Diagnostic plots applied to well-tests in karst systems

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Difficulty to interpret pumping tests in Mixed Flow Karst Systems

> **Duality of flows** in mixed flow karst systems (MFKS):
  * Localized turbulent flow in karst conduits
  * Darcyian or diffuse flow in fractures and porous rock (matrix)

> Wells intercepting the solution conduits are difficult to interpret because **the geometry of cave networks and connections to the matrix are very often unknown**.

> The rate of flow exchange between the matrix and the solution conduits must be identified.
Theory: Diagnostic plot

> Origin: oil exploration

> Principle: plot the drawdown derivative versus time

Theis radial (2D) solution

Boundary conditions
Flow dimension
Anisotropy, double porosity

Slope:
\[ \nu = \lim_{t \to \infty} \frac{d}{d \log t} \left[ \log(ds/d\ln t) \right] \]

Flow dimension:
\[ n = 2 - 2\nu \]
Diagnostic plot of a test in a well intersecting a vertical fracture (finite length & finite permeability)
Diagnostic plot of a test in a well intersecting a vertical fracture (finite length & finite permeability)

Bilinear flow

Drawdown derivative

Time

v = 0.25

Pumped well

Karst conduit

Conduit linear flow

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Diagnostic plot of a test in a well intersecting a vertical fracture (finite length & finite permeability)
Diagnostic plot of a test in a well intersecting a vertical fracture (finite length & finite permeability)

- Conduit linear flow
- Pseudo-radial flow
- Pumped well
- Karst conduit

Pseudo-radial flow

Drawdown derivative vs. Time

$\nu = 0$
Two cases of wells intersecting karst conduits

2 cases:
- PWa intersects the main karst conduit
- PWb intersects a small karst conduit
Case 1: Pumping test into the main karst conduit
(Cent-Fonts karst system)

Pumping test characteristics:
- one month duration
- pumping rate: 400 l/s
- spring discharge: 255 l/s

Legend:
- Diffuse/Darcian flow in matrix
- Conduit flow in drainage system

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Case 1: diagnostic plot

- **v = 1**
  - Karst conduits storage

- **v = 0.7**
  - Linear flow

**Pump stop**

- Drawdown
- Derivative
Interpretation using Classical Analytical Solutions

Classical analytical solutions are not able to properly simulate the measured drawdown at the pumping well in the karst conduit:

- Theis solution underestimates drawdown for short times
- Barker solution overestimates drawdown for short times.

Moreover, the significance of estimated parameters \((T, S)\) is questionable.
The duality of flows is modeled using a double continuum model with:
- Reservoir 1 (conduit network): assumed highly permeable with a uniform water level $h_c$
- Reservoir 2 (matrix): assumed porous with Darcyan flows towards conduits and uniform water level $h_m$

$\beta$ is the exchange flow between matrix and conduits
Modeling Results using One-dimensional flow in the matrix

The model simulates very well the drawdown in the karst conduit, including the first pump stop (PS1) and the recovery phase (PS3).

Into the matrix, the trend of drawdown is rather well represented.

**Main parameters:**
- $L = 5000 \text{ m}$
- $S_c = 1900 \text{ m}^2$
- $T_m = 1.6 \times 10^{-5} \text{ m}^2/\text{s}$
- $S_m = 0.007$

**free surface area of dewatering conduit network $S_c$ (vertical shafts and variably saturated conduits)**

$\Phi = 0.00006$
Case 2: Pumping test into a secondary karst conduit
(Robol well in Corbieres karst)

Three phases:
- Bilinear flow
- Pseudo-radial flow
- Boundary
Conclusion

> Diagnostic plot is useful to identify the flow phases during a pumping test into a karst conduit
> It contributes to choose the suitable model / analytical solution for the interpretation
> Specific solutions exist for other types of conditions: double porosity, epikarst contribution...