DE LA RECHERCHE À L'INDUSTRIE

SIMULTANEOUS ESTIMATION OF GROUNDWATER RECHARGE AND HYDRODYNAMIC PARAMETERS FOR GROUNDWATER FLOW MODELING

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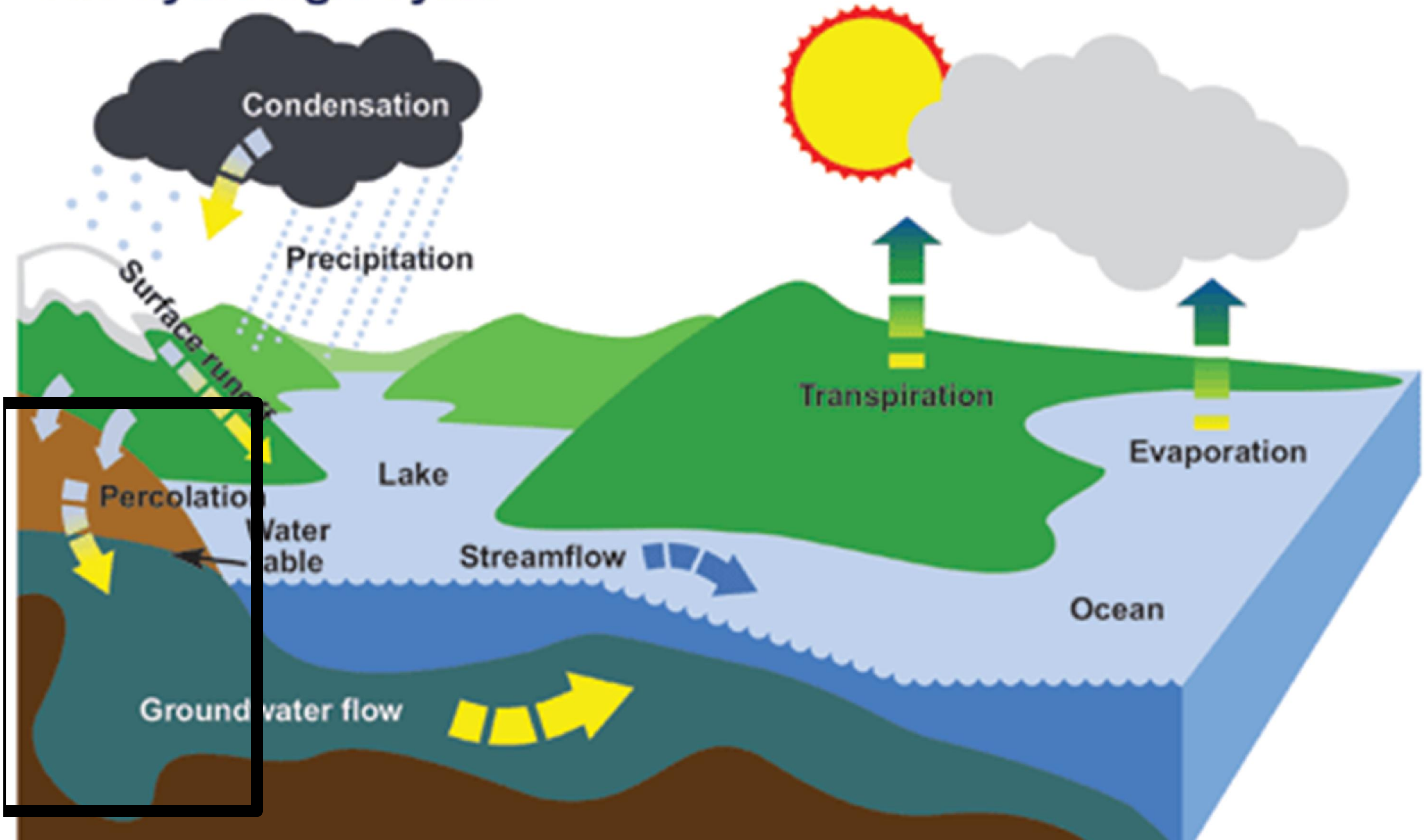
INTRODUCTION

The hydrologic cycle



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INTRODUCTION

- **Groundwater (aquifers)**: 3rd freshwater reservoir on the planet
- Replenished essentially by precipitation through **groundwater recharge**
- The r
- Threa
- Usua ls (Hydraulic heads)
- **Phys**

