KUALA LUMPUR 2012 WORLD GAS CONFERENCE

25th world gas conference

"Gas: Sustaining Future Global Growth"

BETTER WATER PRODUCTION FORECASTS FOR ENHANCED PERFORMANCES

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Wednesday 6th June

CS2.2: Optimising Underground Gas Storage Capacities

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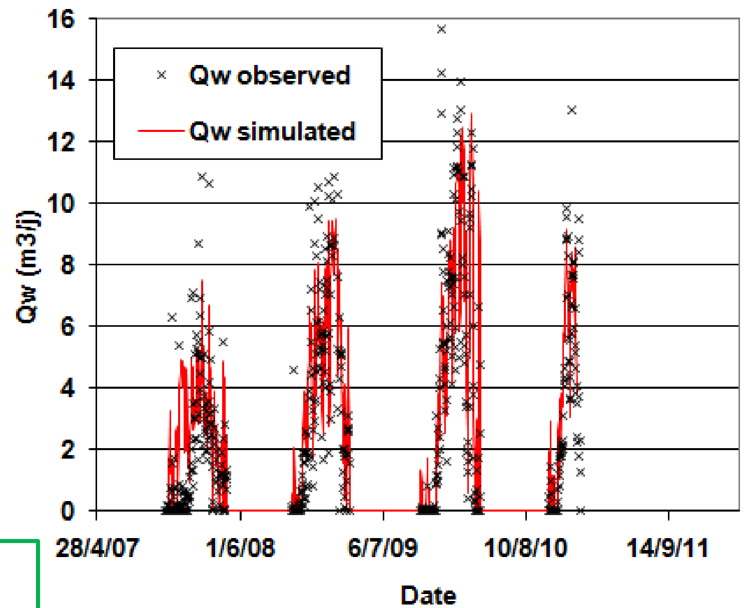
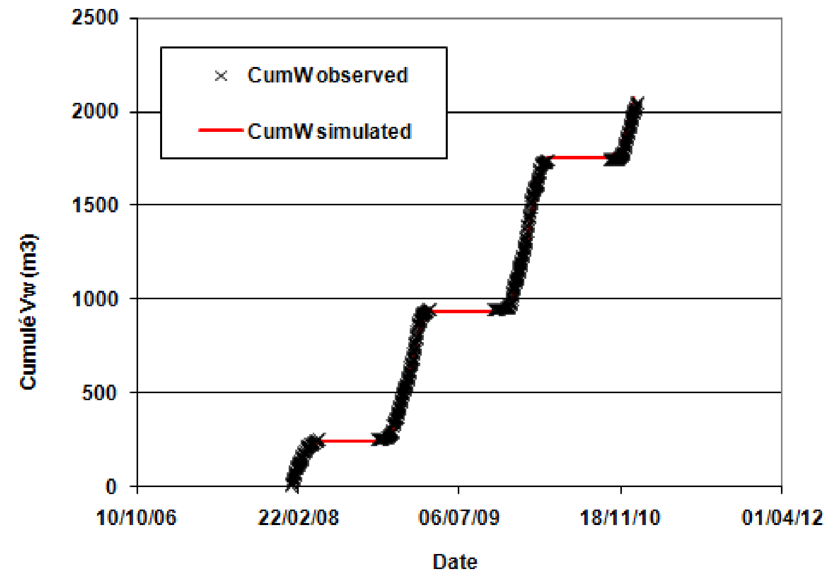
Context

- **Water production**
  - ***A wide issue***
    - **Aquifer storage**
    - **Converted depleted reservoir with active aquifer**
  - ***A key issue***
    - **Drive the overall performance (max rate, gas recovery)**
    - **Associated costs (no possibility to re-inject in subsurface)**
  - ***A complex issue***
    - **Various scales are relevant**
      - **Field scale: gas / water interface position**
      - ➢ **Importance of injection strategy**
      - **Well scale: local deformation of the gas / water interface**
      - ➢ **Importance of withdrawal strategy**
      - **Time scale: "memory" effect at repeated high solicitation**
      - ➢ **Importance of pluri-annual strategy**

➡ Are we able to reproduce these mechanisms in order to anticipate reservoir behaviour and its performance?

Contribution of this work





NB: Data
Frequency
Density
Accuracy
= key point

To show that various approaches exist to model in a consistent and predictive manner the water production

Field forecasts (global)

Well forecasts (local)

Optimize gas placement

Delay well stop date

Enhanced management

Outline

- Field scale
  - Two-phase flow in porous medium (Darcy)
  - Available tools
  - Examples of history matching (daily and cumulative productions)

- Well scale
  - Gas/water interface stability (coning)
  - Avalaible tools
  - Examples of history matching

- Time scale
  - Evidences of pluri-annual effects
  - Origin and consequences in term of performance

- Conclusions and perspectives

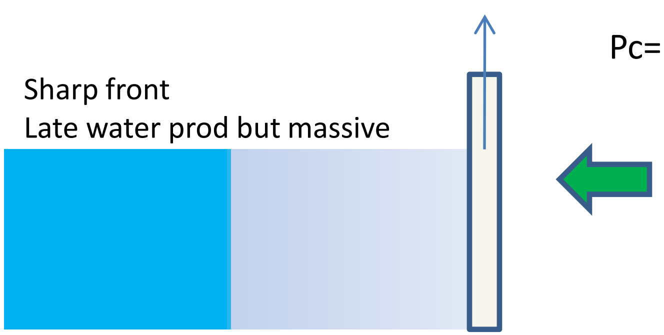
Two-phase flow in porous medium (Darcy)

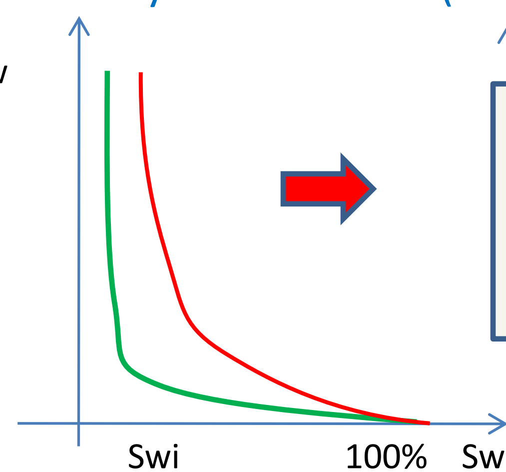
Global effect

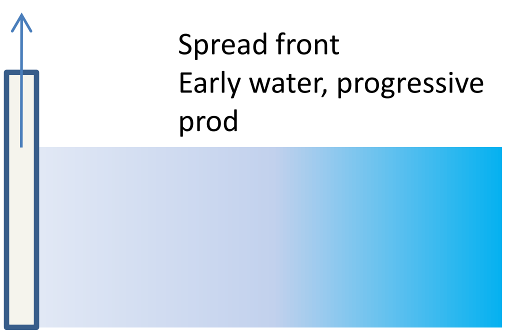
- Basis of what is implemented in numerical models
  - Relative permeabilities (Kr) : gas and water mobilities
  - Capillary pressure (Pc) : saturation state
  - Hysteresis (trapped gas)

