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Eau, Terre et Environnement

Estimation of infiltration in boreal soils of Quebec, James Bay area

Evaluation des infiltrations dans les sols boréaux du moyen-nord Québécois, région de la baie James

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CWRA 2008

Hydro Québec

Plan

Objectives

To present a method to characterize :

(i) Hydrological/hydrous properties of boreal soils

(ii) Infiltration

→ For hydrological modelling of a boreal watershed (method only no results yet)

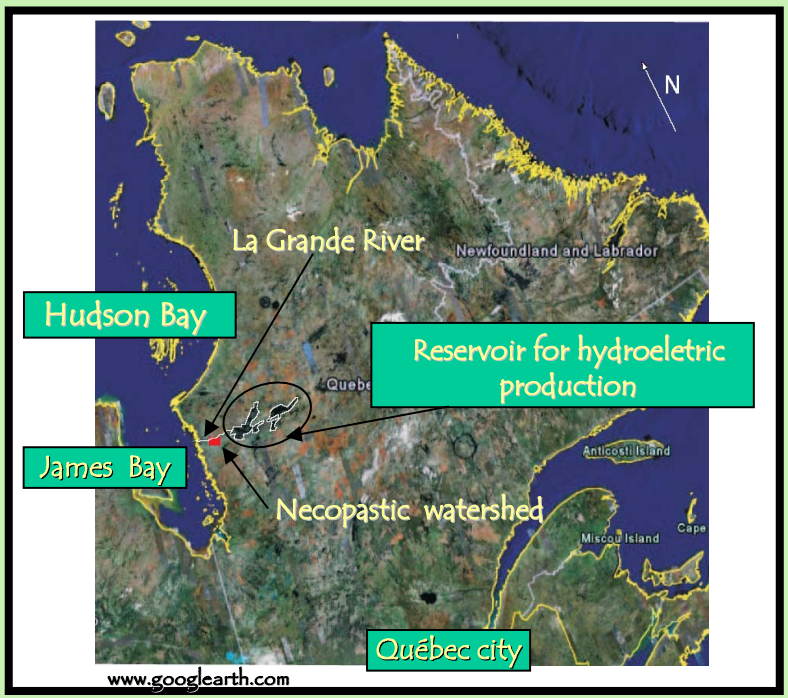
Plan

1. Contexts
2. Non-destructive sampling method
3. Hydrological properties of individual soil horizons
4. Hydrodynamic Analysis of soil monoliths
5. Modelling of large-size soil columns
6. Expected results

Geographical context

Site location and description

- Pedological sampling → Nécopastic watershed (240 km^2)
- 50 kilometers East of James Bay (54°N, 78°O), next to La Grande River, between LG1 and LG2 dams.
- Vegetation : Forests + Bogs



Interest context

Environmental and economic contexts

- Current and potential hydroelectric production
→ Numerous dams or projects

- Vegetation blankets and soils are very diversified. They contribute to the water supply of reservoirs

Pedological context

The boreal soils and their hydrous properties remain relatively unknown

- Variability of boreal pedology is underestimated - Boreal soils are not uniform and monotonous !

  Main soil : - purely organic soils
  - organic Podzols
  - mineral soils

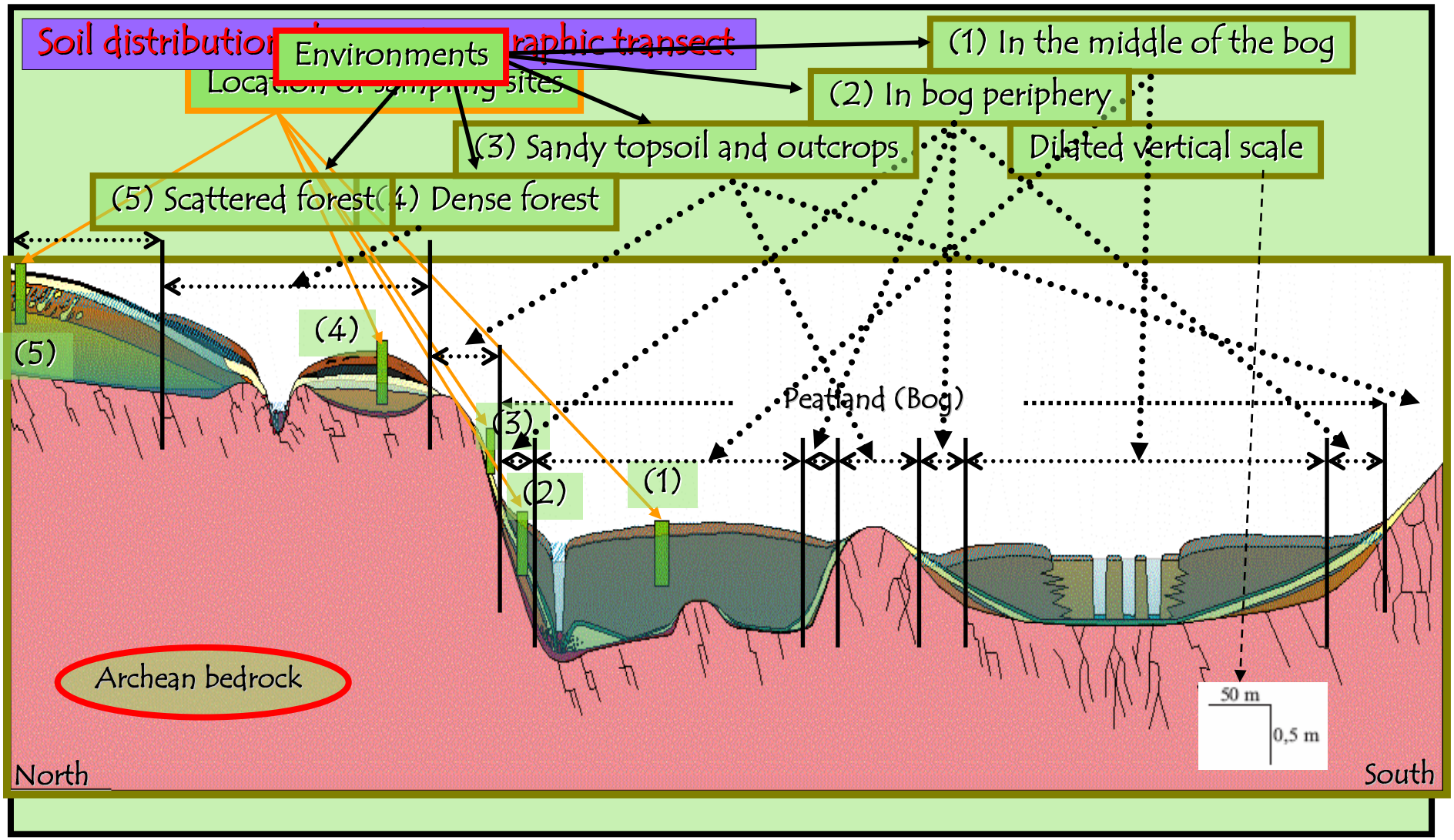
  Main blankets : - mosses
  - lichens
  - organic layers (humus and litters)

- Pedological horizons are diverse and each of them possess unique physical and hydrous properties. It is not only peat and sand!

Questions :

- Influence of moss, lichen blankets and humus horizons on infiltration ?
- Influence of organo-mineral interfaces ?
- Variable responses (linked to soil type)

