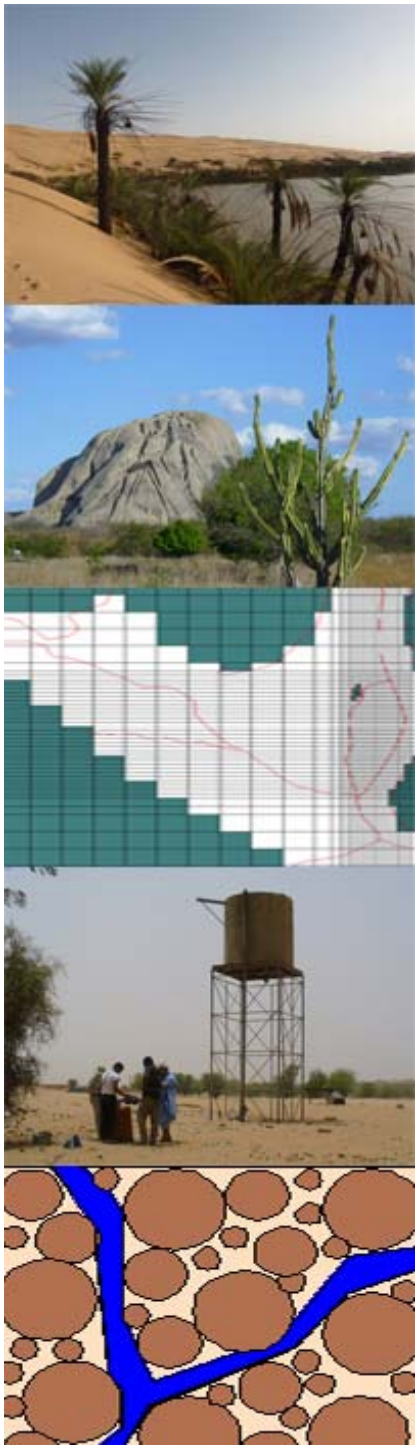

# Groundwater modelling in semi-arid Africa: challenges and lessons


**Christian LEDUC**

**IRD, UMR G-EAU**

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**Transboundary Aquifers Cooperation in Africa, Tunis, September 2017**

# Context

**ideas and proposals**
**based on various experiences from**
**hydrogeological studies**
**in semi-arid Africa**

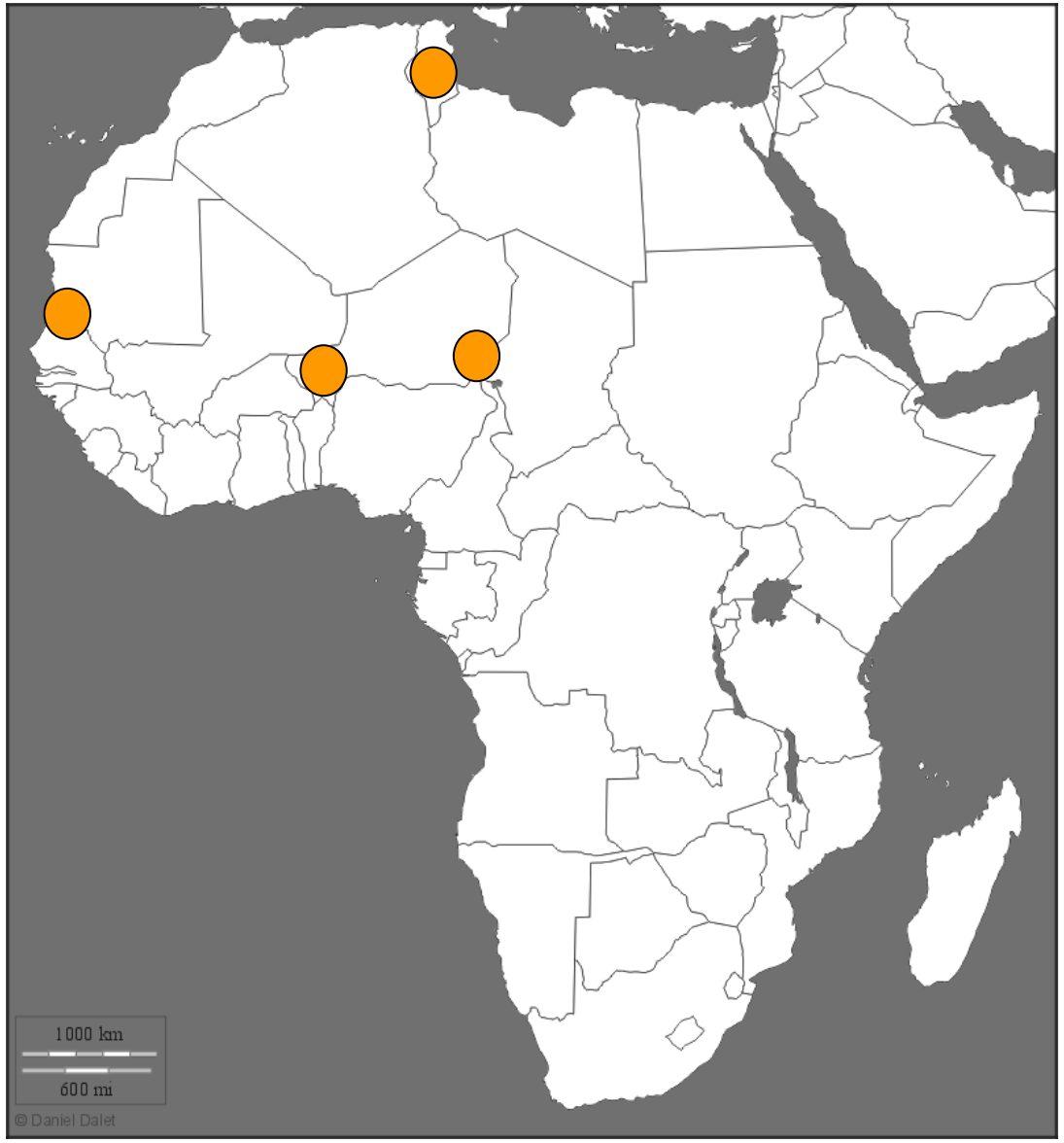
**Merguellil catchment (central Tunisia)**

**Senegal-Mauritania Basin**

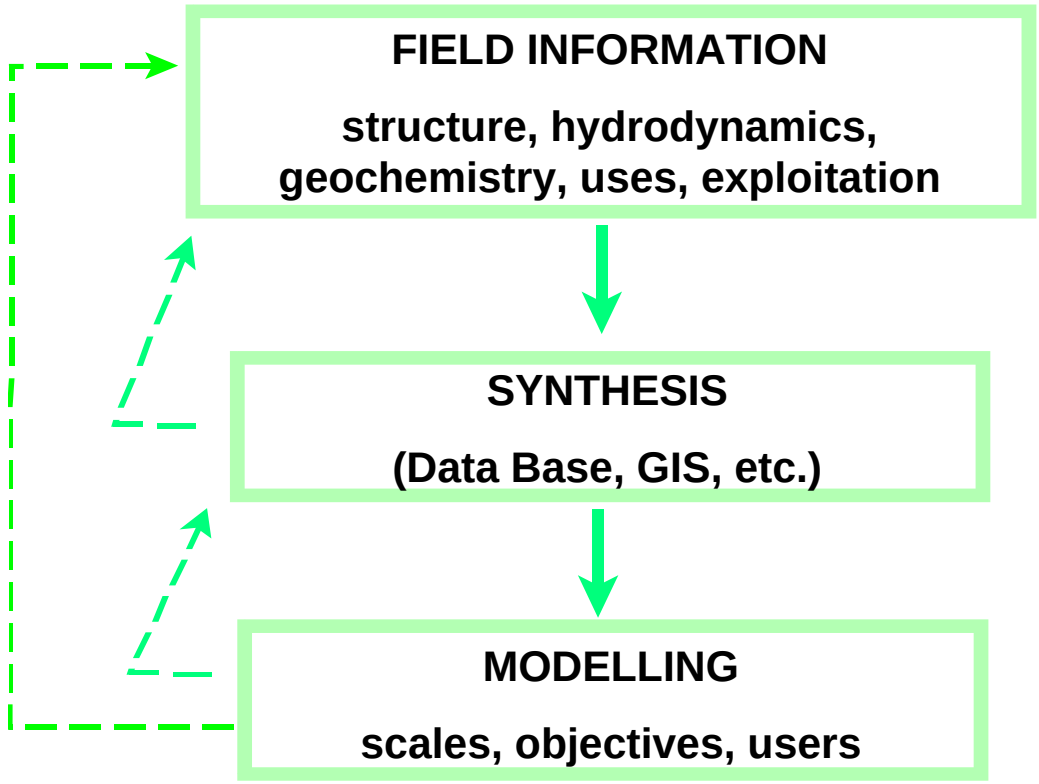
**Iullemeden Basin (SW Niger)**

**Lake Chad Basin**

**and others**



# A step inside an iterative process




a reliable GW modelling requires { time, efforts, high capacities in critical analysis on { data methods results

# A definition of a GW model

**an intellectual construction**

- **integrating a reasonable part of the field complexity**
- **aiming to reproduce the behaviour of the socio-physical system**
- **according to a given level of knowledge**
- **in response to specific questions**
- **without a unique solution**

**an overall quality depending on**

- **data and assumptions**
- **intrinsic capacities of the model and modeller**

> ***As far as the laws of mathematics refer to reality, they are not certain;***
> ***and as far as they are certain, they do not refer to reality***
>
> ***A. Einstein***
> ***English translation of the conference "Geometrie und Erfahrung", Berlin, 1921***

# Complementary aims of a GW model

**A tool for improving knowledge**

**PAST PRESENT future**

**compensation of data scarcity**

**exploration of possible hypotheses**

**overall consistency of elementary interpretations**

**various scales of analysis**

**and**

***/***

**or**

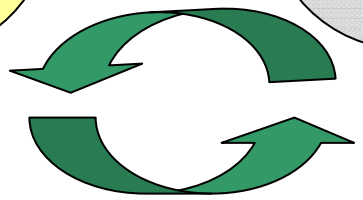
**A tool for improving management**

**past PRESENT FUTURE**

**definition of the water territories**

**support for a dialogue between stakeholders**

**exploration of scenarios**



**necessary interactions**

# Specificities of GW models in semi-arid areas

**Severe limitation by**

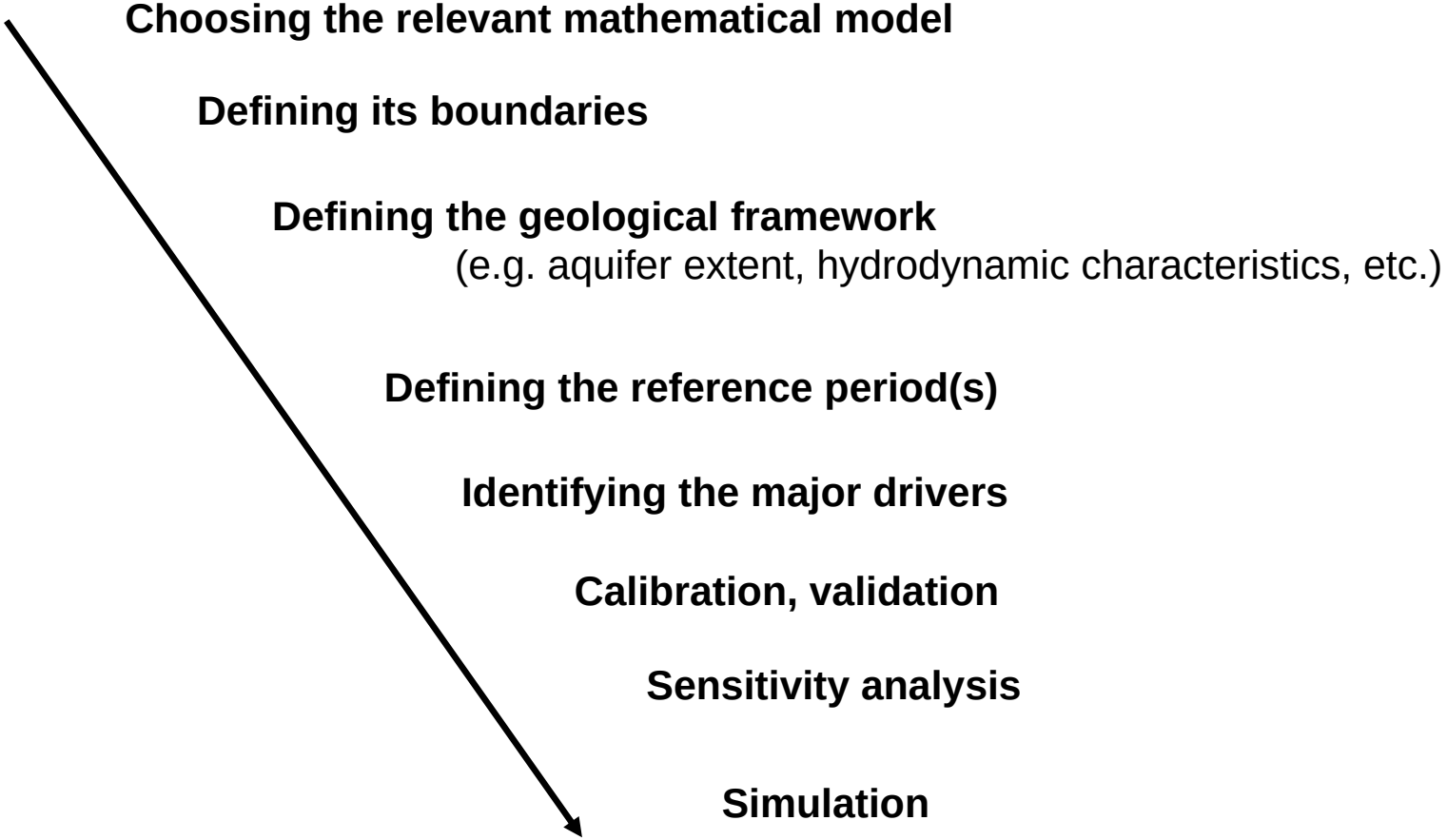
- **quantity, quality, representativeness of data**
- **density of information vs. complexity of physical and social phenomena**
- **rapidity of temporal changes**