Rule out the saturation distribution in the reservoir (Sw)
Major role on kinetic of water production
Few% Sw variation = huge impact (power law)

Pc often neglected in the matching process
often explains the lack of predictivity of the model (water prod)



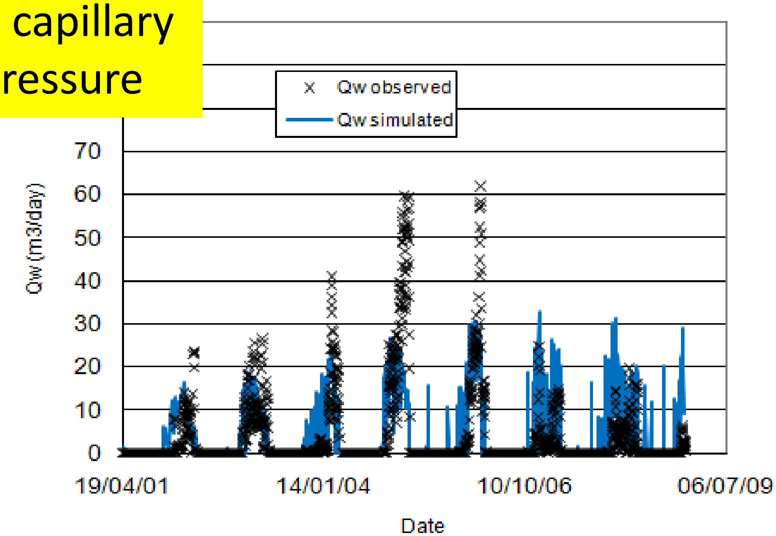




Field 1

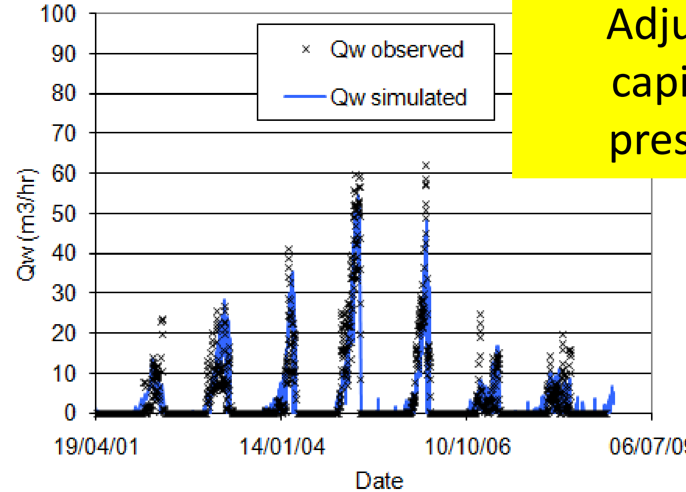
- 1D and 3D models + Automatic procedure
  - To reproduce pressure & water production
  - Tests with different initial values – confirmation of capillary pressure role