Pedological context



Problematic

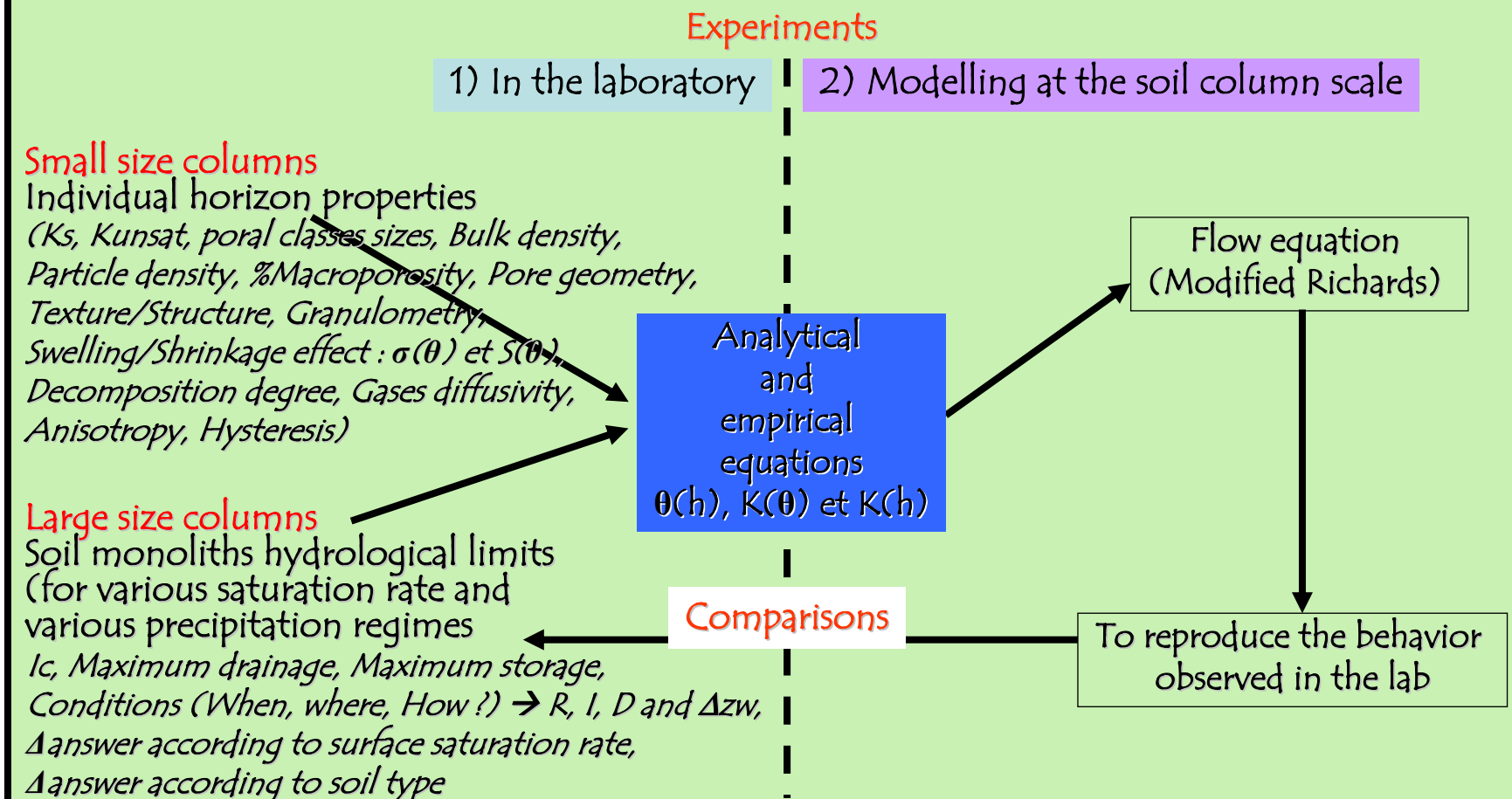
The specificities of boreal organic soils must be considered

Materials → / ↓ Properties	Physico-hydrous properties of organic soils or organic horizons	Physico-hydrous properties of mineral soils or mineral horizons
Porosity	Total porosity > 80% Macroporosity > 50%	Total porosity < 50% Macroporosity < 25%
Retention and hydraulic conductivity curves	θ and K rapidly decrease (between 0 < h < -20 cm) →Strong anisotropy for K →Strong hysteresis (θ and K are smaller during sorption phase)	Varied porosity (wide range of pore sizes) = wide retention strength range
Soil surface saturation rate	Difficult to reach	Easy to reach
Control of the infiltration rate	Top horizons (humus; acrotelm (unsaturated and macroporous)) and moss or lichen blankets	Precipitation regime Ic = f(P) (When P > Ic → Surface runoff)
Ic (Infiltration capability)	Immediate (P < Ic) (*Guertin and al., 1987*) Ic = constant	Ic ≠ constant

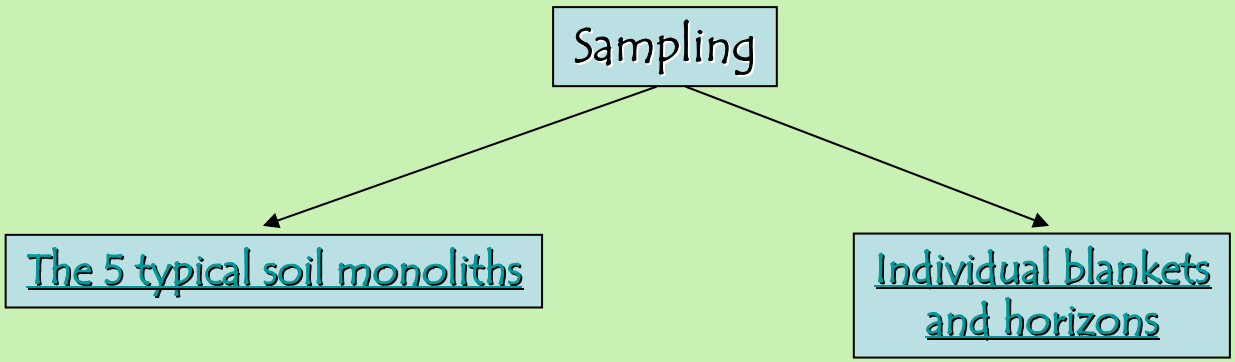
Organic soils curves $\theta(h)$, $K(\theta)$ and $K(h)$ remain unknown in boreal area

Problematic

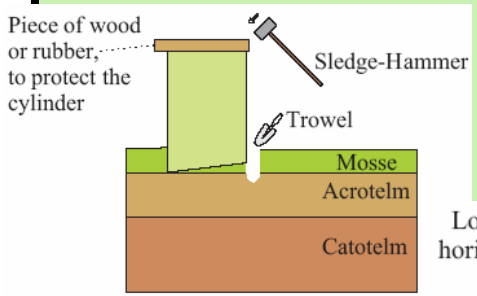
Hydrological behaviors of boreal organic soils → Model adaptation



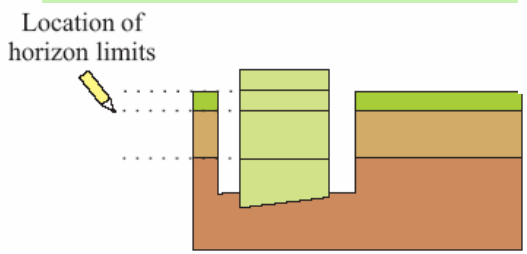
Sampling Objectives Methodology

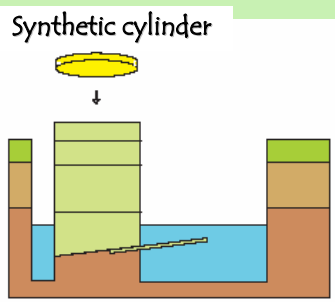


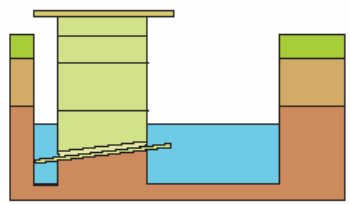
Sampling methodology

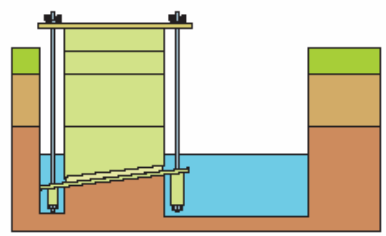


Soil sampling



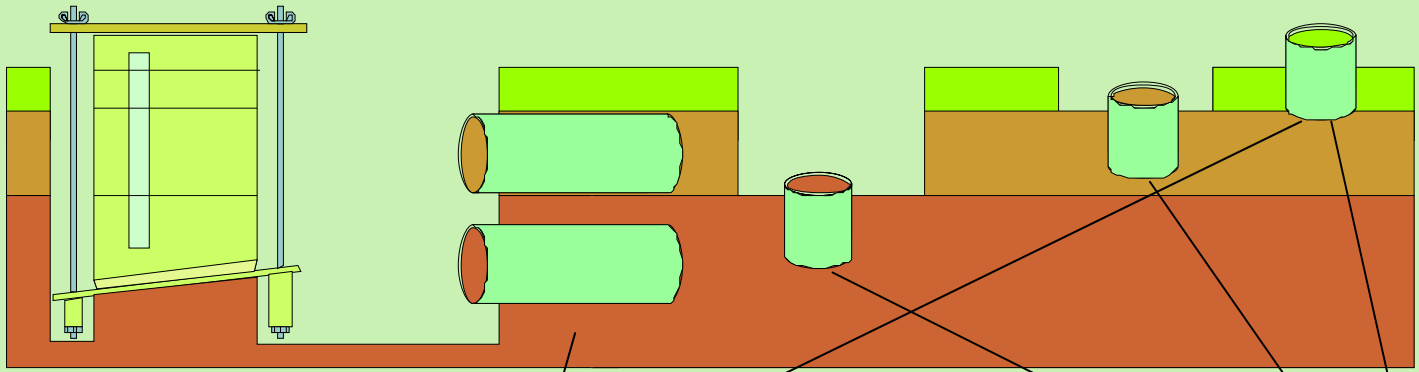


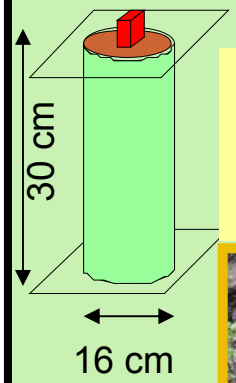




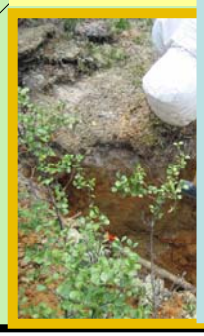
Sampling methodology

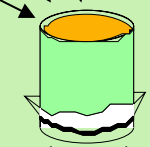
Undisturbed sampling method for blankets and individual horizons





