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Aix*Marseille université

Assessing the safe yield of a karst aquifer by rainfall-discharge modelling



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Abstract

Groundwater flows and storage in karst aquifer are heterogeneous, deeply impacted by karst conduit network. Two main structures are usually used to described flows: matrix and conduits. This conceptual view of the aquifer is useful to reduce the karst hydrodynamic functioning to few parameters that can be modelled. Another main property of karst is the drainage of the aquifer by springs, connected to the karst network. Groundwater outflow can then be described by two components: baseflow and quickflow. Quickflow is mainly occurring during floods. Baseflow is the sustainable flow, varying between seasonal low and high flow, and during floods. Quickflow discharging at springs during flood is a part of the water budget that is not stored in the aquifer and is then not available for water supply.

It results that groundwater availability at a spring, i.e. at the outlet of the aquifer, can be assessed by separating the quick and base flows. Studying a spring over years or decades gives insight the mean annual baseflow. We propose to define the safe yield that can be withdrawn from a karst aquifer close to the outlet as the mean inter-annual baseflow. For this purpose, lumped rainfall-discharge models are efficient tools to easily separate flow components from spring data.

The modular karst modelling tool *KarstMod* is used in this study. This is a free open tool, made by the French National Karst Observatory Service. We focus on the Dardennes springs case study (South-East France). This aquifer is already used for water supply; twenty years of data are available. This is a typical karst aquifer, with huge flash flood up to 30 m³/s in few hours, and a mean total discharge close to 0.7 m³/s. We show that the mean annual baseflow is quite constant over the years while the rainfall is highly variable.

Keywords : sustainable water budget, groundwater management, model, SNO Karst, hydrograph separation

Goals

- Use a rainfall-discharge model to discuss the water withdrawal management
- Perform hydrograph separation of a karst spring
- Calculate the safe yield available for water supply in order to respect the groundwater storage reserve

Method : KarstMod, a 1D modular platform for Rainfall-Discharge-Level modelling

Modelling workflow

Set up a simple

ow Aim of Ka platform

yet relevant model structure ↓ Choose performance criteria

Define warm-up, calibration & validation periods

Select parameter set that yields the best performance

Check internal consistency, parameters sensitivity, hydrograph characteristics

Proceed to further interpretation

Freely available at : <u>www.sokarst.org</u>

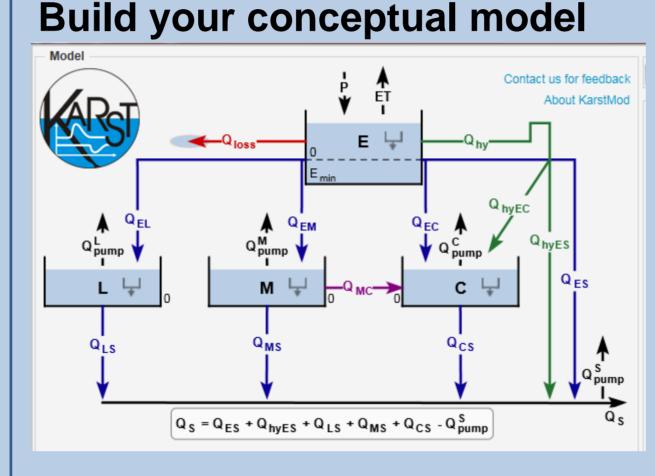
- Infinite characteristic time transfer function

- Provide a friendly environment of 1D rainfall / water level / discharge modelling

 Provide analytical solutions, whenever possible

 Automatic calibration tools, equifinality and sensitivity analysis

- Promote good modelling practices



- Classical configuration (Maillet-type law)