No capillary pressure



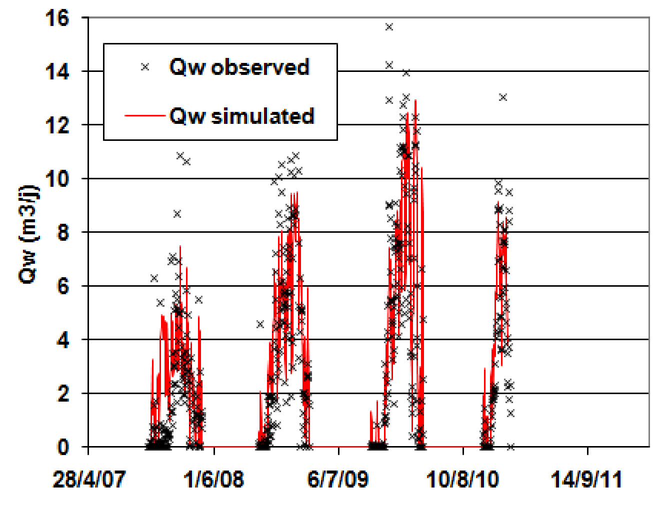
High water rates are missed

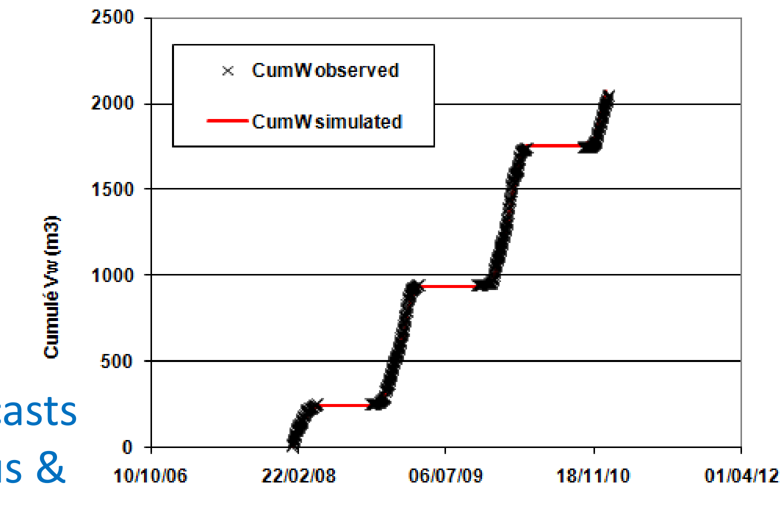
Adjusted capillary pressure



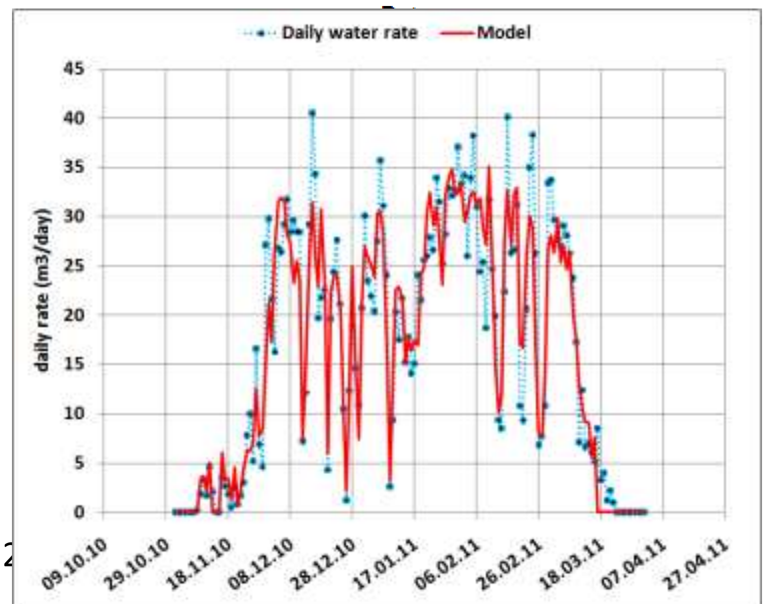
Large variabilities well reproduced by the model

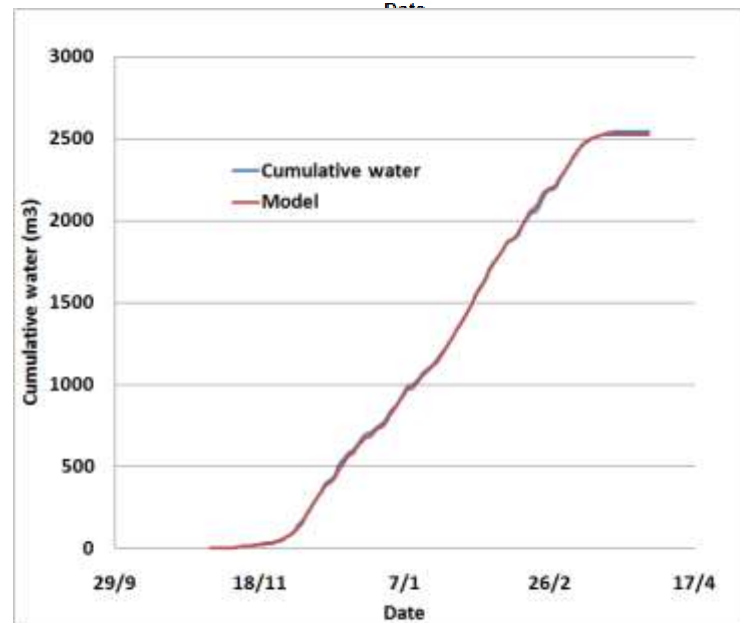
Field 2 & 3





Relevant forecasts (instantaneous & cumulative)





CS 2

Outline

- Field (or global) scale
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- Well scale
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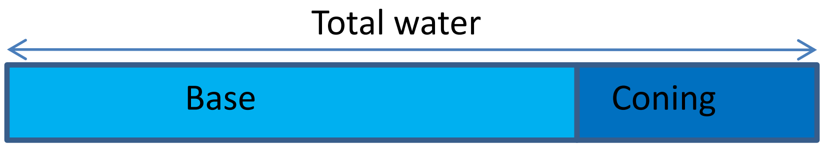
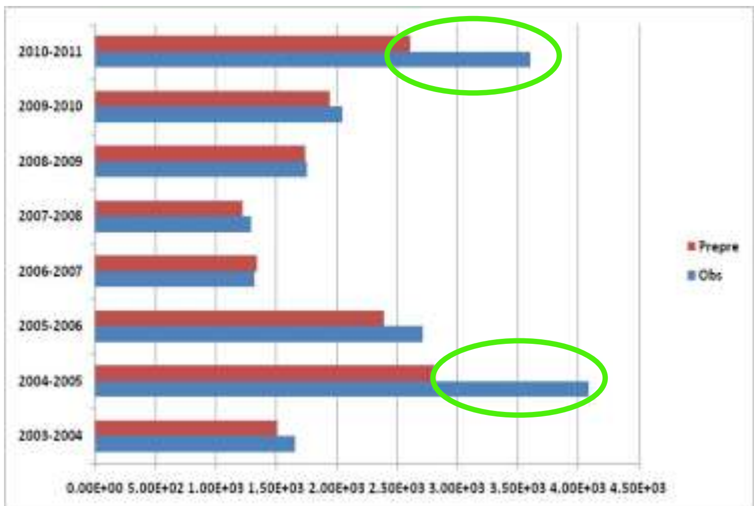
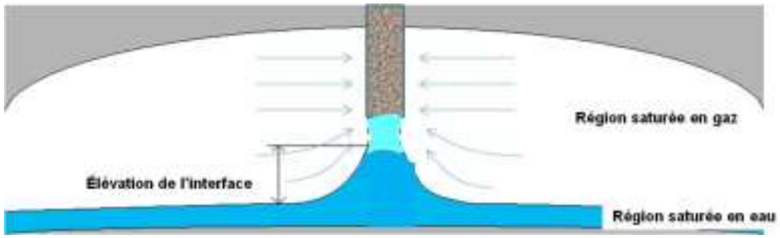
Coning water
Another possible contribution



Global scale
Pluri-annual effects possible

Well scale
Local mechanism
Rather annual effect (critical rate)





