Water resources modeling in highly anthropized basins (how to account for agricultural and irrigation practices)

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Water resources modeling in highly anthropized basins

(how to account for agricultural and irrigation practices)
Example on the Garonne basin (France)

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Project REGARD : http://www.cnrm-game.fr/spip.php?article809&lang=en

Introduction

An increasing number of basins are anthropized over the world

Parameterizations :

- Irrigation : based on demand (calibrated), uptake from reservoirs or groundwater
- Hydropower : depend on the demand (complex dams networks in mountains)

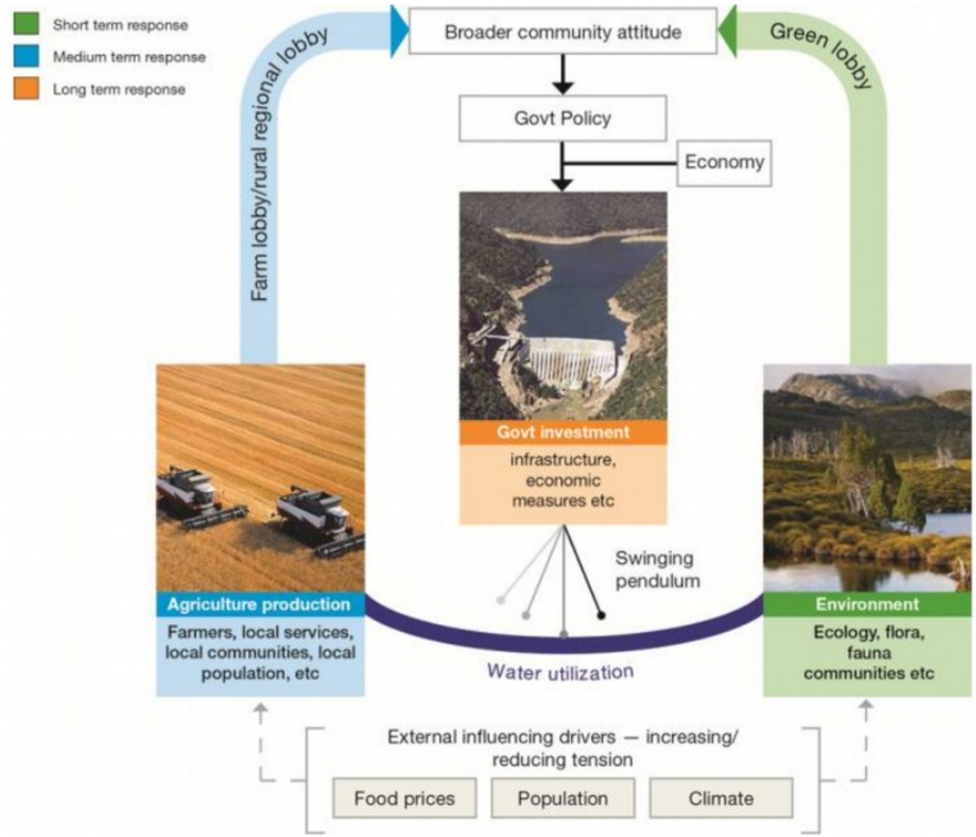
(see WaterGAP and the talk by Petra Döll)