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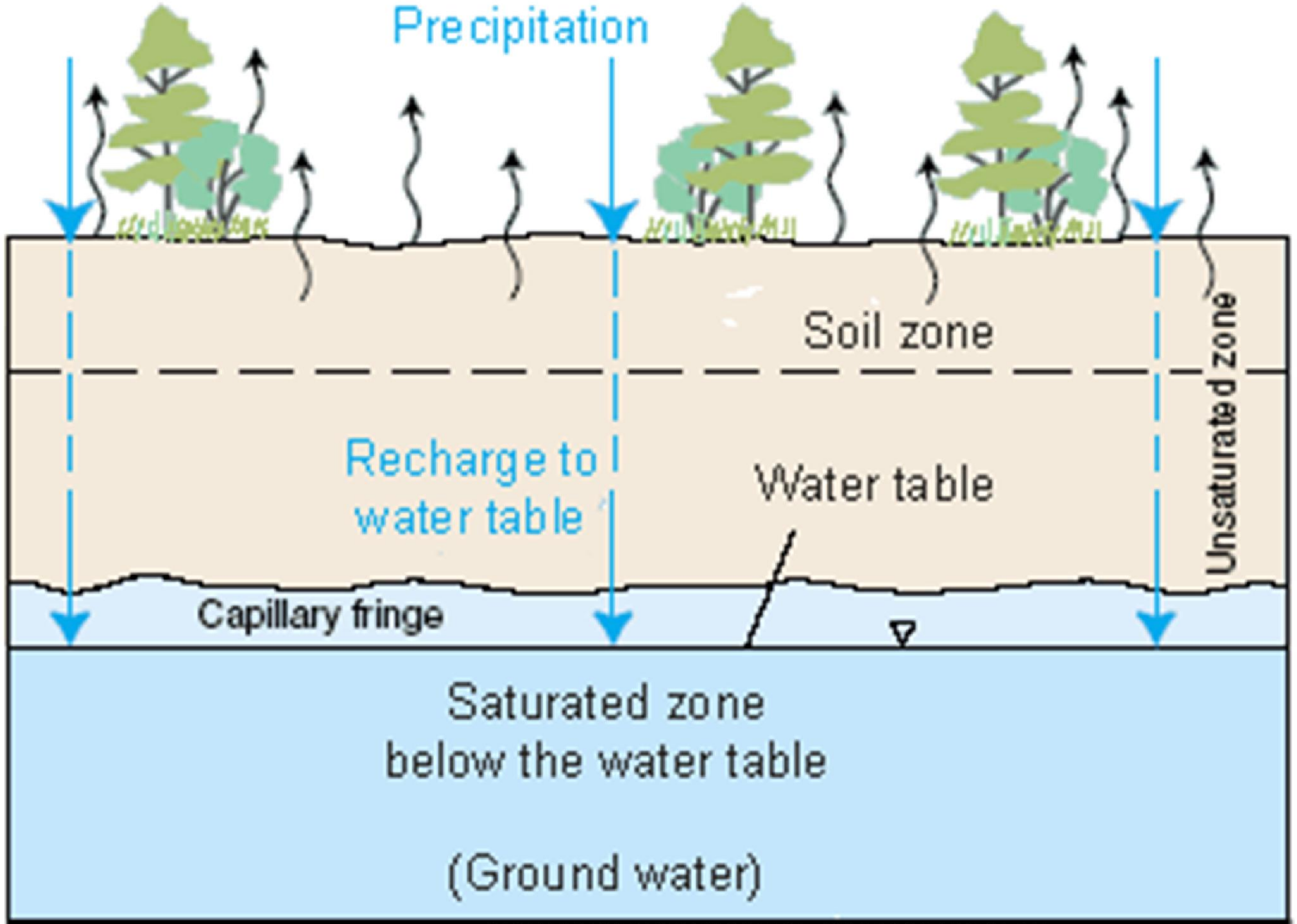
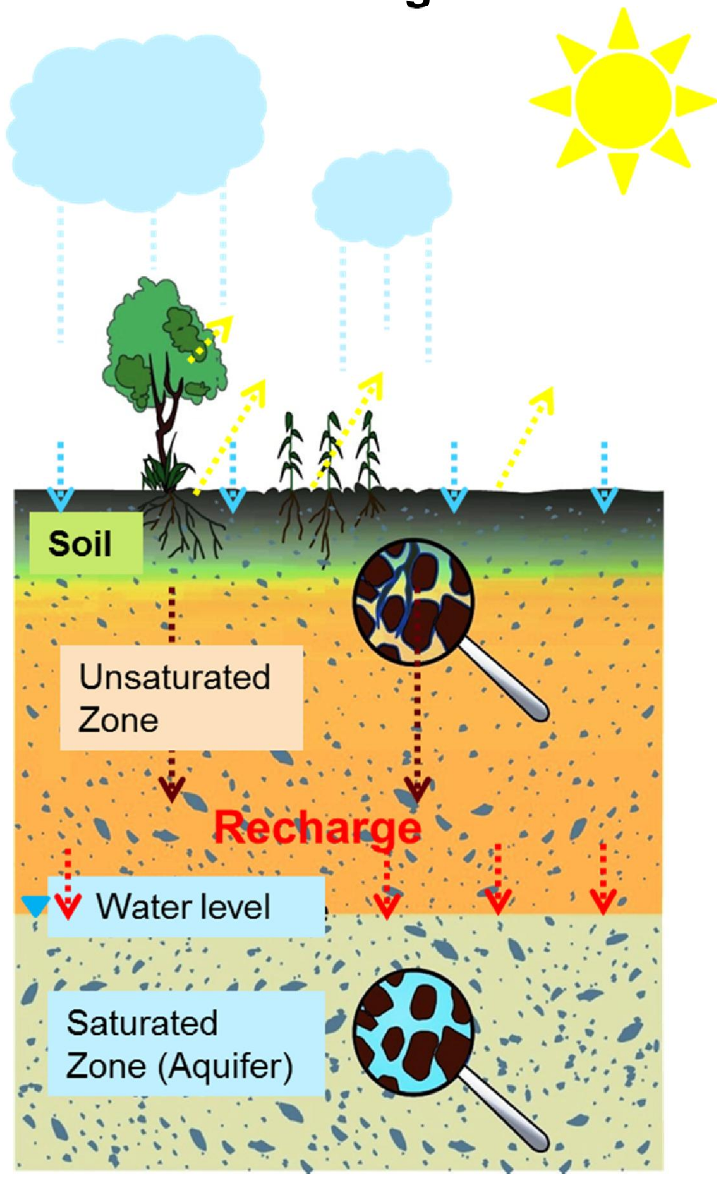
Valu it, q_s includes groundwater recharge



GROUNDWATER RECHARGE

Recharge : water transfer from precipitation to groundwater



☺ Groundwater flow models: **Sophisticated and accurate**

☹ Recharge modeling: **Challenge**

- **Complex hydrological component**

Groundwater recharge depends on:

- Climatic conditions
- Vegetation
- Soil and root zone
- Unsaturated zone

Values can not be directly measured

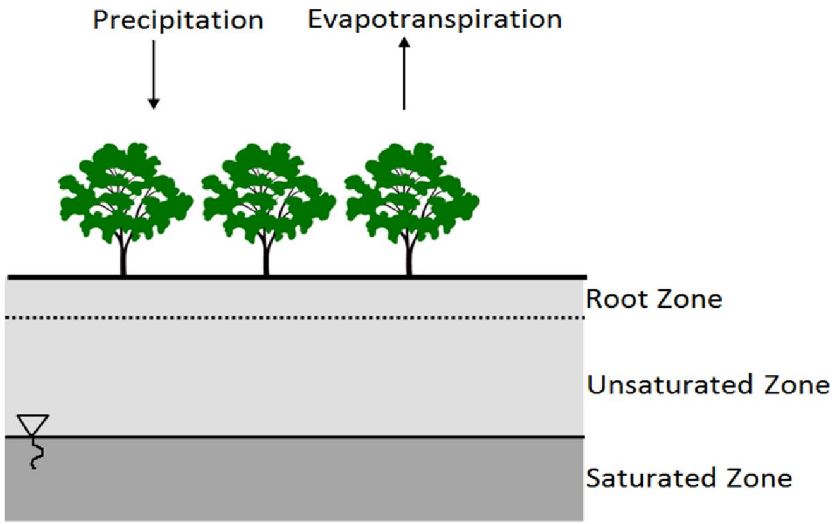
Estimation

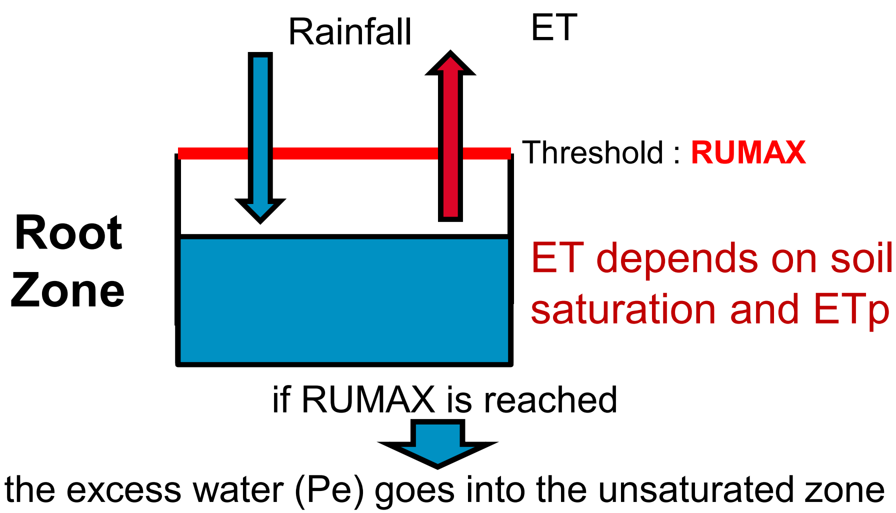
- Direct methods: lysimeters, TDR
- Empirical methods
- Tracers
- **Conceptual model**

