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Improving pumping tests interpretation in carbonate aquifers with diagnostic plot method

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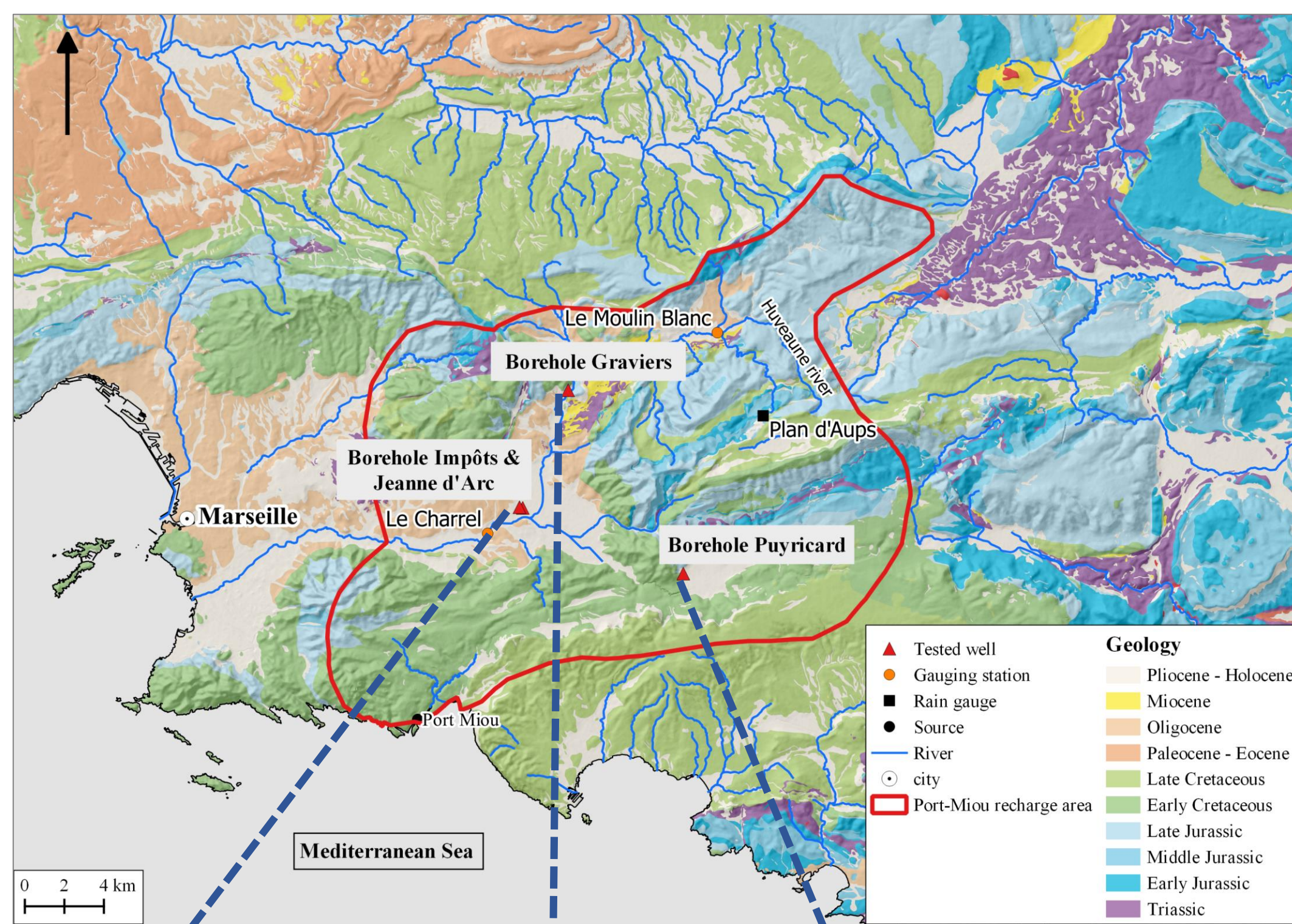
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Introduction

