Karst conduit geometry – reduction of ambiguity by using a multiple signal approach for numerical hybrid models

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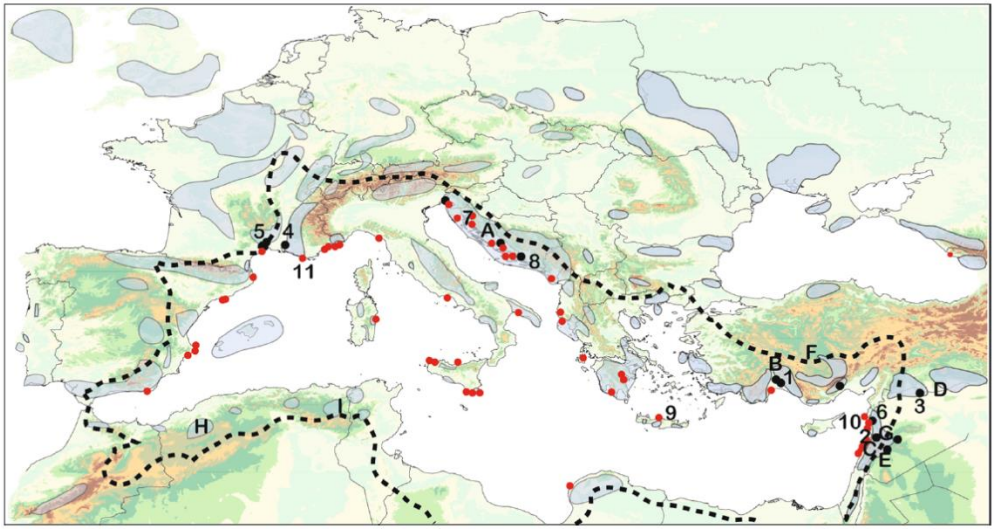
Motivation



Bakalowicz (2015)

- civil and economical water demand

+

- mass tourism particularly during the dry summer seasons

(Over)exploitation of groundwater resources

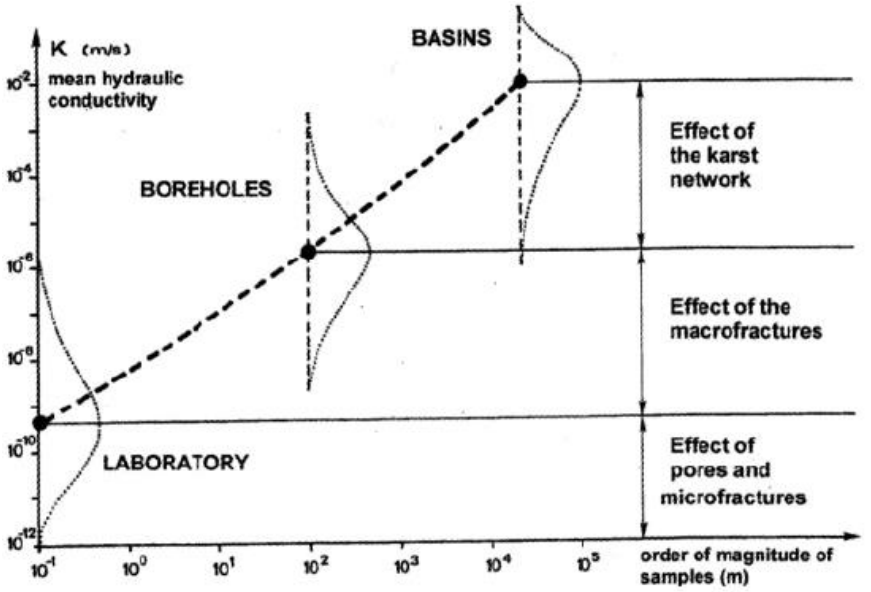
- many settlements were founded around karstic springs serving as exclusive fresh water source
- supply millions of inhabitants with fresh water throughout the Mediterranean
- hazards for human life when intensive precipitation events induce flash floods [e.g. Nimes 2002]
- contamination

Evaluation of karstic springs needed to be focused along the whole Mediterranean

Dörfliger et al. (2009)

Motivation

- **laboratory scale:** characteristic high storage but low permeability
- **borehole/local scale:** permeability of the rock volume is increased by the secondary porosity
- **regional scale:** dominated by solution enlarged features



Kiraly (2002)

- small-scale hydraulic test characterize hydraulic parameters only on local-scale
- lumped parameter models are not able to represent flow on different scales

Hybrid model – CFPM1

General equations of the Conduit-Flow-Process-Mode 1 (CFPM1):

laminar flow inside the fissured/fractured matrix:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)\pm W = S_s\left(\frac{\partial h}{\partial t}\right)$$

laminar flow inside the conduit system (Hagen Poiseuille):

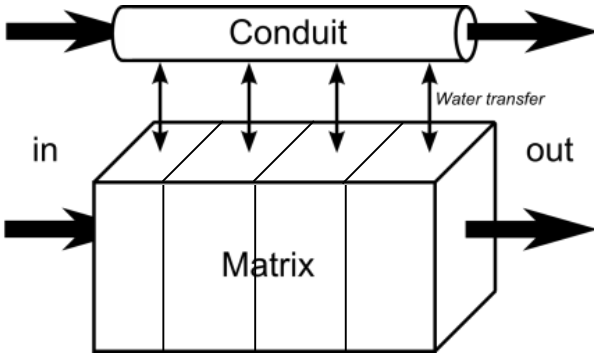
$$v = -\frac{d^2}{32}\frac{g}{\nu}I$$

turbulent flow inside the conduit system (Colebrook-White):

$$v = 2log\left(\frac{k_c}{3.71d}+\frac{2.51\nu}{d\sqrt{2gdI}}\right)\sqrt{2gdI}$$