Complexities of recharge

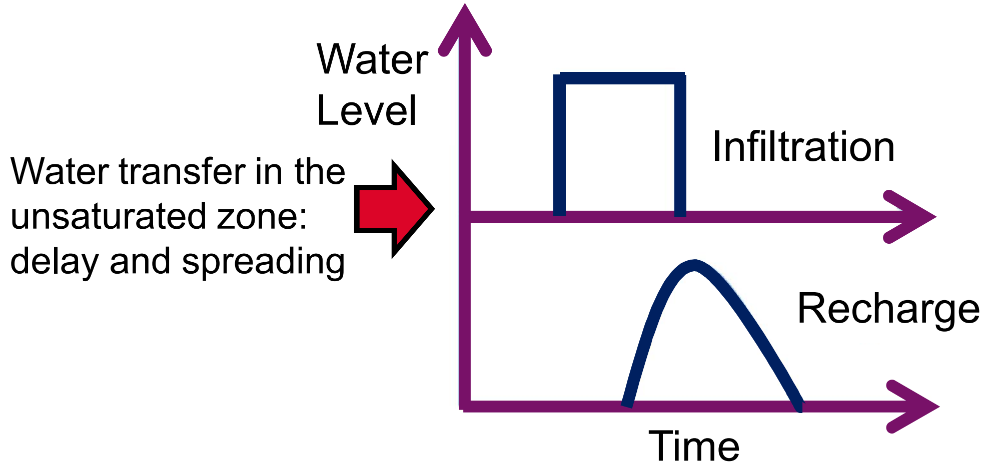
Physical models are difficult to use

CONCEPTUAL MODEL :NASH

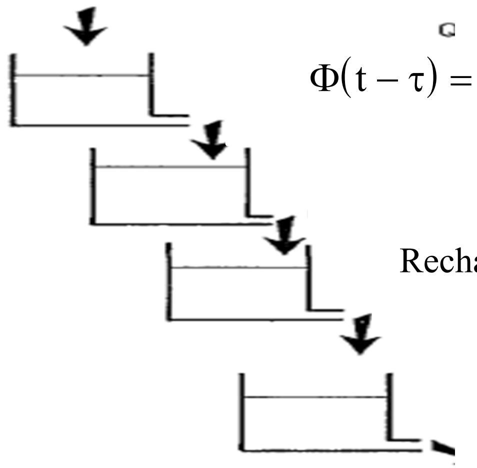




Hydrodynamic in the unsaturated zone



Modeling : propagation of a unit pulse signal



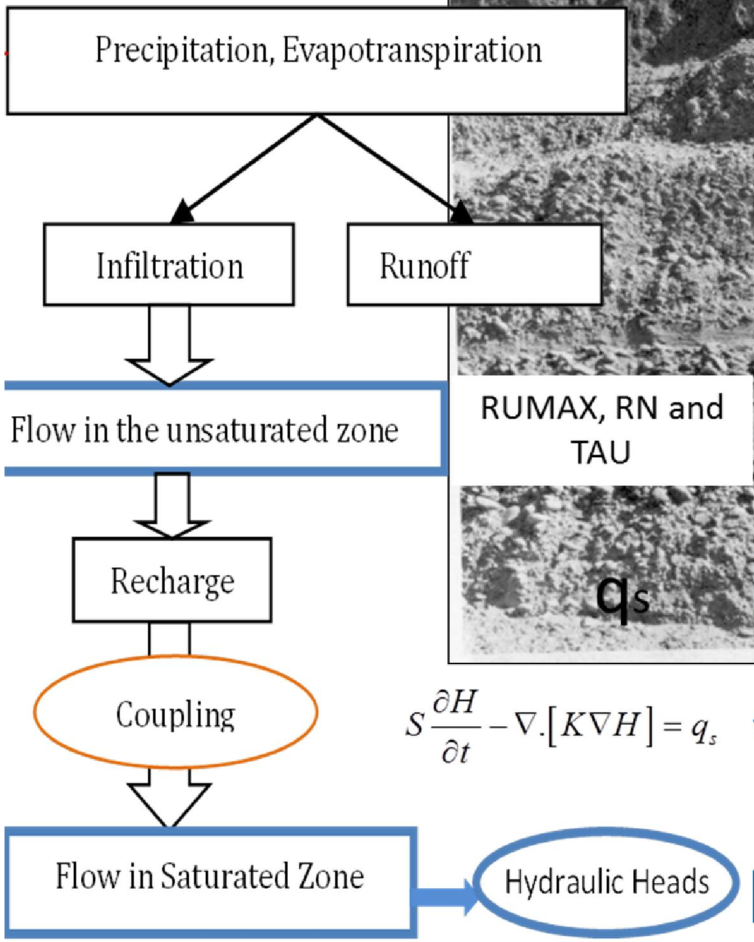
$$\Phi(t-\tau) = \frac{1}{\Gamma(Rn)Tau} e^{-\frac{(t-\tau)}{Tau}} \left(\frac{t-\tau}{Tau}\right)^{(Rn-1)}$$

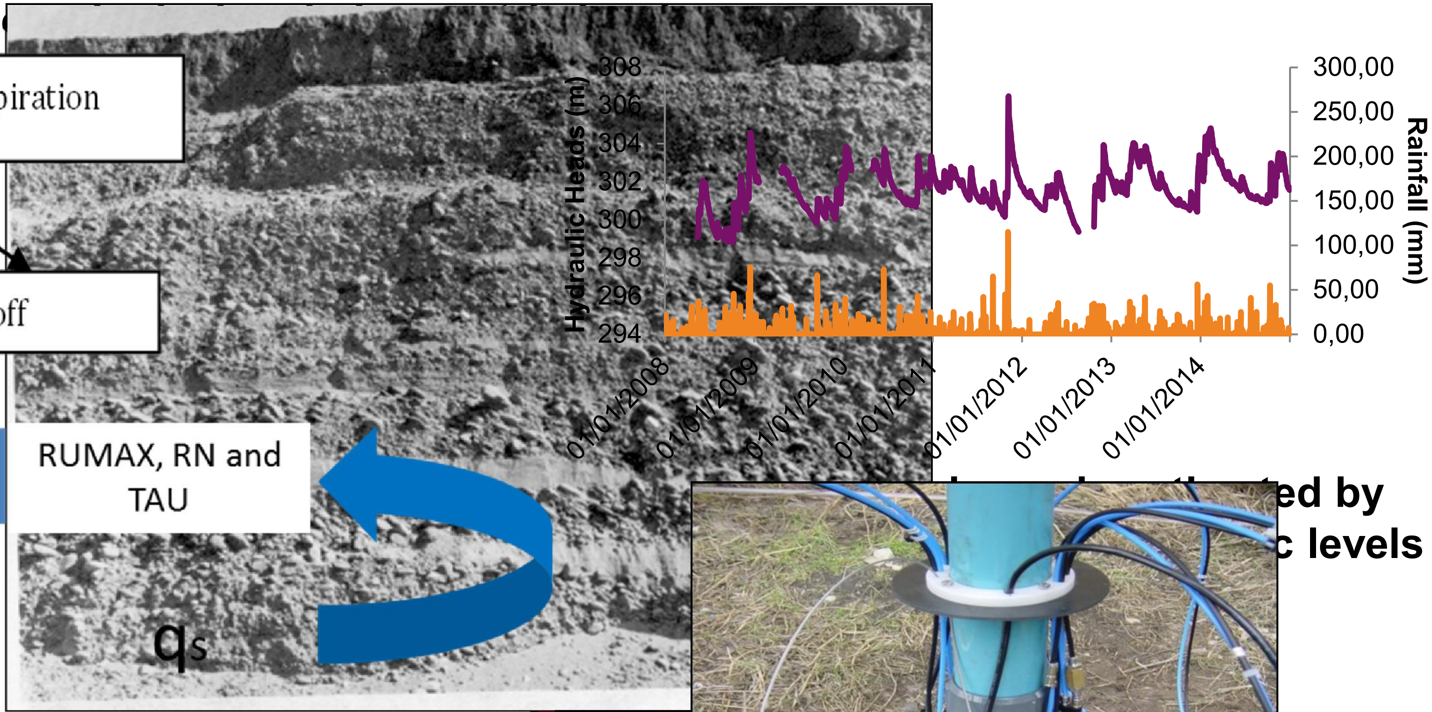
$$\text{Recharge}^{n+1} = \sum_{k=0}^{n} Pe^{k+1} \int_{t_k}^{t_{k+1}} \Phi\left(t^{n+1}-\tau\right) d\tau$$