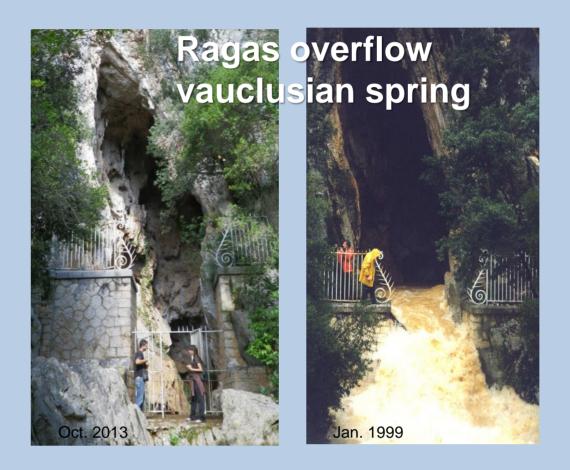
Choose discharge laws

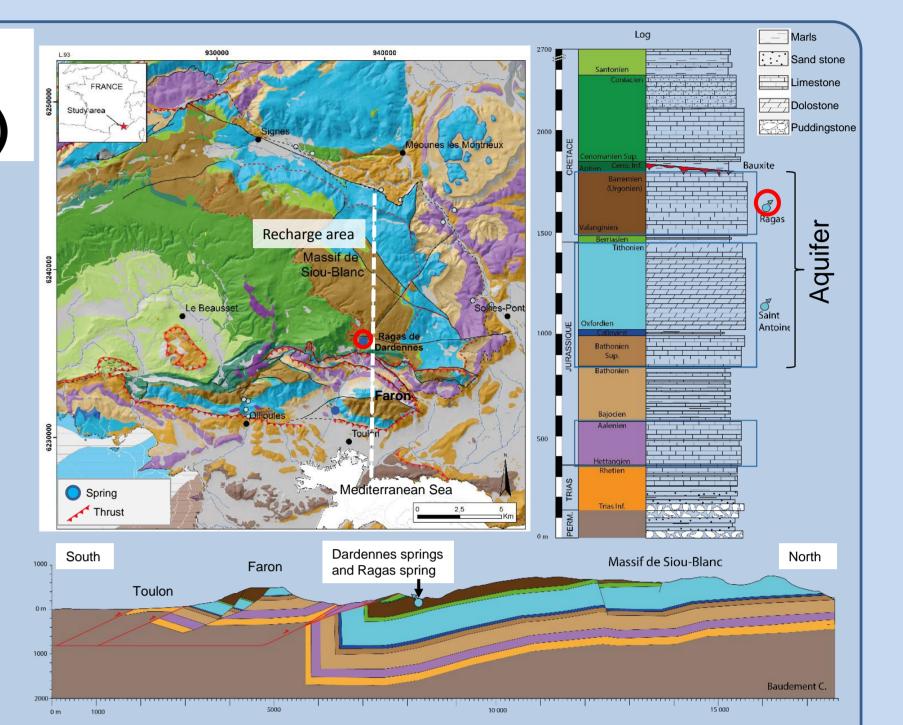
- Linear discharge law

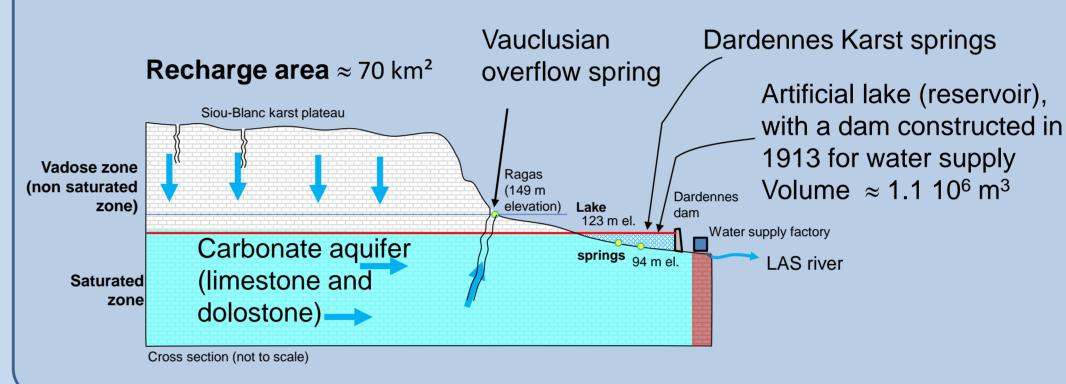
 $Q_{AB}(t) = k_{AB} \times A(t)^{\alpha_{AB}}$

- Non-linear discharge law
- Activation thresholds
- Soil available water content
- Hysteretic discharge law
- 0, 1, 2 or 3 lower reservoirs
- Pumping / Losses
- Interconnection between lower reservoirs

Case study : Dardennes aquifer (Toulon, SE France)