Important volume of water missed during high sollicitation campaigns

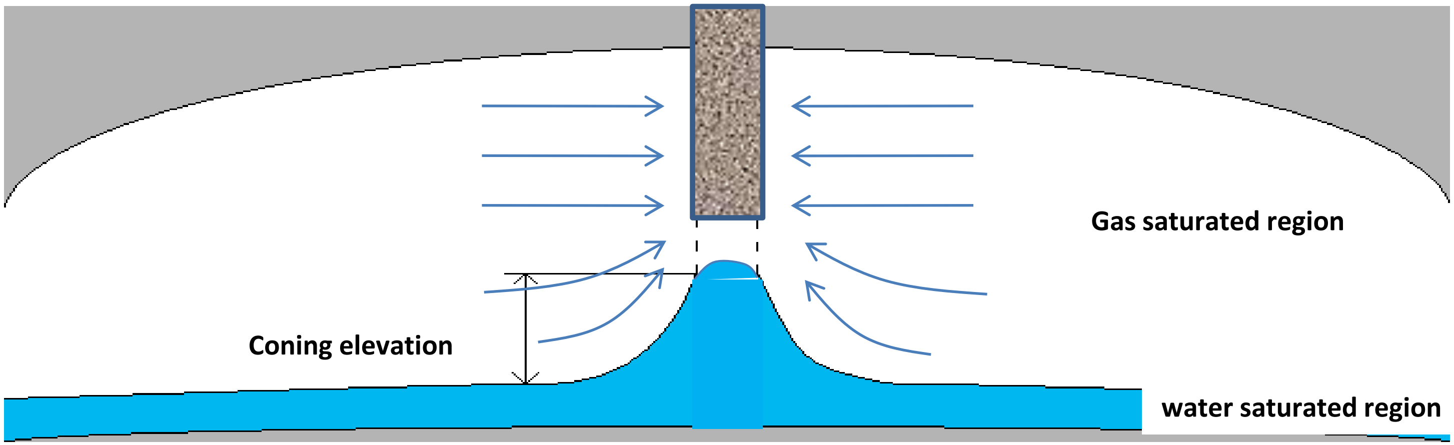
→ Need to account for coning contribution

CS 2.2

Gas/water interface stability (coning) (1)

Local effect

Gas rate below the critical rate: deformed interface but no water at the well



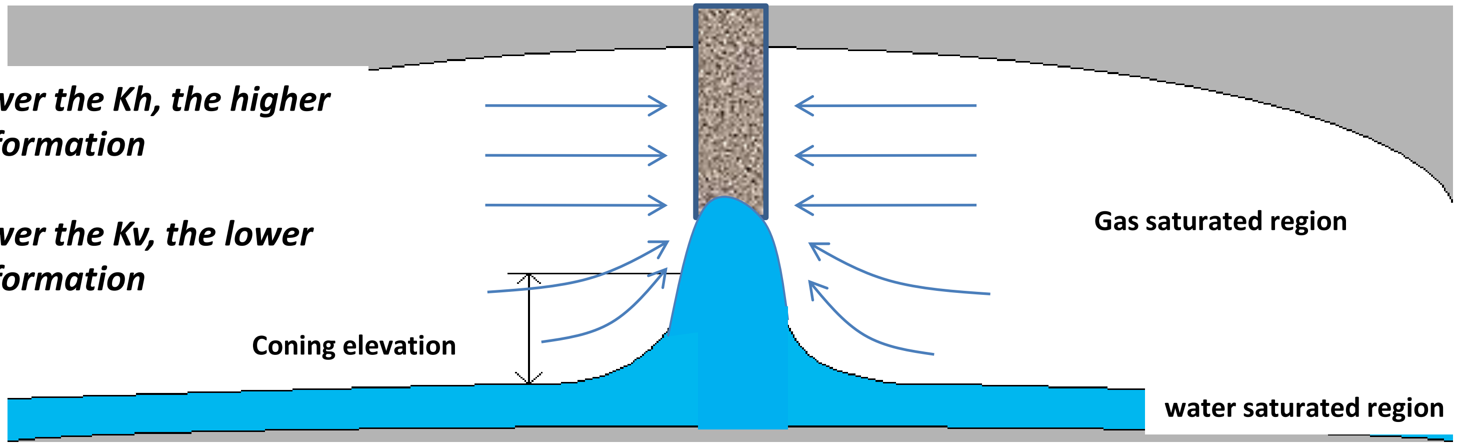
Equilibrium

Viscous F.
Versus
Gravity F.

Gas rate above the critical rate: water at the well – massive production

The lower the Kh, the higher the deformation

The lower the Kv, the lower the deformation

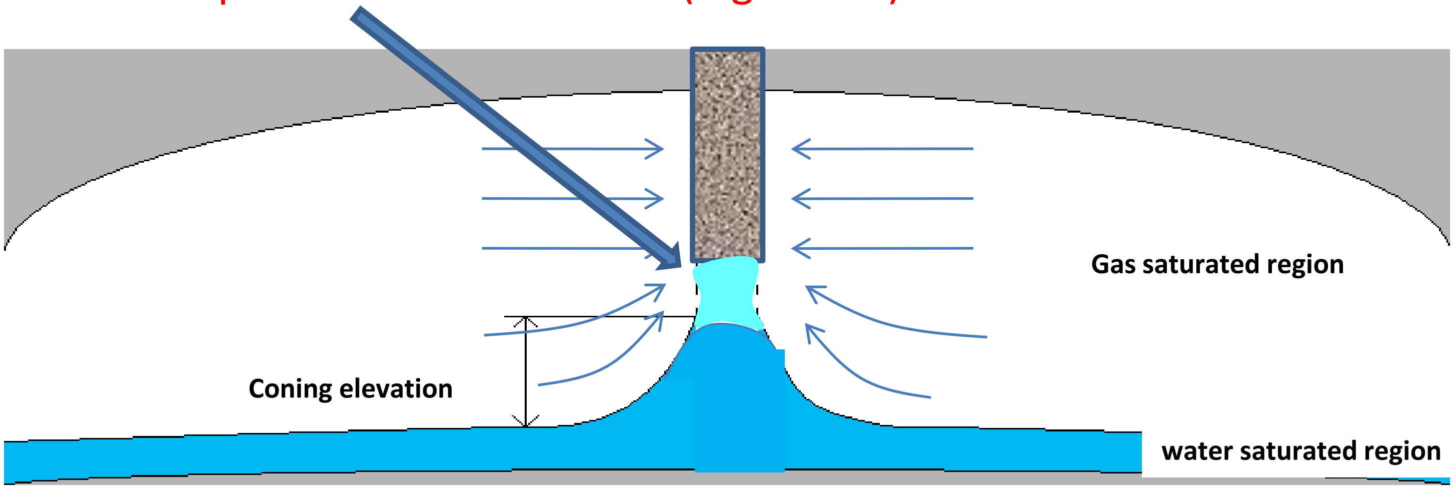


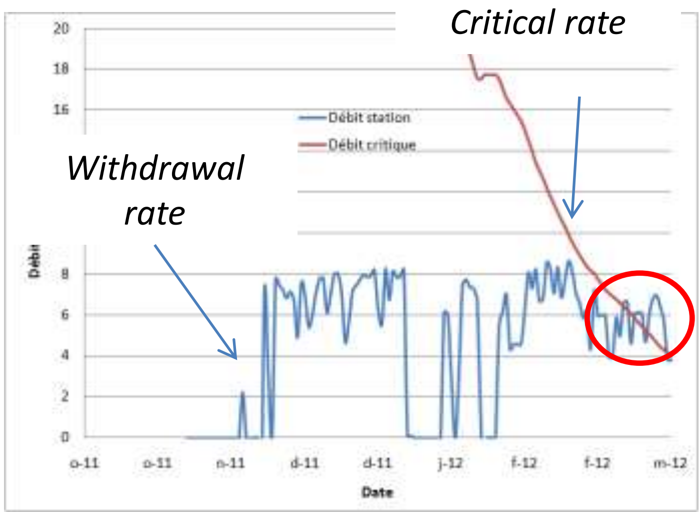
Gas/water interface stability (coning) (2)

