A hillslope-based aquifer model of free-surface flows in crystalline regions

Example of Brittany (France)

Quentin Courtois[1], Jean-Raynald de Dreuzy[1], Laurent Longuevergne[1], Jean Marçais[1], Charlotte Le Traon[1], Florence Habets[2]

[1]*Géosciences Rennes, UMR 6118, Université de Rennes 1, France*
[2]*Metis, UMR 7619, Université Pierre et Marie Curie, Paris, France*

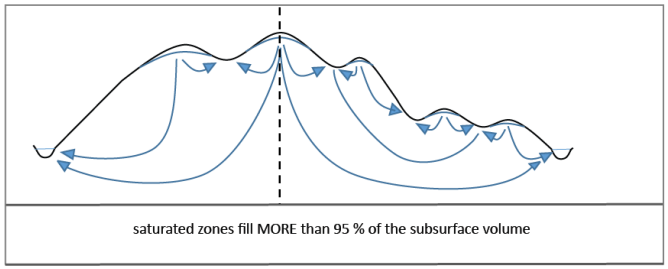
Context

- How does **groundwater** contribute to **water cycle** in **heterogeneous crystalline** context ?

=> Main **aquifers** are **shallow** and with **low lateral extension**

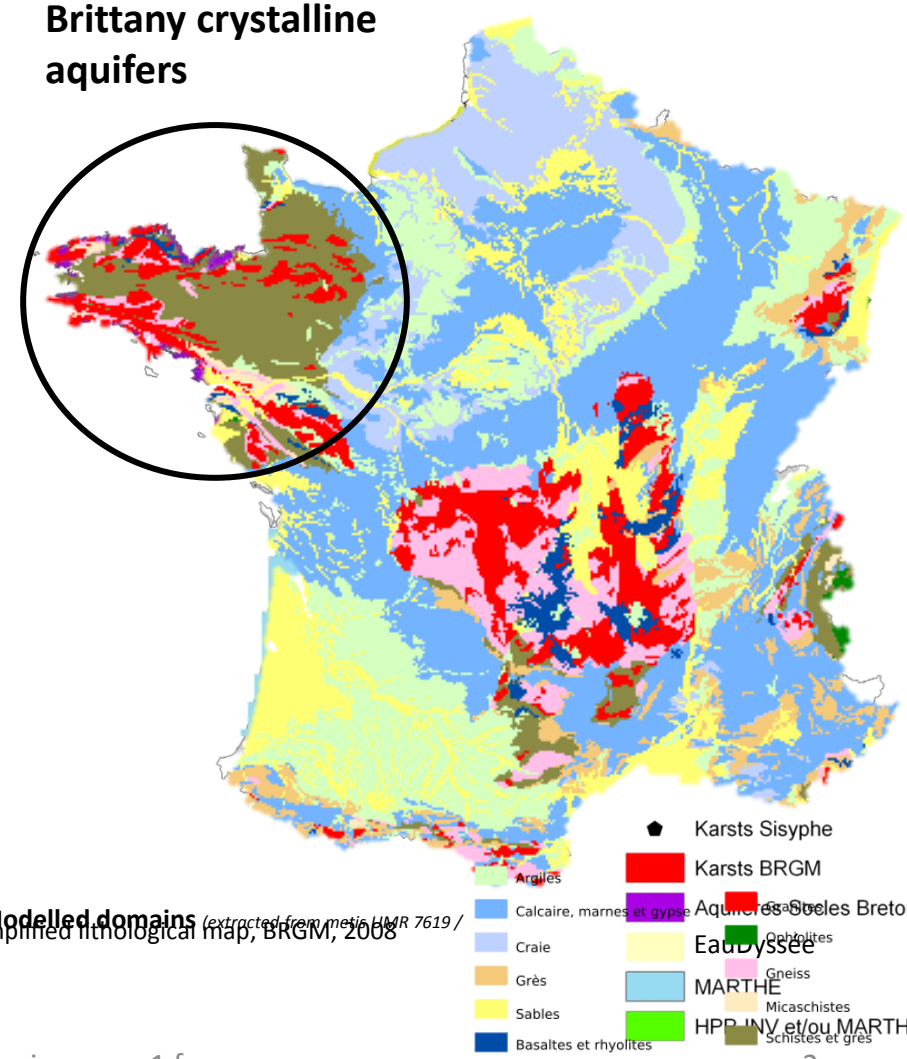
Flow mainly **controlled** by **topography**

(Kolbe et al 2016)



Haitjema, H. M., and S. Mitchell-Bruker (2005), Are water tables a subdued replica of the topography?, *Ground Water*, *43*(6), 781-786,

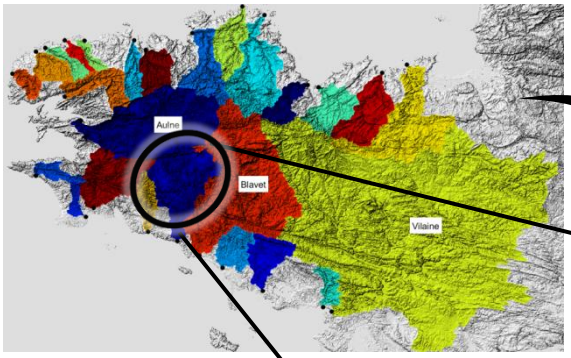
Brittany crystalline aquifers



AquiFr Modelled domains *(extracted from metis UMR 7619 / AquiFR)*

Simplified lithological map, BRGM, 2008

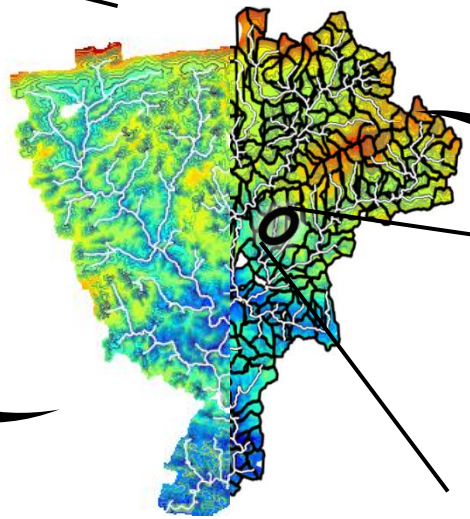
How to predict Brittany aquifers behaviour ?