**Importance of**

- **long-term processes**
- **exceptional events**
- **rapid changes**

**Interests of exploring processes that cannot be measured directly in the field**

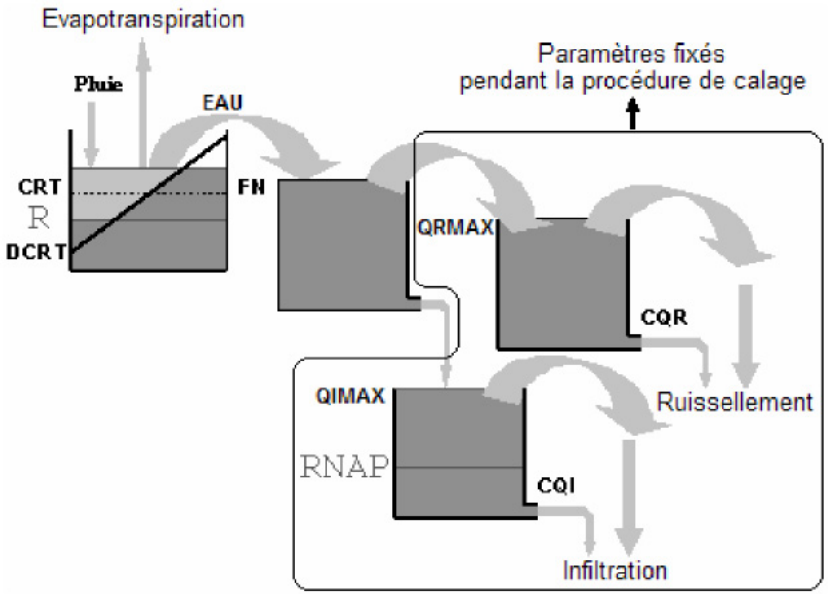
# The classical succession of steps



# Choosing the relevant GW model

**mathematics adapted to processes**

- **porous medium**
- **fractured medium**
- **black box**



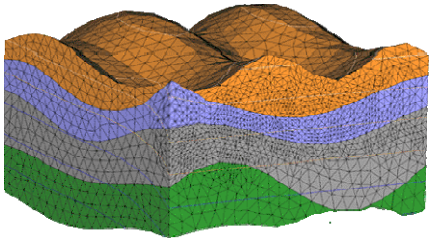

**black box and other empirical models**

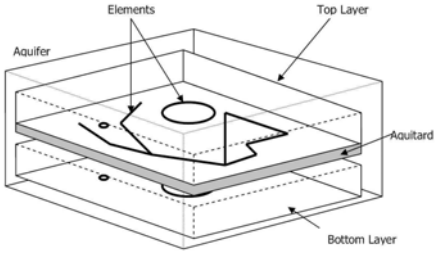
**operationality**

**management of data, I/O**

**satisfying level of accuracy**

**skilfullness of the modeller/user**






**physically based (e.g. Darcy)**

# Boundaries of the model

**relevant scales in space and over time**

**(data, objectives of knowledge vs. management)**

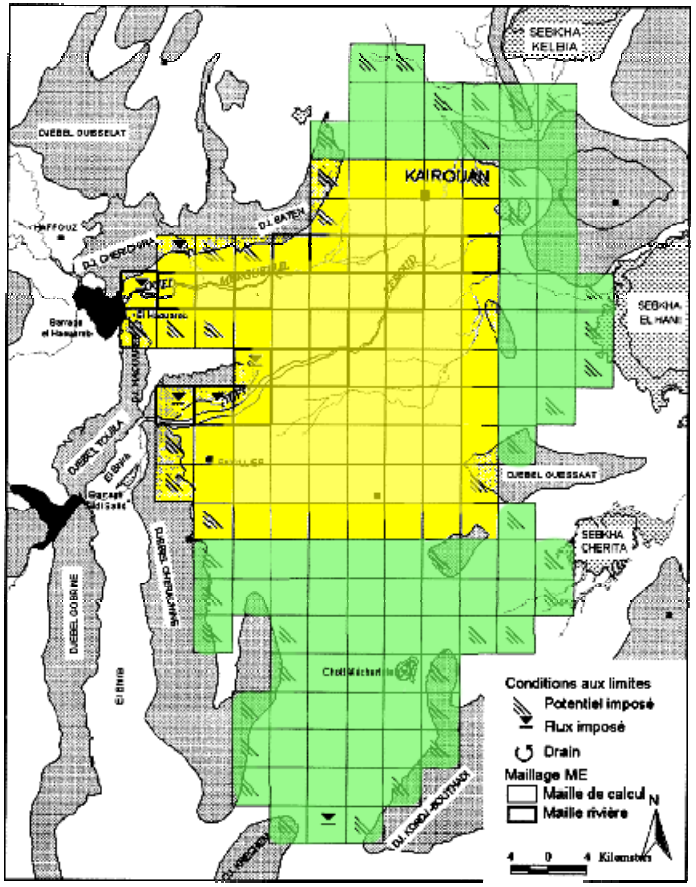
**major processes (in the present and future state)**

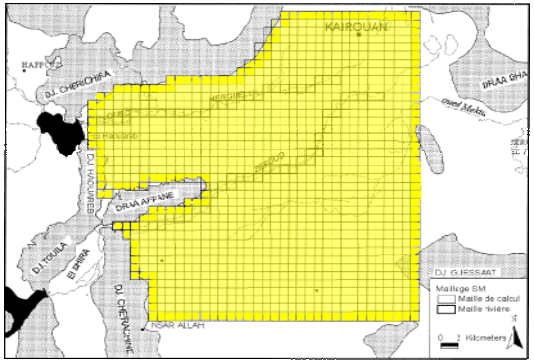
**requirements vs. neglegts**

**internal vs. external interactions**

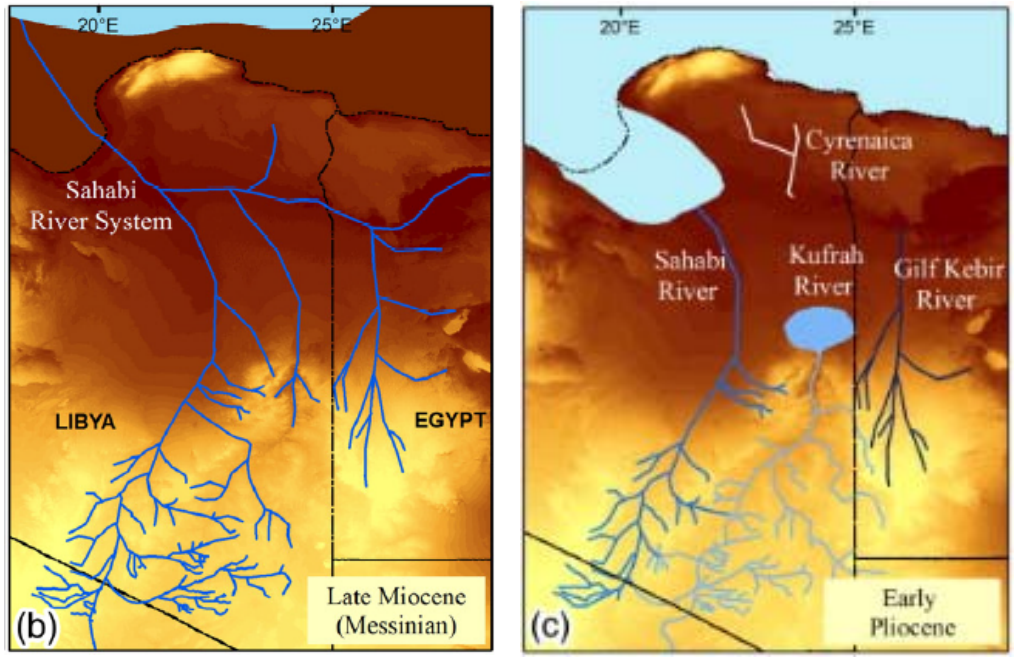
**influences of boundaries on calculation**

**i.e. exhaustiveness vs. relevancy and efficiency**

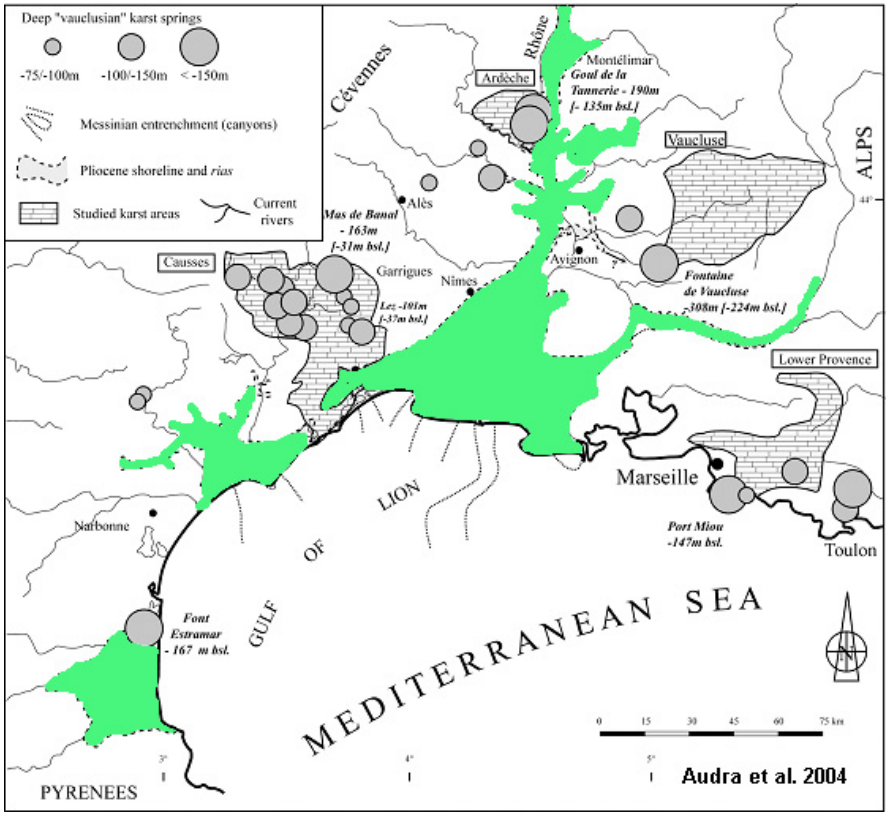


# The geological framework

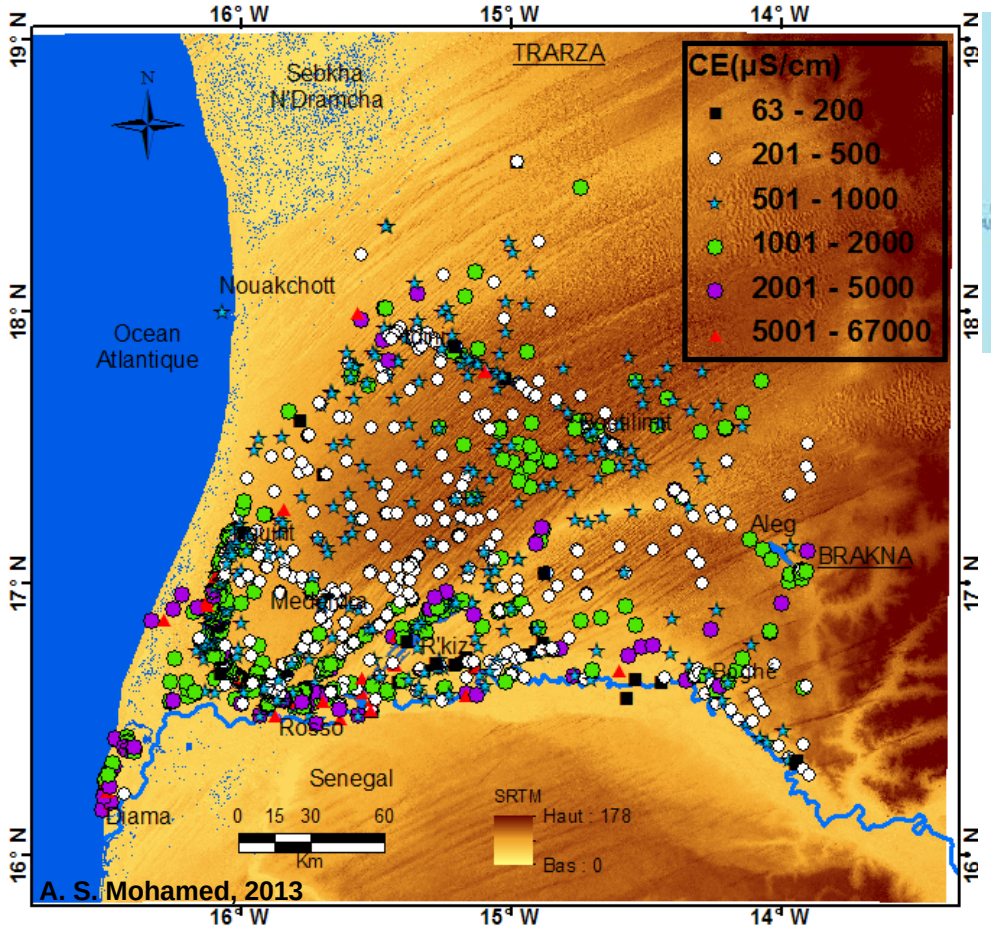



***The Kufrah paleoriver (Libya)***




***Messinian rias in SE France and karstic springs***

# The geological framework (2)

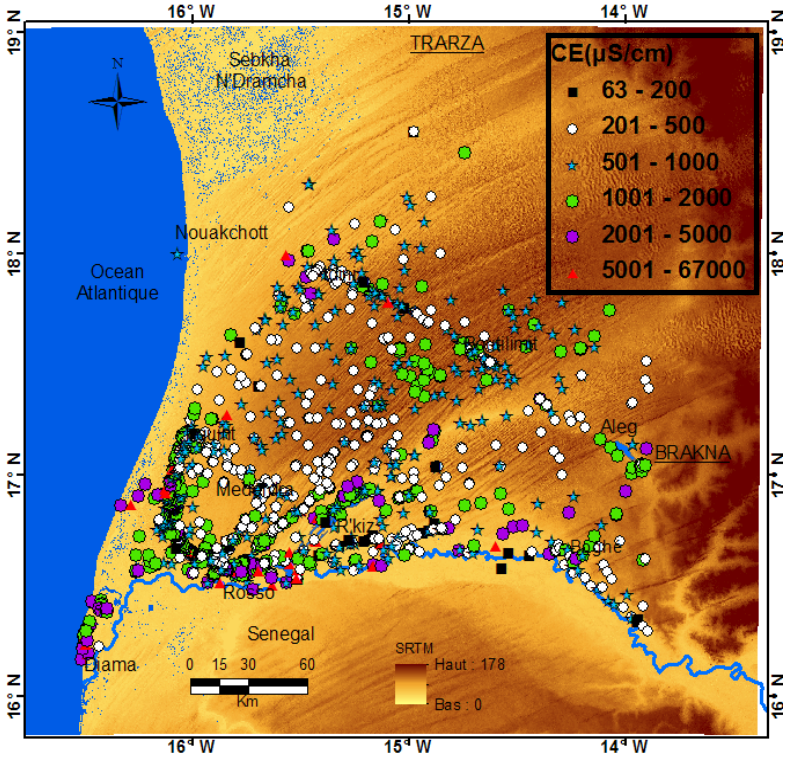


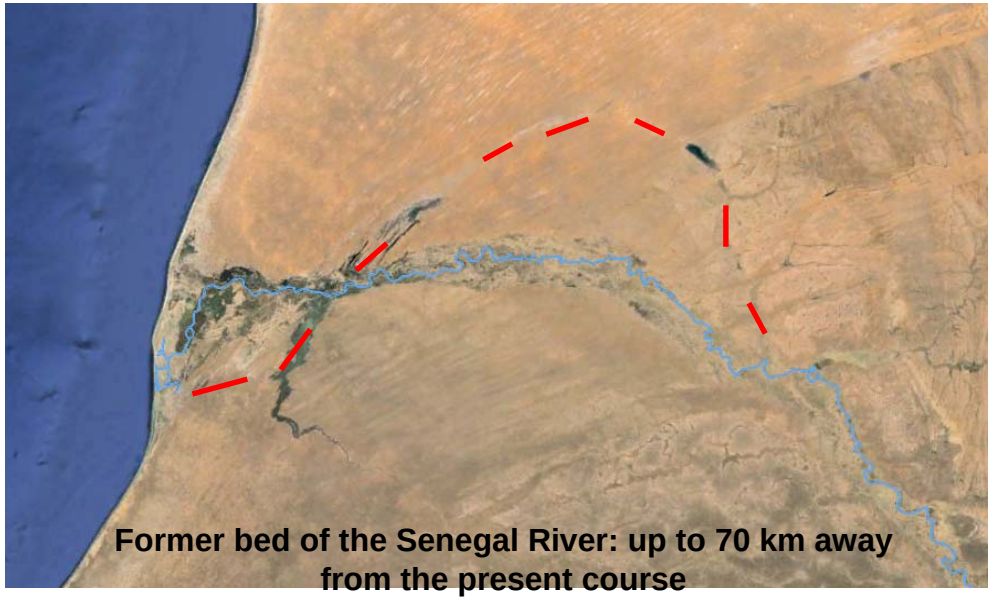


| CE (µS.cm$^{-1}$) | % |
|---|---|
| < 200 | 2 |
| 200-500 | 30 |
| 500-1000 | 35 |
| 1000-2000 | 22 |
| 2000-5000 | 8 |
| > 5000 | 3 |