Local effect

Once the critical rate overshooted, the situation is not reversible

Preferential path for the water flow (higher Sw)

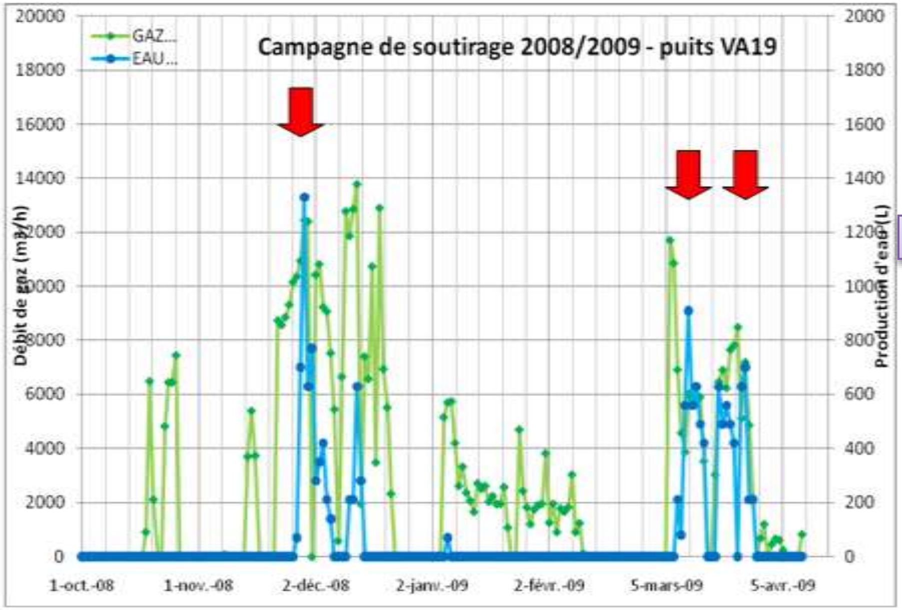


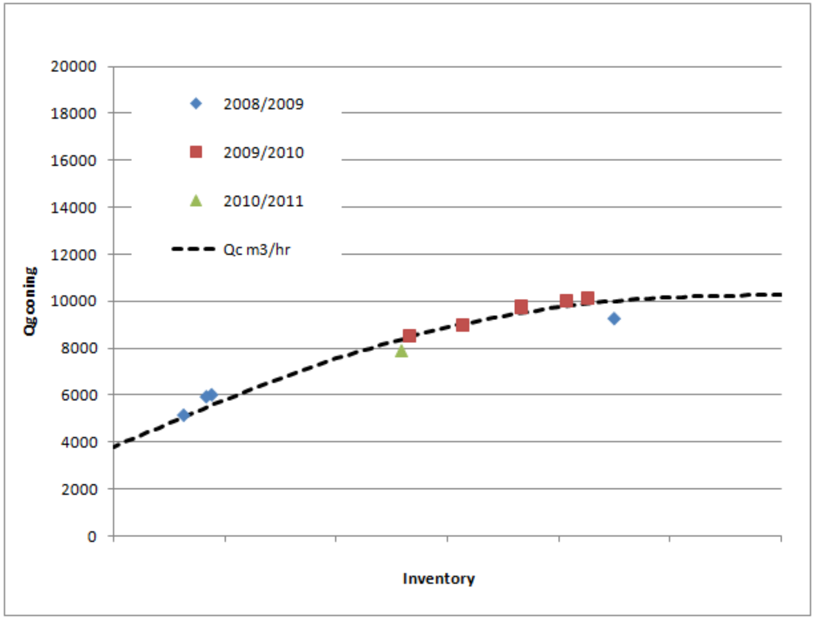


Importance of rate control at the end of withdrawal

Well by well approach needed (structural location and heterogeneity)

Approach followed to obtain critical rates





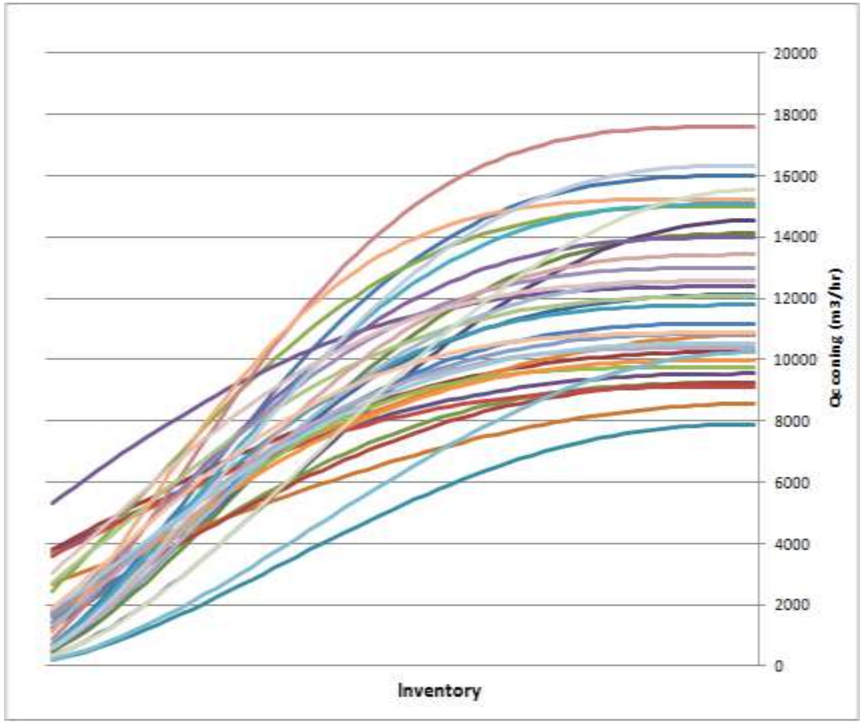
For each well, analysis of the 3 last campaigns to determine « observed » critical rate as a function of inventory