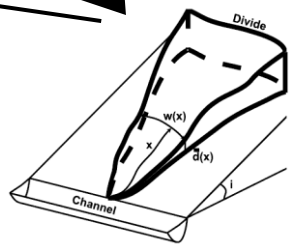


Brittany main watersheds

1. Watershed segmentation

2. Watershed Disaggregating





Troch, P. A., et al. (2003).

3. Hillslope Simulation

4. Flow Aggregating

$$Q_{river} = \sum_{hillslopes} Q_{hillslope}$$

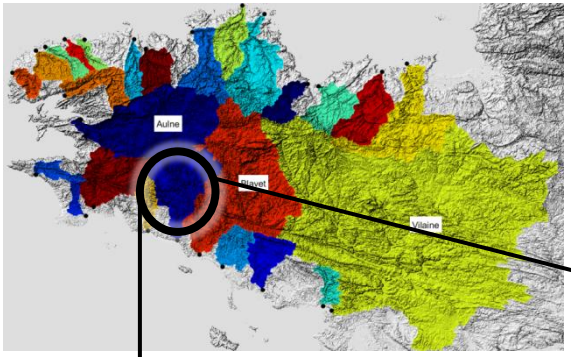
5. Spatialisation / Location

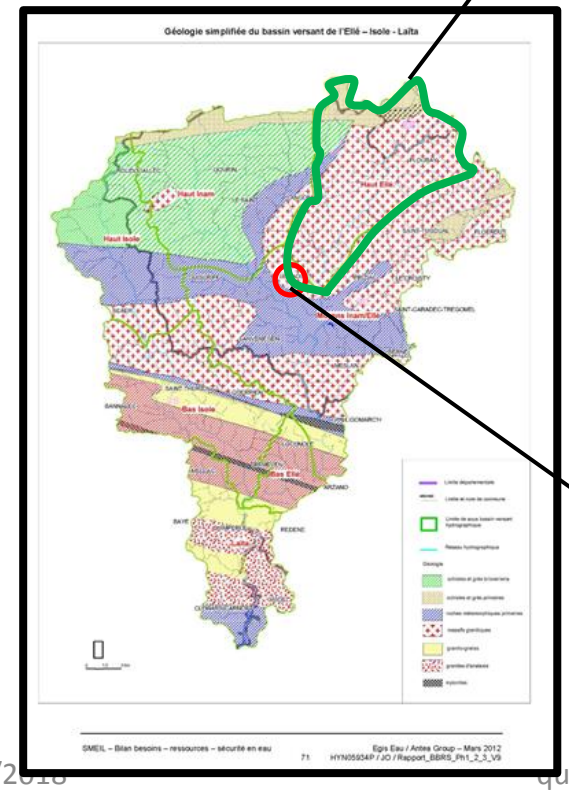
$$\begin{cases} \dfrac{\partial S}{\partial t}(x,t) = -\dfrac{\partial Q}{\partial x}(x,t) + \boldsymbol{N}(t)\boldsymbol{w}(x) \\ Q(x,t) = -\dfrac{\boldsymbol{k}S(x,t)}{\boldsymbol{f}}\left(\cos\theta\,\dfrac{\partial}{\partial x}\left(\dfrac{S}{\boldsymbol{f}\boldsymbol{w}}\right)(x,t) + \sin\boldsymbol{\theta}\right) \\ 0 \le S(x,t) \le S_c(x) \\ S(x,t) < S_c(x) \ \textbf{or} \ -\dfrac{\partial Q}{\partial x}(x,t) + \boldsymbol{N}(t)\boldsymbol{w}(x) < 0 \end{cases}$$

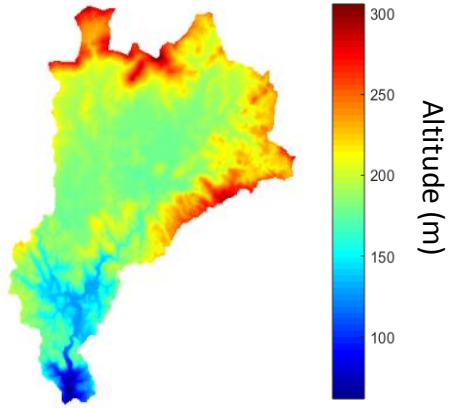
Geomorphology, Hydrodynamics, Meteorology