**The present distribution of GW salinity is not explained by mineralogical variations in aquifer sediments.**

# The geological framework (3)

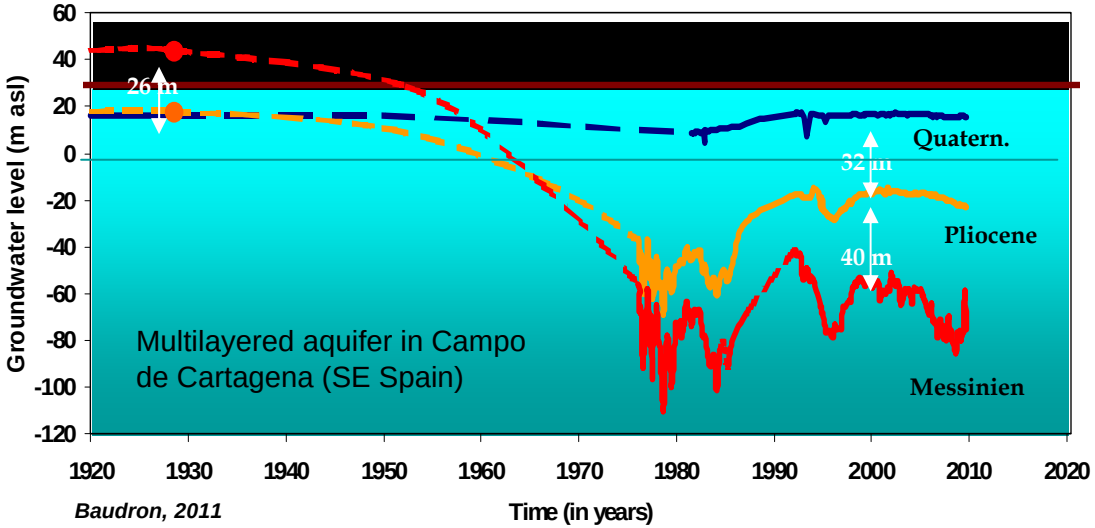



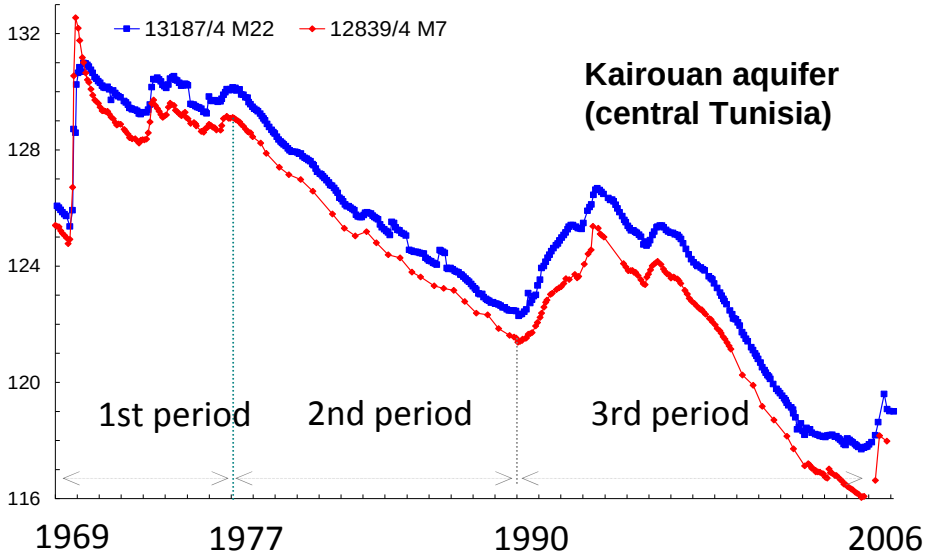

**The present distribution of GW salinity is primarily explained by**

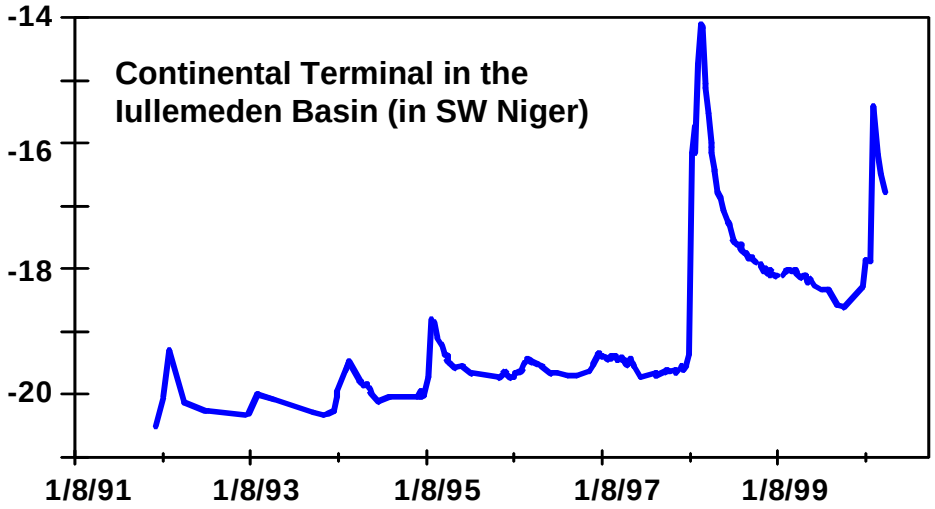
**- Holocene eustatic fluctuations, ans seawater intrusion up to 200 km upstream in the Senegal valley,**

**- changes in the location of the Senegal River bed.**

# Defining the reference period



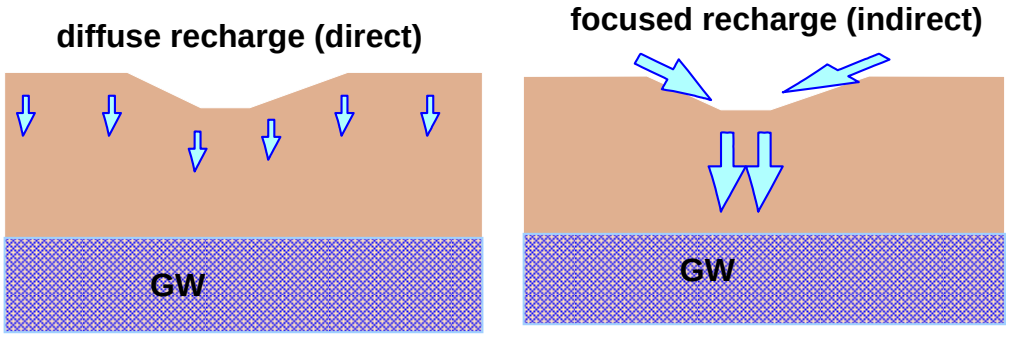

**In most semi-arid regions, we had to refer to an "old" period (1960 or before):**

**- more stable conditions**

**- increased uncertainty on data**

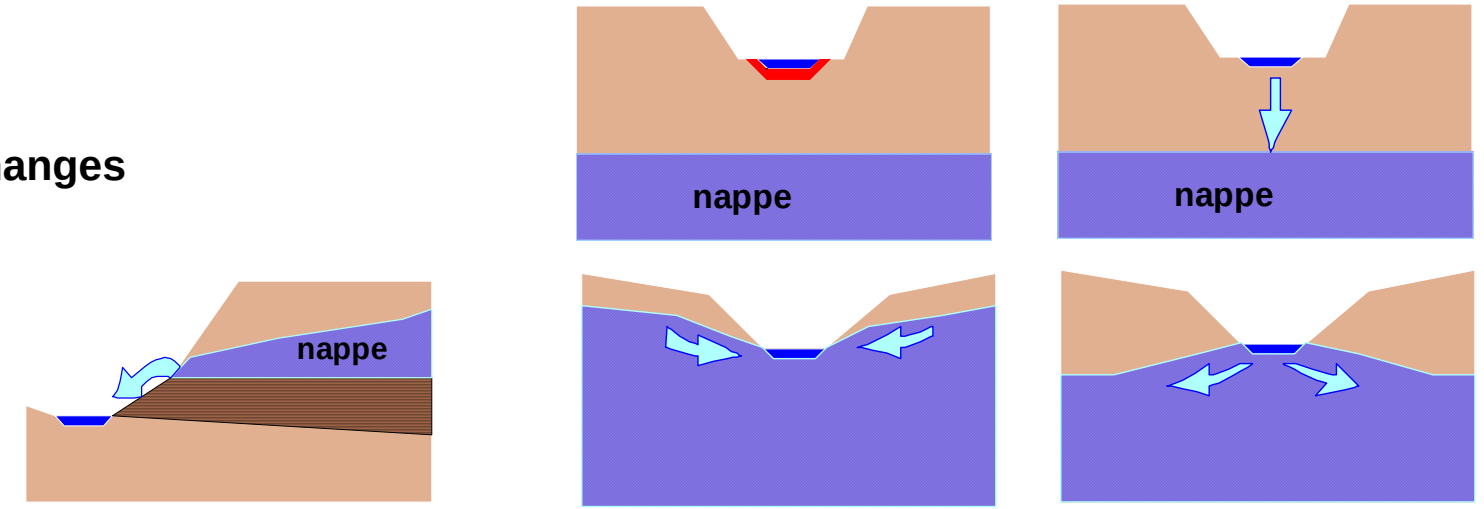
# Example of the recharge identification: processes

**rainfall infiltration**



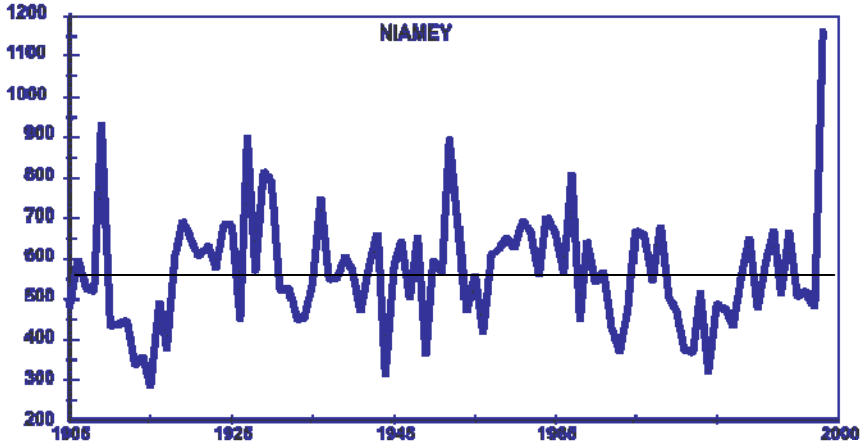

**proportion of focused recharge is assumed to increase with aridity**

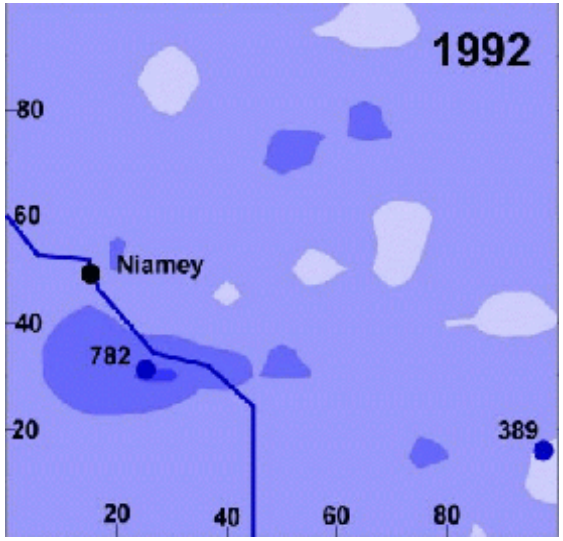
**surface-GW exchanges**

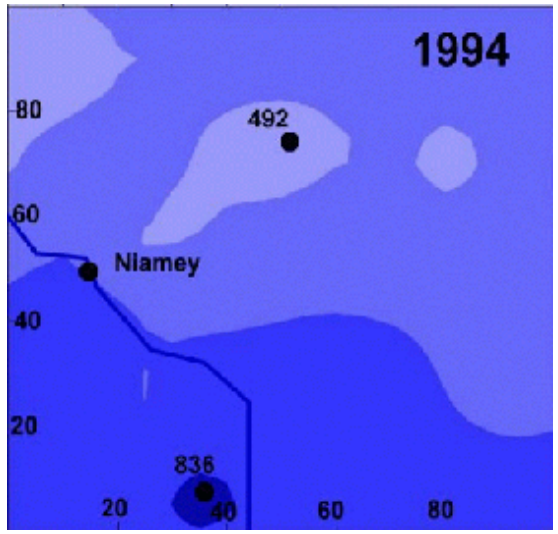


# Example of the recharge identification: rainfall

**Variations of rainfall in space over time**



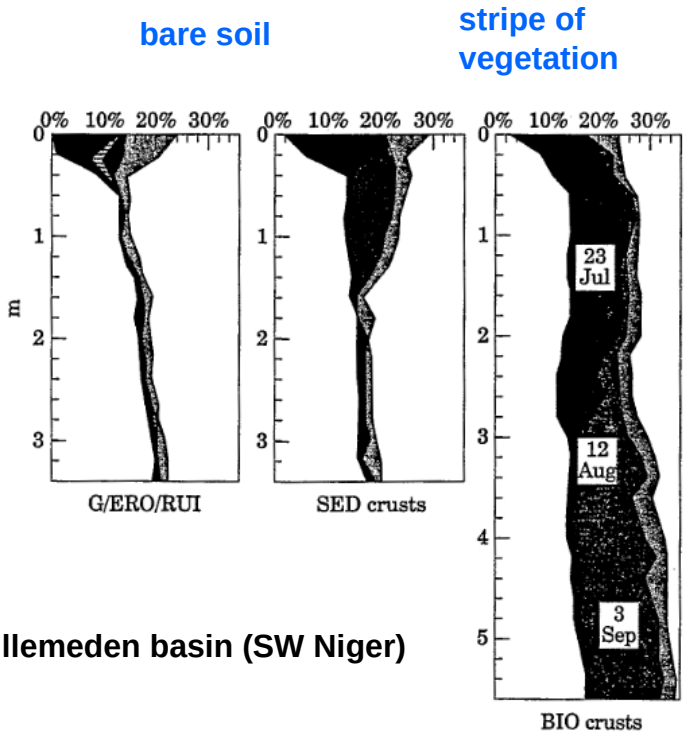



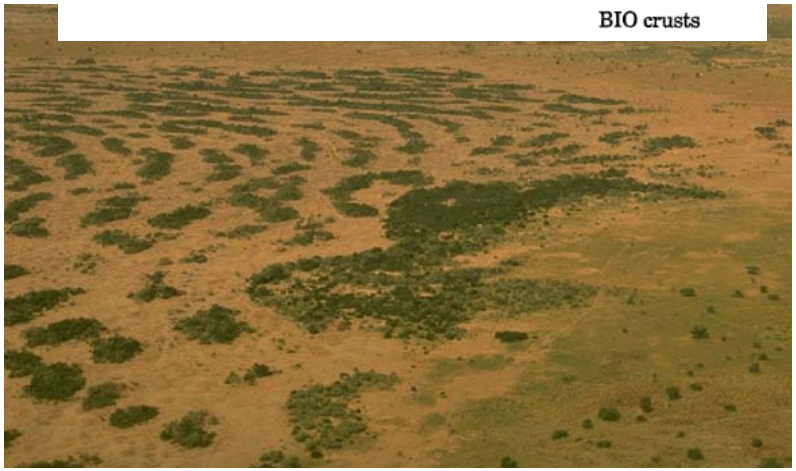

**largely exceeding the density of observation networks**

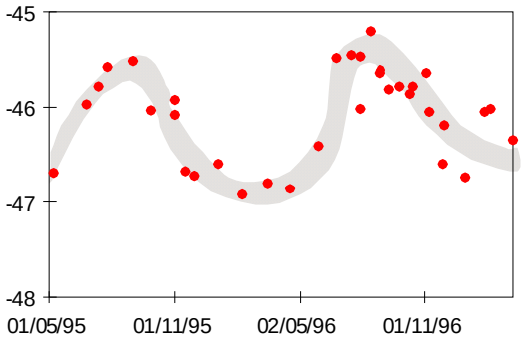
# Example of the recharge identification: rainfall