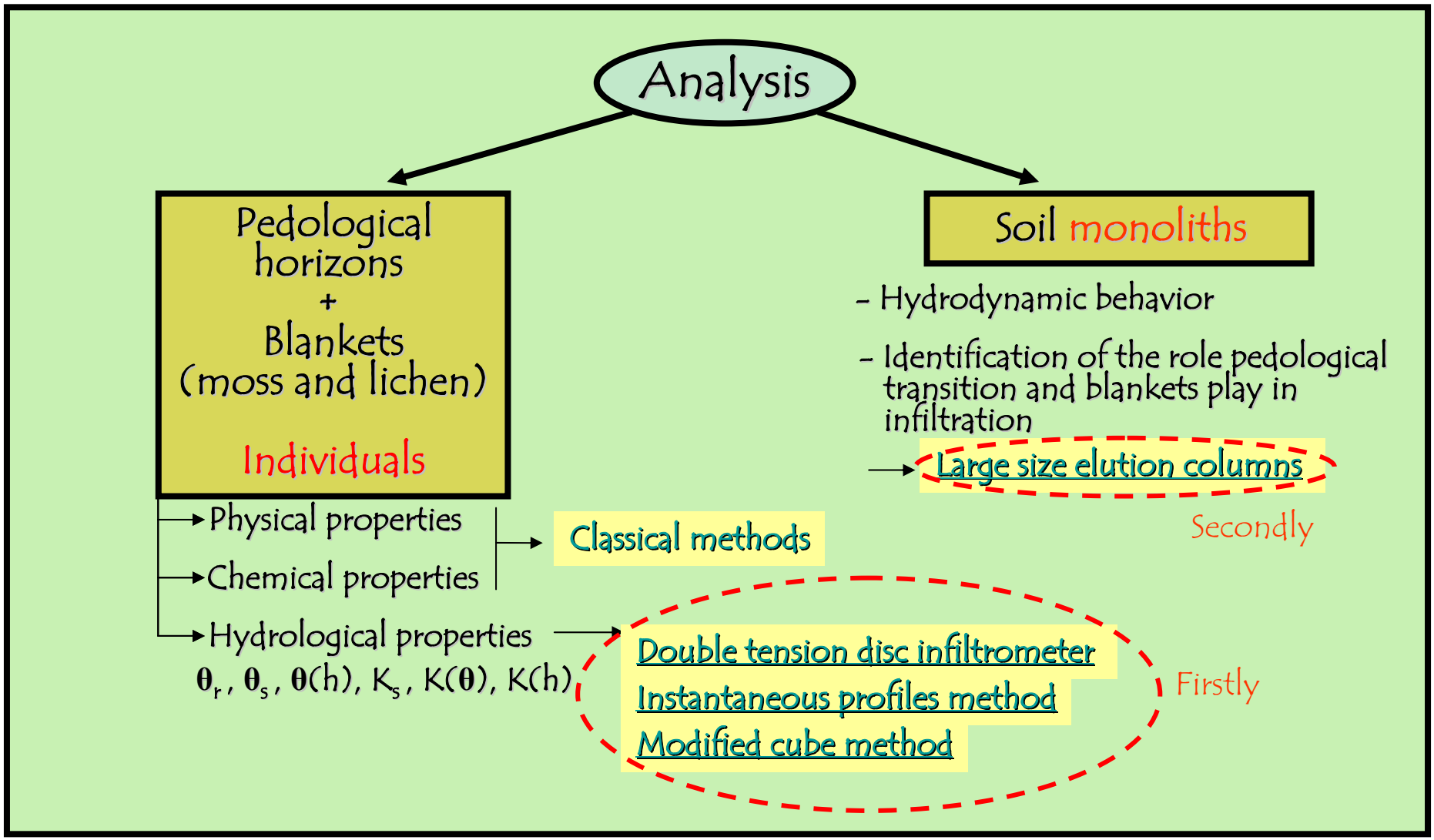
Blankets (moss, lichen, humus)
+ Σ Ped
→ Calib bes Ka = f (θ)



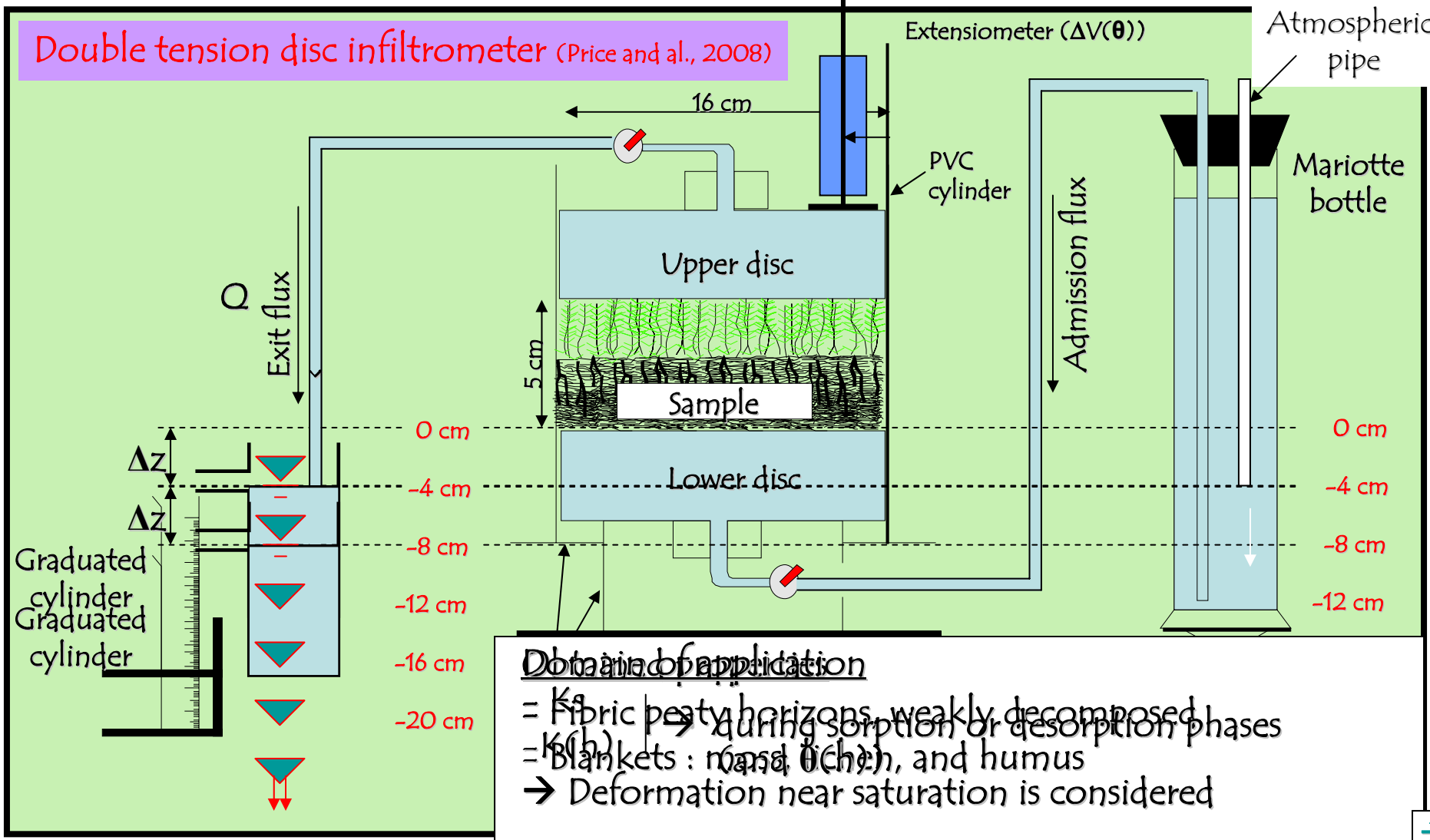


Blankets (moss, lichen, humus)
+ Σ Pedological horizons
→ Physical, chemical, hydrous and hydrological properties