quentin.courtois@univ-rennes1.fr

Case Study – Ellé au Faouët : Watershed

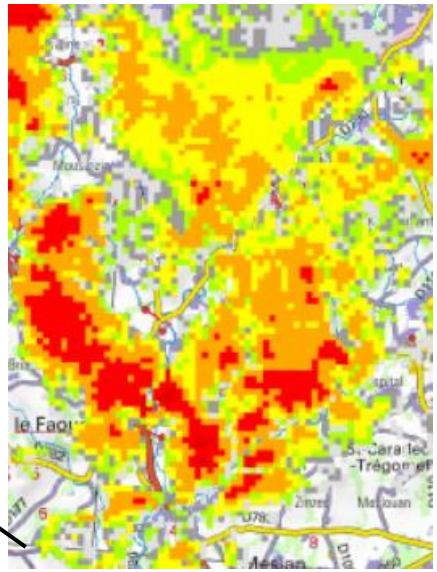






Watershed topograpy

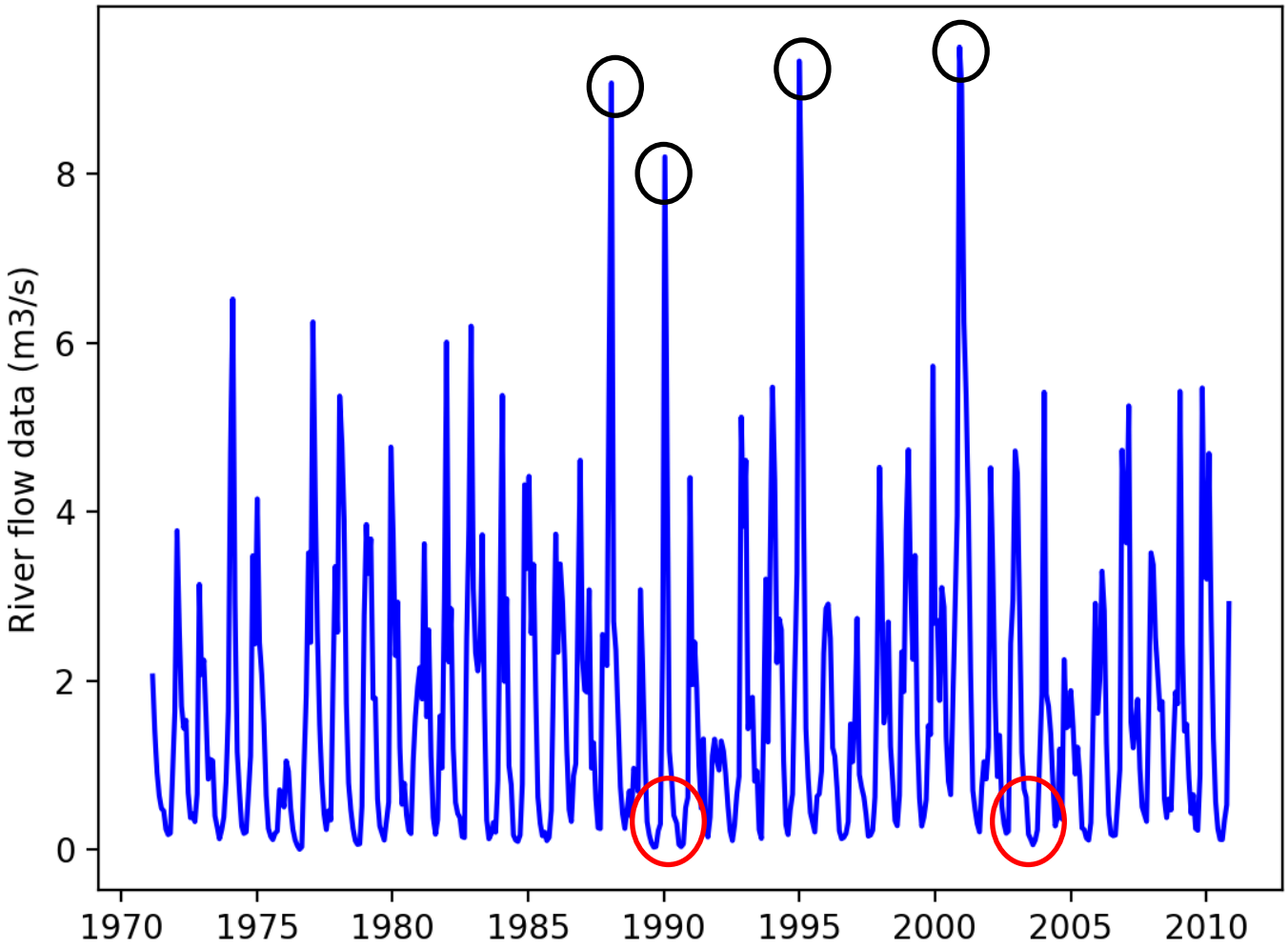
- Outlet : Faouet
- Area : ~138 km²
- Number of hillslopes : 138
- Mean hillslope area : 1 km²
- Mean slope : ~1.7%



Regolith thickness model, BRGM, 2017

- Mainly **granite with thick regolith layer**.
- A **relatively thick aquifer** is supposed to exist in **regolith**
- A relatively low permeability is expected but a **high porosity**
- **Negligible deep flow**