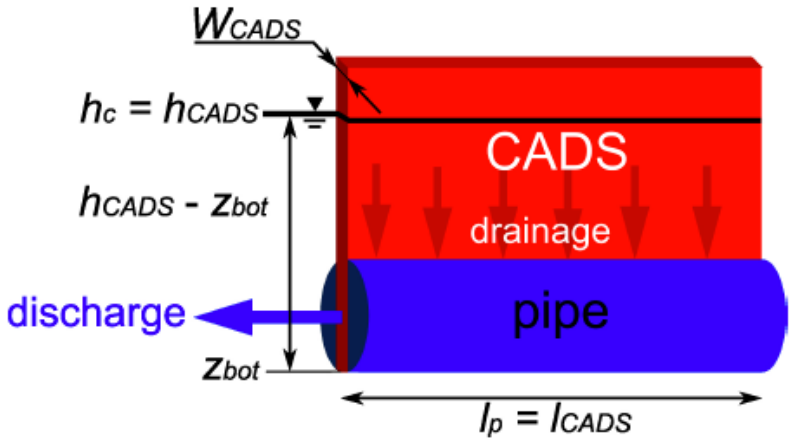
exchange flow between matrix and conduit:

$$Q_{ex} = \alpha_{j,i,k}(h_{in} - h_{j,i,k})$$



Reimann (unpub.)

Hybrid model – CFPM1



Reimann et al. (2014)

Hydraulical connection between conduit and CADS:

$$h_{CADS} = h_c$$

Volume of the CADS for each conduit node:

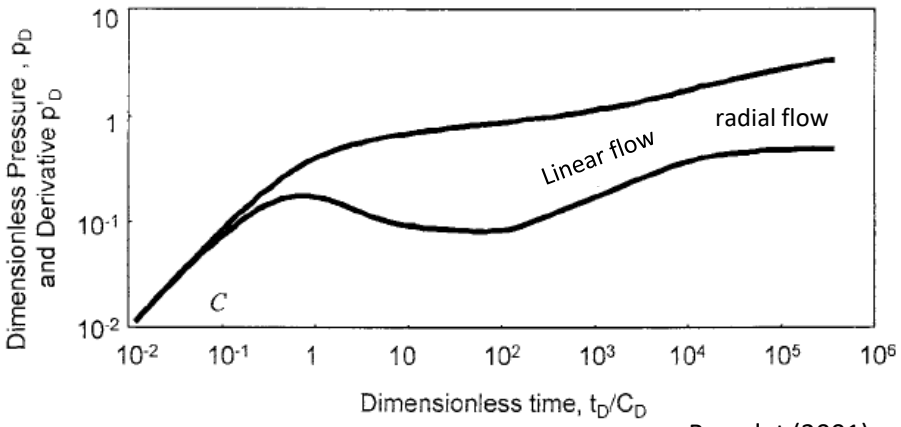
$$V_{CADS} = l_{CADS} W_{CADS} (h_{CADS} - z_{bot});$$

$$h_{CADS} > z_{bot}$$

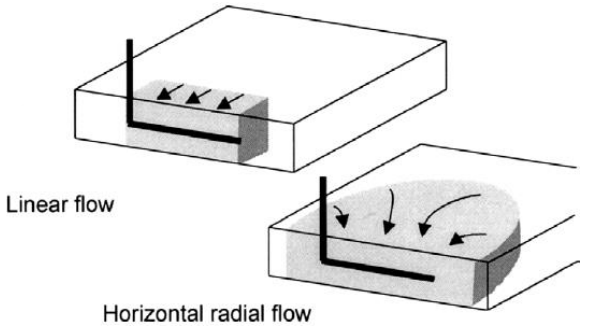
Conduit-associated drainable storage (CADS):

- an additional fast-responding local storage is necessary to represent dynamic processes
- CAD-Storage is directly connected to the conduit flow system but is not part of the pipe flow (flow equations)

Pumping test analysis – diagnostic plots



Bourdet (2001)



Bourdet (2001)

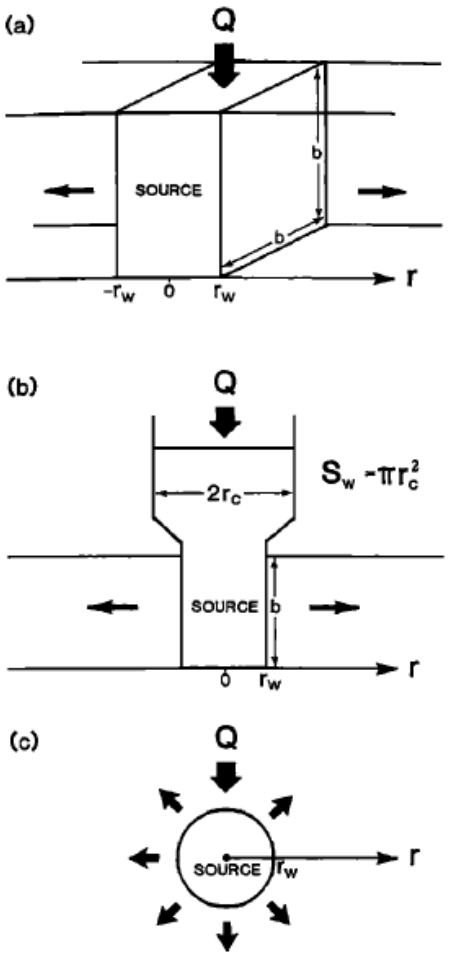
Derivative: $$s' = \frac{\partial s}{\partial \ln t}$$

s	Drawdown [L]
t	Time [T]