## Transformation of rainfall into recharge

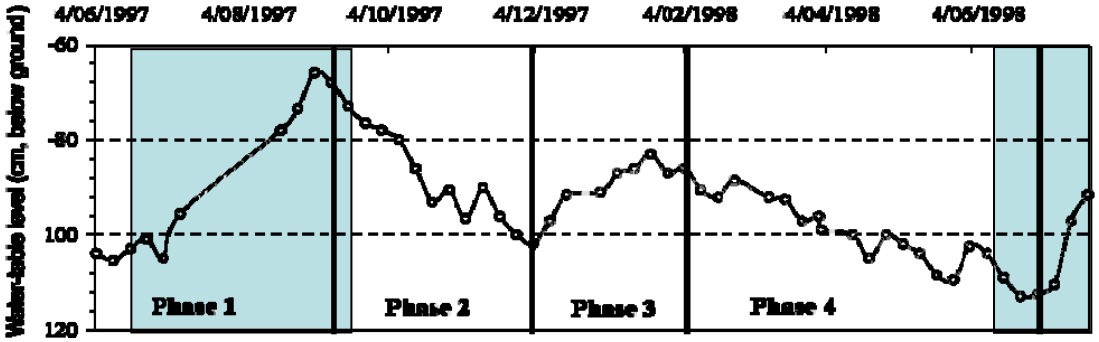



Iullemeden basin (SW Niger)






seasonal variation



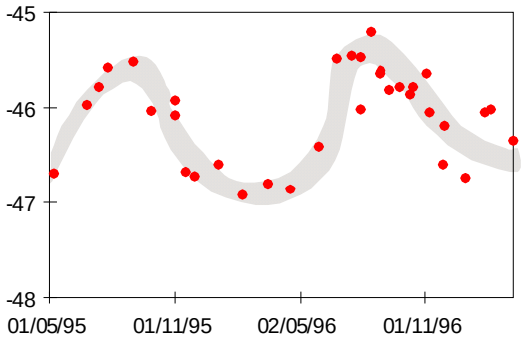

one rainy season, two GW rises per year

(Lake Chad Basin)

# Example of the recharge identification: rainfall

**Observations from the Iullemeden Basin**

**over a very short distance, in a phreatic aquifer open to rainfall infiltration**

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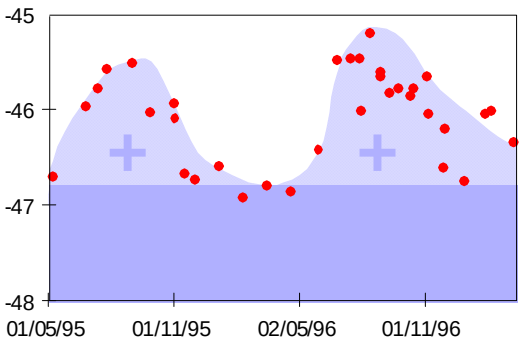
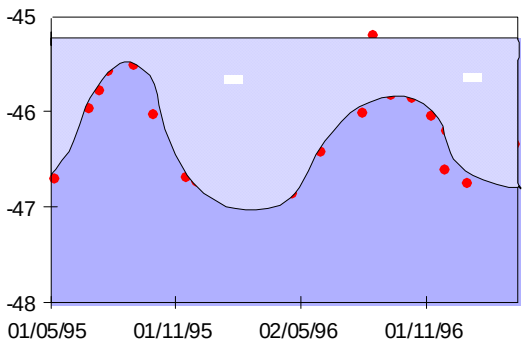
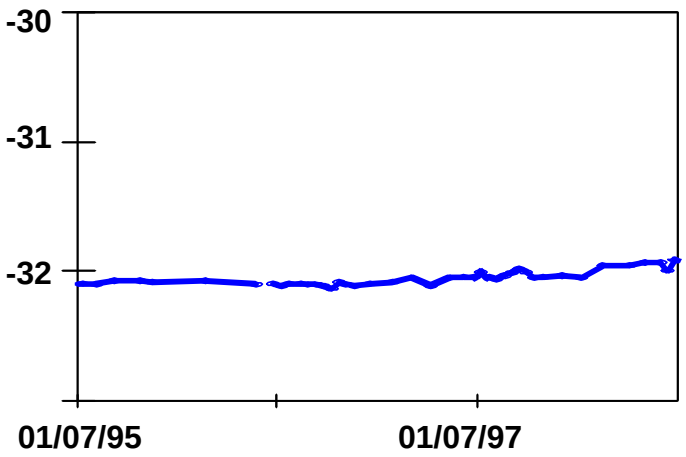


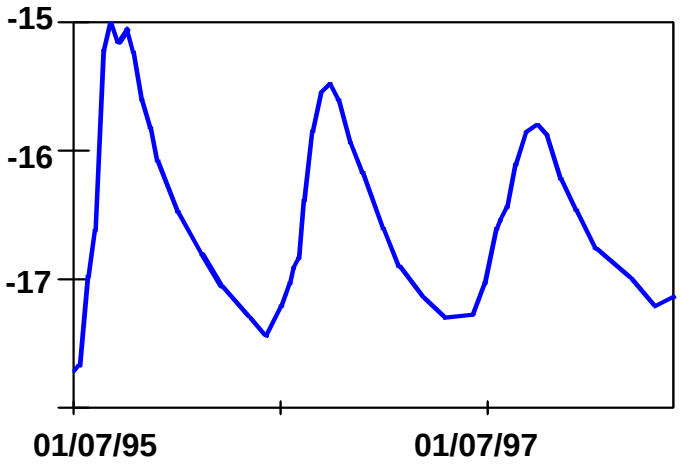

**or**




**?**

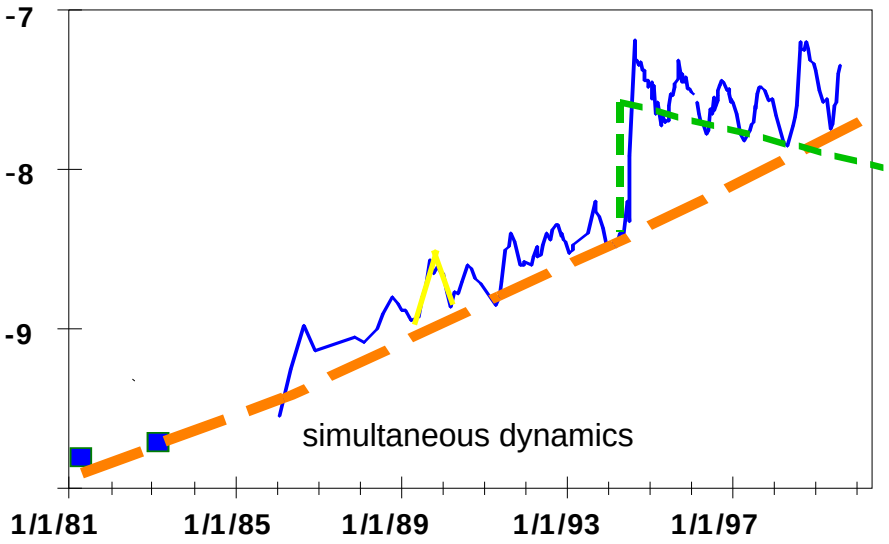
**seasonal variation** **seasonal increase** **seasonal decrease**

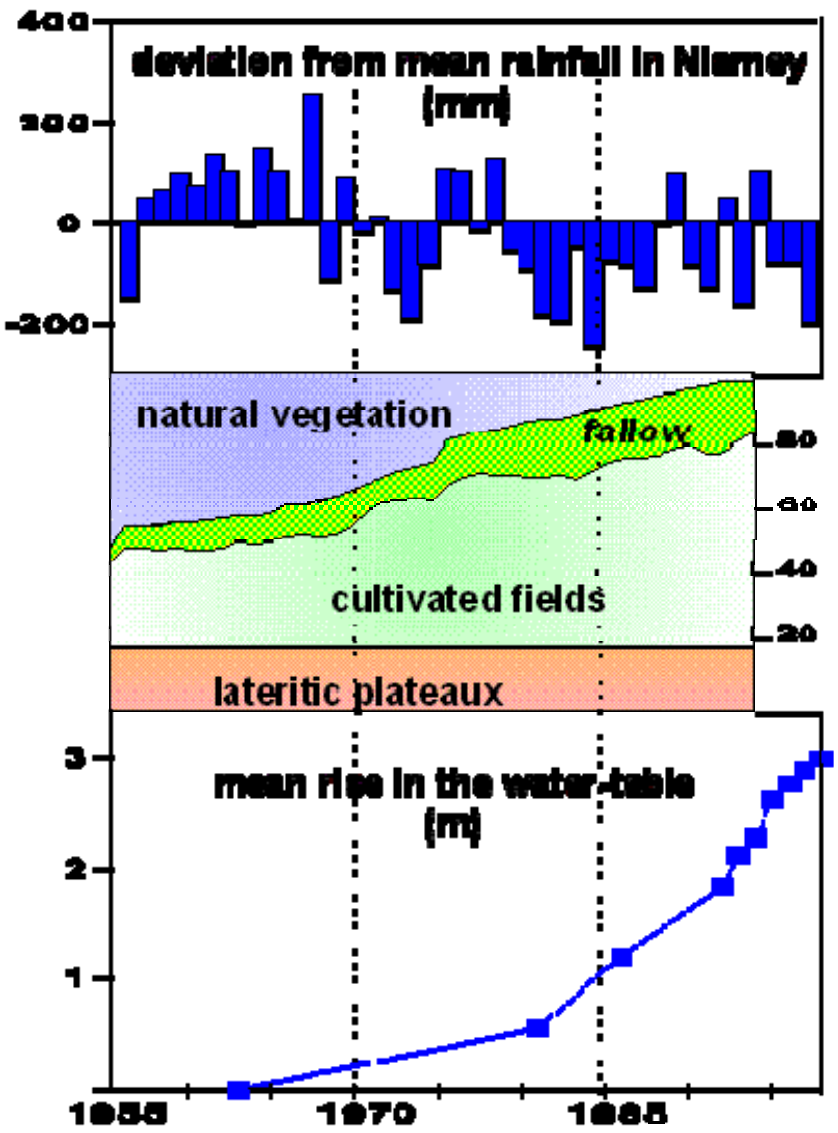


# Example of the recharge identification: rainfall

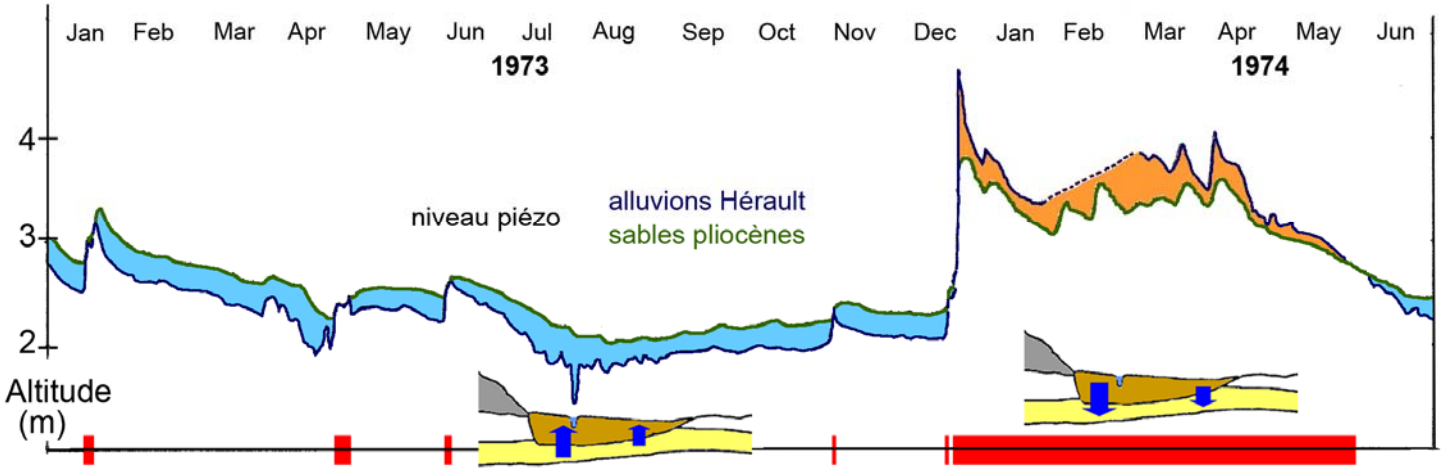
## Long term changes in the Iullemeden Basin



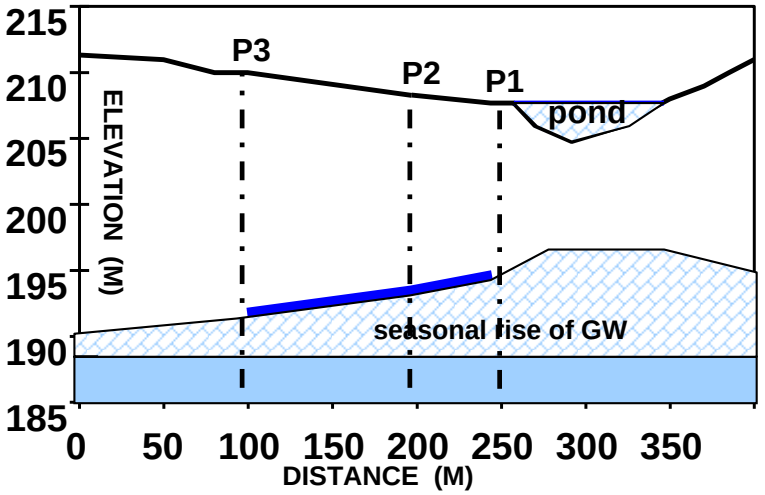
# Example of the recharge identification: surface-GW exchanges

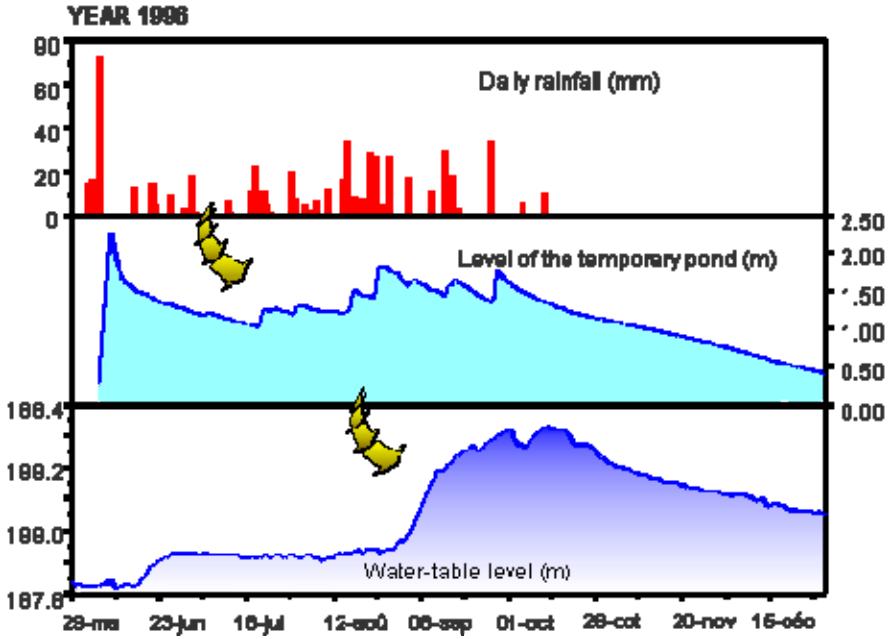
**Pliocene aquifer in the Mediterranean France**




**Exceptional event (once in 20 years), with a long inversion of gradient**

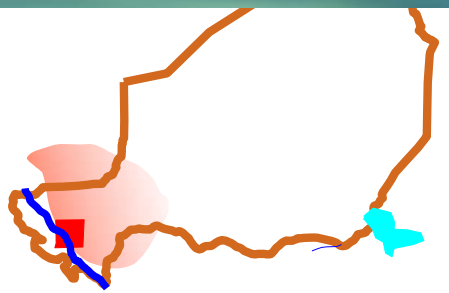
# Example of the recharge identification: surface-GW exchanges