Case Study – Ellé au Faouët : Available data

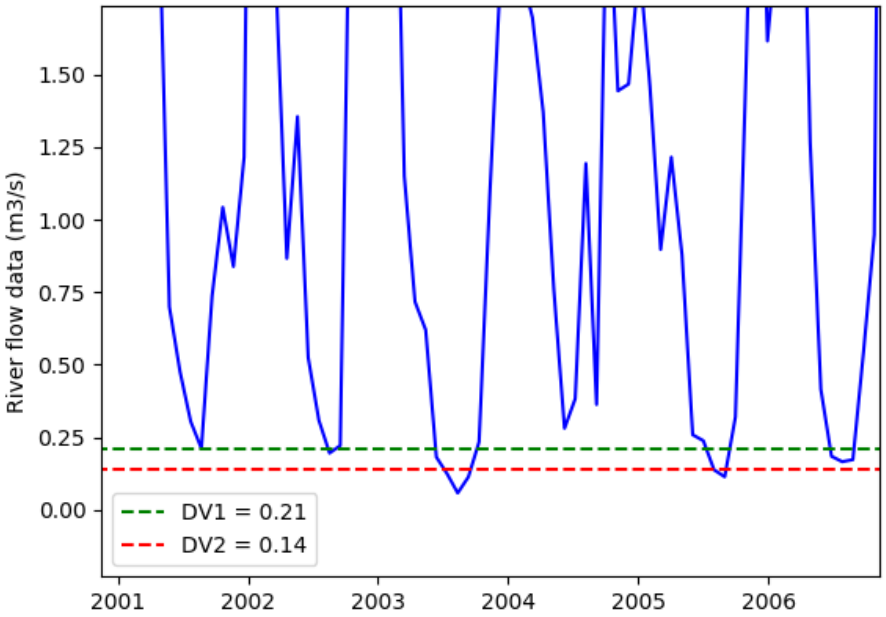


High peak flow

Low drought flow

Case Study – Ellé au Faouët : Available data

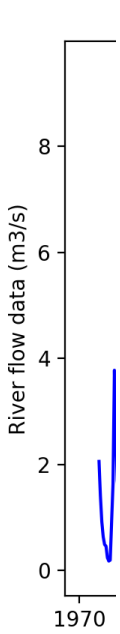
Drought

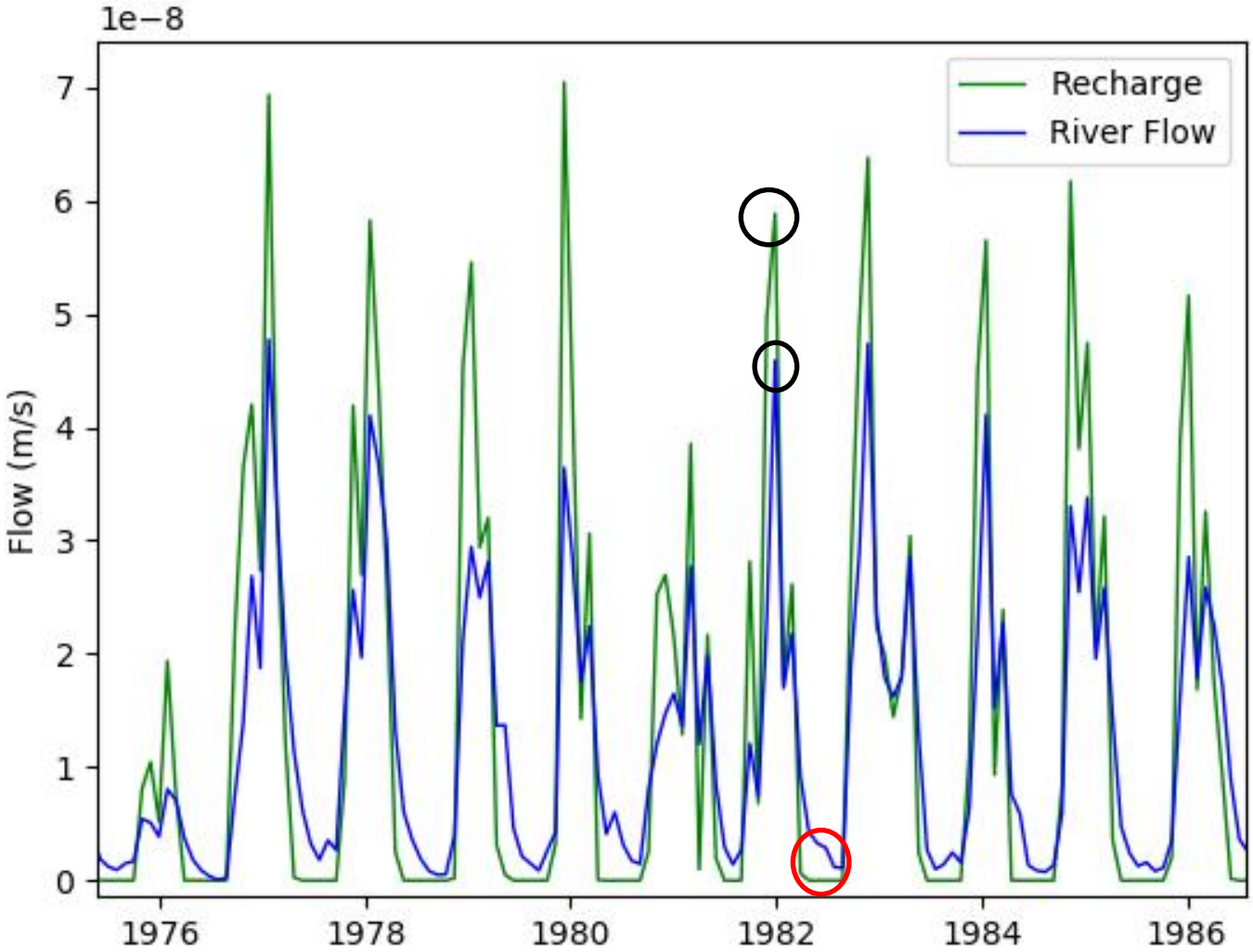


Drought Flow limit exceeding (2003, 2005, 2006)
(DV1 & DV2 : alert flow during drought)

Flooding

Quimperlé city-center flooded (03-Jan-2014) at the junction point between Isole and Elle (+ 4,71m)