Three main periods:

1) early time response, which is mainly influenced by direct storage (wellbore and/or conduit storage)
2) intermediate time response, which is influenced by unrestricted reservoir flow (linear, radial flow)
3) late time response, which is mainly influenced by reservoir boundary conditions

Pumping test analysis – flow dimension



Barker (1988)

Flow area:
Barker (1988)

$$A(r)_n = b^{3-n}\alpha_n r^{n-1}$$

with

$$\text{area} = \alpha_n = \frac{2\pi^{n/2}}{\Gamma(n/2)}$$

for n=1:

$$A_1 = 2b^2$$

for n=2:

$$A_2 = 2\pi r b$$

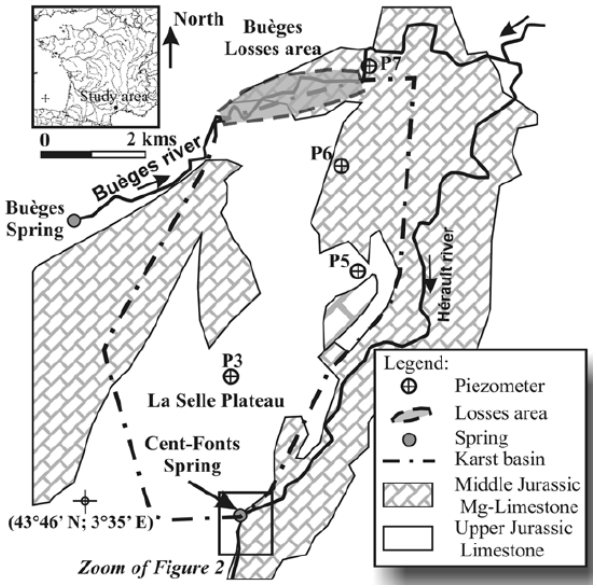
Flow dimension:
Beauheim et al. (2004)

$$n = \frac{d\log A}{d\log r}$$

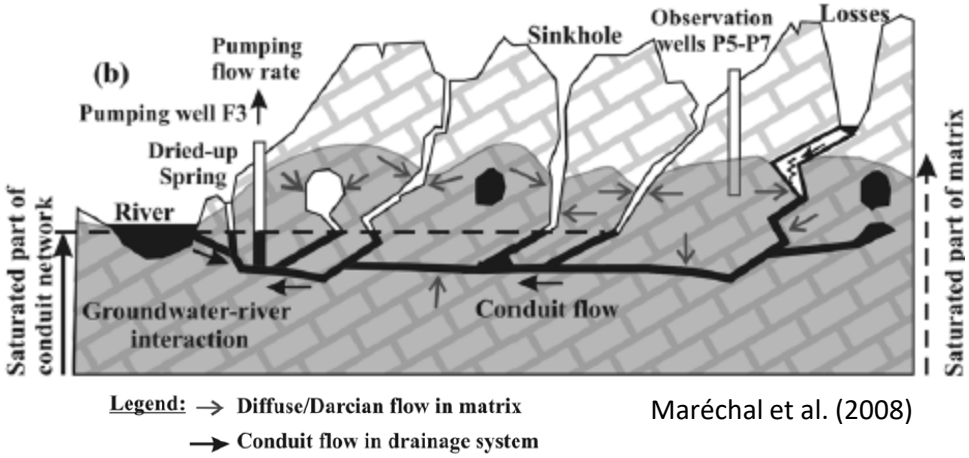
for n=1: constant flow area

for n=2: linear increase of flow area with increasing radius

Large scale pumping test– Cent Fonts



Maréchal et al. (2008)



Maréchal et al. (2008)

