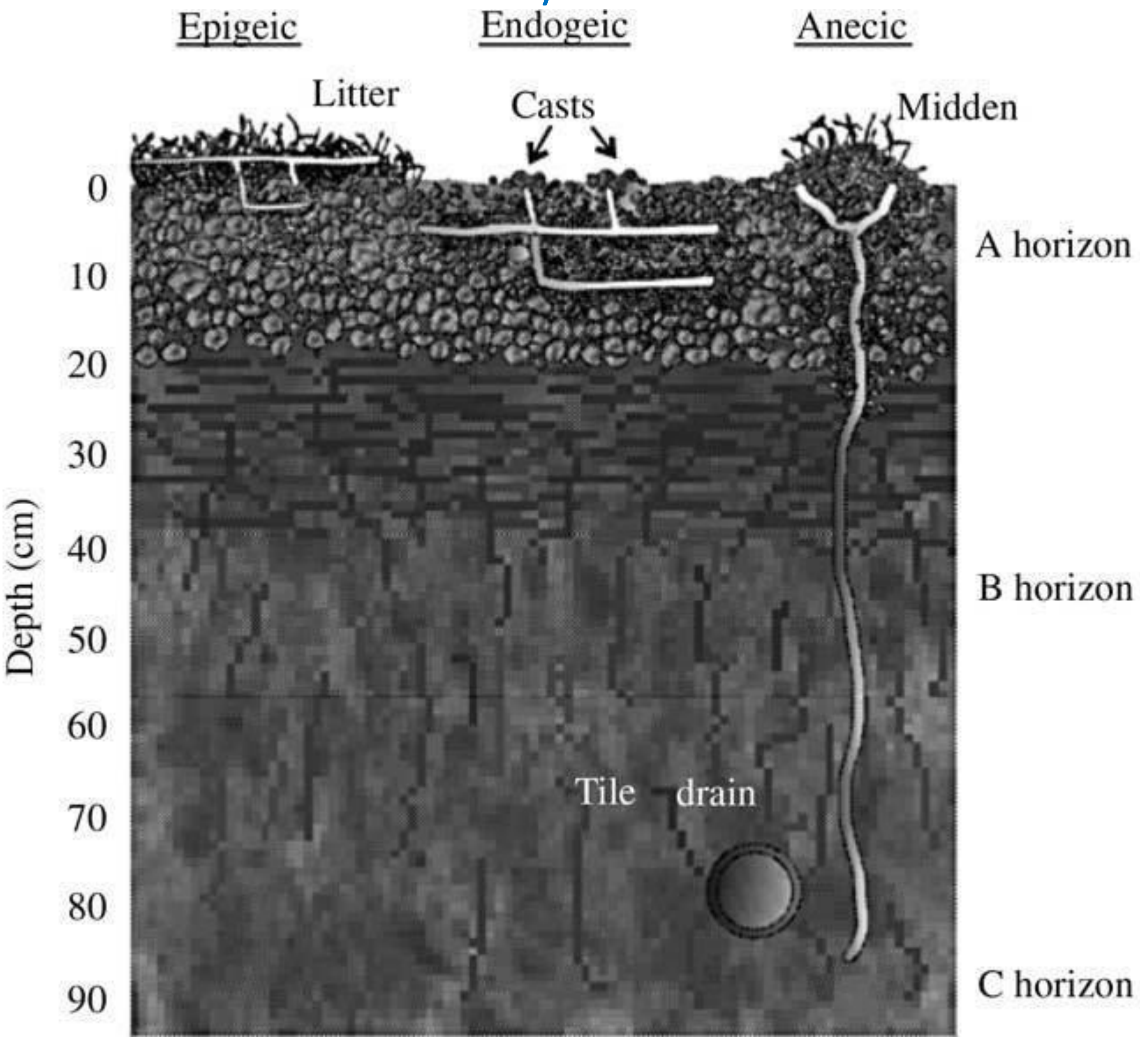
THE MESSAGE FROM *PLANET SOIL* TO *SPACESHIP OPTAIN MODELING*

Time left for questions?

Effect of soil biota on soil hydraulic properties - example

Shipitalo, M. 2002. Encyclopedia of Soil Science.