→ Limited gas rate variation but important water rate variation

Extrapolation over the whole range of inventory using an analytical model

Hoyland et al. (1989) Muskat & Wyckoff (viscous versus gravity forces)

Coning analysis added value
Integration



Operational recommendations

Updated performance curves

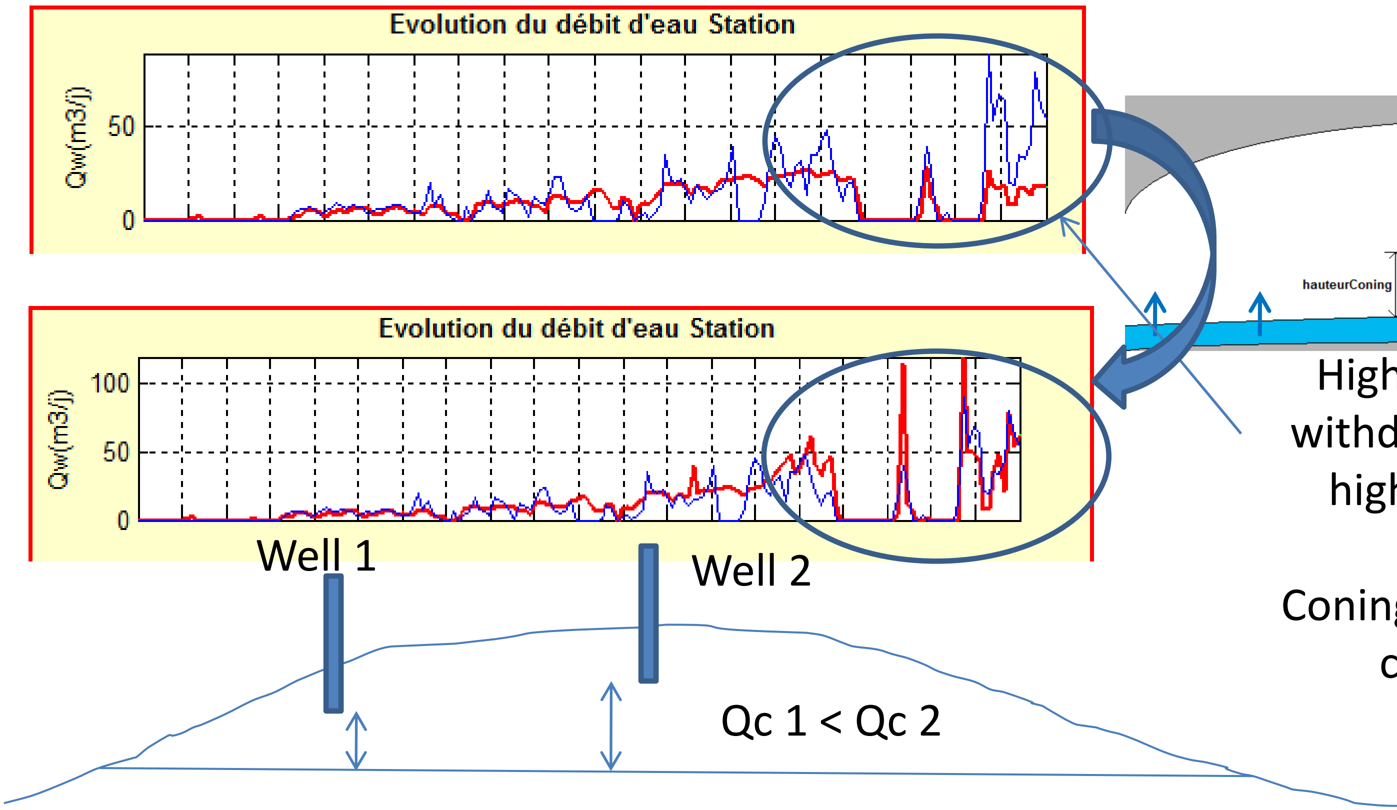
Integration in numerical tools

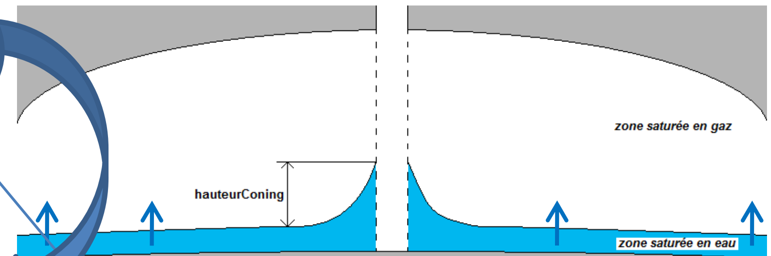
Production data are very rich
(data mining)

Important variability from one well to another
(plateau rate and decreasing part → need for adjusted rates)

Coning modelling added value (1)

Fields scale results





High rates at the end of withdrawal contributed to high water production

Coning modeling leads to a consistent match

Critical rate constraint adapted to
- Structural well position
- local heterogeneities (geological & petrophysics)
- well completion

Enhanced management of the end of withdrawal

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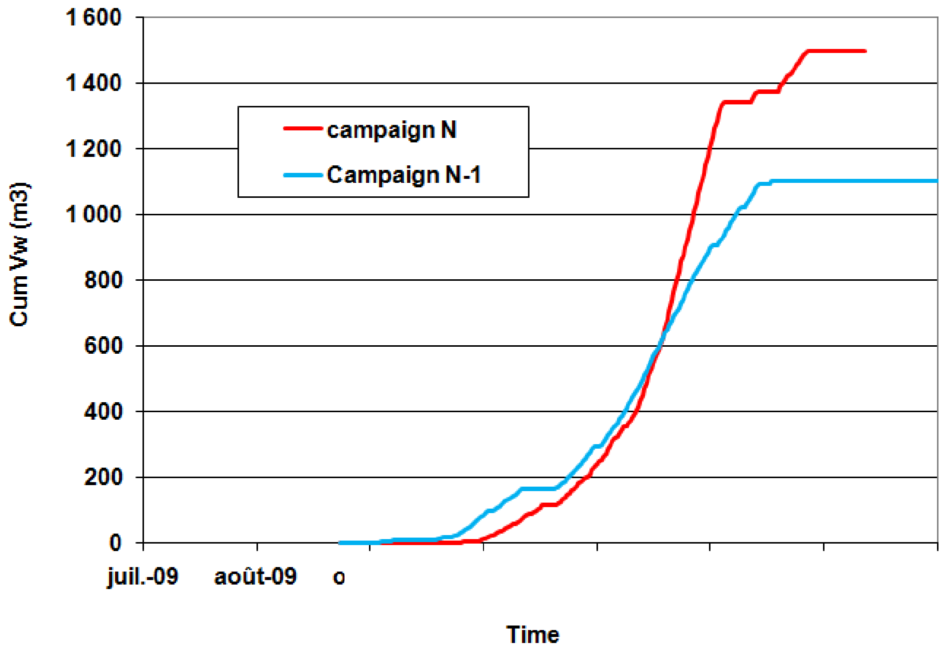
Pluri-annual effects (1)