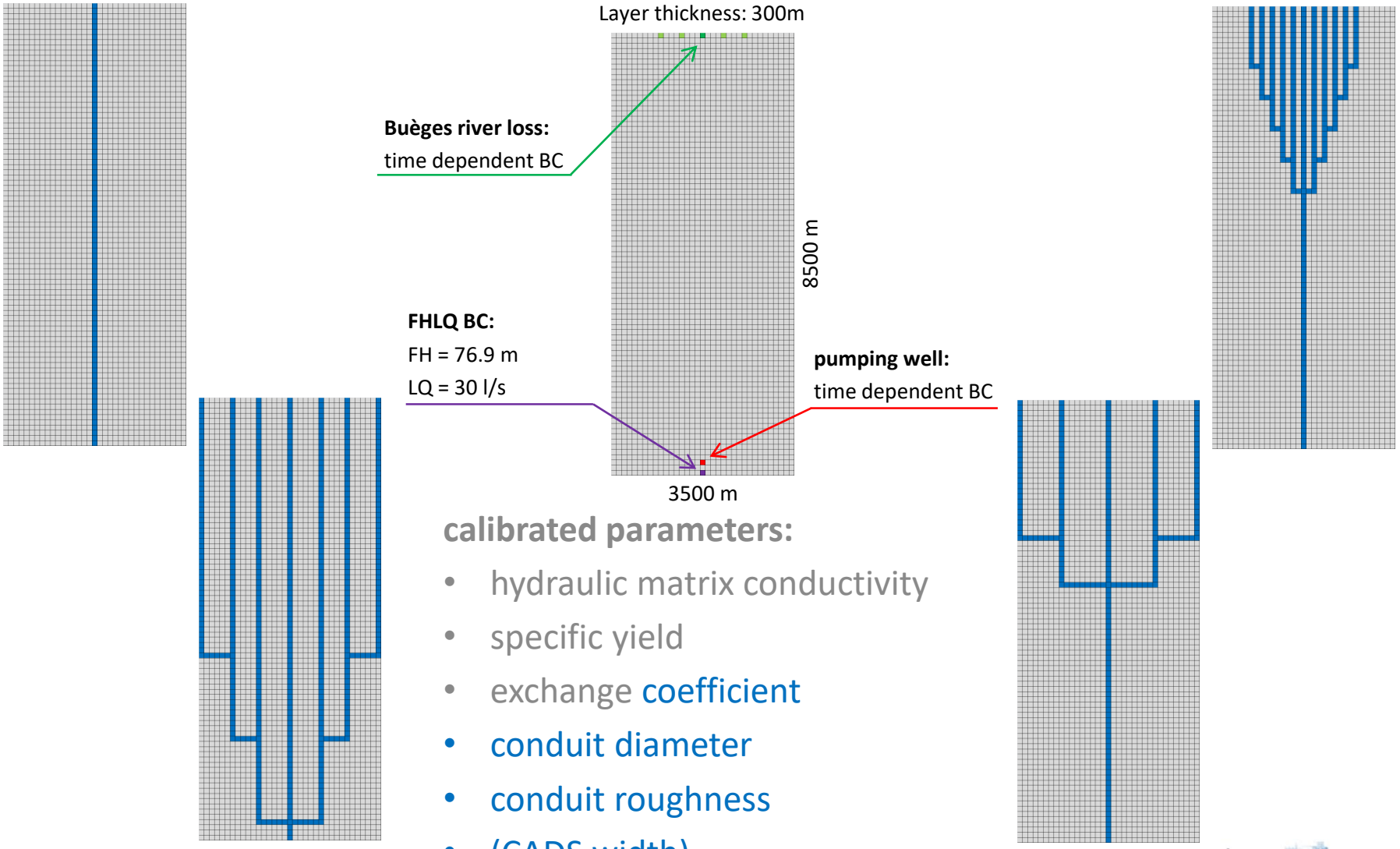
Type	Flow Component	Volume, m³	Contribution to Total, %	Contribution to Total, %
Natural	Matrix natural contribution	710,165	60.8	64.8
	Buèges losses	46,710	4.0	
Induced by pumping	Matrix induced flow	239,864	20.5	35.2
	Hérault infiltration	92,124	7.9	
	conduits dewatering	78,525	6.7	
	Total	1,167,387	100	100

Maréchal et al. (2008)

additional information:

- free-surface area of dewatering conduit network: 1900 m²
- conduit volume: 80000 – 200000 m³
- approximatly 6 m matrix drawdown