Nash parameters: **RUMAX, RN, TAU**

PARAMETERS ESTIMATION

- ☹ Model uses constants called parameters
- ☹ **Aquifers are highly heterogeneous** → **Parameters are not known accurately or even unknown** in natural environments
- ☹ Available data: **met**





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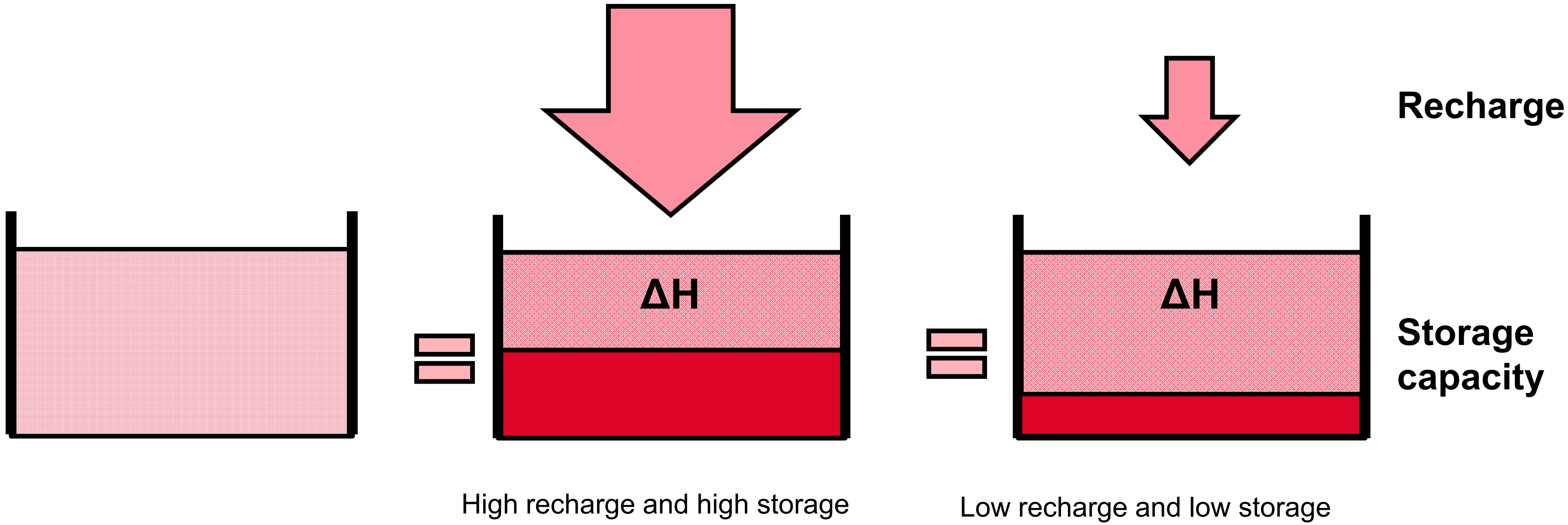
GLOBAL SENSITIVITY ANALYSIS

☹ **Correlation between recharge and storage capacity (S and q_s)**

Recharge and storage capacity lead to the same effect



☺ Calibration is performed over time and space
☺ But… recharge is variable over time while the storage capacity is constant
☺ Aquifer has two states : transient and steady

OB24

Slide 7

OB24 voir si on laisse comme ça le KgradH...?
Olivier BILDSTEIN; 07/09/2016

GLOBAL SENSITIVITY ANALYSIS

Diffusivity equation

$$\mathbf{S}\frac{\partial H}{\partial t} - \nabla.\left[\mathbf{K}\nabla H\right] = q_s\left(\mathbf{RUMAX}, \mathbf{RN}, \mathbf{TAU}\right)$$

- **When recharge is zero (summer)**
  - Steady state

    $$-\nabla.\left[\mathbf{K}\nabla H\right] = 0$$ → Determination of **K**

  - Transient state

    $$\mathbf{S}\frac{\partial H}{\partial t} - \nabla.\left[\mathbf{K}\nabla H\right] = 0$$ → Determination of **S** knowing K

- **During recharge period (winter)**

$$\mathbf{S}\frac{\partial H}{\partial t} - \nabla.\left[\mathbf{K}\nabla H\right] = q_s\left(\mathbf{RUMAX}, \mathbf{RN}, \mathbf{TAU}\right)$$ → Determination of **RUMAX, RN and TAU** knowing K and S

☺ Global sensitivity analysis

Assess the calibration approach and guide the parameter estimation

GLOBAL SENSITIVITY ANALYSIS

Uncertain parameters: variability ranges known ➡ Quantify the effects of parameters uncertainty

Global sensitivity analysis: focuses on the output uncertainty over the entire range of values of the input parameters both single and in combination with one another

S,K,RN,RUMAX and **TAU** are parameters and **H** the state variable

$$\mathbf{S}\frac{\partial H}{\partial t} - \nabla.[\mathbf{K}\nabla H] = q_s(\mathbf{RUMAX}, \mathbf{RN}, \mathbf{TAU})$$

☹ Parameters are unknowns
☺ Variability ranges knowns

n simulations with different values of **parameters**

n values of **H**

Study the effects of variations of **each parameter** on **H**

Variance based approach:
Sobol Indices

Surrogate model: Chaos polynomial expansion

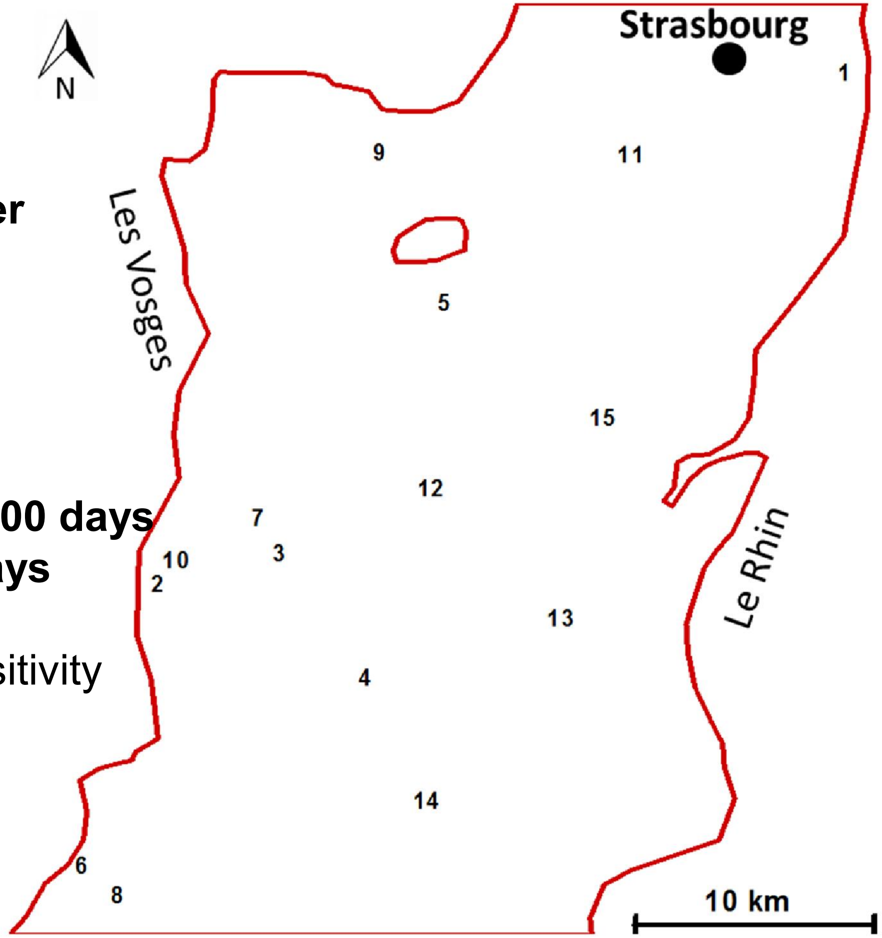
FIELD BASED

- **A subdomain of the Upper Rhine alluvial aquifer** widely studied at Université de Strasbourg