*transformation rainfall/pond/GW*

# Example of the Continental Terminal aquifer (SW Niger)



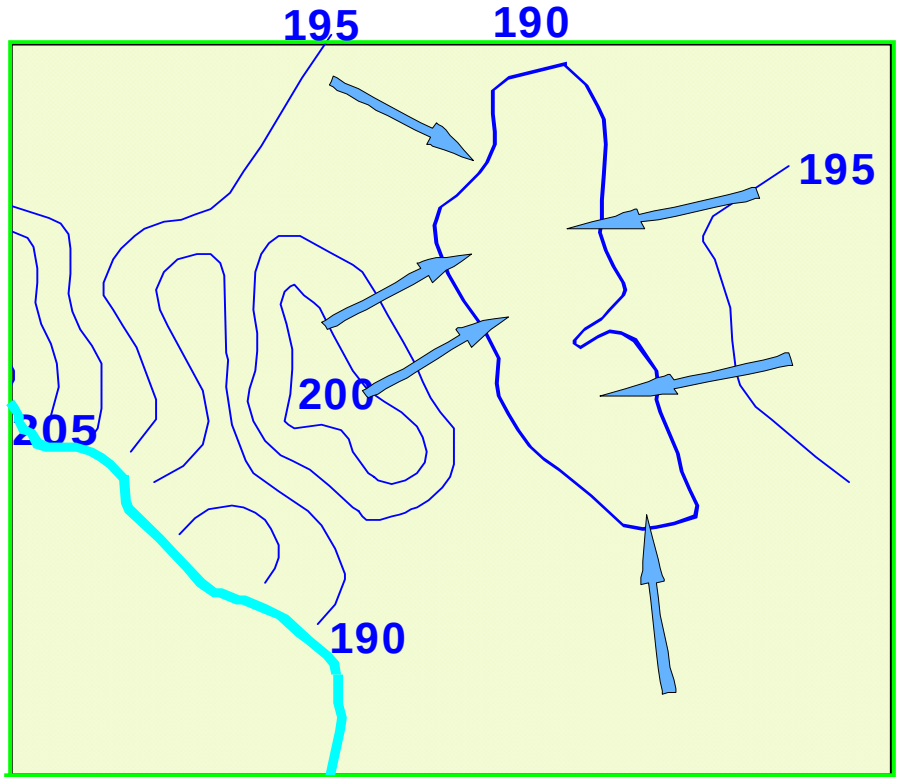
**focused study over 100*100 km$^2$**

**further validation over a wider area**

**small hydraulic gradients**

**singularity of closed depressions**

**visible annual infitration**



# Example of the Continental Terminal aquifer

**two models:**

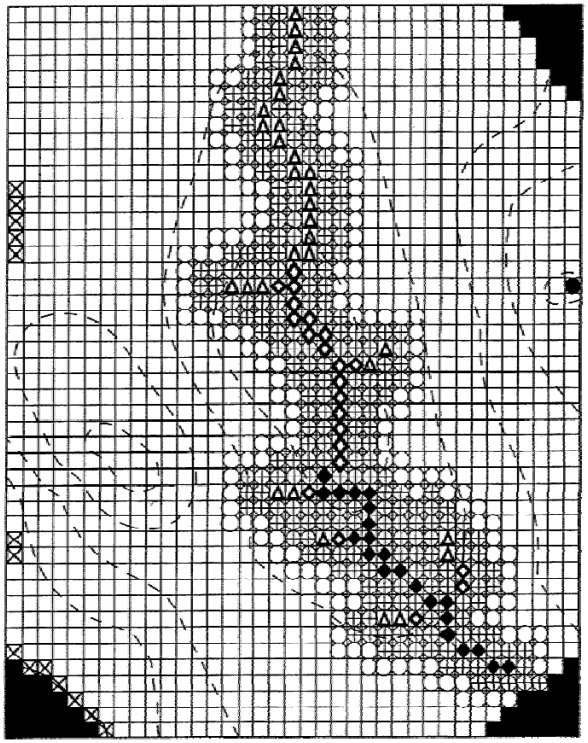
- **calibration on a steady state in the 1960s**
- **transient simulation from 1960s to 1990s**
- **only a small part of the aquifer**
- **strong constraint because of the closed depression**

**GW model only (G. Favreau, 2000), surface-GW (S. Massuel, 2005)**

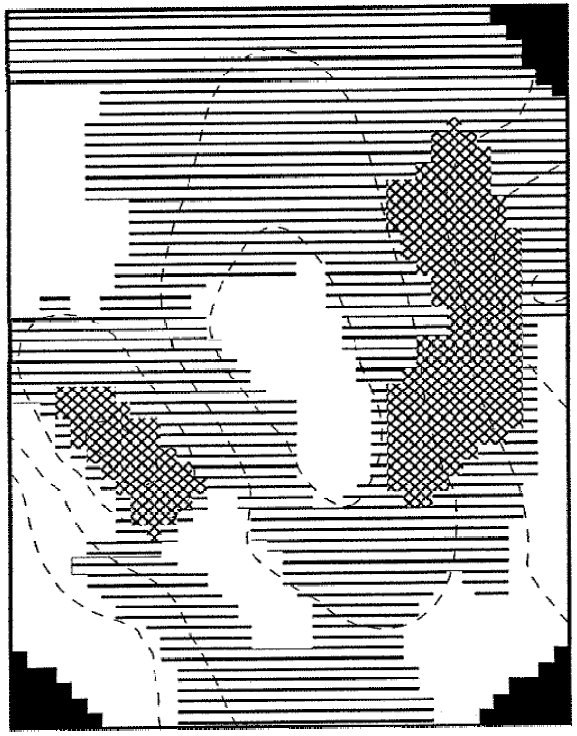
**in both cases, satisfying comparison between measurements and modelled levels**

# Example of the Continental Terminal aquifer

## First model (GW only)

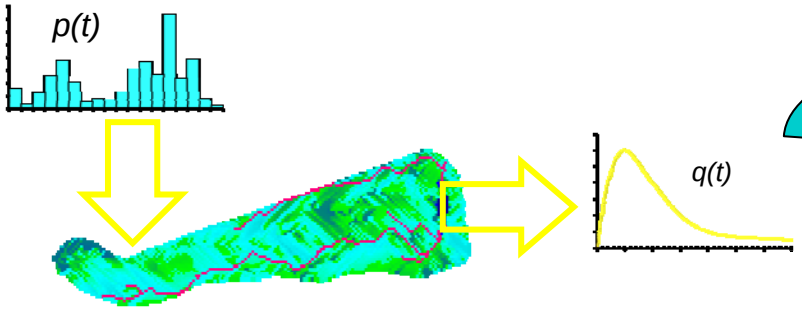


uniform recharge (1 mm/year)



permeability ($10^{-6}$ $10^{-3}$ m/s)

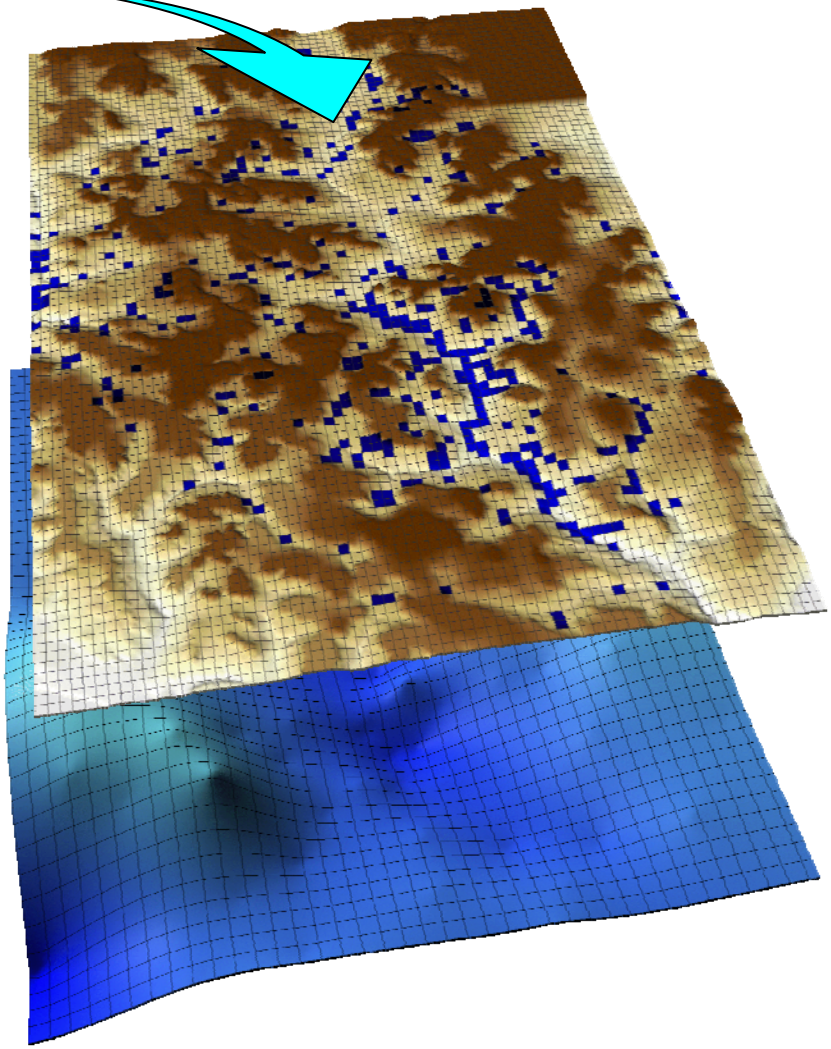
# Example of the Continental Terminal aquifer