Carbonate aquifers, and especially karstic systems, are known to contribute significantly to the freshwater supply worldwide. Quantitative and qualitative methods have been developed for several years to study the characteristic of the reservoir based on hydrological behaviour, geochemical parameters and more recently flow models. Carbonate aquifers are heterogeneous media that can be modelled as equivalent porous medium, fractured medium, conduit networks and matrix. Porous aquifer can also be found in carbonate context, e.g. alluvial aquifer or polje. In this case, hydrodynamic parameters could be classically determine with pumping tests and Theis interpretation method for an hypothetical homogeneous and isotropic aquifer. Bourdet proposed the diagnostic plot method based on the drawdown derivative to identify conceptual flow model of an aquifer and to improve the interpretation of pumping tests in heterogeneous aquifers such as fractured or karstic aquifers.

Case study

- Located in the **South-East of France**
- **Carbonate reservoir** (limestone, dolostone, mixed siliciclastic-carbonate rocks)
- **Alluvial aquifer**
- **Regional outlet of the groundwater resources at Port-Miou submarine spring**



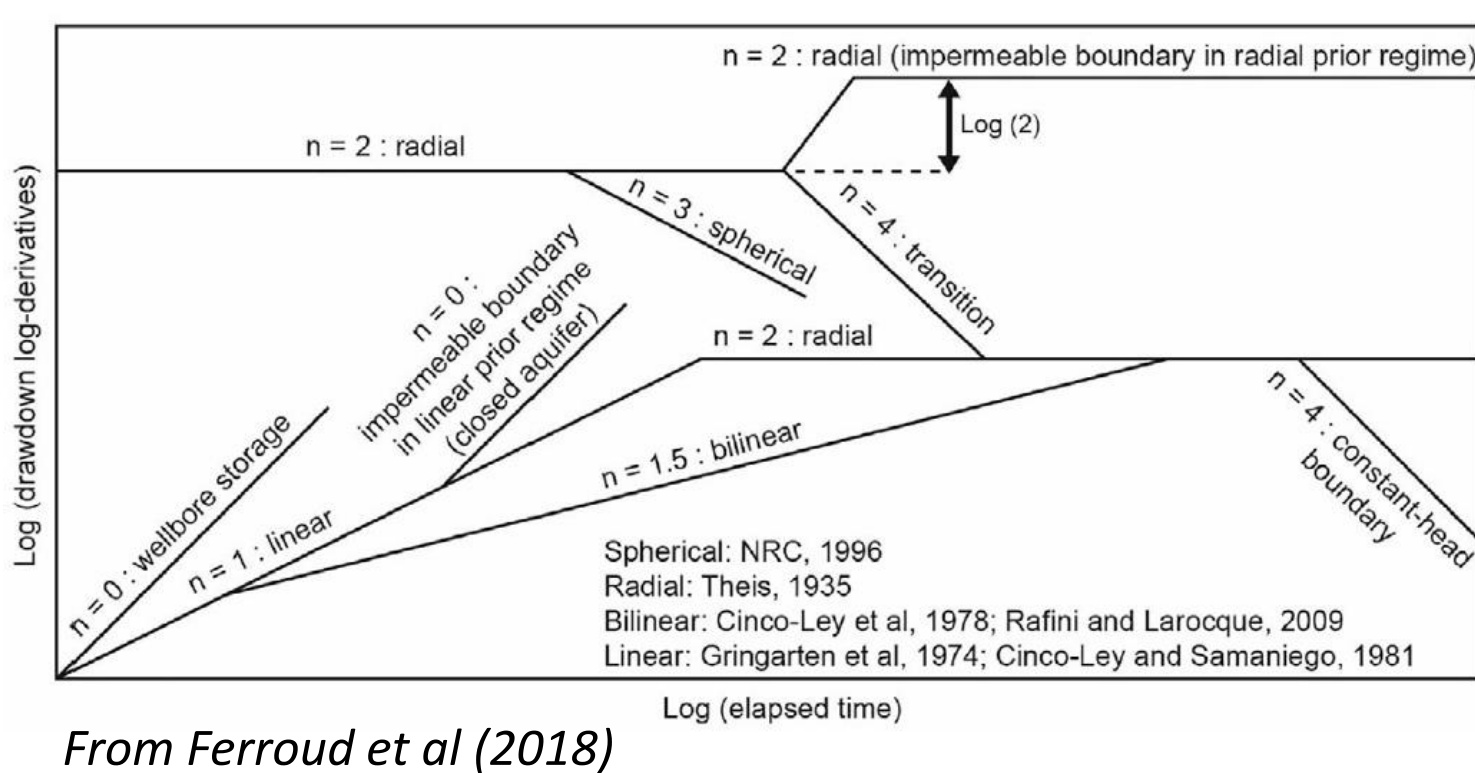
Hydrogeological context

a:
Two pumping tests in an alluvial-type aquifer composed of Oligocene to quaternary sediments
Borehole Impôts
Pumping duration: 73h
Discharge rate: 324 m³/h
Borehole Jeanne d'Arc
Pumping duration : 95h
Discharge rate: 374 m³/h

b:
One pumping test in a karst aquifer composed of Late Jurassic dolostone
Borehole Graviers
Pumping duration: 71h
Discharge rate: 377 and 352 m³/h (reduced at 1020 min)

c:
One pumping test in highly fractured Urgonian limestone
Borehole Puyricard
Pumping duration: 15h
Discharge rate: 150 m³/h

Diagnostic plot method



- Method based on the derivative of the drawdown
- Several studies determined flow conceptual model from this method (Ferroud et al., 2018)
- Example in a karst aquifer (Maréchal et al., 2014)

Few examples with n, the flow dimension, and v, the slope:

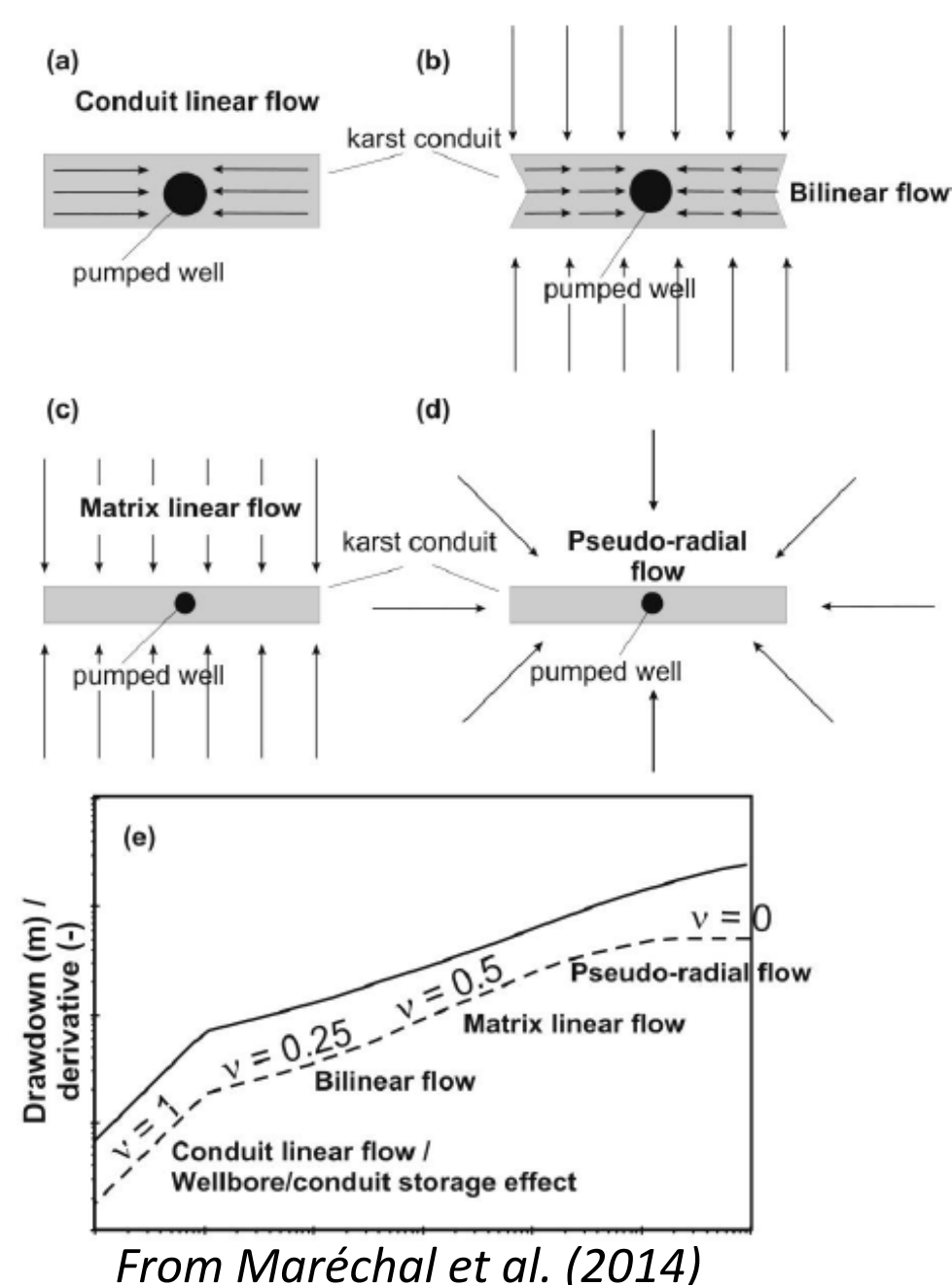
$n = 1 (v = 0.5) \rightarrow$ linear flow associated with fracture in a less conductive matrix or matrix linear flow around a vertical fracture or a channelized alluvial aquifer