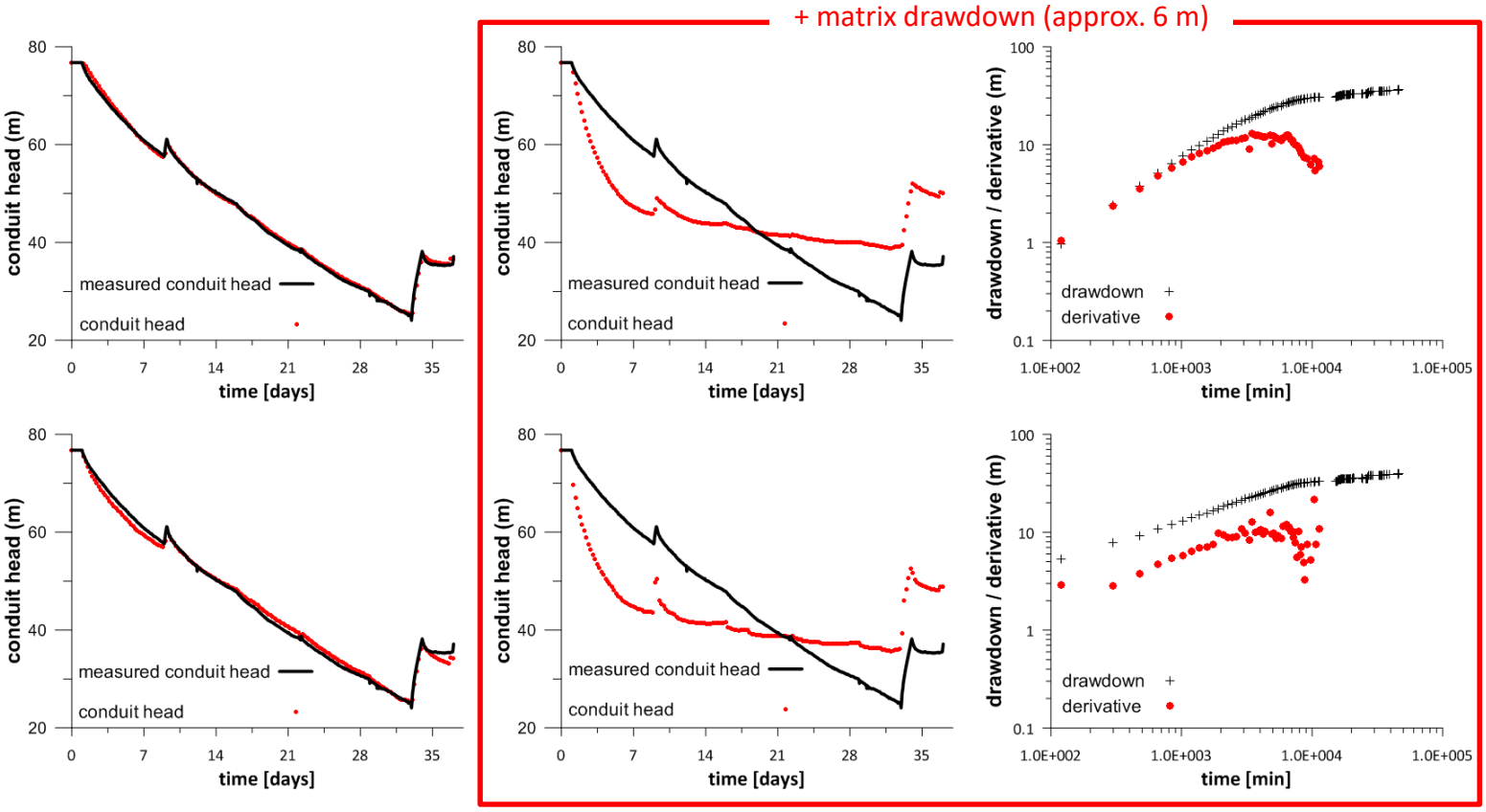
Conceptual model 1: conduit networks



calibrated parameters:

- hydraulic matrix conductivity
- specific yield
- exchange coefficient
- conduit diameter
- conduit roughness
- (CADS width)

Conceptual model 1: conduit and matrix drawdown



- reasonable representation of matrix drawdown
- conduit related parameters are insensitive

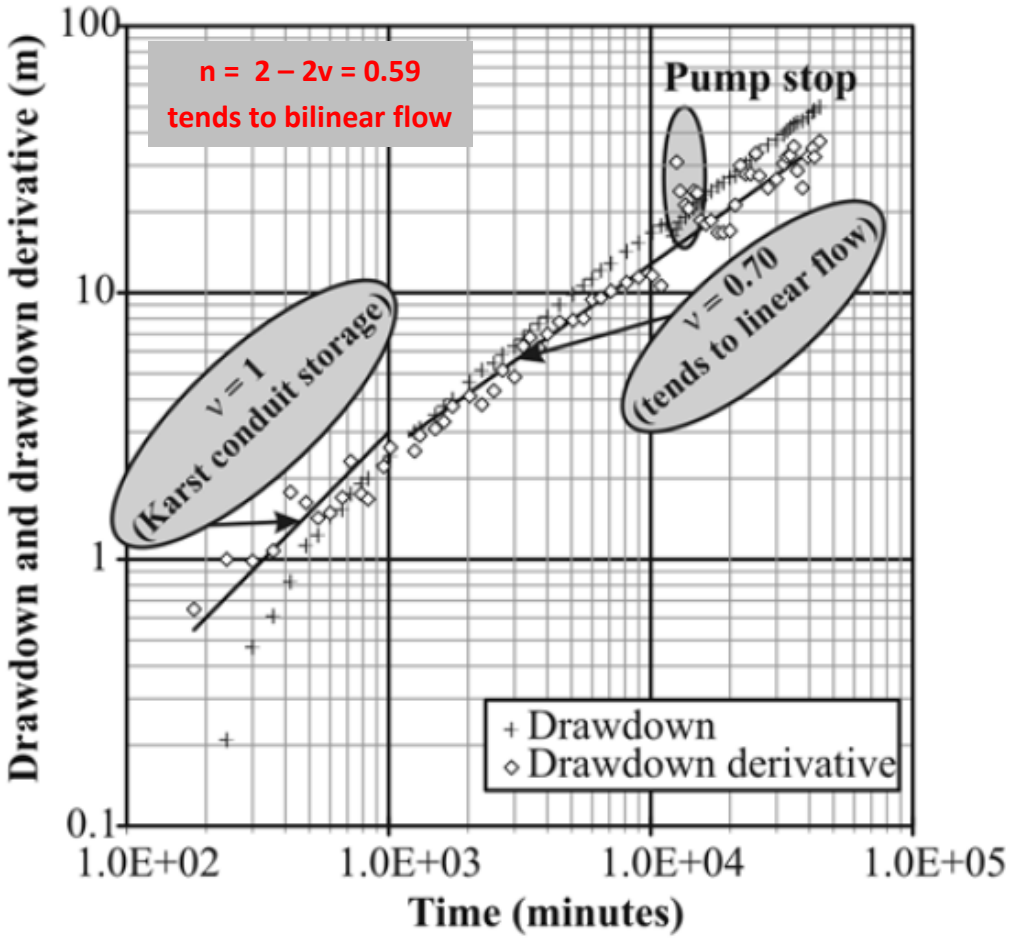
Bilinear flow

bilinear flow :

- flow dimension n= 0.5
- linear fracture/conduit flow superimposed by radial flow

Consequence of **small conductivity contrast**:

- Finite conduit conductivity
  - turbulent flow
  - deposition
  - conduit deformation
- high degree of karstification