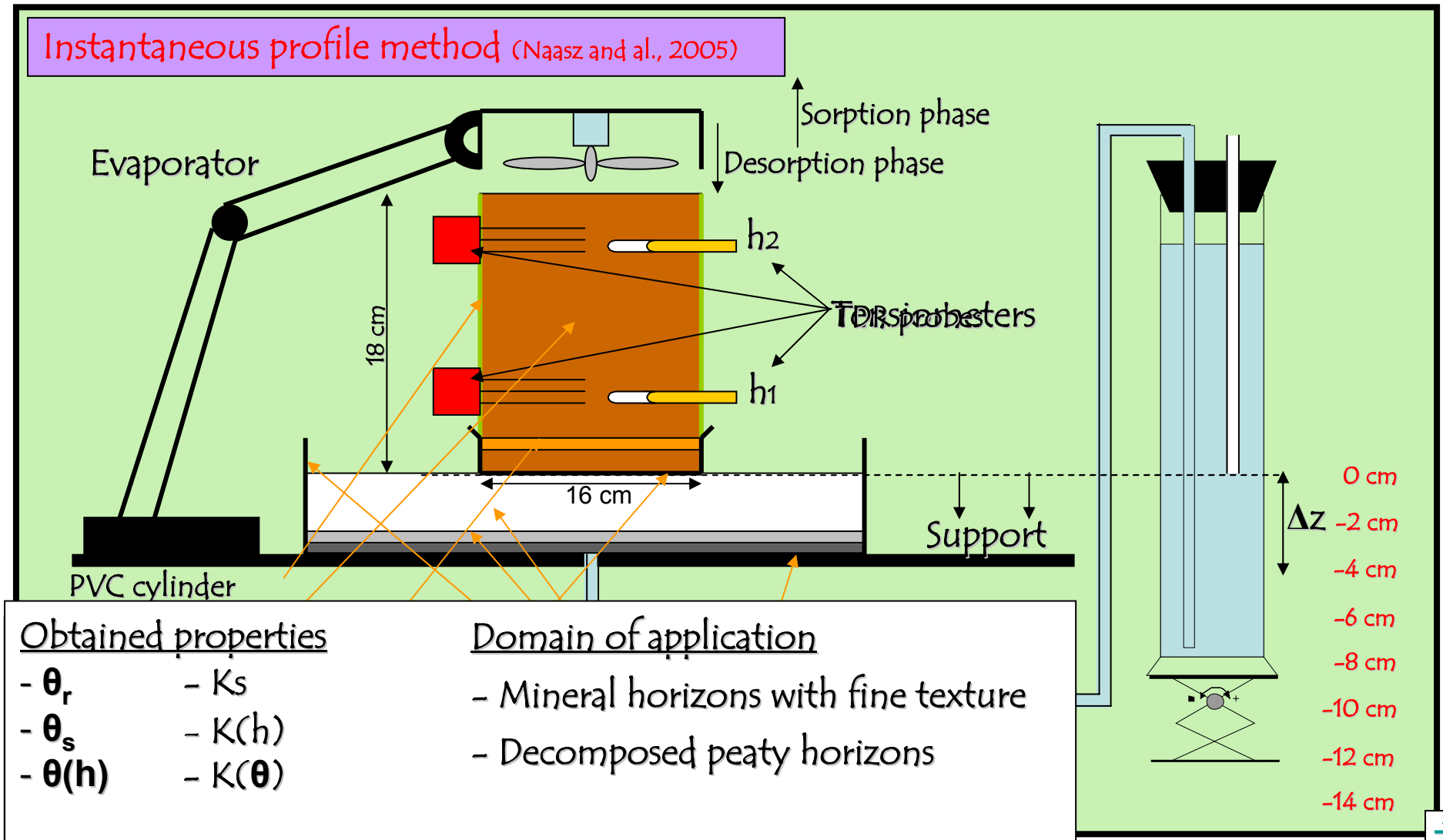
Sampling methodology



Methodology : individualized horizons



Methodology : individualized horizons



Obtained properties

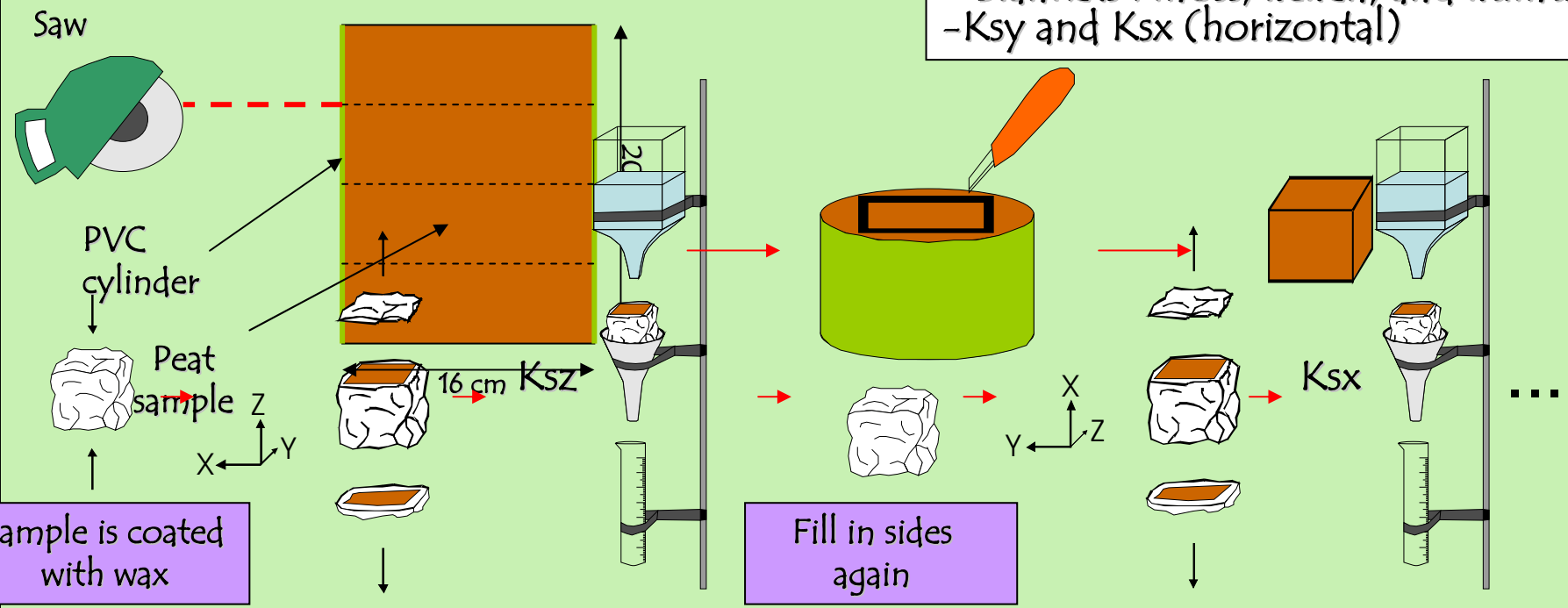
- θ_r – Ks
- θ_s – K(h)
- $\theta(h)$ – K(θ)

Domain of application

- Mineral horizons with fine texture
- Decomposed peaty horizons

Methodology : individualized horizons

Modified cube method (Beckwith and al., 2003)



Obtained properties

Anisotropy (Ks)

- Peaty horizons
- Blankets : moss, lichen, and humus

=Ksz (vertical)

-Ksy and Ksx (horizontal)

Methodology : individualized horizons

- Non-specific equation for general boreal soils
- Non-specific equations for both boreal organic and mineral horizons
- Specific equations for each boreal horizon

Van Genuchten-Mualem model adaptation/adjustment

↑

Ks, Ks anisotropy, K(**θ**), K(h), h(**θ**), θs, θr
Humus / Living blankets / Organic horizons / Mineral horizons