- Average rainfall per year: **1100 mm**
- Average of evapotranspiration per year: **900 mm**

- Simulate variations of piezometric levels during **1500 days**
- Sensitivity analysis performed over the last **450 days**

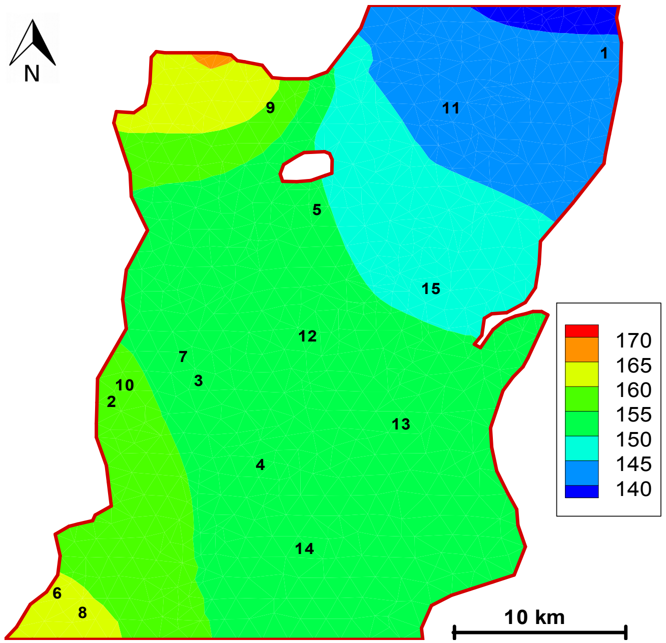
- Investigate spatial and temporal variations of sensitivity indices



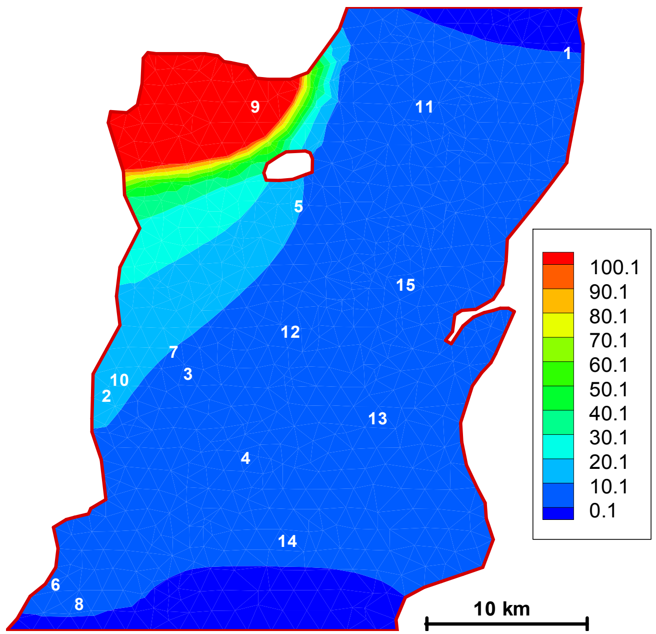
FIELD BASED

- Nash parameters for recharge: **RUMAX, RN, TAU**
- Aquifer parameters: **K and S**
- Parameters defined by zones **(Zonation)** → 20 parameters