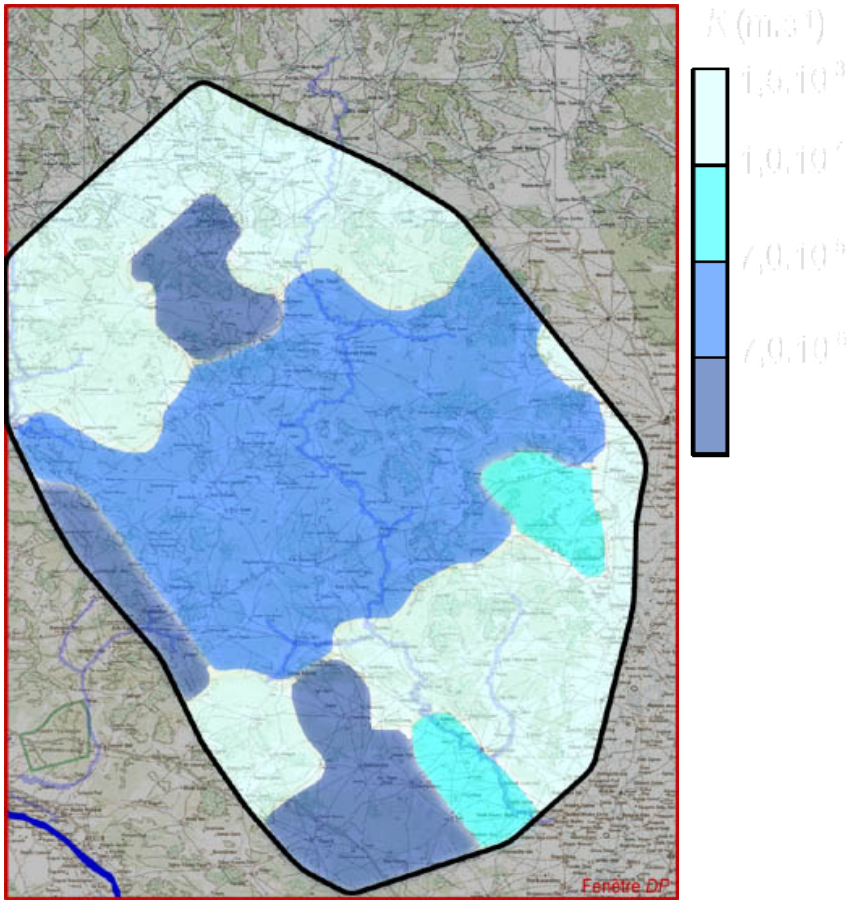

**Second model**

**variable recharge**

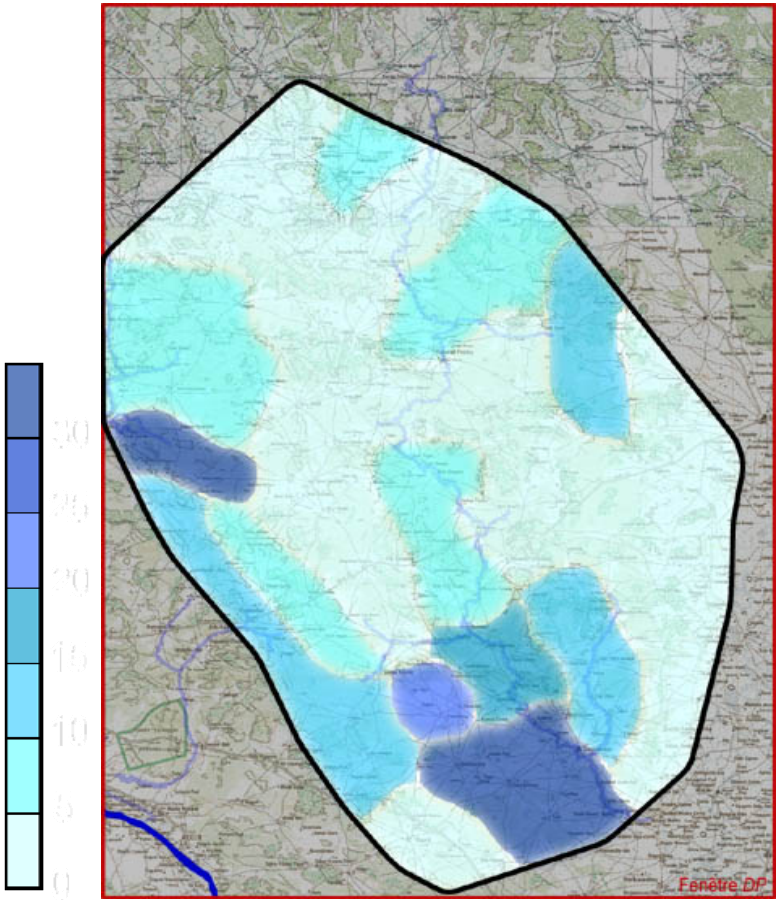
**limited variation in permeability**



# Example of the Continental Terminal aquifer

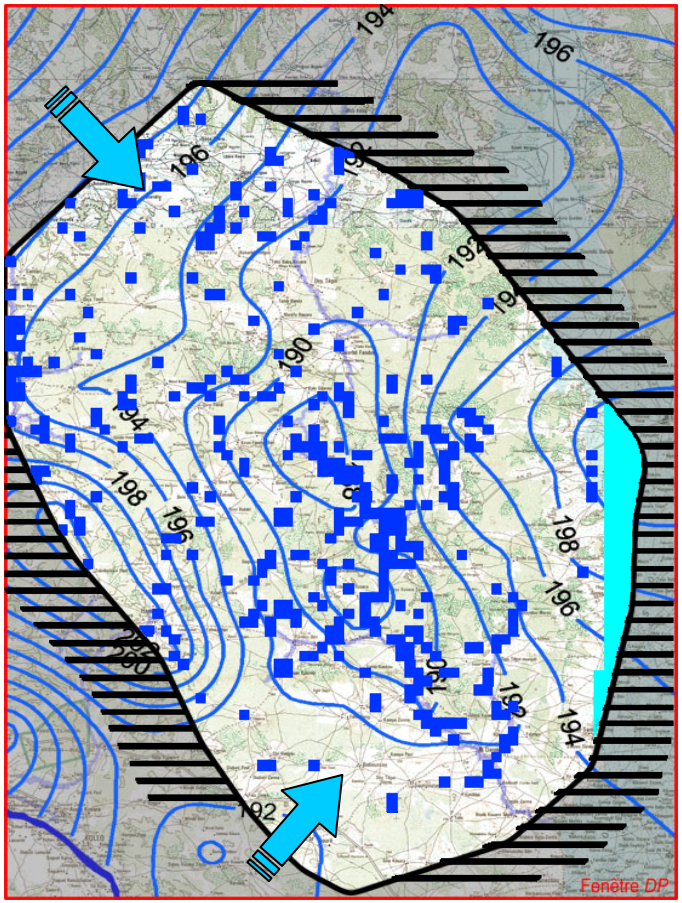



permeability

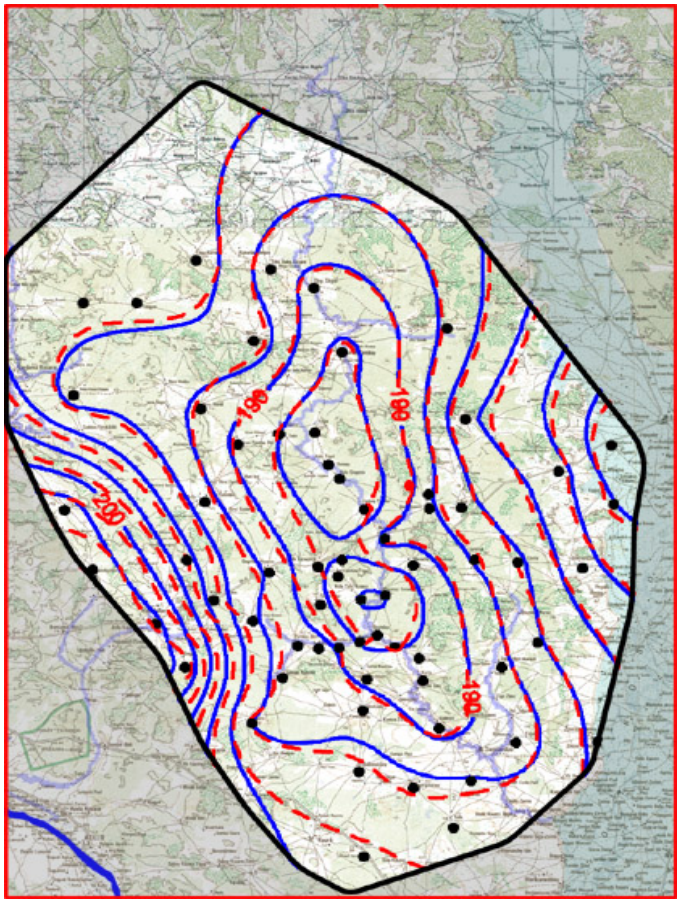



porosity

# Example of the Continental Terminal aquifer




location of GW recharge areas




GW levels observed-modelled

# Example of the Continental Terminal aquifer

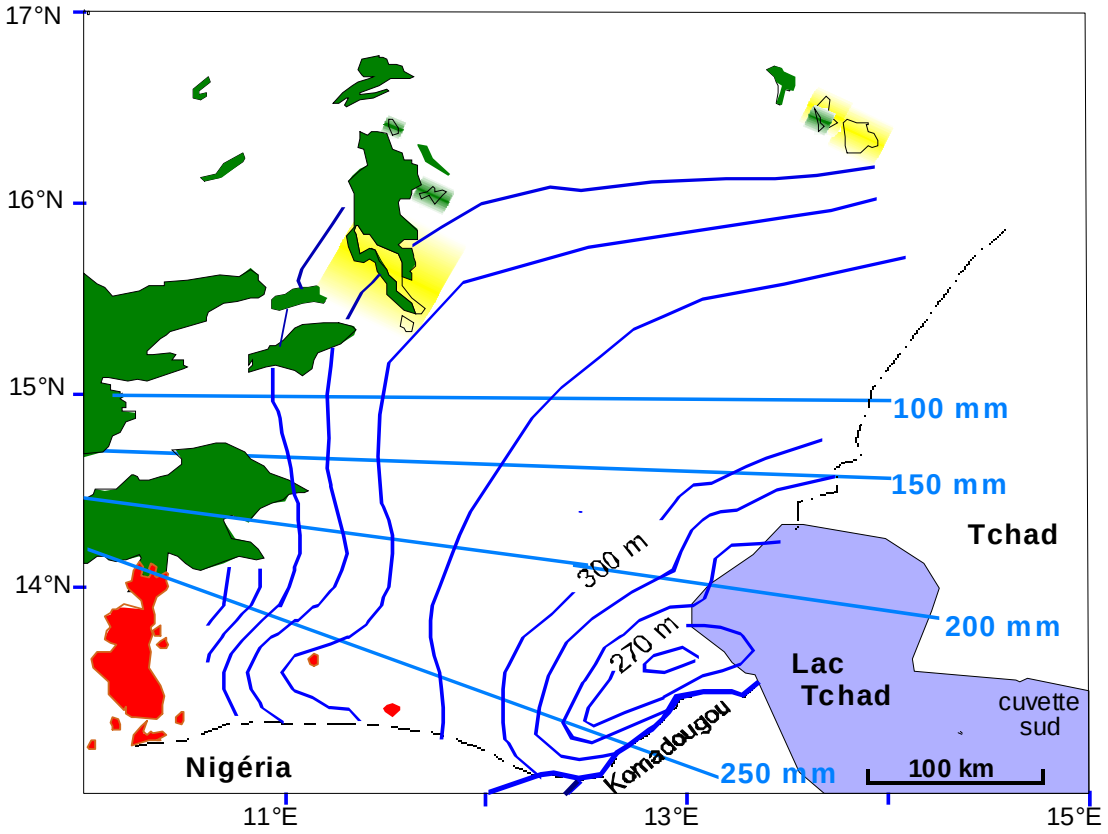
**In this region anthropization is progressive but fundamental**

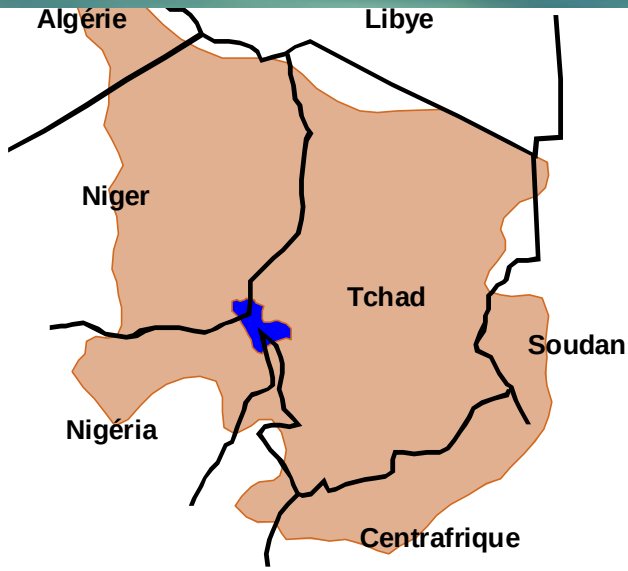
**2 models, with different assumptions and objectives**

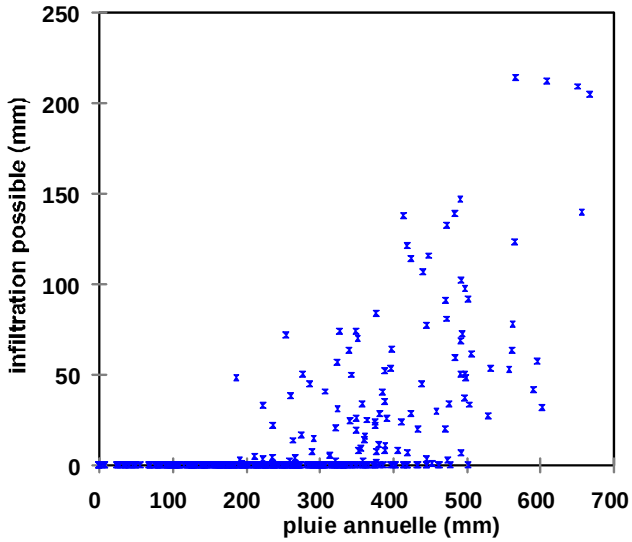
**similar quality of modelled GW levels**

**assumptions significantly different**

# Example of the Lake Chad Basin Quaternay aquifer



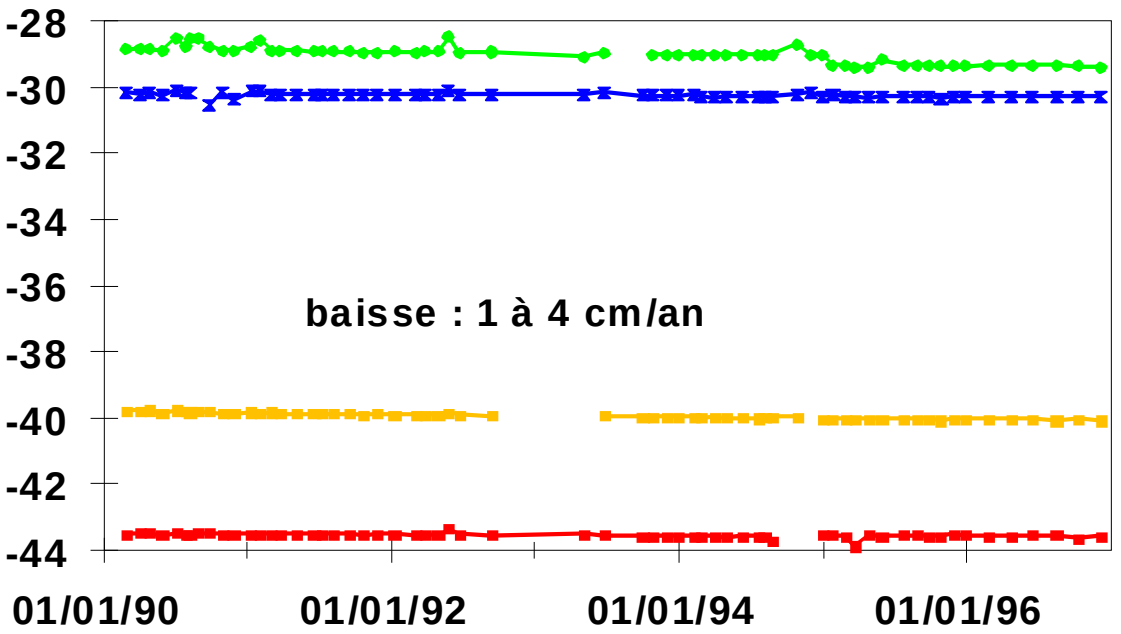




**infiltration calculated with a tank model with a daily time step**

# Example of the Lake Chad Basin Quaternay aquifer

**long-term variation**




**seasonal:** up to 1 m in oases between sandy dunes

variation close to Lake Chad and rivers

no clear variation elsewhere

**interannual :** variation in inflow from rivers and Lake

poor variations elsewhere

# Example of the Lake Chad Basin Quaternay aquifer

**heterogeneous and scarce data, unevenly distributed in space and over time**

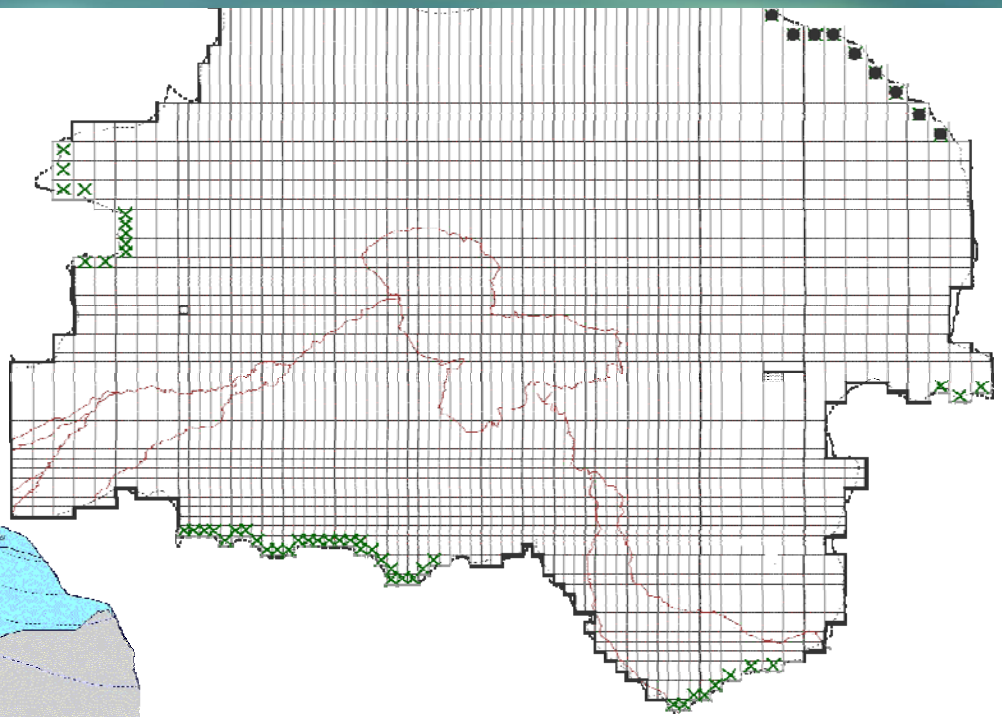
**GW greatlu constrained by several closed piezometric depressions**

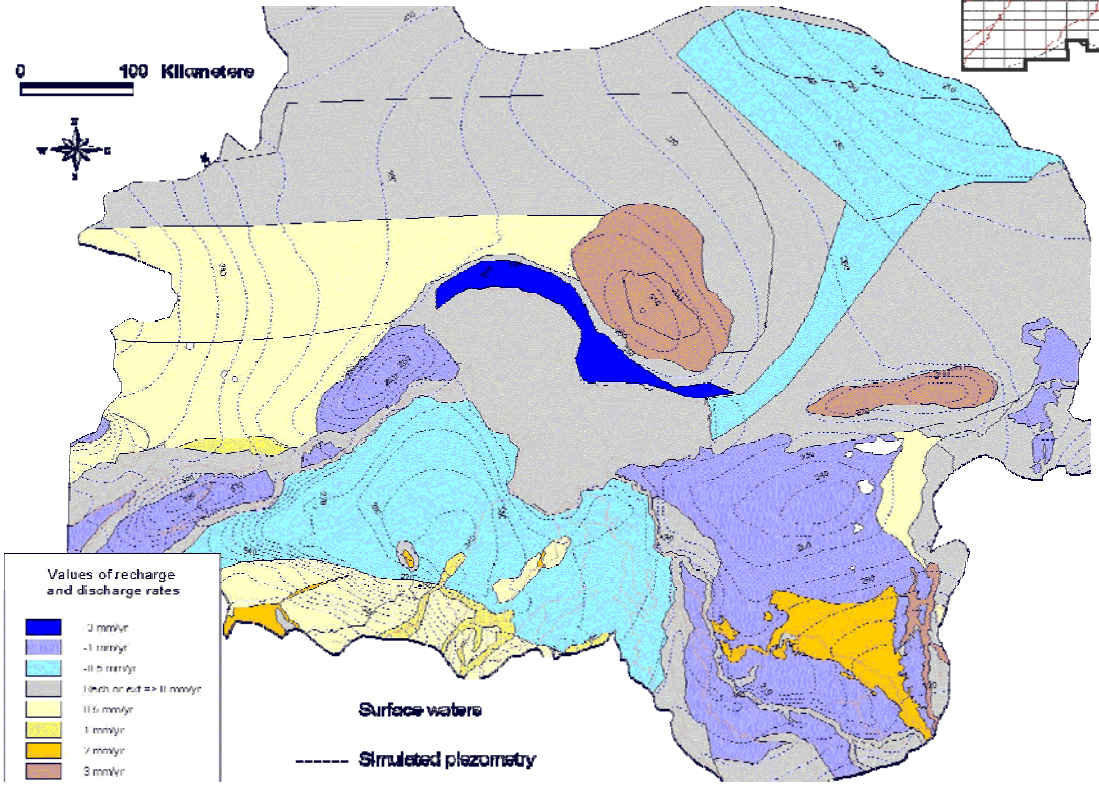
**various GW models at different scales**