Peak flow

Recession

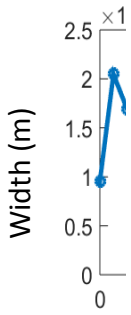
Case Study – Ellé au Faouët : Modelling

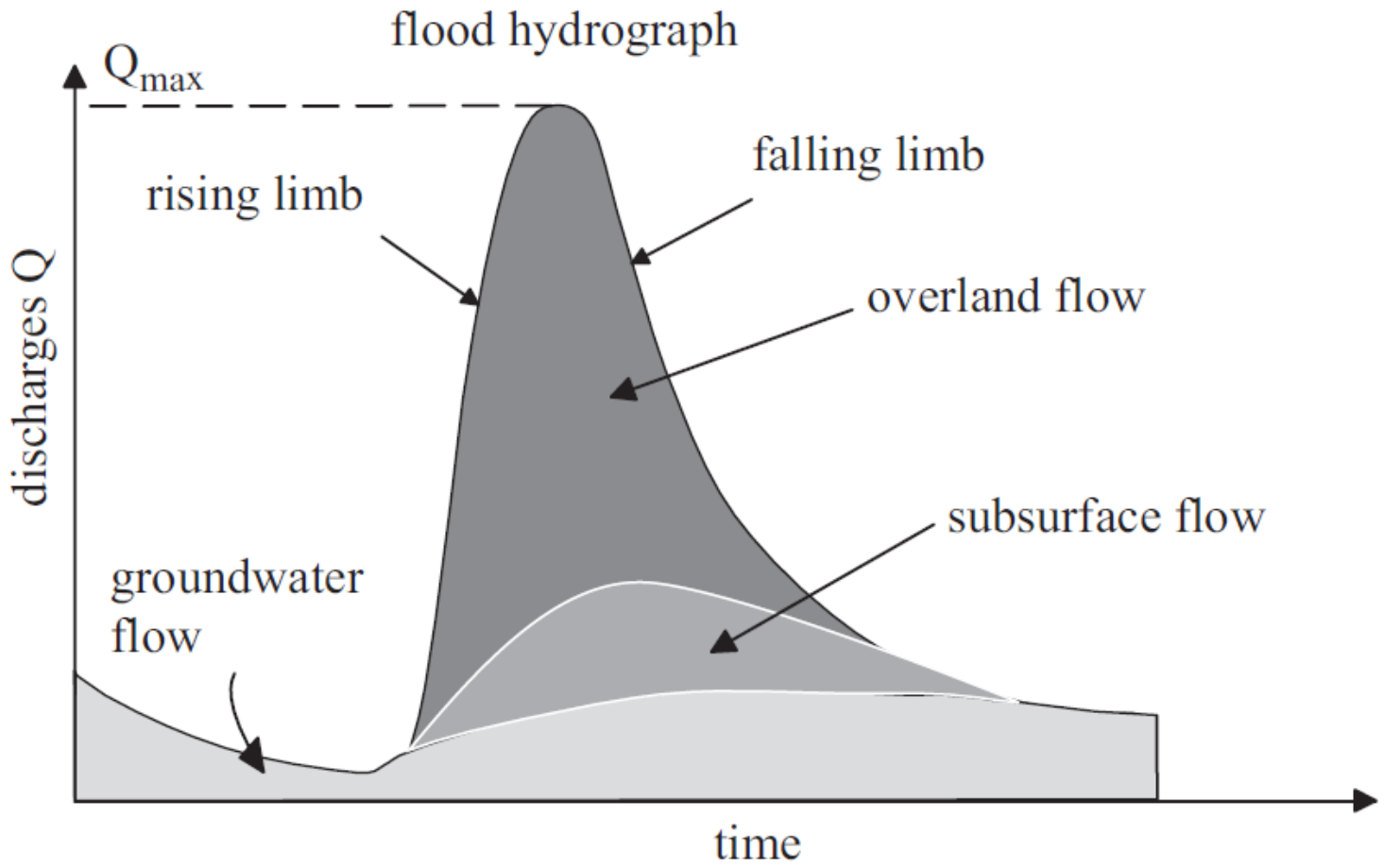
(1

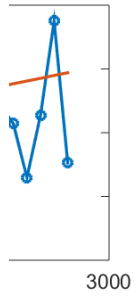
S =

(2