Mean and variance of the hydraulic head



Mean

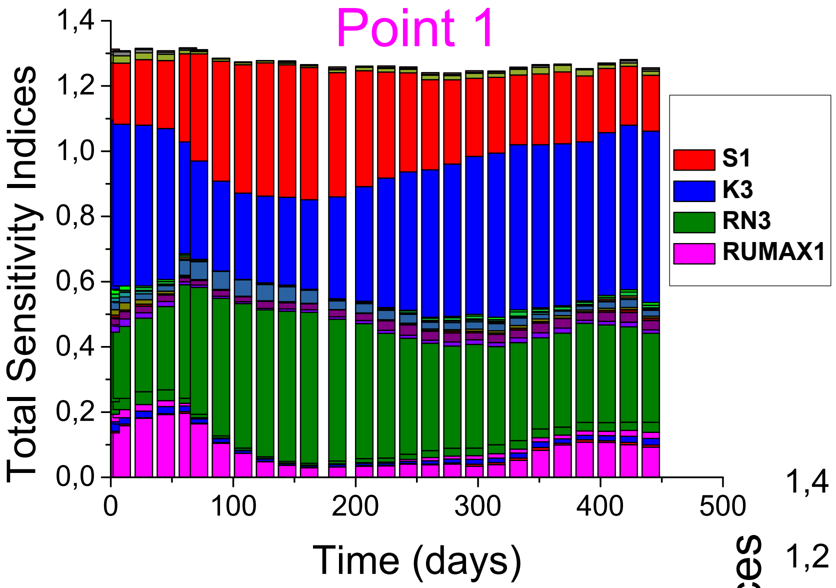


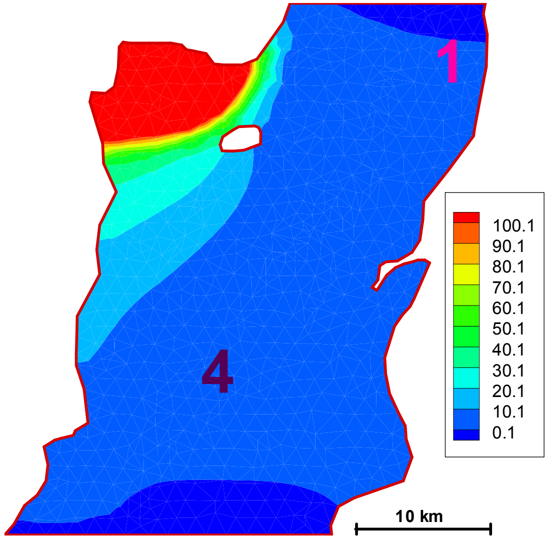
Variance

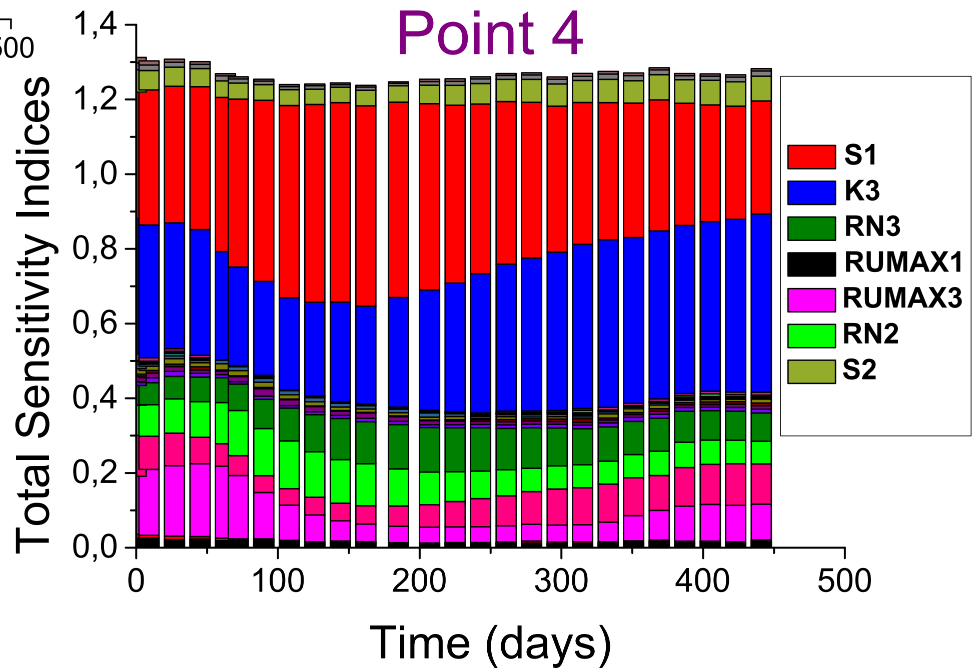
- Hydraulic heads range between 140 and 165 m
- Variance ranges between 0 and 100: the imposed boundaries have the lowest variance

RESULTS

Temporal variation of sensitivity indices



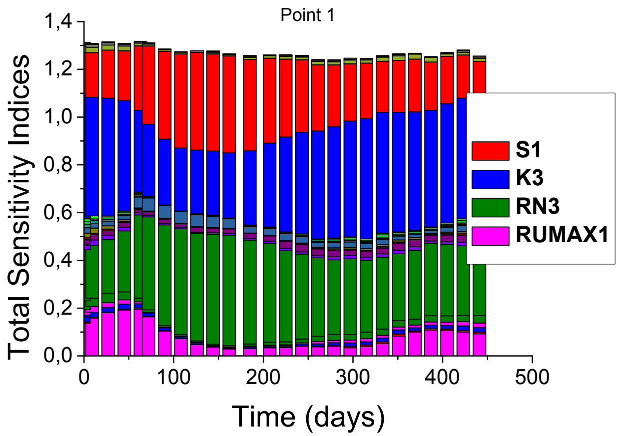


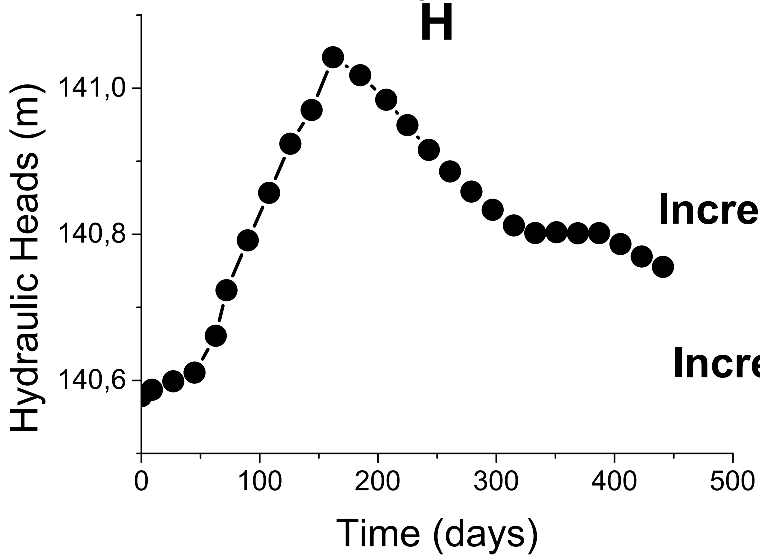


Influential parameters: **S, K, RUMAX and RN**

HYDRODYNAMIC PARAMETERS

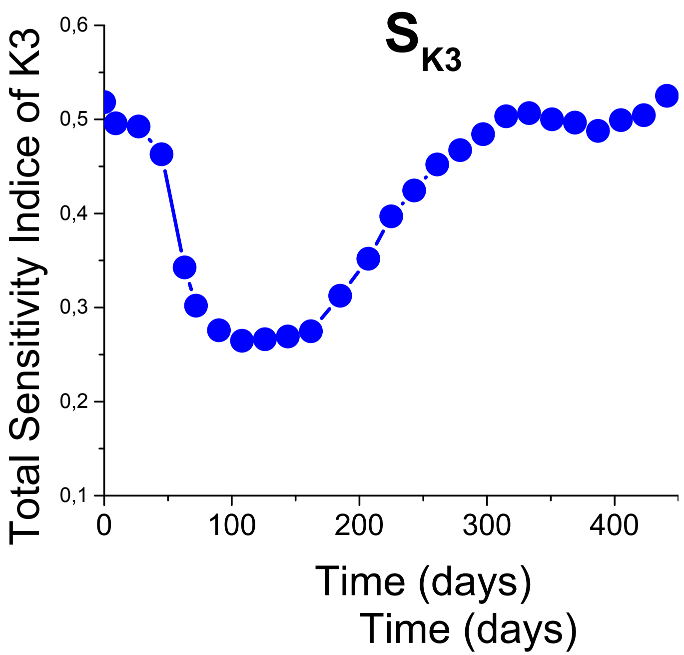
Temporal variation of sensitivity indices at point 1