↓

Bulk density
Particle density
Decomposition degree
Granulometry …

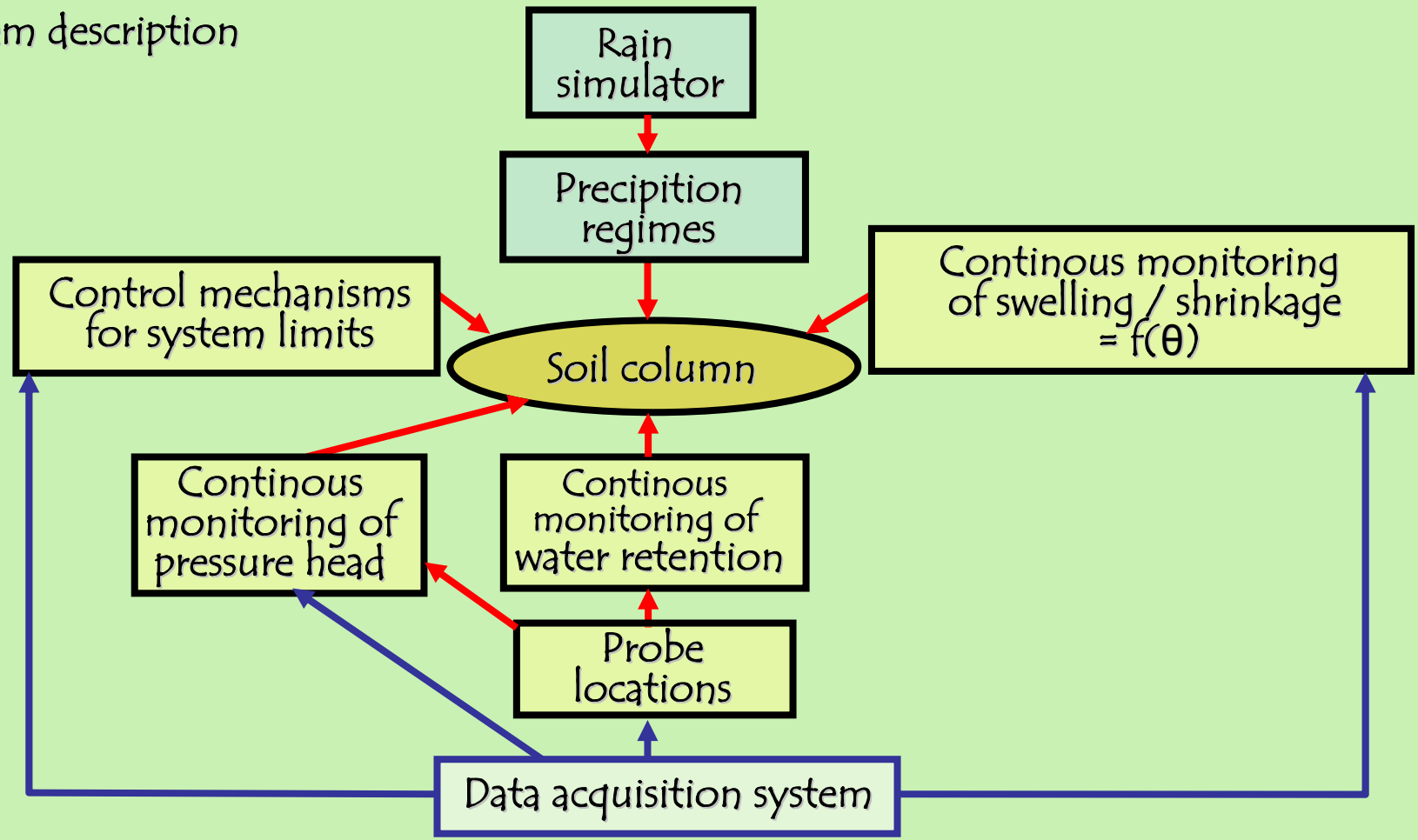
Pedotransfert function (PTF) for **θ**(h) and K(**θ**)

- Non-specific equation for general boreal soils
- Non-specific equations: for both boreal organic and mineral horizons
- Specific equations for each boreal horizon

Methodology : individualized horizons

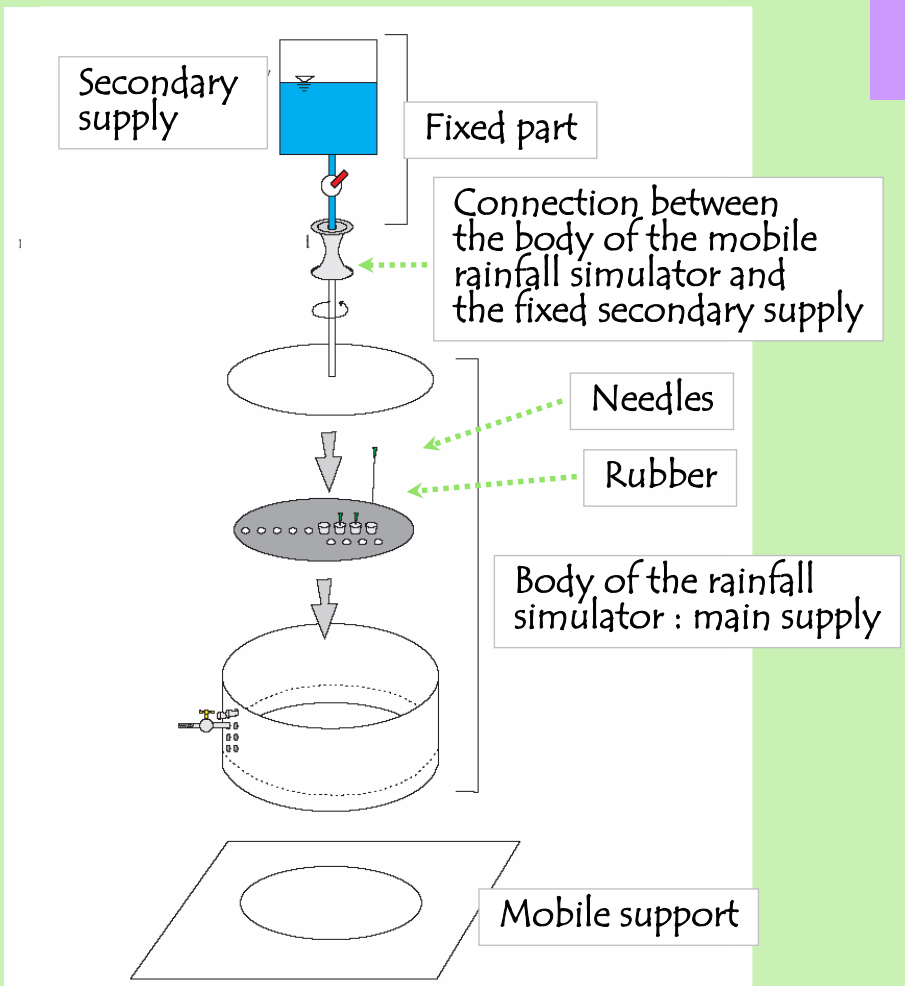
Infiltration on large size columns (Yang and al., 2004 and 2006 ; Legout, 2005)

System description



Methodology : soil monoliths

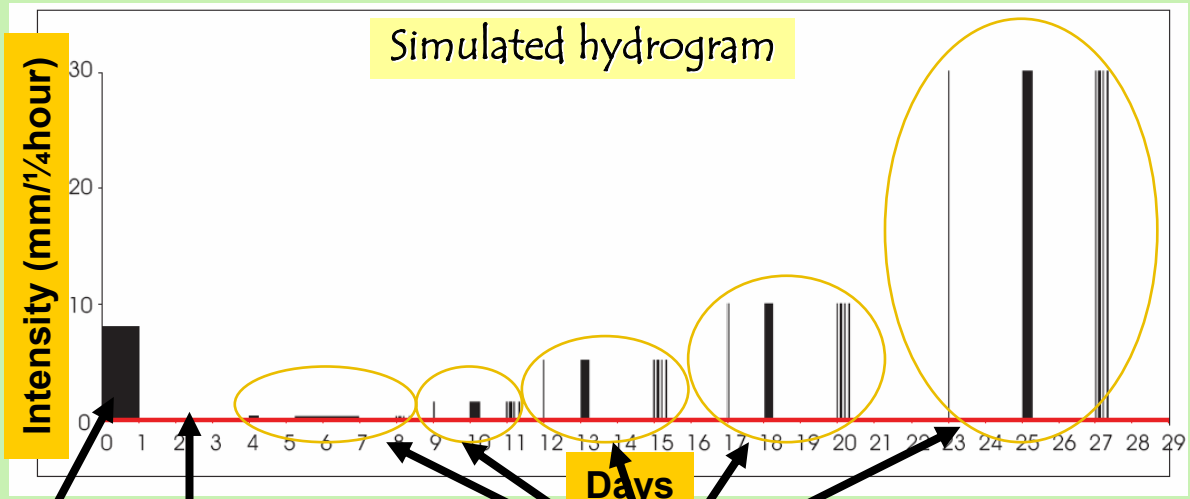
Schematic diagram of the infiltration column apparatus : rainfall simulator



Range of simulated rainfalls (James Bay)
- Common event : 0.4 mm/h
- Extreme event : 30 mm/h