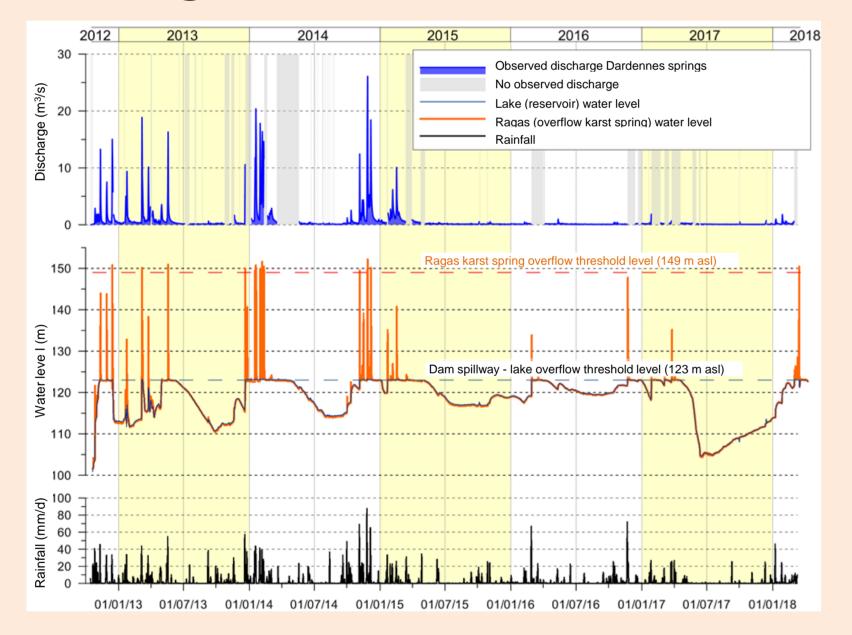








Discharge and water level time series



- Discharge : 2 main flow components → Baseflow + Quickflow
- Karst flash-floods : a highly connected karst network from the recharge area to the springs
- Threshold for quickflow activation : no flood during low flow period, no flood for the first high rate rainfall in autumn
- Threshold for soil water content (no recharge during summer)

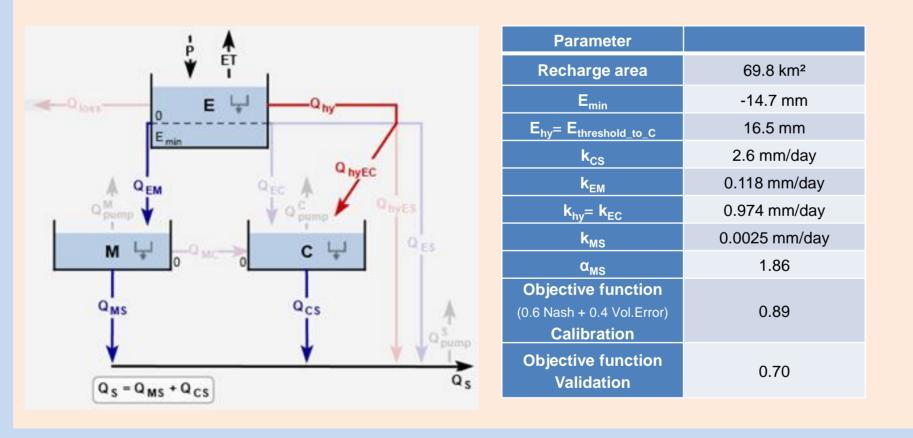
Results and discussion

Goal of the modelling :

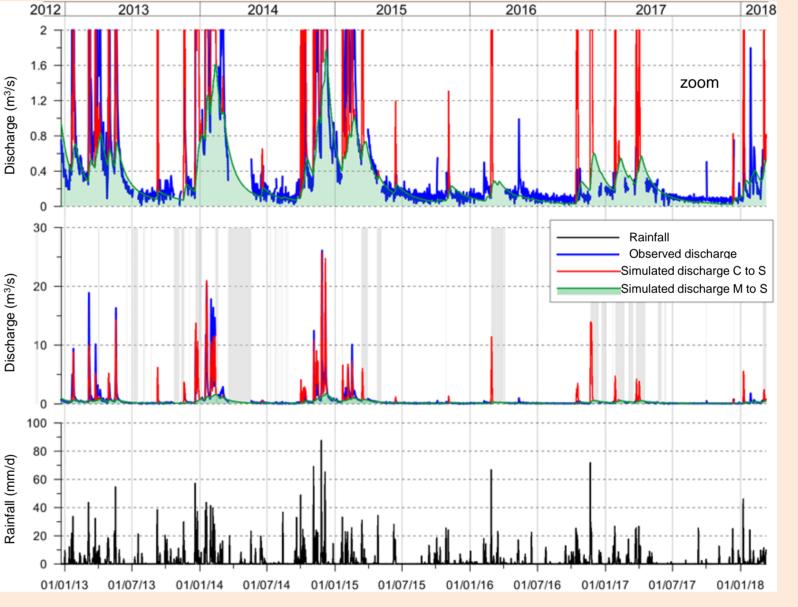
Hydrograph separation of the Dardennes springs discharge : low flow (or matrix flow) and quickflow (or conduit flow)