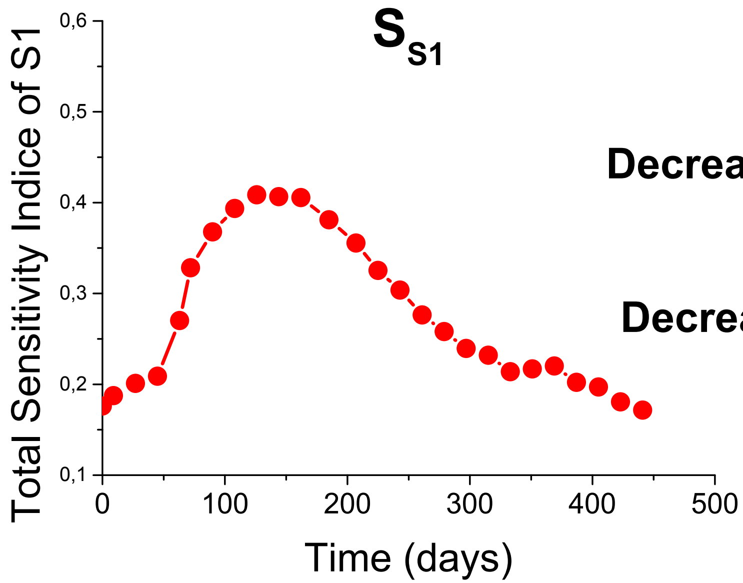




Increase of piezometric level

Increase of the influence of storage capacity



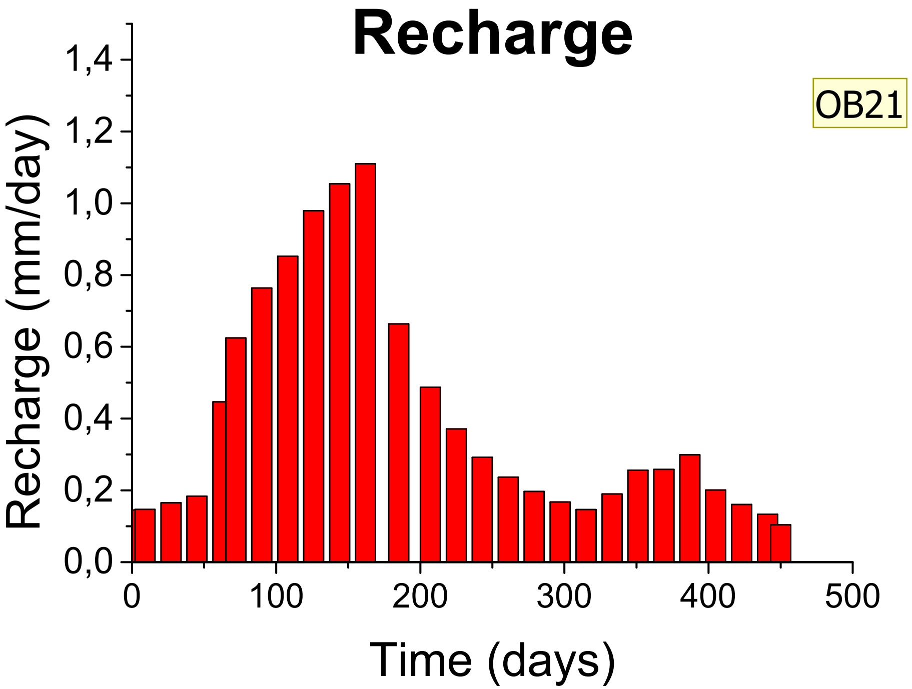


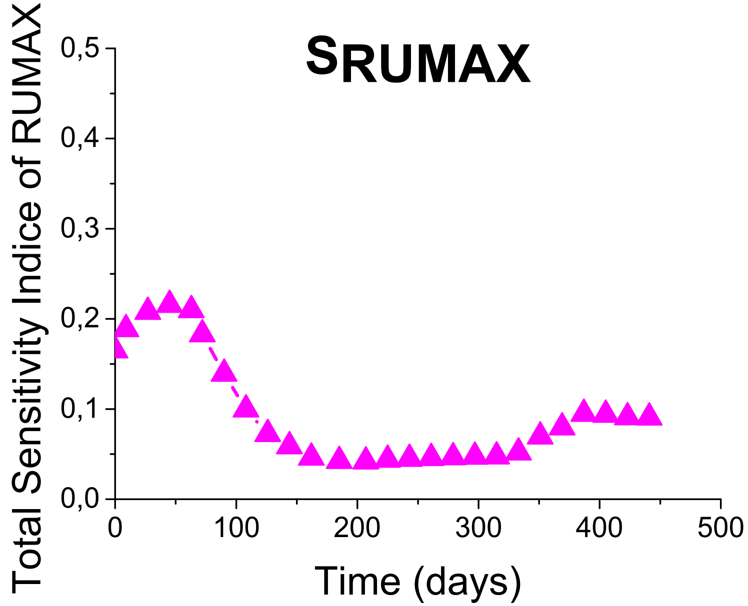
Decrease of piezometric level

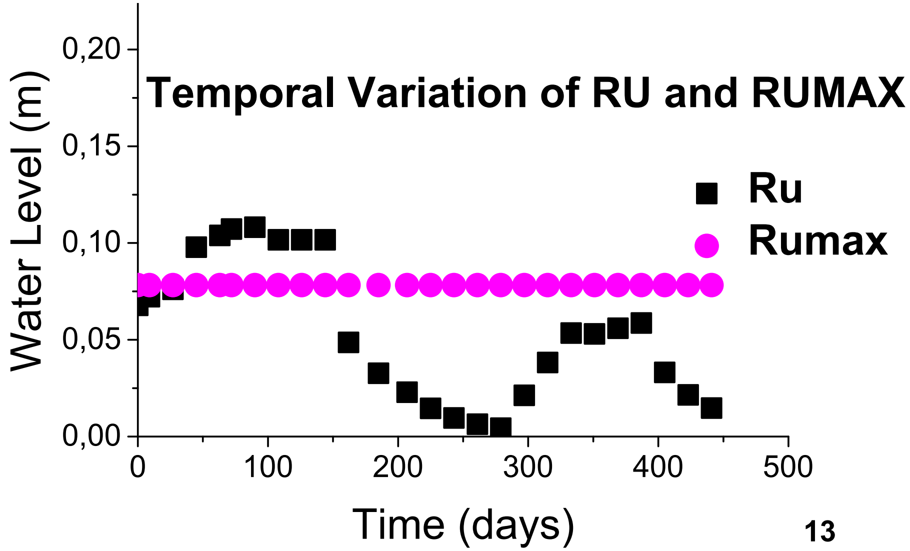
Decrease of the influence of permeability

NASH PARAMETERS

Temporal variation of sensitivity indices at point 1







RN: water transfer in the unsaturated zone (delay and spreading)
RUMAX: threshold parameter

Slide 14

OB21 attention: enlever les barres d'erreur
Olivier BILDSTEIN; 07/09/2016

CONCLUSION

- Determination of influential parameters

  Nash: RUMAX and RN
  Groundwater flow: K and S

- Interactions between the parameters are not really significant compared to the parameters' main effects

- Temporal variation of parameter sensitivity

  Nash: saturation of the 1st reservoir (RUMAX) and recharge (RN)
  Permeability: decrease of the hydraulic heads
  Storage capacity: increase of the hydraulic heads

- Weak interactions between aquifer and recharge parameters

Confirmation of the feasibility of simultaneous estimation of recharge and groundwater flow parameters

Thank you for your attention

SOBOL INDICES : CHAOS POLYNOMIAL EXPANSION

Let us consider a model with y as output and n input parameters, X the parameters vector

- **ANOVA decomposition** : $y = f_0 + \sum_{i=1}^{n} f_i(x_i) + \sum_{j>1}^{n} f_{ij}(x_i, x_j) + ... + f_{1,2,...,n}(x_1, x_2, ..., x_n)$

f_i : contribution of single parameter i to the output
f_{ij} : contribution of the combined effect of parameters i and j to the output

$$H = H_0 + f_s(S) + f_K(K) + f_{RN}(RN) + f_{RN,K}(RN, K) + f_{S,K}(S, K) + ...$$

Orthogonality of f ➡ $V = \sum_{i=1}^{n} V_i + \sum_{j>1}^{n} V_{ij} + ... + V_{1,....,n}$

- **Sensitivity (Sobol) Indices :** $S_i = \frac{V_i}{V} ; S_{ij} = \frac{V_{ij}}{V}$

Computation of f ➡ **Polynomial expansion**

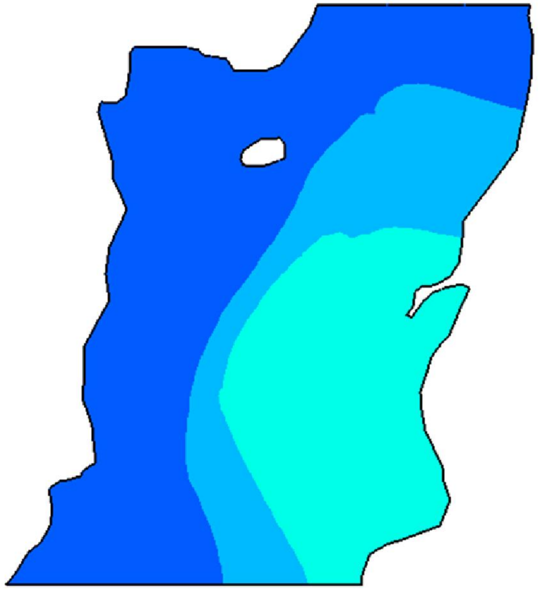
- **Chaos polynomial expansion**

$$y = \sum_{j=0}^{+\infty} a_j \psi_j(x_1, ..., x_n)$$

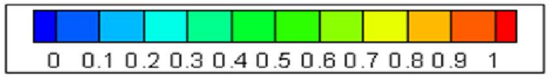
x : variable
Ψ : orthogonal polynomial (Legendre, Hermite)
a : coefficients determined by least squares regression