Diagrammatic representation of the burrows made by the three ecological groups of earthworms as defined by Bouché.



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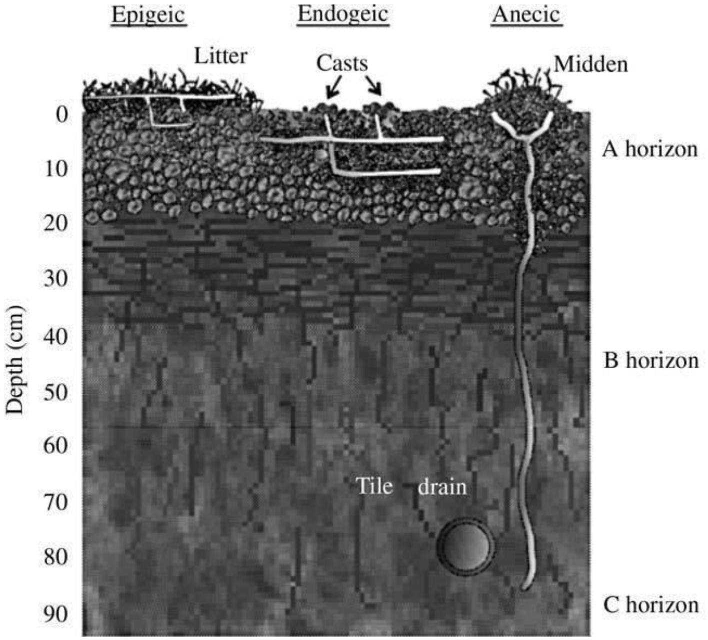
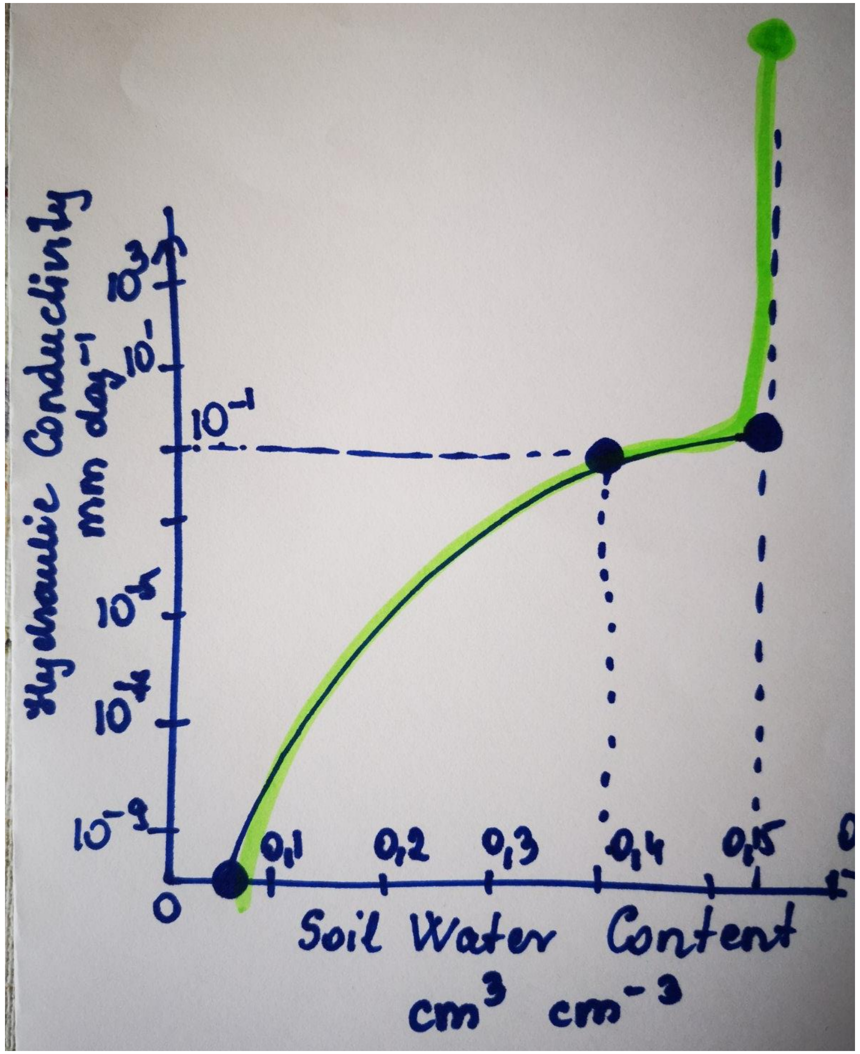