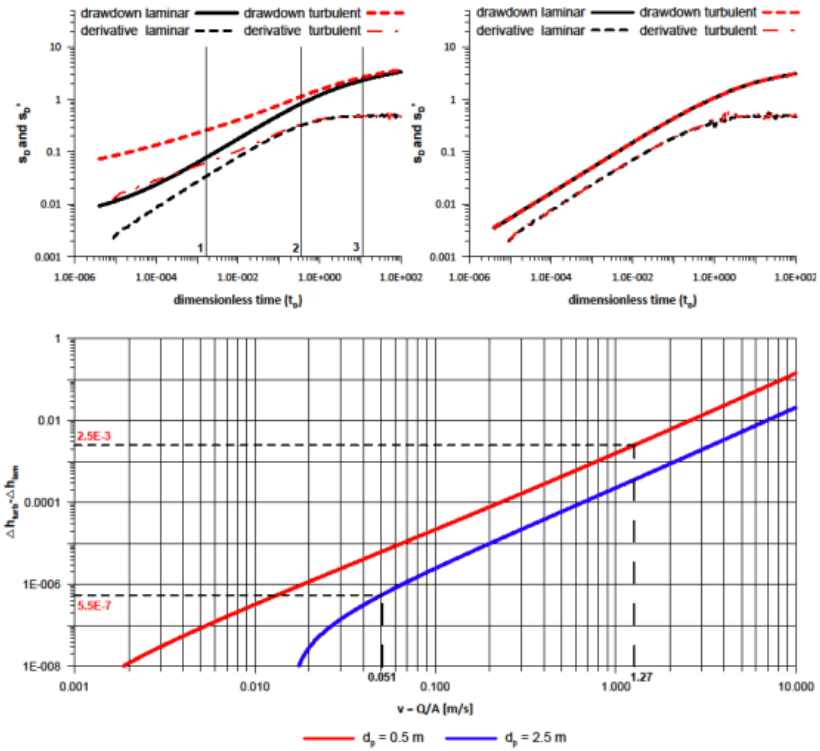


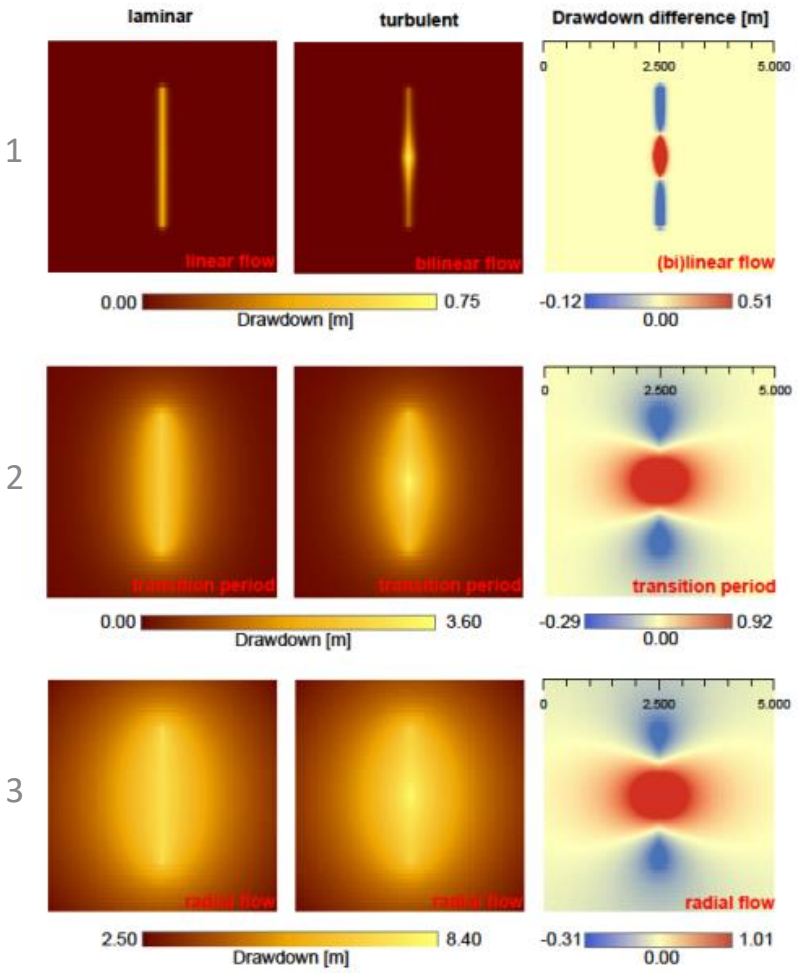
Maréchal et al. (2008)

Bilinear flow

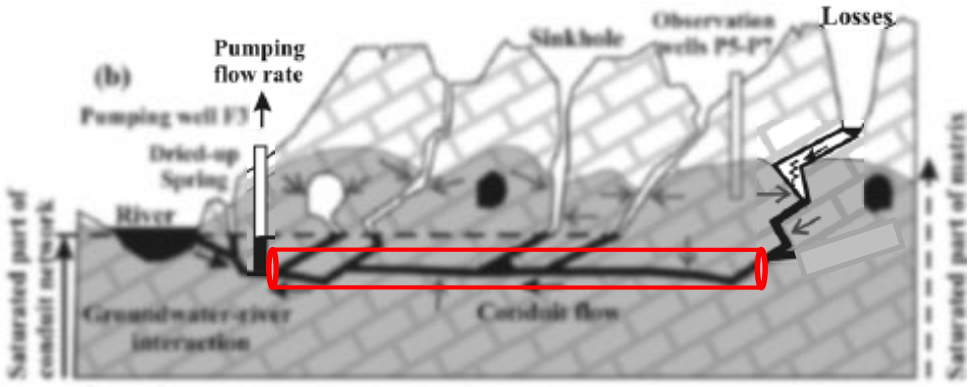
Idealized conduit:

- 3000 m of uniform diameter
- low roughness (kc = 0.01 m)





Bilinear flow



Conduit networks:

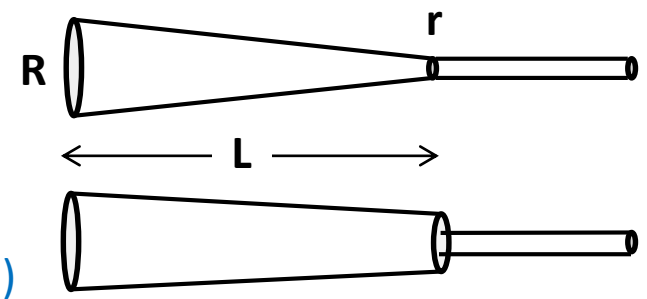
- conduit drawdown: underestimated
- influenced by boundary conditions
  - large-scaleboundary conditions
  - internal boundary conditions

hydraulically ‚unlimited' propagation of drawdown signal along the conduit network

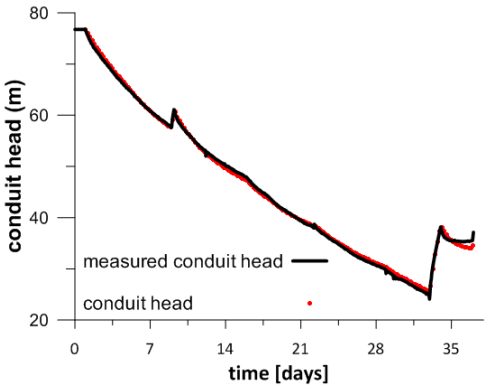
$$V_{cond} = \frac{L\pi}{e}(R^2 + R\,r + r^2)$$

calibrated parameters:

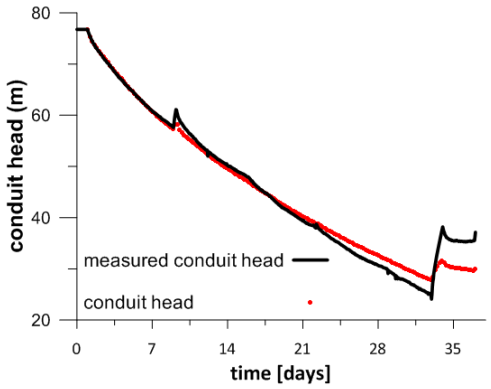
- hydraulic matrix conductivity
- specific yield
- exchange coefficient
- conduit volume
- conduit lenght
- (conduit roughness)

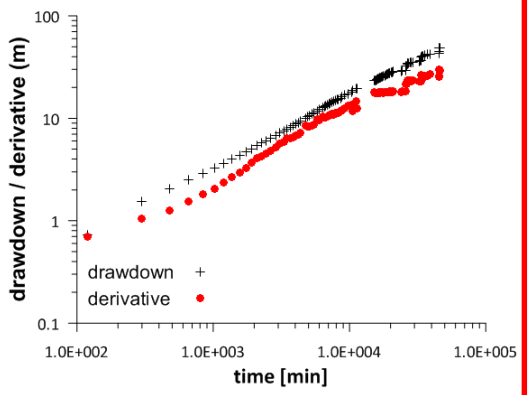


Conceptual model 2: conduit and matrix drawdown



+ matrix drawdown (approx. 6 m)