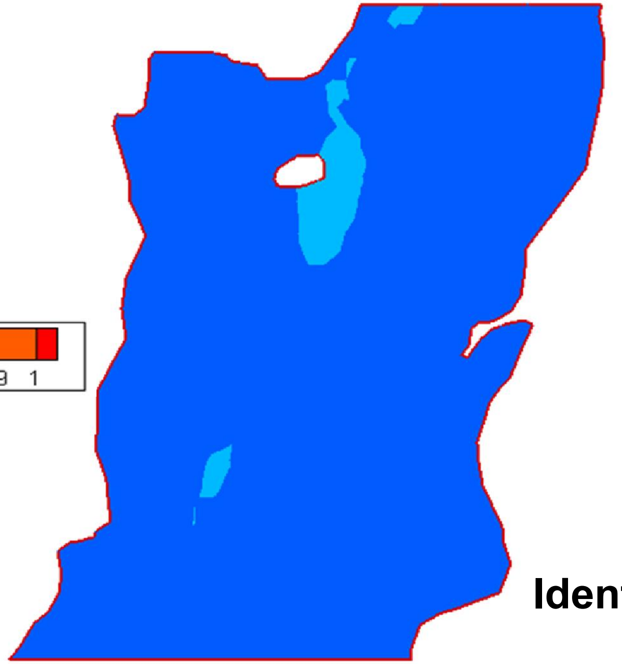
GLOBAL SENSITIVITY ANALYSIS: NASH MODEL

Sensitivity maps over time



S1





RUMAX3

RUMAX3: sensitive from the **1st** to **185th** day

S1: influential between the **185th** and the **346th** day

Weak or even negligible correlations between the 185th and the 346th day

Identification of S

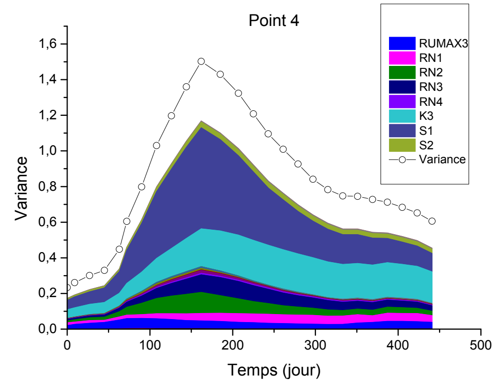
During the first days

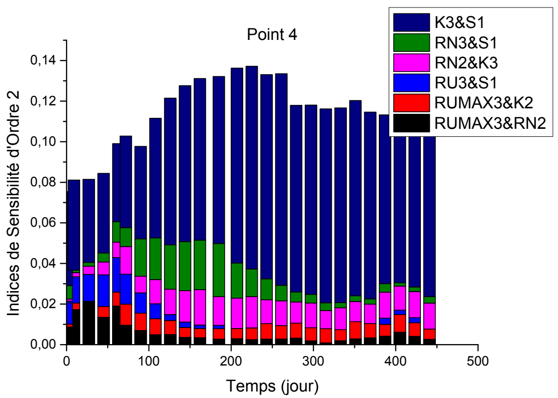
Identification of RUMAX and RN knowing S

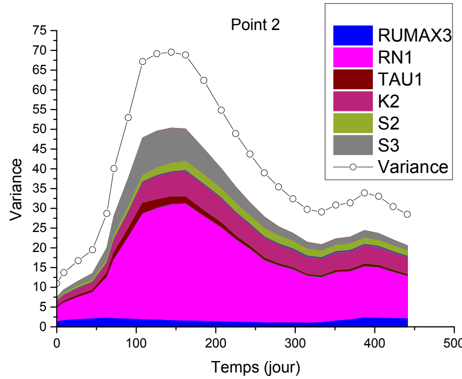
GLOBAL SENSITIVITY ANALYSIS

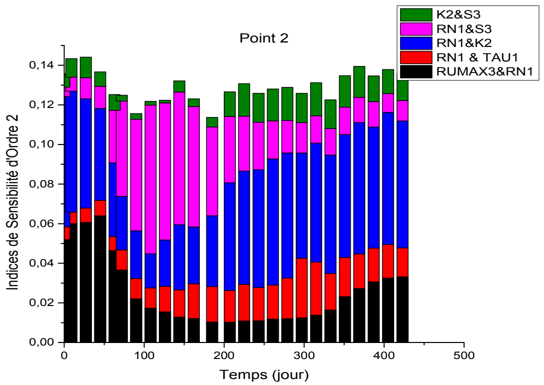
Parameters Interactions

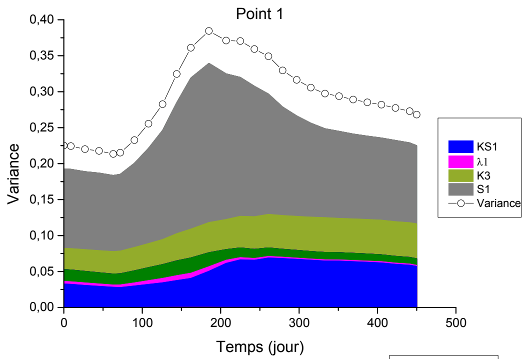
Nash model | **Richards model**

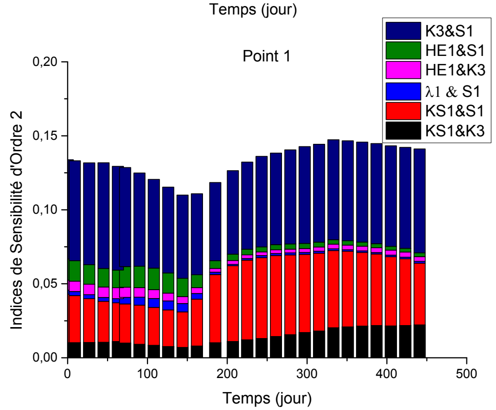






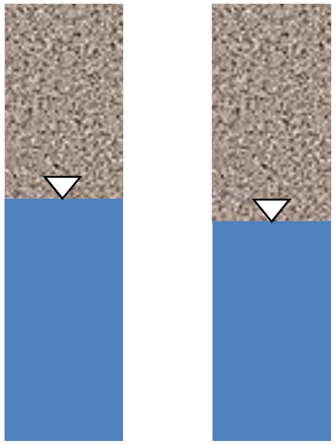






OVERESTIMATION OF RECHARGE

Assumption of constant hydraulic head over decade



$$q_i^n = -K\frac{\partial}{\partial z}(h-z) = K\left(h_{i+\frac{1}{2}}\right)\left(\frac{h_i^n - h_{i+1}^n}{\Delta z_i} + 1\right)$$

If the hydraulic heads decreases, the imposed pressure decreases, and the flux calculated is positive and strong

If the hydraulic heads increases, the imposed pressure increases, and the flux calculated is negative

RESOLUTION OF RICHARDS EQUATION