Methodology : soil monoliths

Schematic diagram of the infiltration column apparatus :
Artificial hyetogram

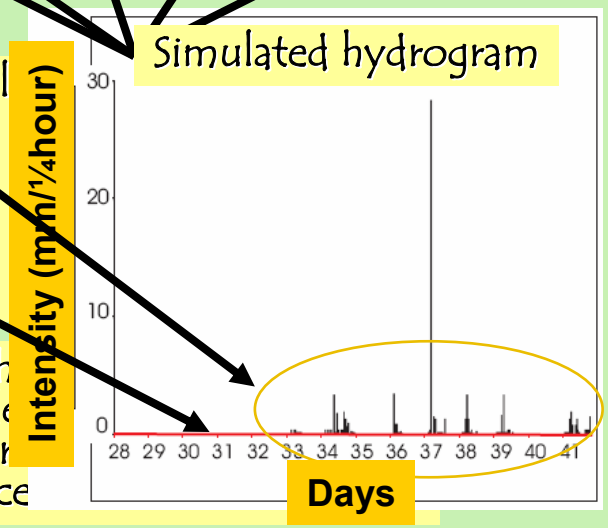


Representative weekly hyetogram
(July and August 2006 – 2007)

Initial drainage
Long duration drainage

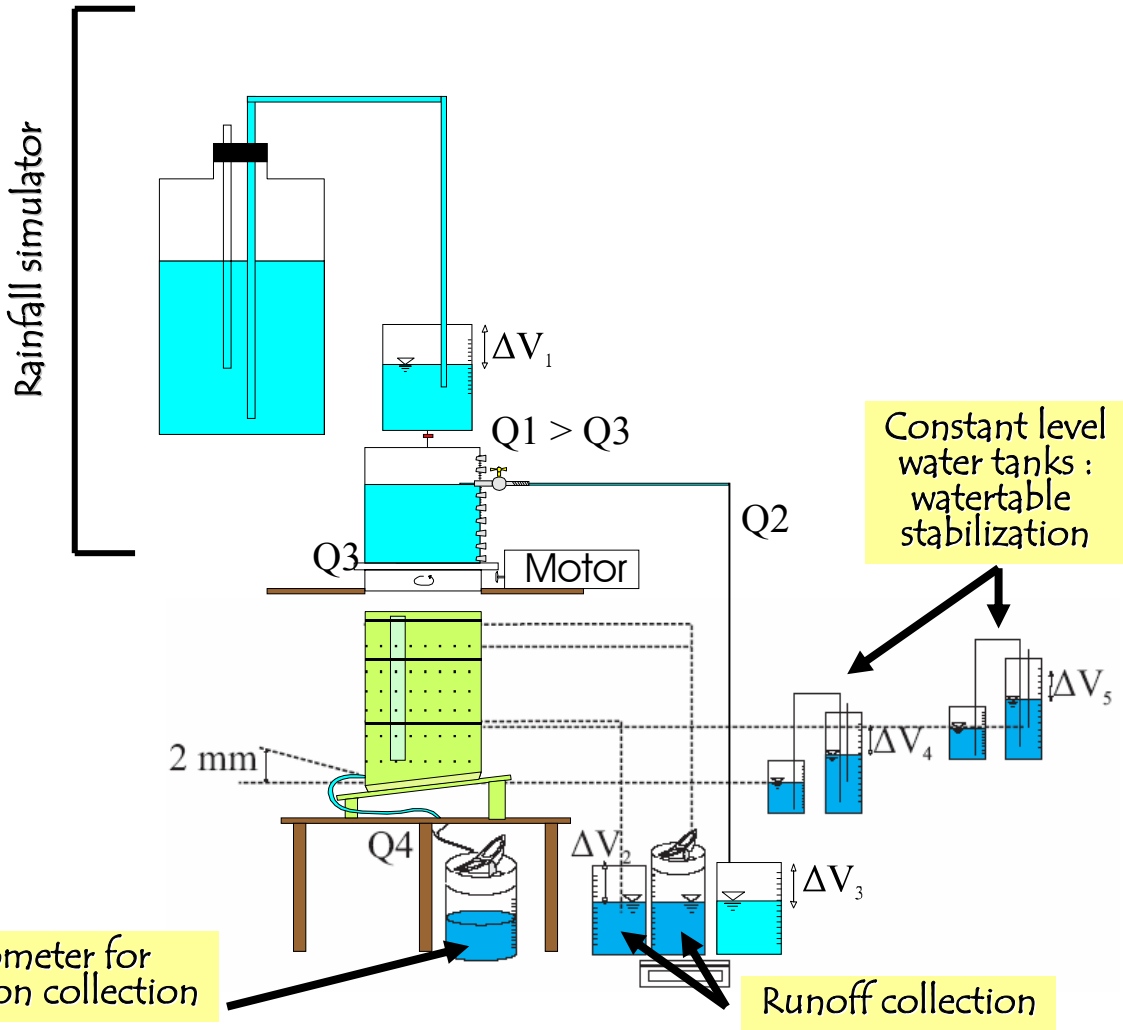
5 pl
–
–
–
–

For each
– A fl
– A pr
– Succe



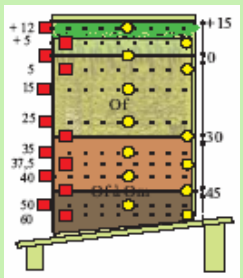
Methodology : soil monoliths

Schematic diagram of the infiltration column apparatus : Illustration of water connection devices (with the peat column)

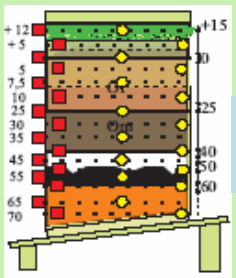


Methodology : soil monoliths

Schematic diagram of the infiltration column apparatus : Electronic and computing connections

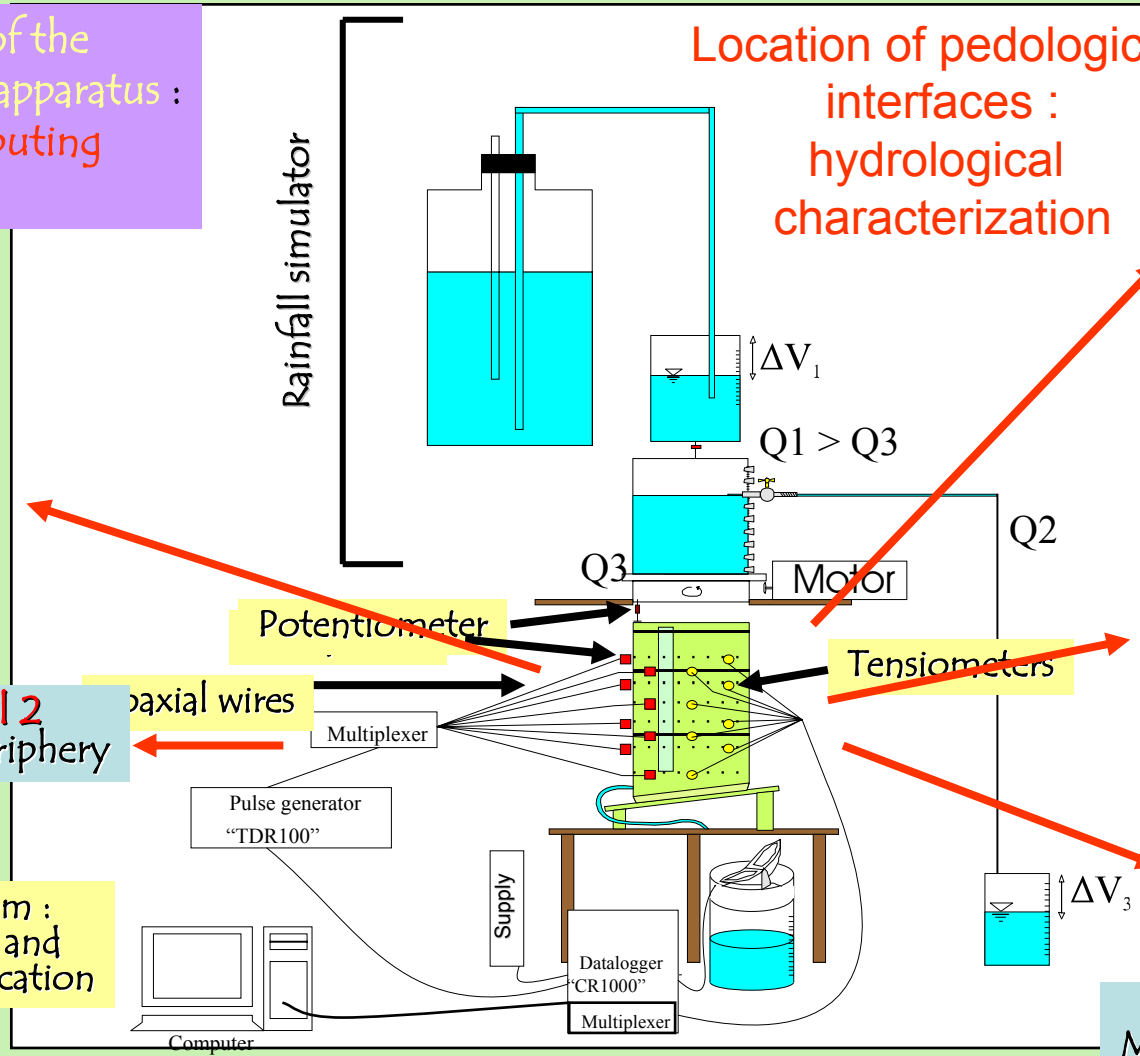


Soil 1
Bog

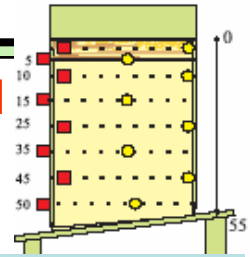


Soil 2
Bog periphery

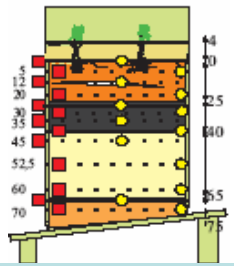
Control system : data reception and program modification