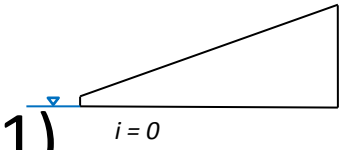
S = *S*



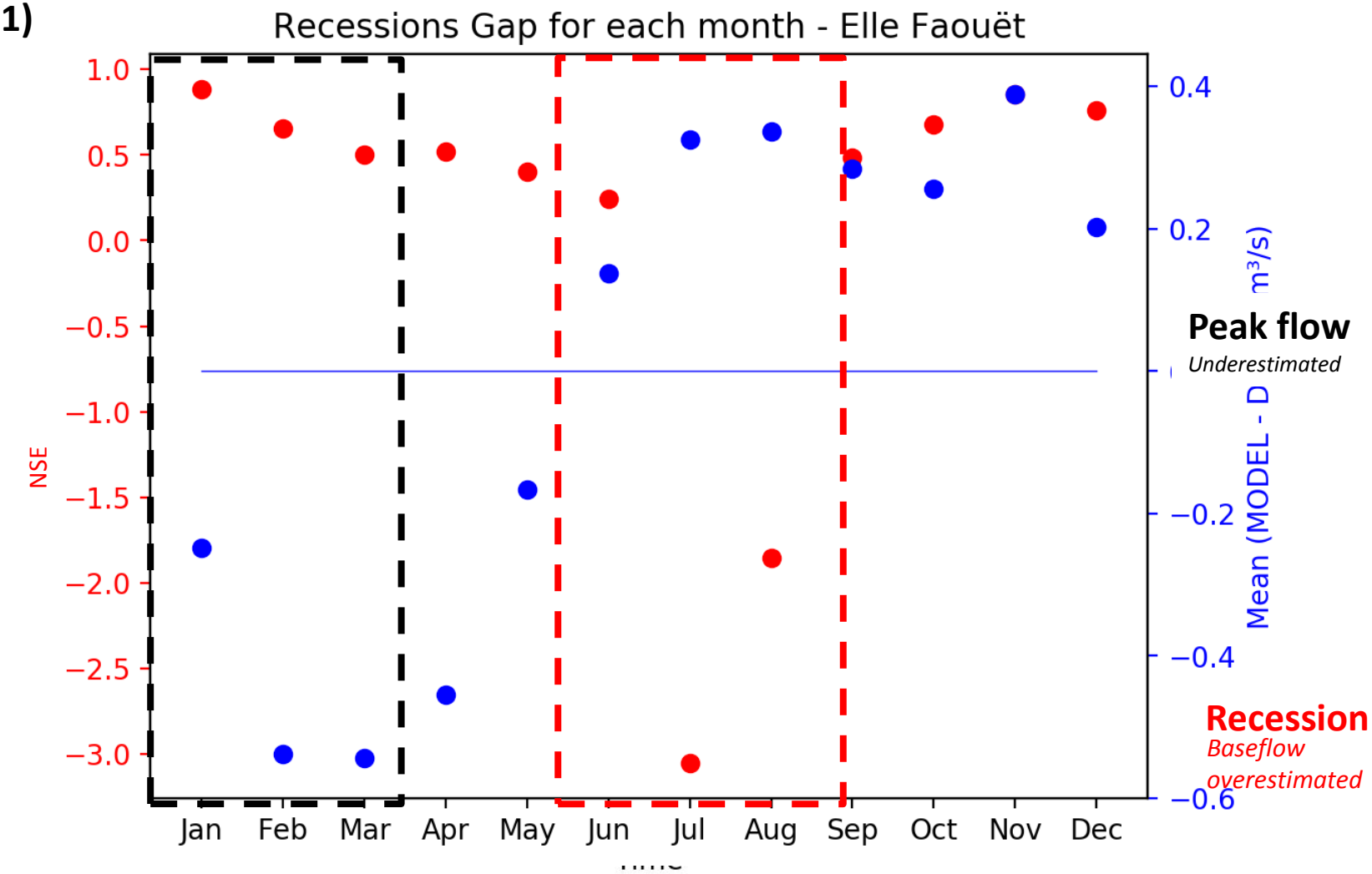




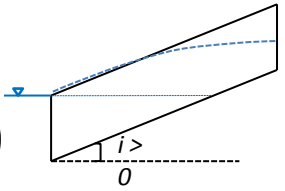
Case Study – Ellé au Faouët : Modelling (1)



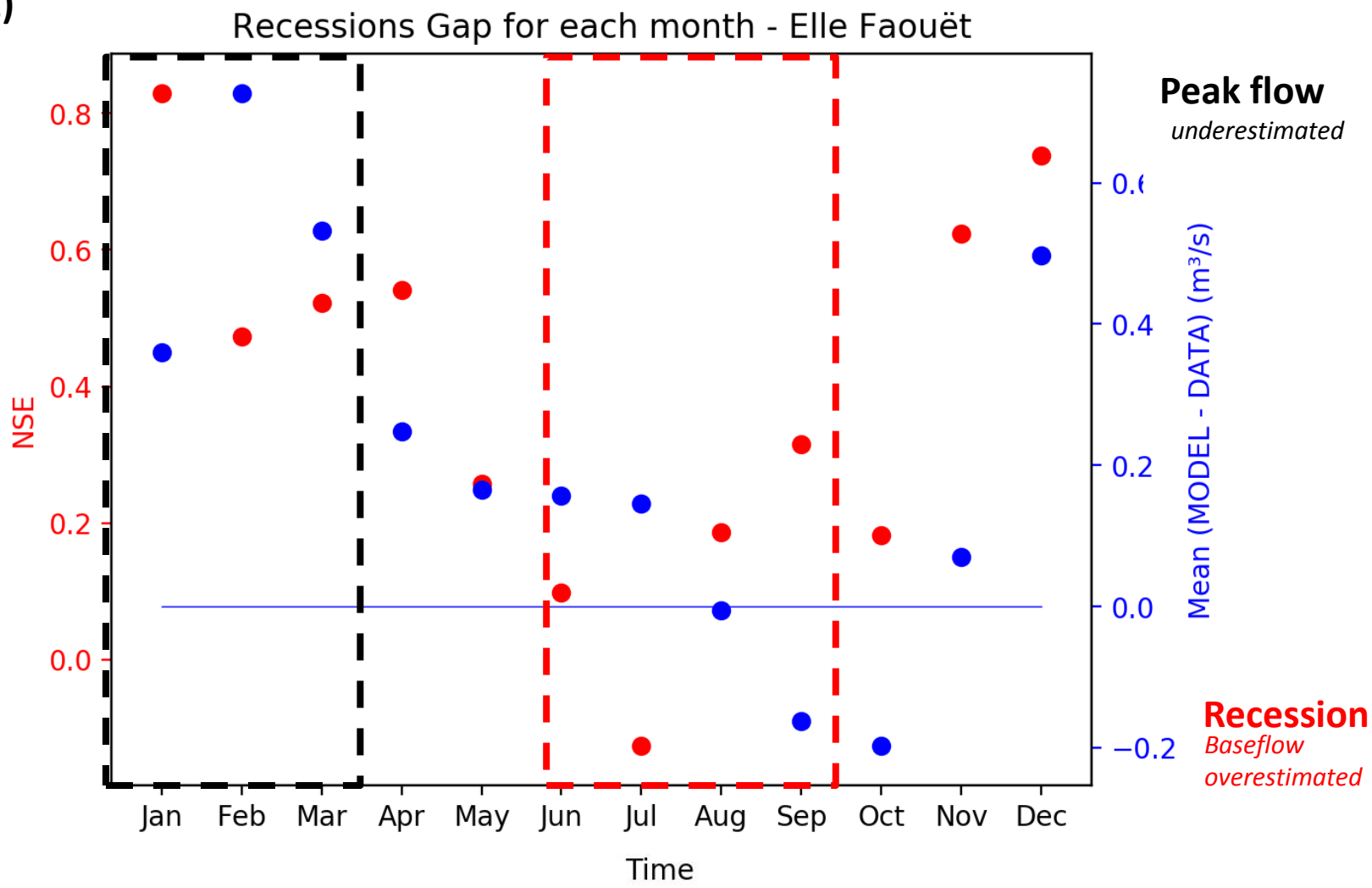
(1)