- **the whole aquifer**
- **closed depressions**
- **local sub-units**

# Example of the Lake Chad Basin Quaternay aquifer

**example of a general model (M. Leblanc, 2003)**

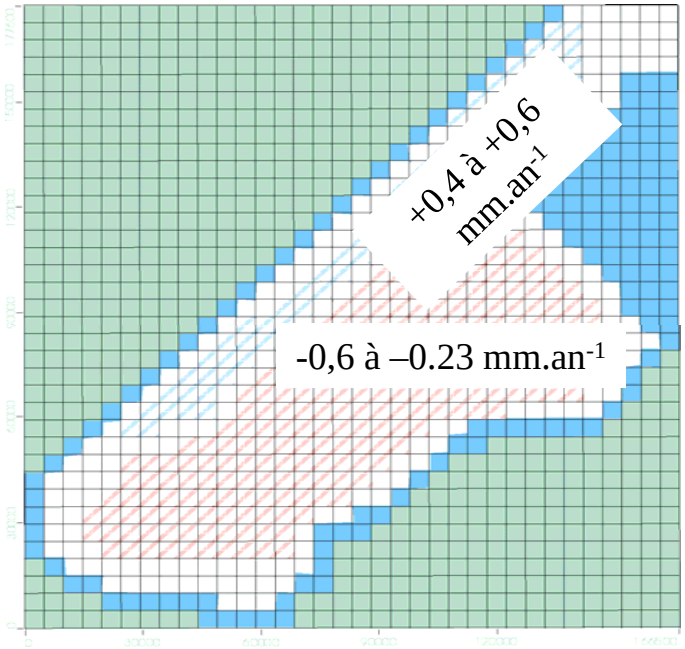


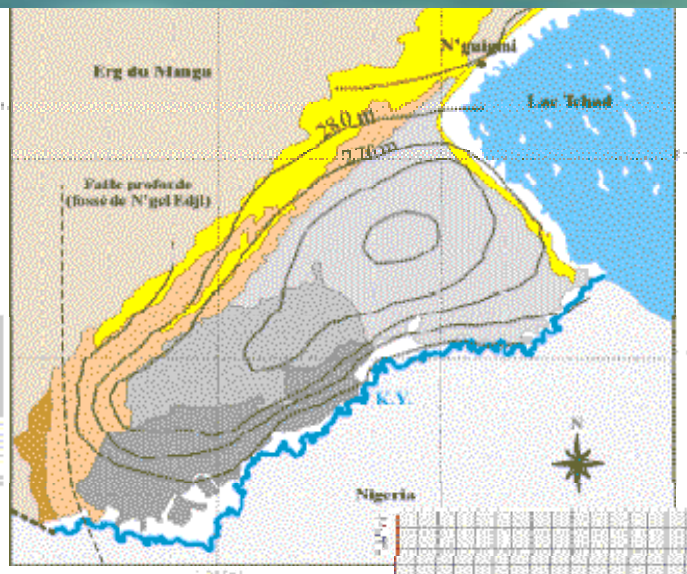


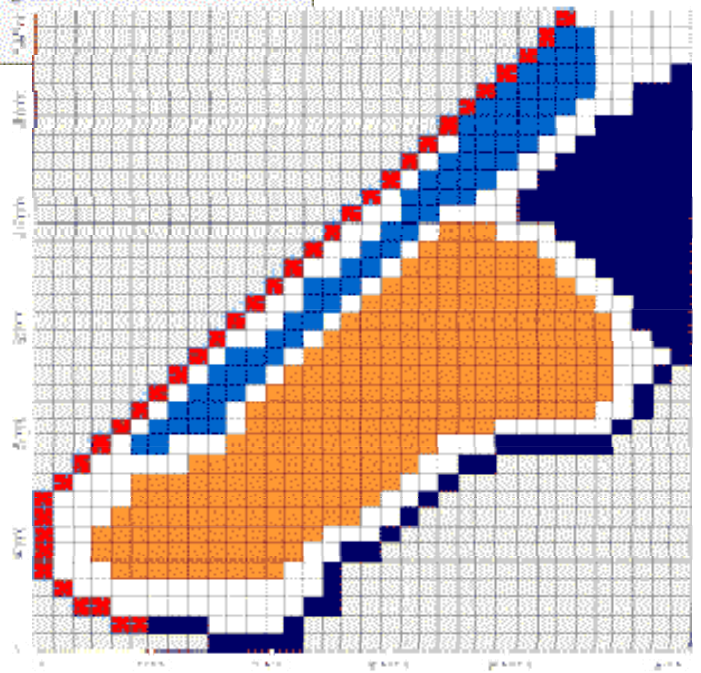
# Example of the Lake Chad Basin Quaternay aquifer

**example of a sub-regional model:**

**the Kadzell closed depression (Gaultier, 2004)**



# Example of the Lake Chad Basin Quaternay aquifer

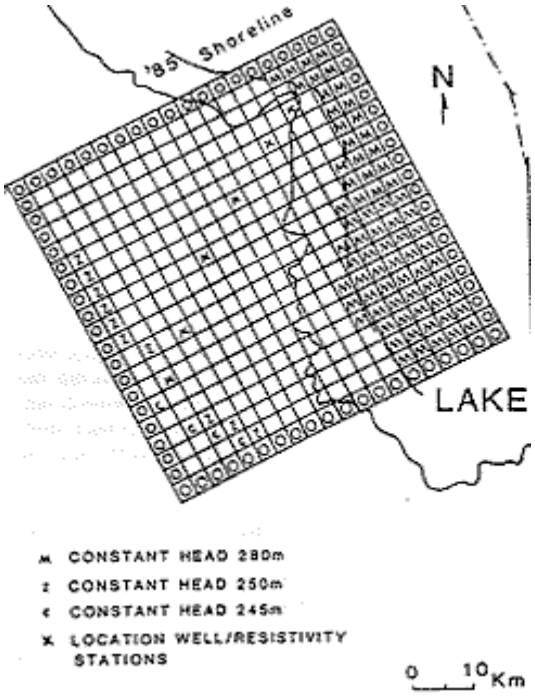
**poorly reliable example:**

**local model in NE Nigeria**

**unrealistic conditions**

**heavy assumptions**

**very limited interest**



# Example of the Lake Chad Basin Quaternay aquifer

**Another example of a local model (NE Nigeria) by Carter**

**local NE Nigeria : Carter + 50 mm/year**

**regional Manga Niger :**

**LL + 1 mm/year**

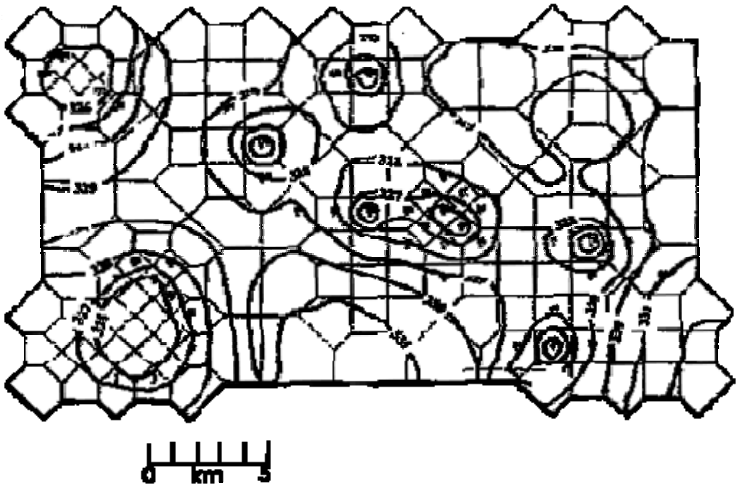
**Gaultier + 0,5 mm/year**

**whole aquifer :**

**Eberschweiler + 0**

**Leblanc +/- 1 mm/year**

**compensation of K and I/O**




***no exchange with the rest of the aquifer***

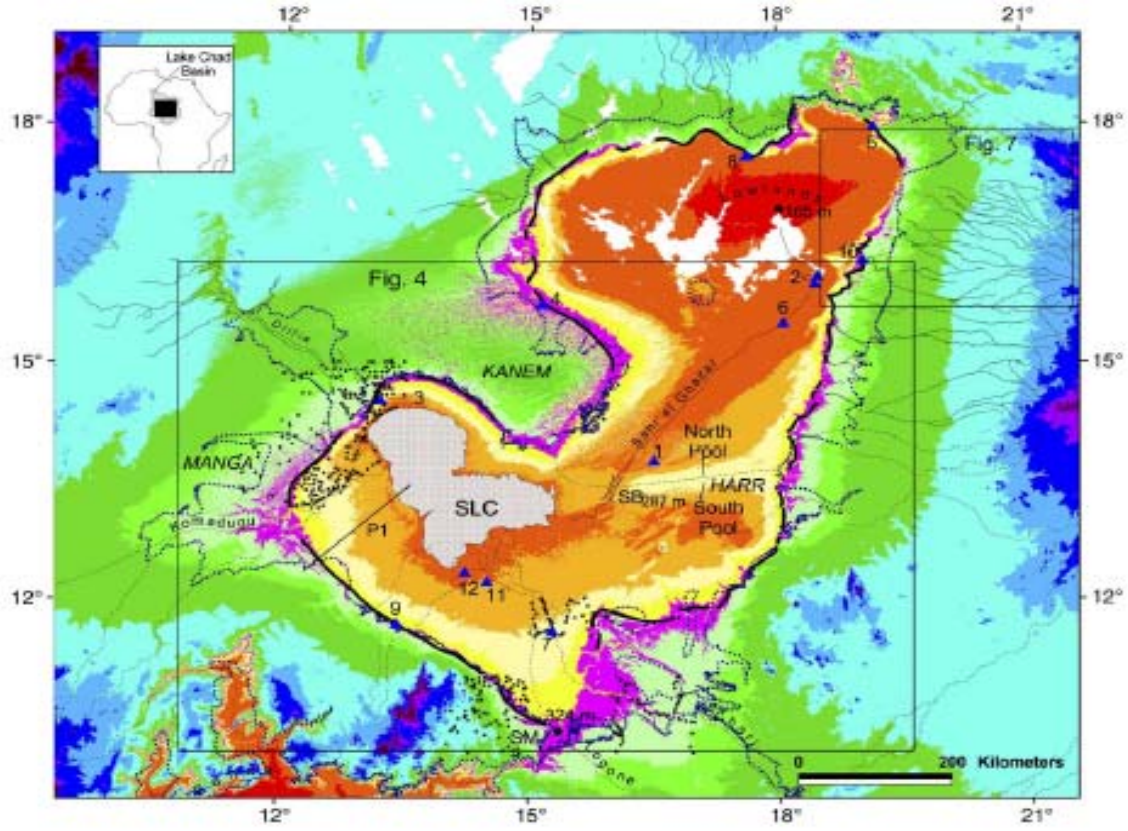
**recharge 50 mm/year, Evap=5 mm/day**

**K=2.10$^{-4}$ m/s and S = 38 %**

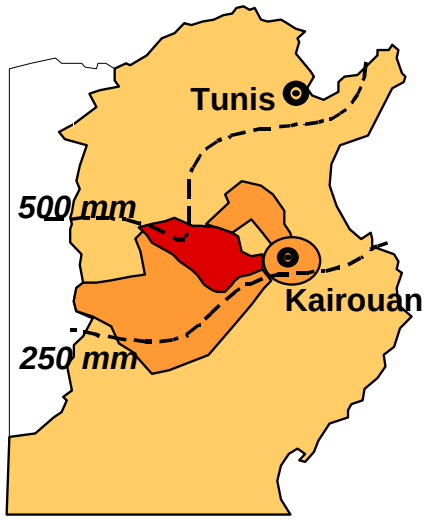
# Example of the Lake Chad Basin Quaternay aquifer

**considering millenia paléohydrologique**

**Mega-Chad 6000 years ago**

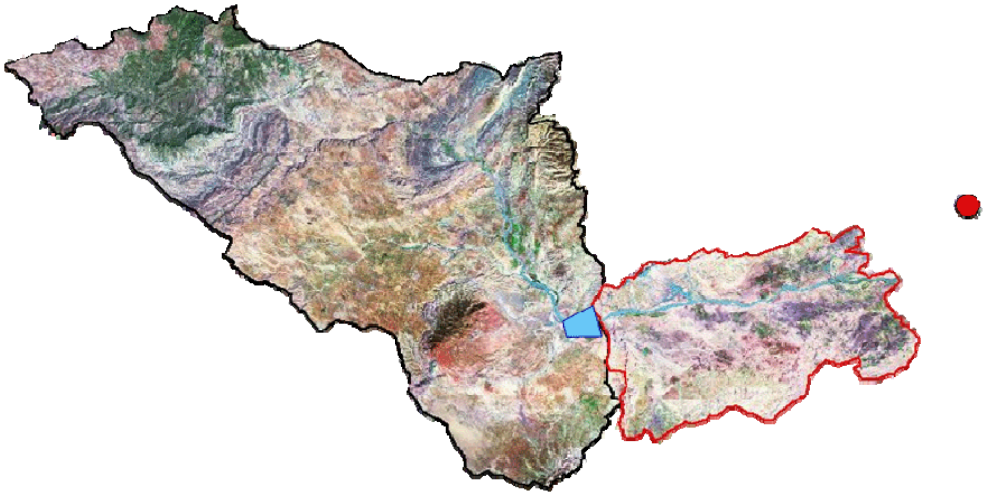


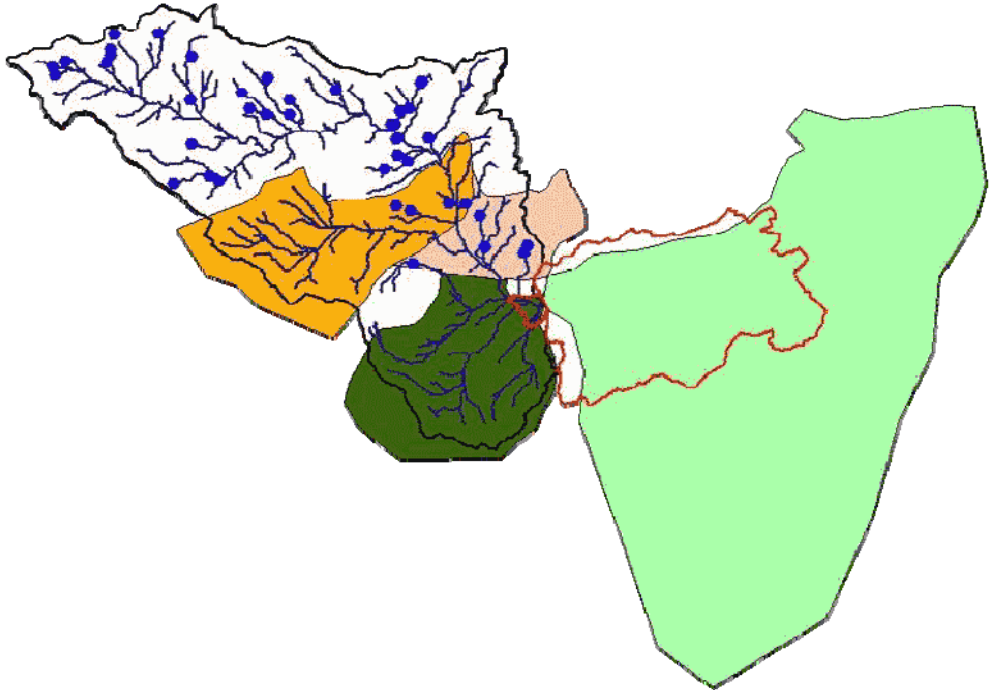
# Example of the Merguellil catchment (Kairouan region, central Tunisia)