Structure of the conceptual KarstMod model :

- 1 reservoir (E) for precipitations (P), evapotranspiration (ETP) and recharge budget. Thresholds for soil water content and floods.
- 2 lower reservoirs (M and C) for low flow and quick flow.
- No exchange between M and C, in order to quantity directly baseflow (Q_{MS}) and flood flow (Q_{CS}) at the spring $(Q_S = Q_{MS} + Q_{CS})$.
- Classical configuration, with linear discharge laws and 1 non-linear law from C to the Spring (to account for flashy variations)







 Annual average simulated value of the total discharge :

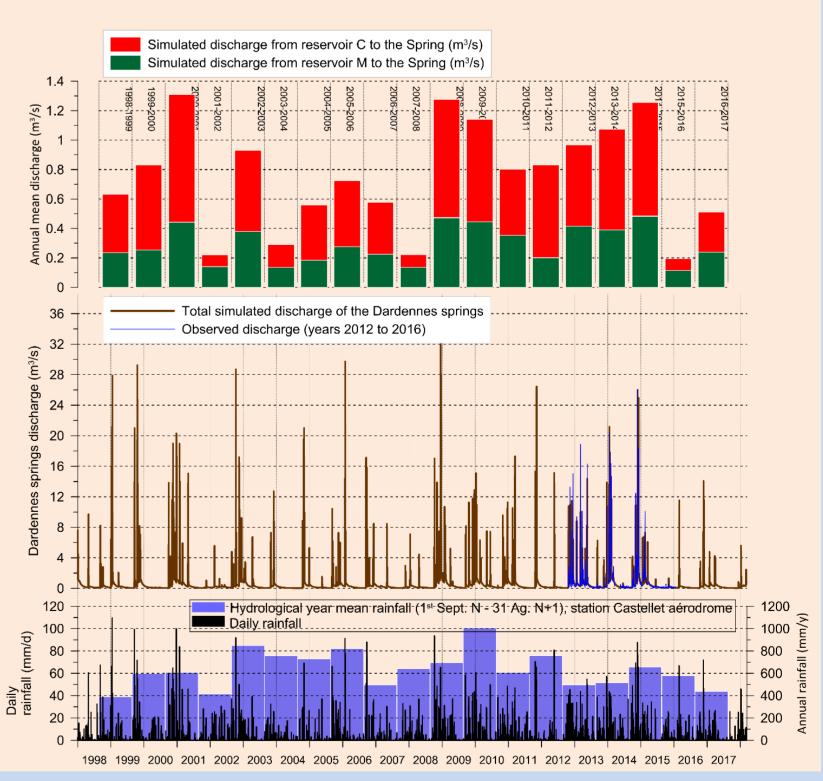
- **dry year** 2015-2016 : 0.19 m³/s (6*10⁶ m³/year)
- **wet year** 2014-2015 : 1.24 m³/s (39*10⁶ m³/year).
- During floods, a large part of the flow is discharging from C.
- A remaining high baseflow (reservoir M) even after 2 very dry years (2015 to 2017)

Long time series modelling (20 years)

- Simulated discharge from reservoir M to the spring
- = Mean interannual baseflow
- = 0.29 m³/s (9*10⁶m³/y)

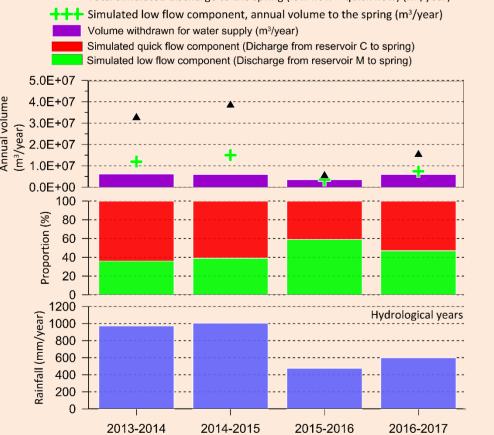
Mean interannual total discharge = $0.73 \text{ m}^3/\text{s}$

→A safe yield at the springs can be proposed, equivalent to the mean interannual baseflow.