$n = 2 (v = 0) \rightarrow$ radial flow associated with homogeneous aquifer but also applicable in various aquifers (early stage or late stage in fractured media)

For a radial flow, it is possible to determine the apparent transmissivity T_{app} (m²/s): $T_{app} = \frac{2.3Q}{4\pi a}$

Q: Discharge = 1 m³/h because of the normalized derivative
a: Plateau elevation of the derivative

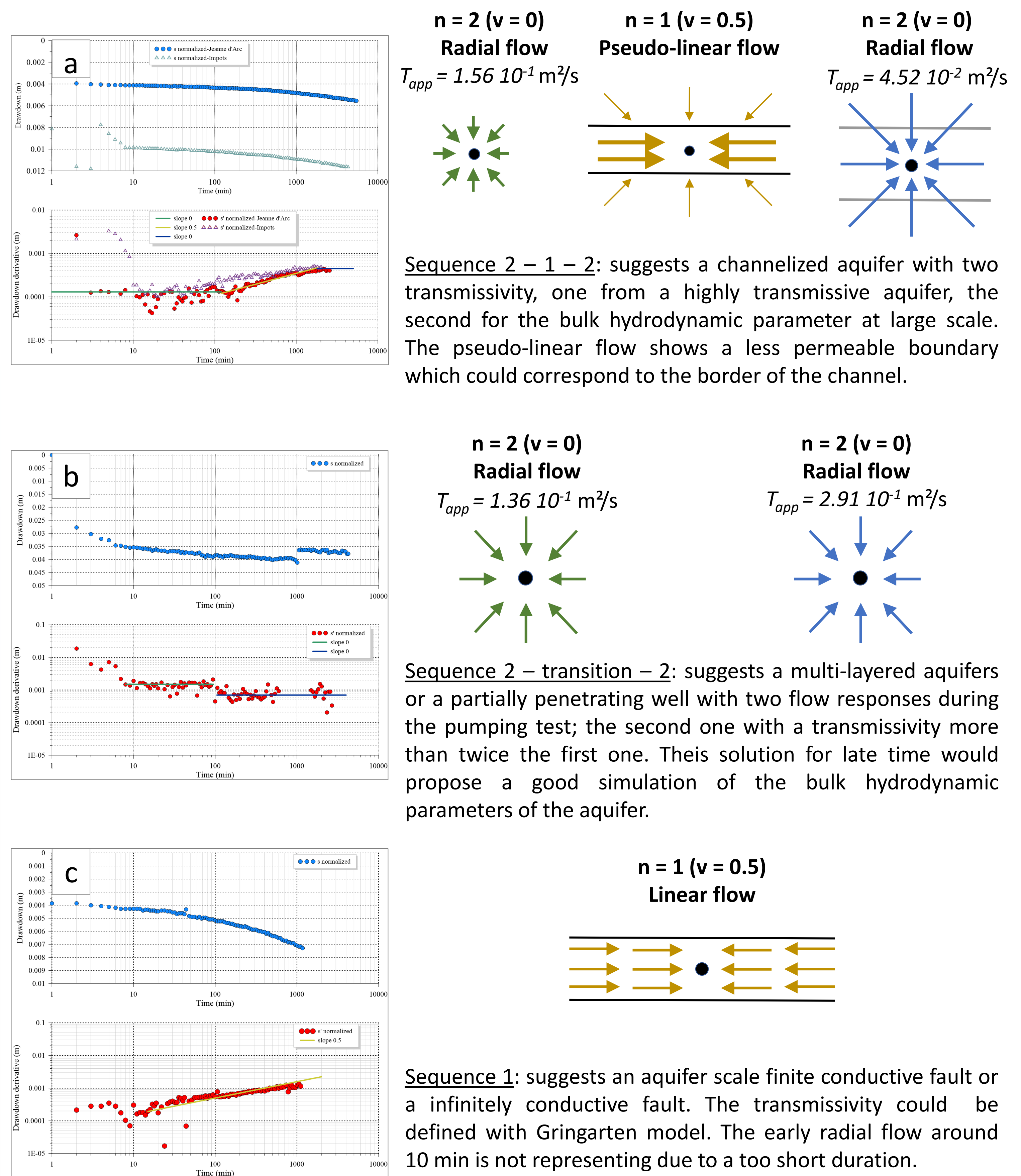
Ferroud A., Rafini S., Chesnaux R. (2018). Using flow dimension sequences to interpret non-uniform aquifers with constant-rate pumping-tests: A review. Journal of Hydrology X. 2. 100003. 10.1016/j.hydrox.2018.100003.
Maréchal J.C., Ladouche B., Dewandel B., Fleury P., Dörfli N. (2014). Diagnostic plots applied to well-tests in karst systems. H2Karst Research in Limestone Hydrogeology, Environmental Earth Sciences. 10:1007/978-3-319-06139-9_9.



Goals

- **Improve the use of pumping tests in carbonate aquifer**
- **Use of the diagnostic plot method to identify conceptual flow models of heterogeneous aquifers**
- **Determine the potential resources for freshwater supply in carbonate environment**

Results and Conceptual flow models



Sequence 2 – 1 – 2: suggests a channelized aquifer with two transmissivity, one from a highly transmissive aquifer, the second for the bulk hydrodynamic parameter at large scale. The pseudo-linear flow shows a less permeable boundary which could correspond to the border of the channel.

Sequence 2 – transition – 2: suggests a multi-layered aquifers or a partially penetrating well with two flow responses during the pumping test; the second one with a transmissivity more than twice the first one. This solution for late time would propose a good simulation of the bulk hydrodynamic parameters of the aquifer.

Sequence 1: suggests an aquifer scale finite conductive fault or a infinitely conductive fault. The transmissivity could be defined with Gringarten model. The early radial flow around 10 min is not representing due to a too short duration.

Discussion - Conclusion

- **In the case b (“Borehole Graviers”), the hydrodynamic response can be assimilated to a porous media. The aquifer can be view as a “ghost” zone with intense karstification**
- **The diagnostic plot method allows the definition of a conceptual flow model from the succession of flow regimes identified with the derivative of the drawdown**
- **It can be used indifferently in karst, fractured or alluvial aquifers**
- **Pumping tests in karst aquifers could be interpreted in a suitable way through Theis solution when the late derivative of the drawdown shows radial flow**