Findings from the data analysis

Two consecutive years with similar inj/prod profiles

BUT very different water production profiles (amplification)

Not improved by ''optimized'' trajectory (small-long rate, re-injection, ..)



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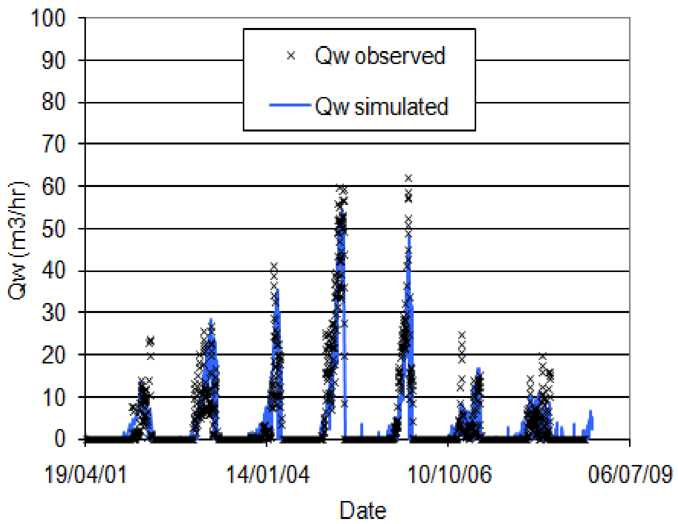


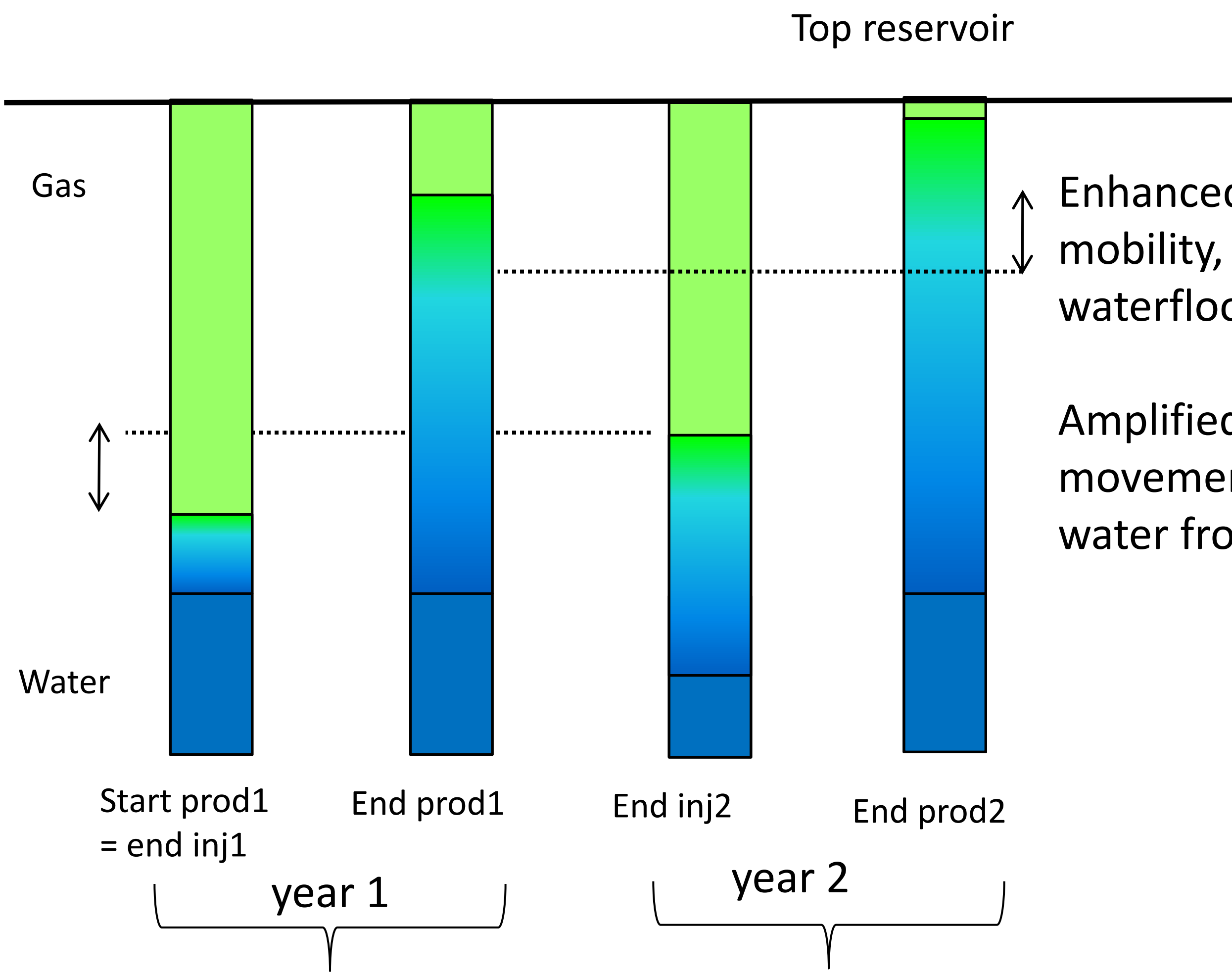
It suggests a memory effect of the storage at a pluri-annual scale

Pluri-annual effects (2)

Suspected explanation

End injection after important withdraw.