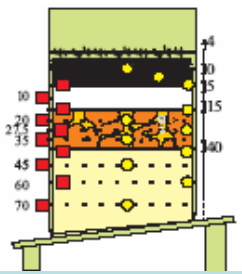
Location of pedological interfaces : hydrological characterization



Soil 3
Strong slope



Soil 4
Plateau border



Soil 5
Middle of plateau

Methodology: soil monoliths

Modelling

Modelling applied to boreal soil columns

Objectives

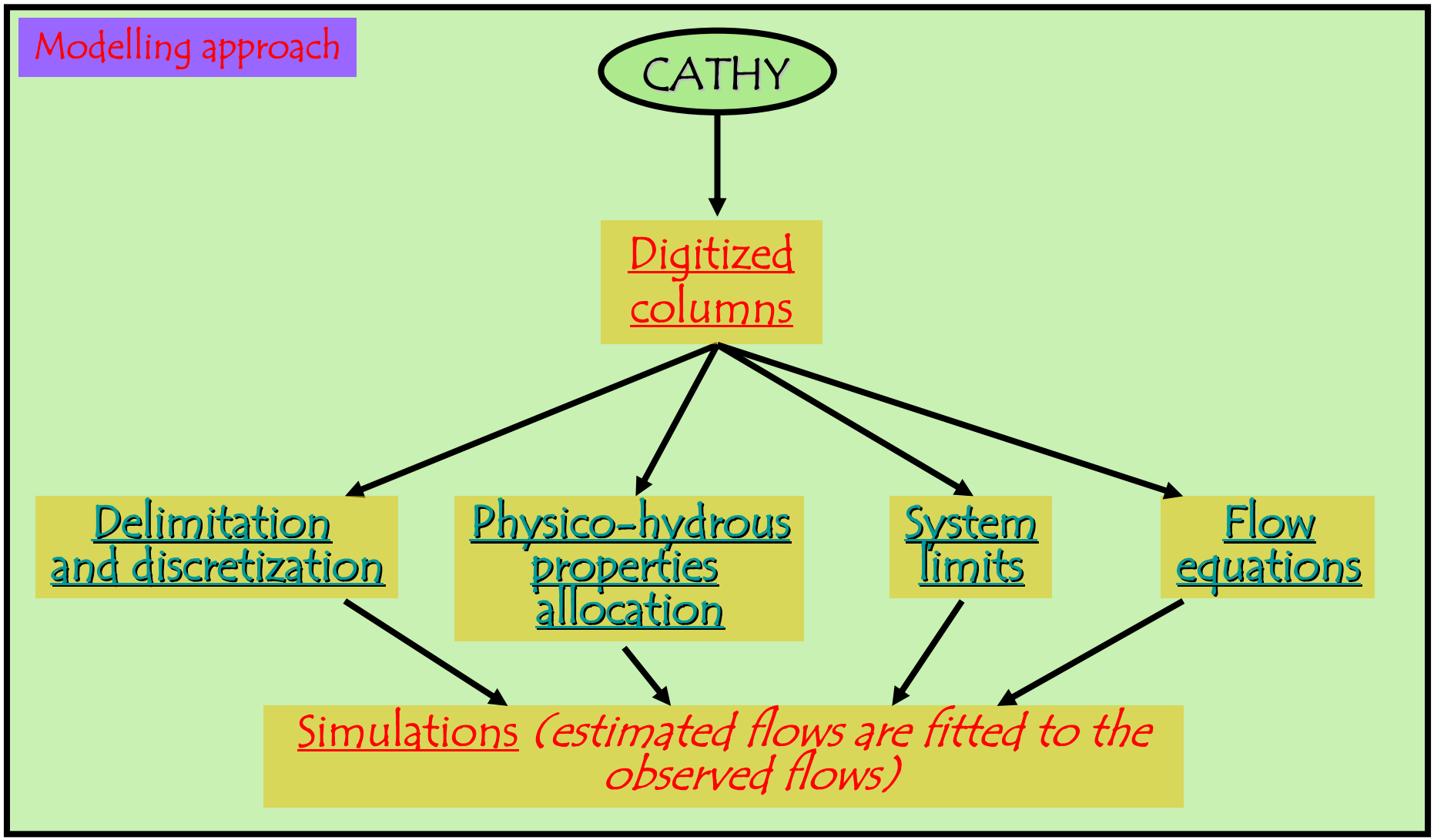
→ Test, adapt and validate a model for boreal soils

- Several curves $\theta(h)$ et $K(\theta)$ will be tested
- Several flow equations will be tested

→ Understand, reproduce and model hydrodynamic behavior

- Find equations for : I, E, ET, R, D, ΔStorage
- Estimate the predominance of all physico-hydrous properties in these processes

Modelling

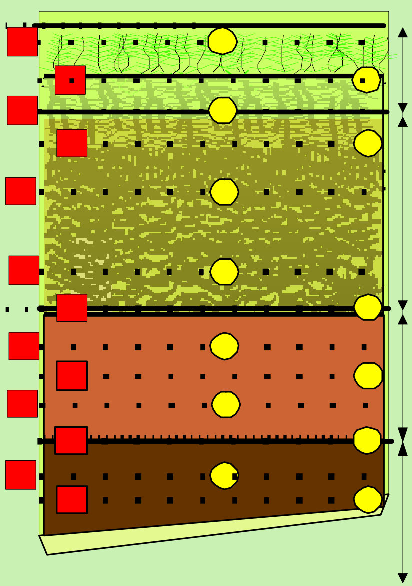

Modelling approach
CATHY
Digitized columns
Delimitation and discretization
Physico-hydrous properties allocation
System limits
Flow equations
Simulations (estimated flows are fitted to the observed flows)

Modelling

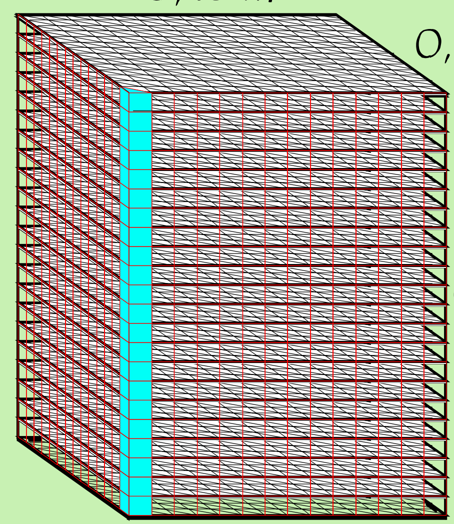
Spatial delimitation and discretization

Ex : Soil 1 in the middle of the bog

Laboratory column



Digitalized column



1/ Define the system (section and depth)

2/ Discretization : Finite elements method

→ Surface fine meshing :

- Regular and homogeneous partitionment   P → R + I
- Good interactions between each groundwater levels
- Precision of h, θ et K profiles → comparisons with equivalent depths on laboratory column

2-1/ vertical
2-2/ horizontal : 81 levels (roughly every centimeter)
2-3/ K1000 cells → 11000