Case Study – Ellé au Faouët : Modelling (2)



(2)



Conclusions

- Brittany **crystalline aquifers** are **shallow**. **Flow** is mainly controlled by **topography**.

- Data show that an **underground compartiment** is needed to link meteorogical data to river flow.

- So they can be modelled as simple **1D hillslopes** directly **connected to the river.**

- Hillslope, and so **regolith structure** controls the ability of the model to describe **recessions dynamic**.

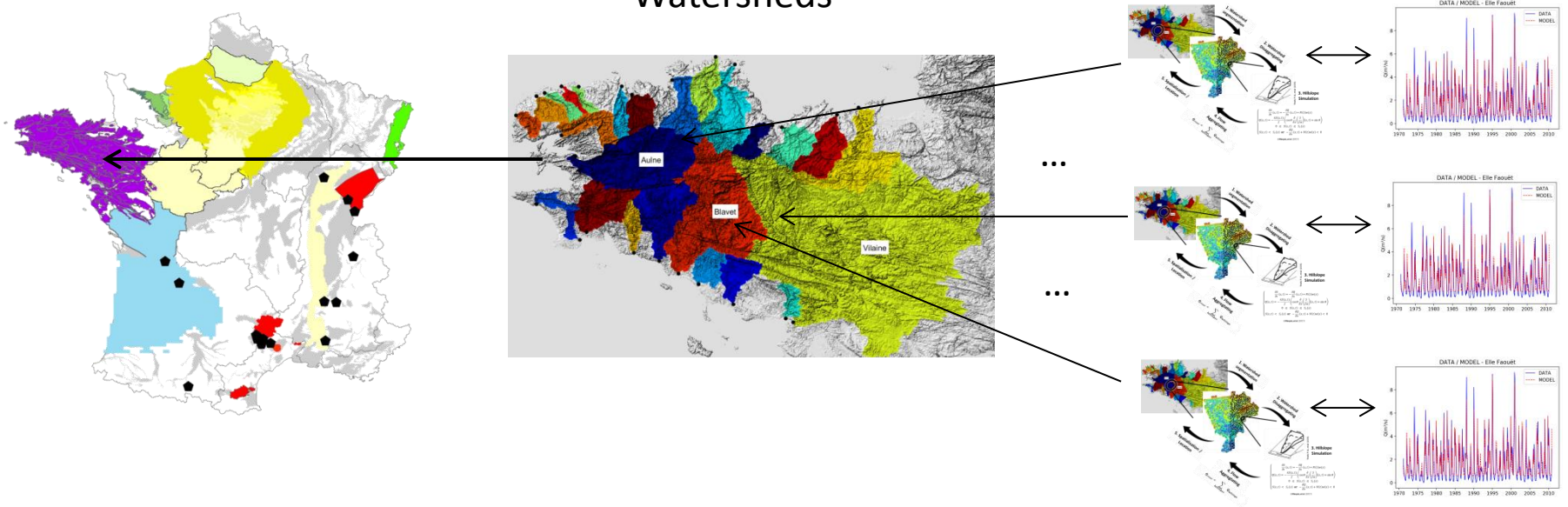
Perspectives

AquiFR

Brittany Watersheds

Model

Fit



Kolbe, T., et al.(2016). "Coupling 3D groundwater modeling with CFC-based age dating to classify local groundwater circulation in an unconfined crystalline aquifer." Journal of Hydrology **543**(Part A): 31-46.

Troch, P. A., C. Paniconi and E. E. van Loon (2003). "Hillslope-storage Boussinesq model for subsurface flow and variable source areas along complex hillslopes: 1. Formulation and characteristic response." Water Resources Research **39**(11).

Marçais, et al.(2017). "Dynamic coupling of subsurface and seepage flows solved within a regularized partition formulation." ADWR.