Higher water saturation

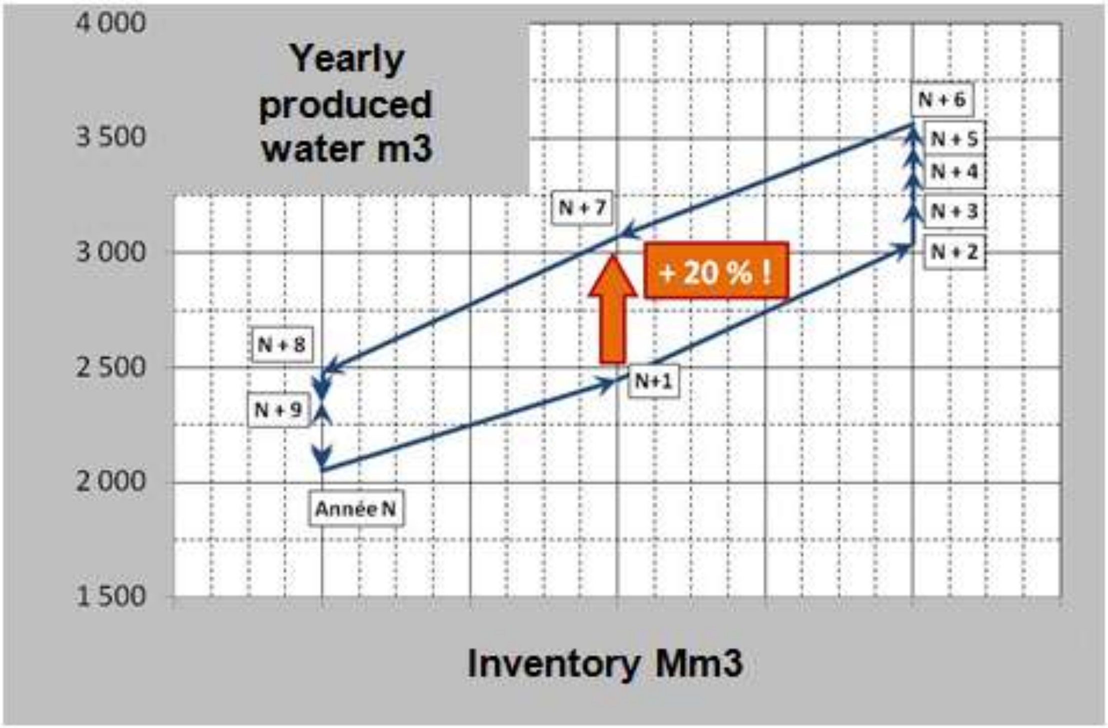


Enhanced water mobility, faster waterflooding.

Amplified movement of the water front

Pluri-annual effects (3)

Hysteresis loop



Quasi reversible mode when working gas (WG) produced is « small »

Hysteresis phenomena when high sollicitations are repeated

One level of storage cycling = One equilibrium state with the aquifer

Changing sollicitation mode makes the aquifer adapt (time depend on the reservoir)

New equilibrium => higher water production (new saturation range)

Conclusions - perspectives

- Several tools available to model water
  - Field or well scale
  - Operational support or long term studies
  - Importance to account for the relevant physical mechanisms
    - » Capillary pressure is important
    - » Coning effect plays a major role at the end of withdrawal
  - Water production can result from a pluri-annual effect

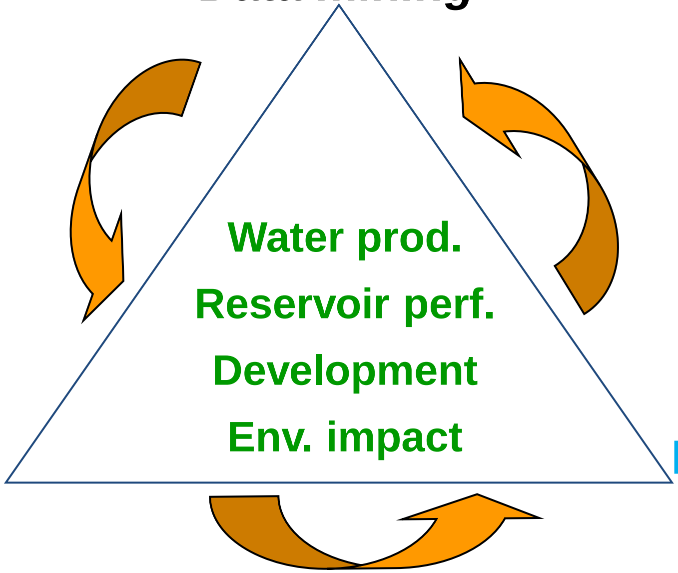
- These tools contributes to the performance
  - Better management of the end of withdrawal
  - Minimization of the water produced

- Perspectives
  - Integrated tool
    - » « Real time » analysis
    - » Optimized trajectories (pluri-annual effect)

Available tools

Short-term

Data mining



Short-medium-term

Genetic algorithm

Well model

PrePre (1D) (in-house)

Fully implicit – radial geometry

Two-phase flow including hysteresis

Structural shape (gravity effect)

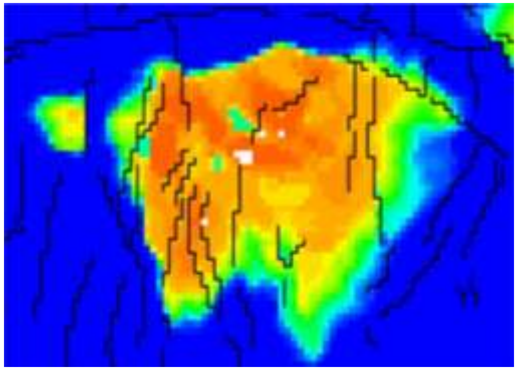
Fast calculation time

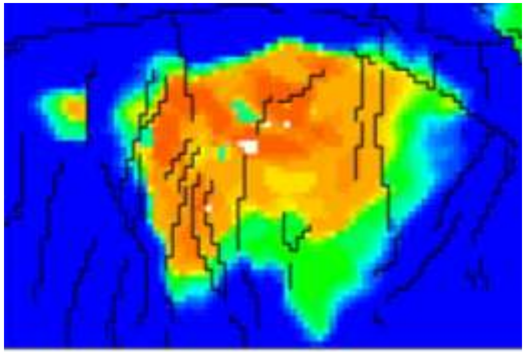
Used on daily basis in operation

Medium-long-term

MULTI (3D) (in-house)

Top view
High inventory





Top view
Low inventory

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