Role of man is essential to understand the long term variations

Outline

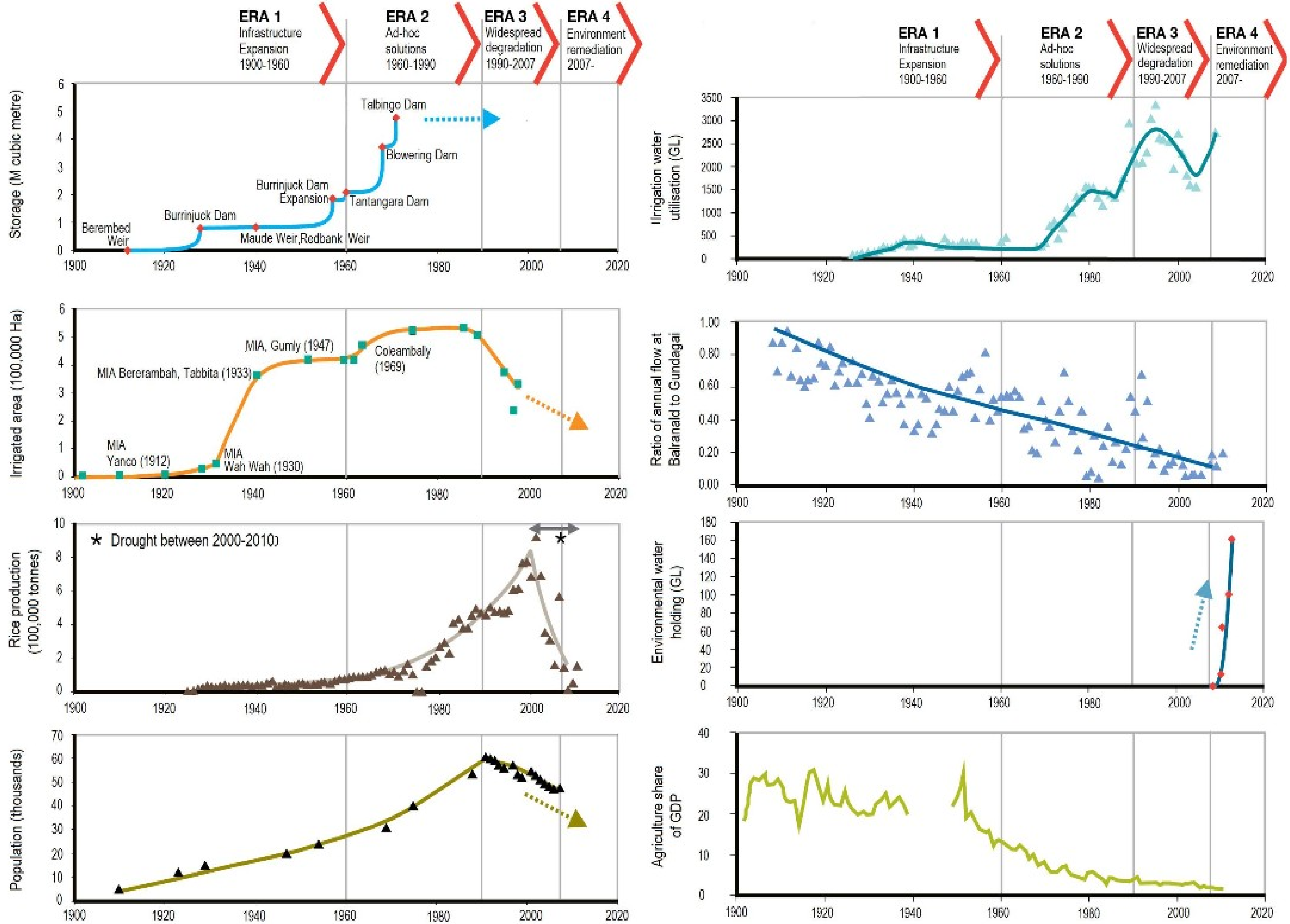
- Introduction to the notion of « socio hydro-system »
  - Example on the Murrumbigee river basin, Australia
- The Garonne river basin, France
  - Presentation of the context
  - The models
  - Irrigation issues
    - Impact on surface fluxes,
    - impact of small farm dams, aquifers
  - The multi agent system and the impact of agricultural scenarios on water consumption

The socio-hydro-system



The Murrumbidgee river basin, Australia, 80 000 km²

Kandasamy et al., HESS, 2014



Kandasamy et al., HESS, 2014

The Garonne basin : a highly anthropized system

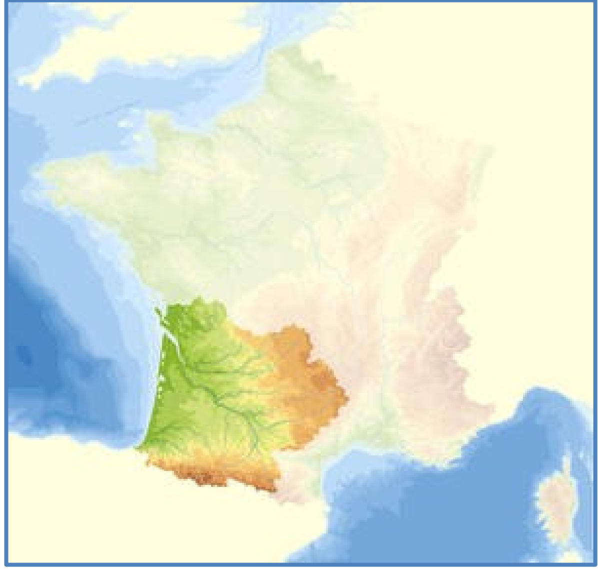
- Crops represent 57 % of the surface
- High number of small farms
- Irrigation : 30 000 farms
  - 600 000 ha (2/3 : maize)
  - 900 millions of m^3

During low flow agriculture=80 % of
the total consumption
Hydro electricity : water release in winter