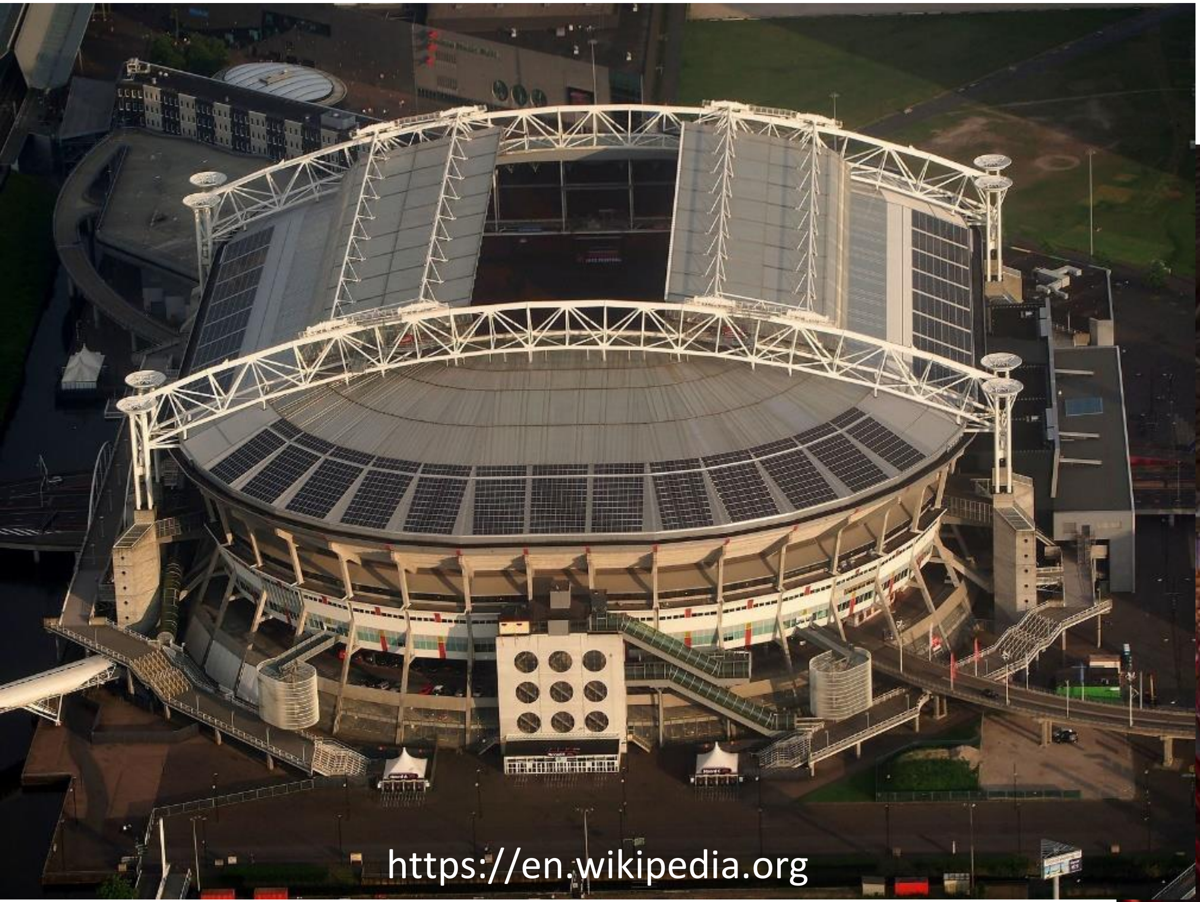


NO curve could be fitted

K(h) represented as a set of data pairs in the SWAP model

The impact of heterogeneous soil behavior on real-world dilemmas:

When the Johan Cruyff ArenA (AJAX Amsterdam ▪) met soil hydrology in 1996



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