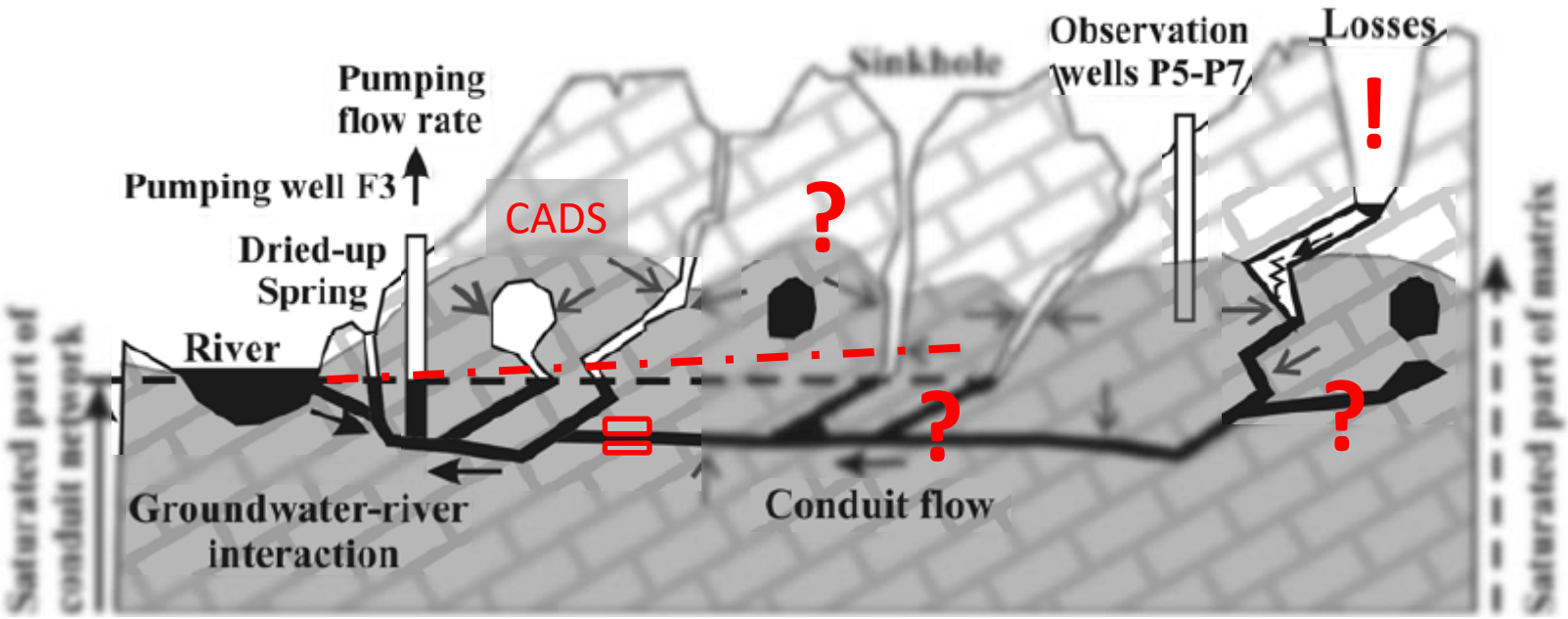


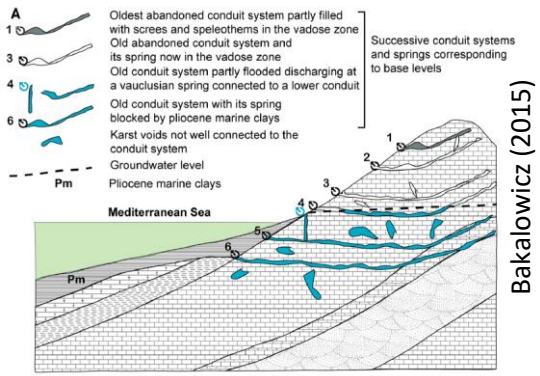


preliminary results:

- acceptable representation of conduit **and** matrix head
- representation of the general flow pattern
- conduit length sensitive to general flow pattern

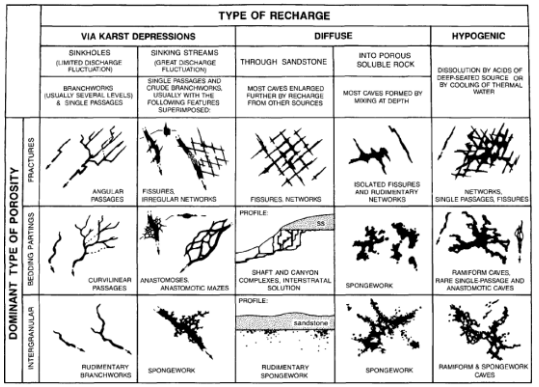
Conclusions



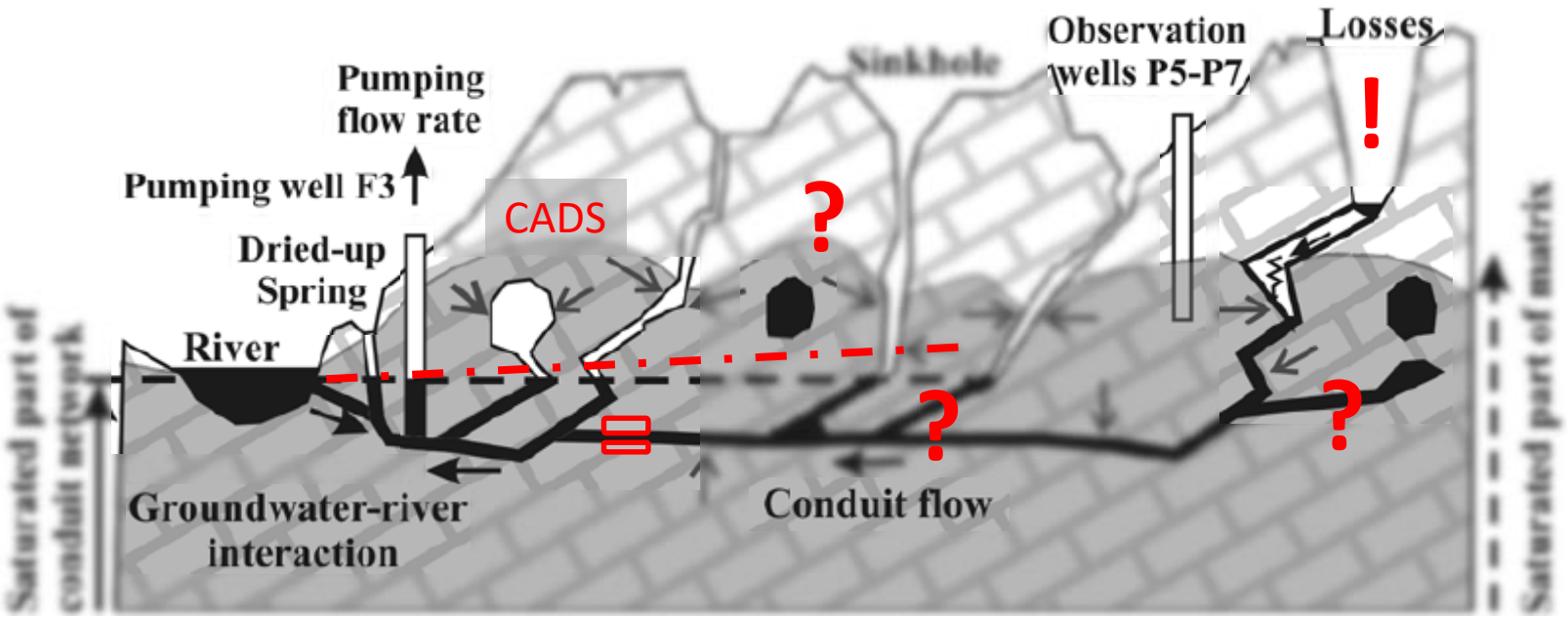


Bakalowicz (2015)

Palmer (1991)



Outlook



- sensitivity analysis
- calibration of hydraulically limited parts of the conduit in terms of travel time by simulation of heat transport
- application on realistic representation of the Cent Fonts catchment

Pic Saint-Loup (Languedoc, France)

Thank you for your attention!

Thanks for the financial support:

DFG

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