More on this work

« **A hillslope-based aquifer model of free-surface flows in crystalline region**s », Q. Courtois. 05/06, 10h15, Grand Large (Posters : n°2)

More on AquiFr project

https://www.metis.upmc.fr/~aqui-fr/

« **The AquiFR hydrogeological modeling platform: evaluation of the 1958-2017 reanalysis for the main regional multilayer aquifers in France**. », J-P. Vergnes 07/06, 10h15, Lammenais 4&5 (S03-2)

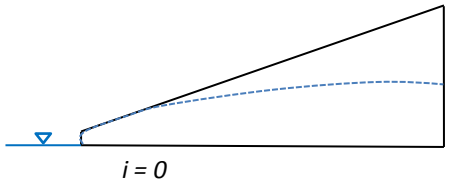
« **The AquiFr project : the future operational modeling platform for the main multilayers aquifers in France** », N. Roux. 07/06, 10h15, Lammenais 4&5 (S03-2)

Thank You !

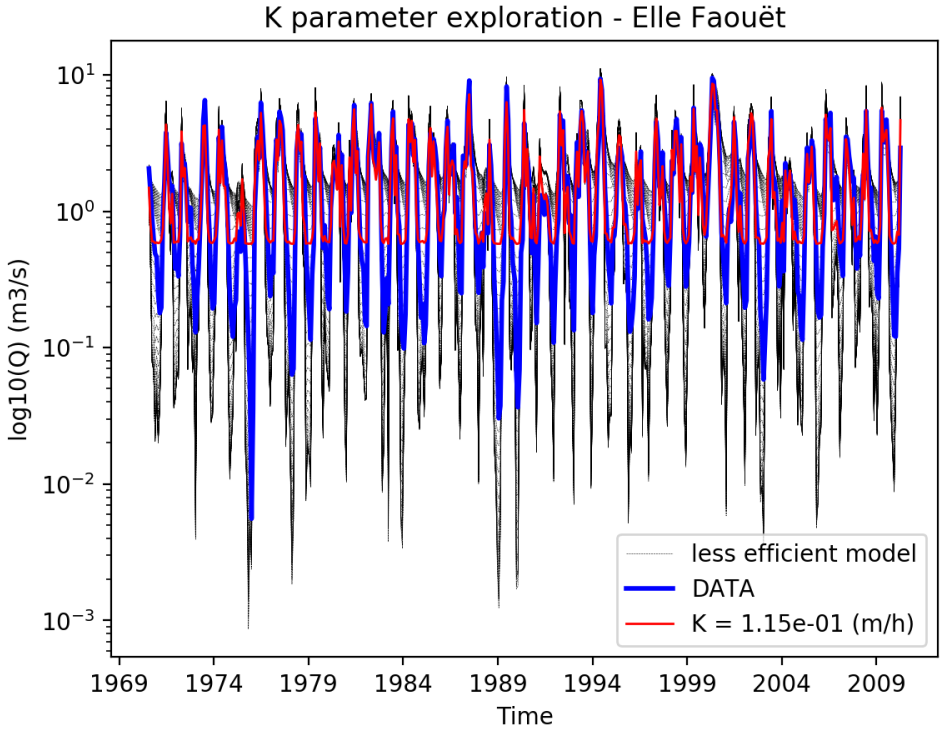
Annexe – Fitting flat bottom

Nashe – Sutcliffe Efficiency (*NSE*):

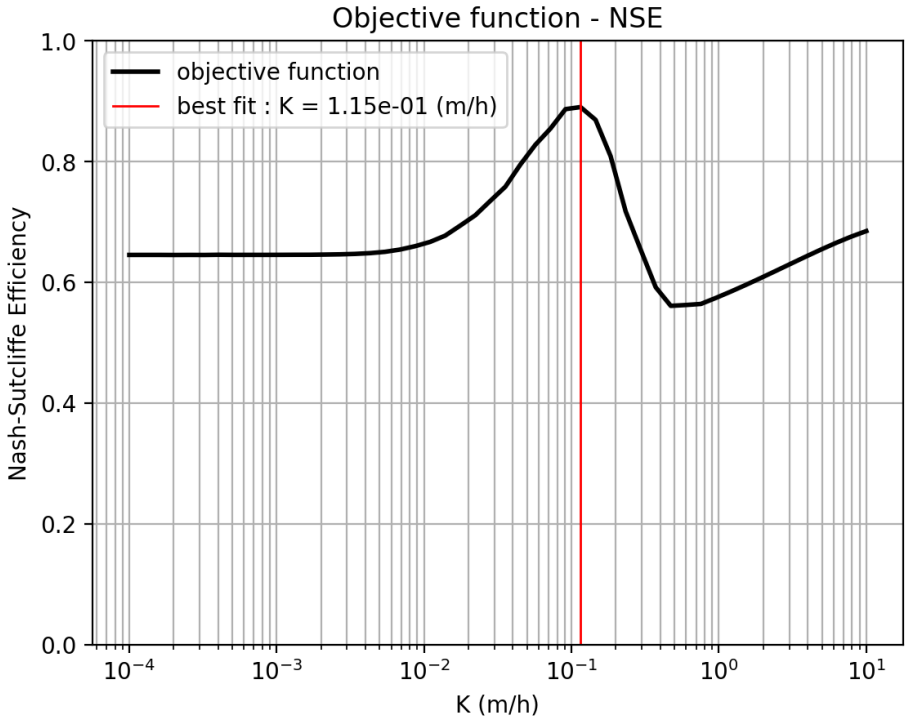
$$NSE = 1 - \frac{\sum_n (Q_{mod} - Q_{obs})^2}{\sum_n (Q_{obs} - \overline{Q_{obs}})^2}$$



Exploration Results (*log(Q) = f(t)*)



Objective Function



Annexe – Fitting sloped bottom