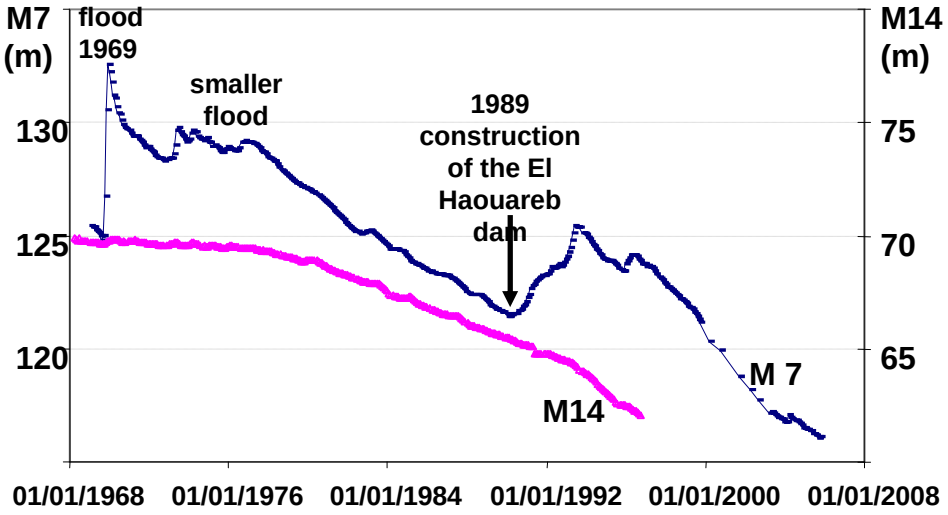



**overexploitation for decades**

**anticipating the future changes**

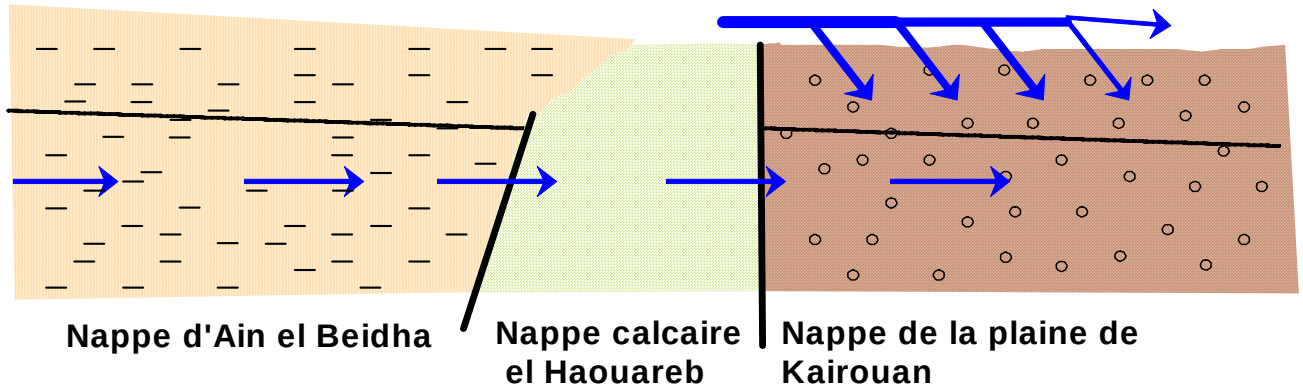




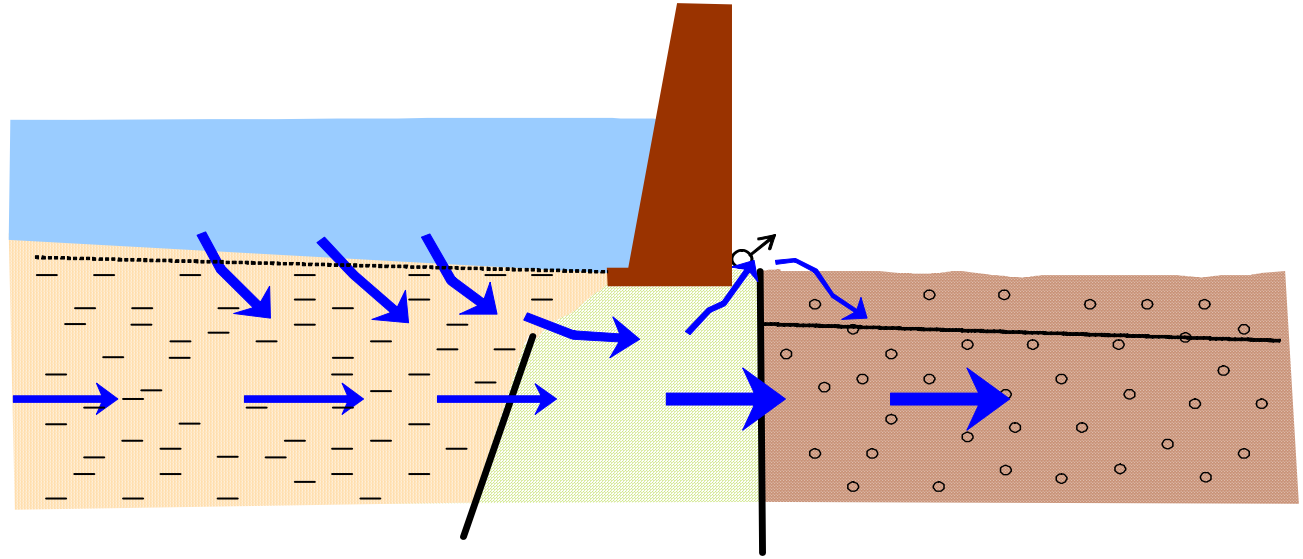


# Example of the Merguellil catchment

**Before the dam**

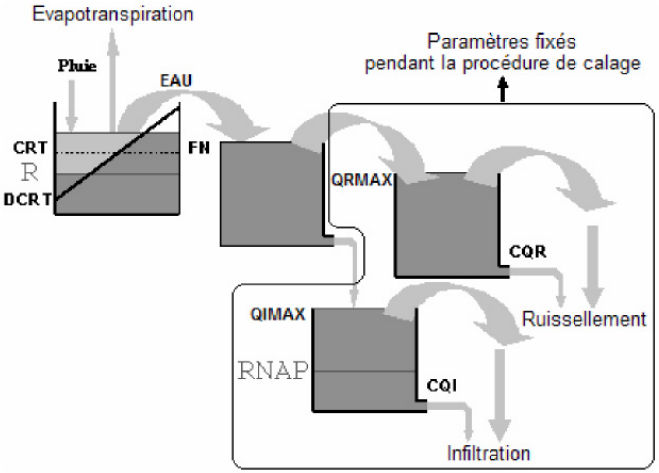


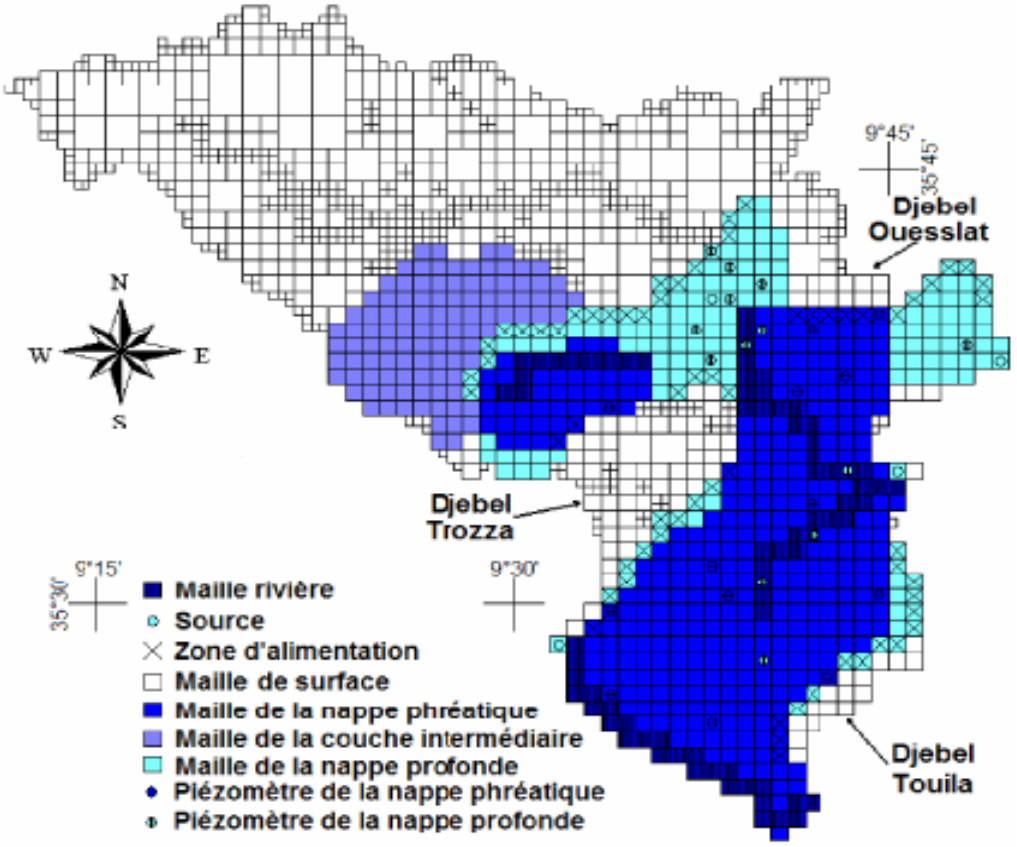

**After the dam**



# Example of the Merguellil catchment

**coupled model surface-GW in the upstream catchment (A. Kingumbi)**




**long work**

**large uncertainty because of environment and data**

**conclusion in contradiction with a parallel work on river flow**

# Example of the Merguellil catchment

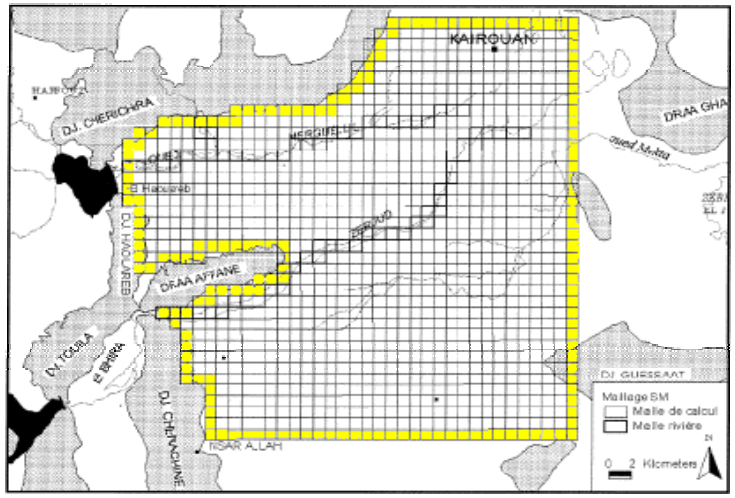
**Kairouan plain aquifer models**

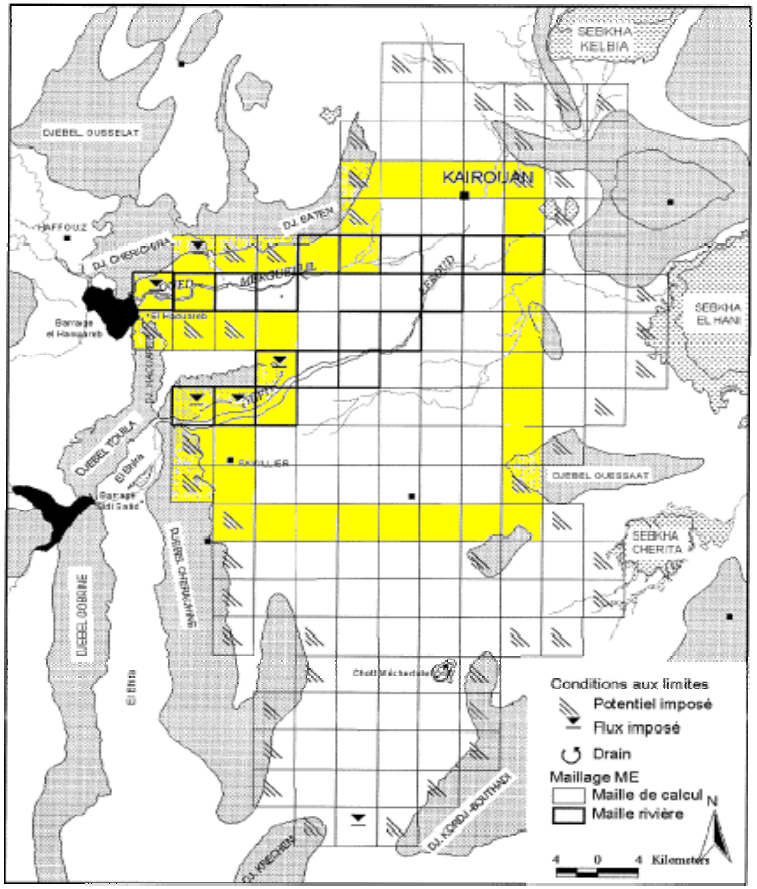
**keeping the same fundamental assumptions**

**relying on official figures**

**results**

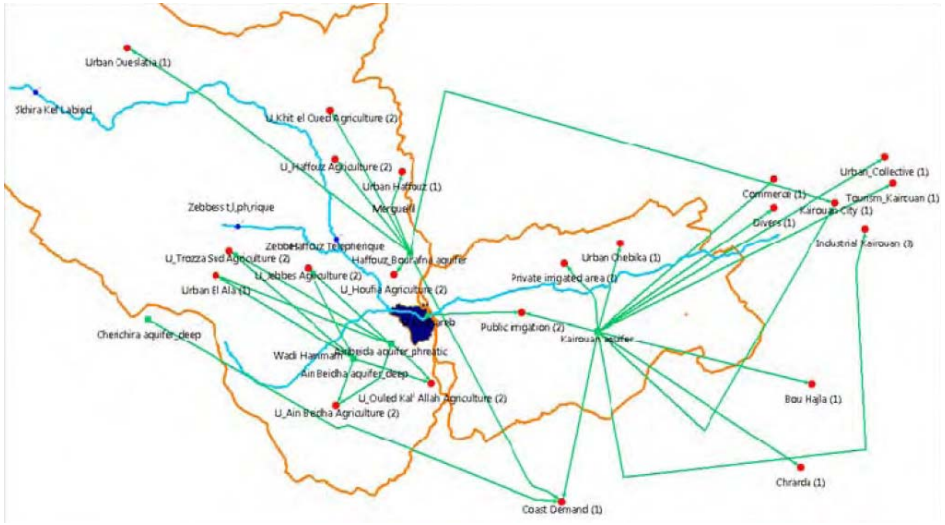
**questionable estimate of flows, and then K**



# Example of the Merguellil catchment

**GW model later imported in a WEAP model**


**up to now, no consideration of GW quality**

**pollution by agriculture**

# Drivers of changes in semi-arid aquifers

**Climate change**

temperature

rainfall

+

**Technical advances**

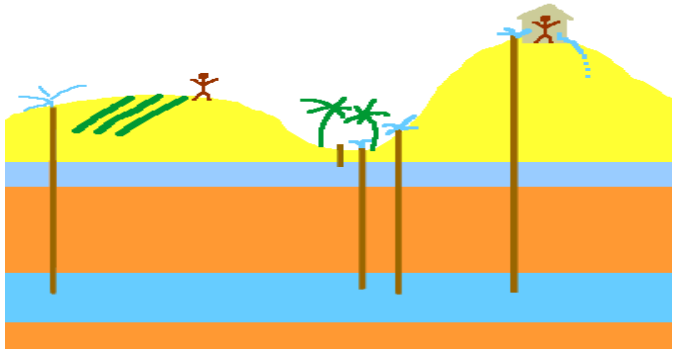
e.g.

drip irrigation
drilling techniques
desalination

**Anthropization**

| Land use | Land cover | Hydraulic control |
|---|---|---|
| W+S conserv. | agric. expansion | exploitation |
| drainage | irrigation | storage-transfer |
| anti-erosion | wetlands | blue/green water |

| Society | Economics | Governance |
|---|---|---|
| urbanization | globalization | national policy |
| littoralization | taxes + subsidies | law enforcement |
| education | investments | structuring of users groups |
| health | | |



# As a possible conclusion

**A major concern is the invisibility of GW**

**- interpolation by hydrogeologists between sites with information**

**- different perceptions of GW (in storage and flow) among**
- **scientists**
- **water users**
- **water managers**

**- no immediate link between an individual action and a change in the GW system**

**- favouring illegal behaviours (pumping, rejection of contamination)**

**- political indifference of authorities (no inauguration, no short-term reaction)**