Groundwater management and model

- ▲ ▲ Total simulated discharge to the spring (low flow + quick flow) (m³/year)
- Quickflow (at the outlet) feeds the river downstream but this volume of



discharging groundwater is no longer available in the aquifer.

- The driest years lead to less floods and a higher baseflow proportion.

Interannual springs baseflow gives the minimum discharge available at the outlet of the karst hydrosystem.

 The current withdrawal uses the groundwater discharge and the reservoir (lake) storage. The annual yield is lower than the springs' baseflow.

 Low flow discharging from M can be used as a proxy to quantify the safe yield for this aquifer. → This safe yield is higher than the annual mean baseflow discharge of the driest years. During these years, the water withdrawal have to be reduced, or can be maintain by pumping in the groundwater reserve below the outlets (the springs). The geological structure offers a very high storage capacity in the saturated zone, with karst conduits for more than 100 meters below the springs.

Conclusion and perspective : an active management to increase the groundwater withdrawal and mitigate the Mediterranean flash-floods

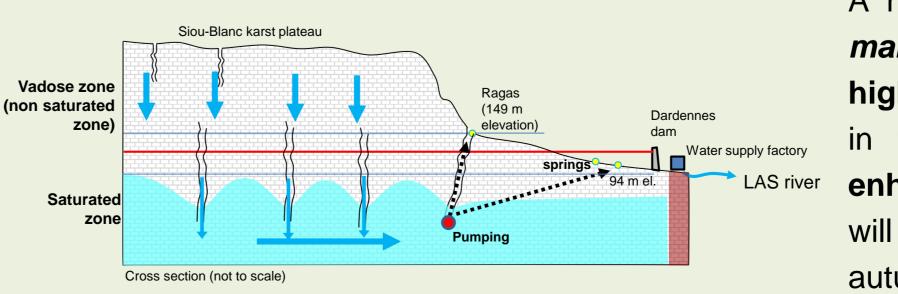
This study showed that the aquifer has a **dual flow components**. **Karst features** allows **quickflow** from the recharge area to the springs that generates **flash-floods**. Floods are naturally **mitigated** in low springflow periods, by **groundwater storage** in the soil/epikarst and aquifer.

The **KarstMod model** was applied for **4 years of daily data**. It gives good results for **rainy and dry** years, with respectively a high succession of floods (2014 and 2015) and a long lasting low flow period (years 2016 and 2017). **A simple model** can thus be used to simulate previous years with meteorological data available.

The simulated baseflow gives the mean low flow available at the Dardennes springs. The mean interannual baseflow is a good estimation of the safe yield naturally available for water supply withdrawal.

Baudement C, B. Arfib, N. Mazzilli, J. Jouves, T. Lamarque, Y. Guglielmi. 2017. Groundwater management of a highly dynamic karst by assessing baseflow and quickflow with a rainfall-discharge model (Dardennes springs, SE France), BSGF – Earth Sciences Bulletin. 188: 40 <u>https://doi.org/10.1051/bsgf/2017203</u> Mazzilli N., V. Guinot, H. Jourde, N. Lecoq, D. Labat, B. Arfib, C. Baudement, C. Danquigny, L. Dal Soglio, D. Bertin (2017) KarstMod: a modelling dedicated to karst systems. Environmental Modelling and Software. <u>http://dx.doi.org/10.1016/j.envsoft.2017.03.015</u> More information on <u>http://www.karsteau.fr/karst/dardennes.html</u>





A new management plan can also be proposed. An *active management* by pumping below the spring level will give a higher rate of water withdrawal, using the groundwater stored in the aquifer. The higly connected karst network will enhance the aquifer recharge, even after periods of drought. It will thus mitigate the first Mediterranean heavy rainfall in autumn by storing a part of the current quickflow giving flash-floods. A part of the pumped water has also to be delivered to the river downstream to respect the aquatic life of the stream.

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