Modelling

Configuration

- Allocation of physical and hydrological properties in every discretized cells

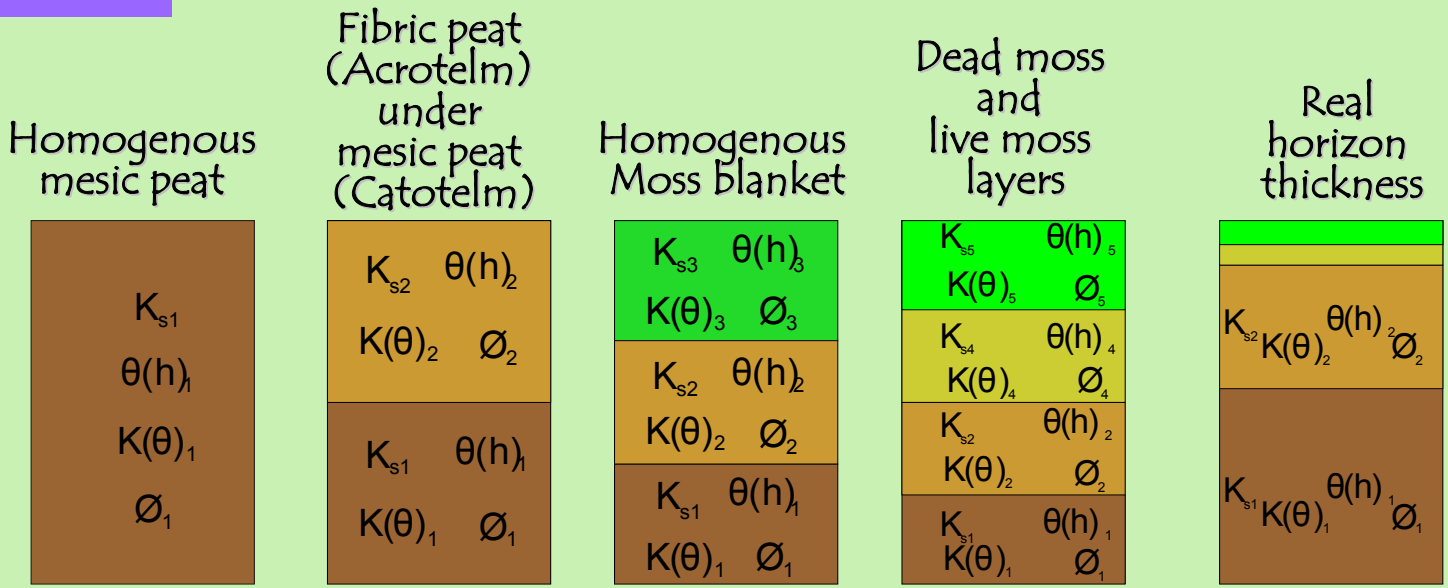
  Ks (Kvs, Khs), K(θ), θ(h), ø(θ), Ss(θ) et σ(θ)

- Several equations θ(h) and K(θ), specific or not, could be included in flow equation:
  - Raw state data
  - Fitted curves with VGM model (*Van Genuchten and al., 1991*)
  - Specific PTF
  - No-specific PTF

- Reconstruction of pedological horizons → Several scenarios are tested

Modelling

Simulations



Complexity and realism increase

Modelling

Flow equations

Richards equation

$$\sigma(S_w)\frac{\partial h}{\partial t} = \nabla * \left[K_s K_r(S_w) * \nabla(h+z)\right] + q$$

With $$\sigma = \phi \frac{\partial Sw}{\partial h}$$

Where

h [L]; **σ** is total storage coefficient [1/L] ; **Sw** is saturation rate = θ/θs ; θ and θs [L^3/L^3] ; **Ss** is specific storage coefficient [1/L] ; **ϕ** is porosity (= θs when swelling/shrinkage is not considered) ; t is time [T]; **Ks** represents saturation hydraulic conductivity [L/T]; **Kr** is relative hydraulic conductivity (= K/Ks) ; **z** is a vector (coordinates x = 0 ; y and z = 1 (positive upward direction) [L] ; **q** represents sinking flux (water taken up by roots) or supplying flux [L3/L3T], *(Paniconi and Putti, 1994)*

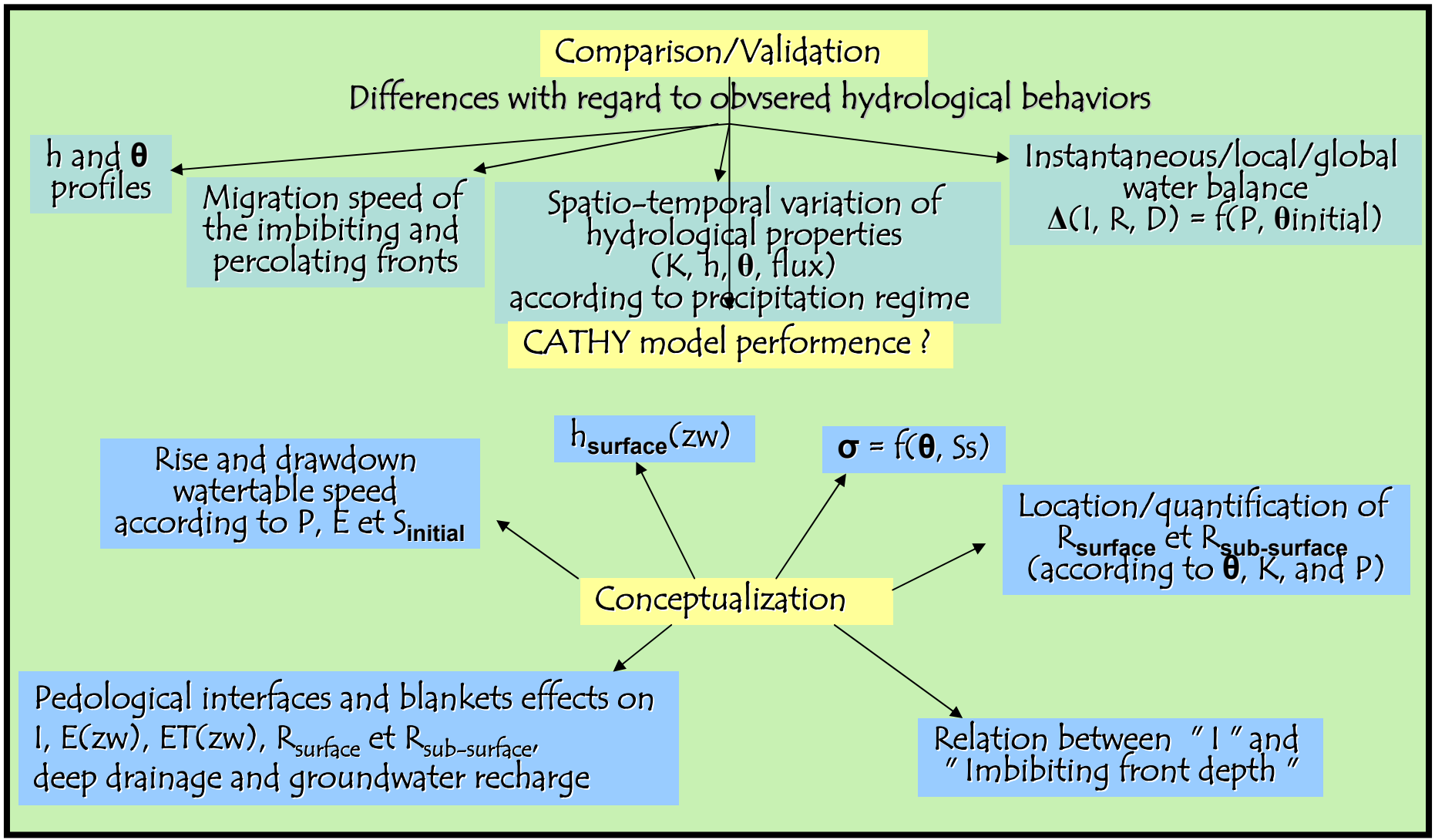
Modified Richards equation

Hydrological behavior simulation by taking account of Ss in **σ** equation

With $$\sigma = \phi \frac{\partial Sw}{\partial h} + Sw * Ss$$

Variation of environment compressibility with water content :
Dependent on Swelling/shrinkage curve

Modelling


Comparison/Validation
Differences with regard to obvsered hydrological behaviors
h and θ profiles
Migration speed of the imbibiting and percolating fronts
Spatio-temporal variation of hydrological properties (K, h, θ, flux) according to precipitation regime
Instantaneous/local/global water balance Δ(I, R, D) = f(P, θinitial)
CATHY model performence ?
Conceptualization
Rise and drawdown watertable speed according to P, E et S initial
h surface(zw)
σ = f(θ, Ss)
Location/quantification of R surface et R sub-surface (according to θ, K, and P)
Pedological interfaces and blankets effects on I, E(zw), ET(zw), R surface et R sub-surface, deep drainage and groundwater recharge
Relation between " I " and " Imbibiting front depth "

Conclusion

This procedure has to allow :

(i) To improve the modelling of soil water dynamics of boreal soils
(ii) To better model the hydrological cycle at the scale of boreal watersheds

We need to determine:

Which are the real input data requirements ?

→ From the succession of scenarios identify:
- What is the minimum complexity level ?
- What is the relative importance of each physico-hydrous property ?

Example : hysteresis, horizon thickness .. ?

→ $\theta(h)$ and $K(\theta)$ specific calibration ?

→ Differentiation of various blanket types influences on E, ET and I ?

→ CATHY applicability and robustness ? Soil types ? Adjustments ?

End