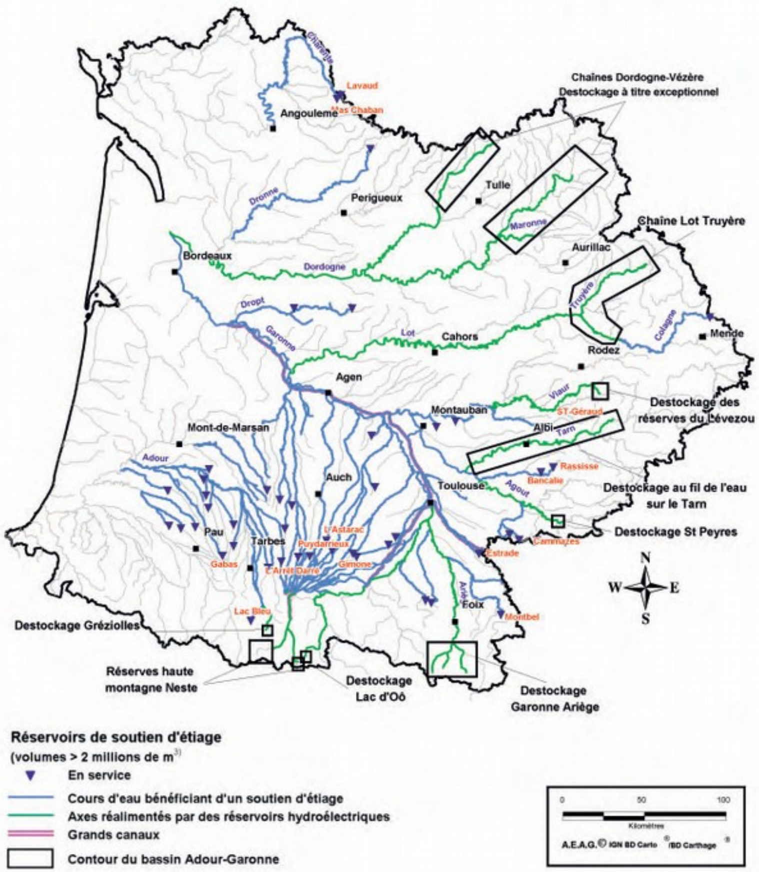
Irrigation storage :

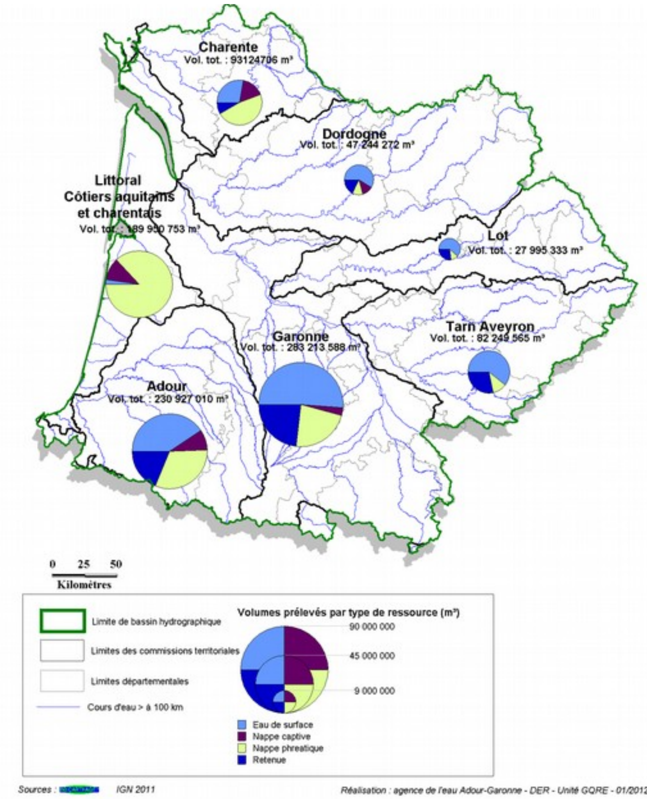
- 300 millions in large reservoirs
- 50 millions in intermediate reservoirs
- 290 millions m3 in more than 1500 small farm dams

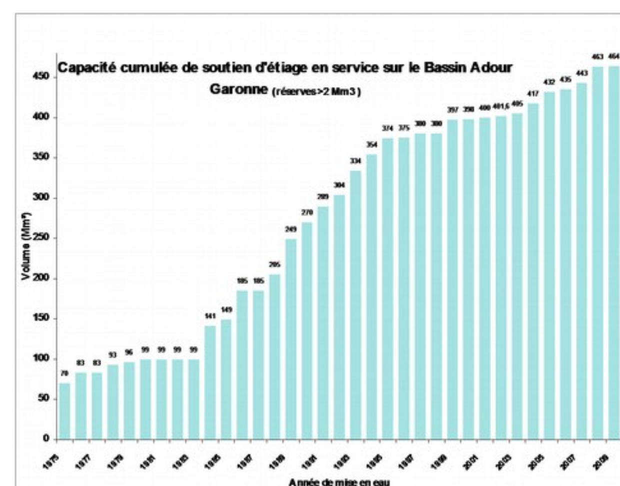
-> Water shortage in summer



The water system







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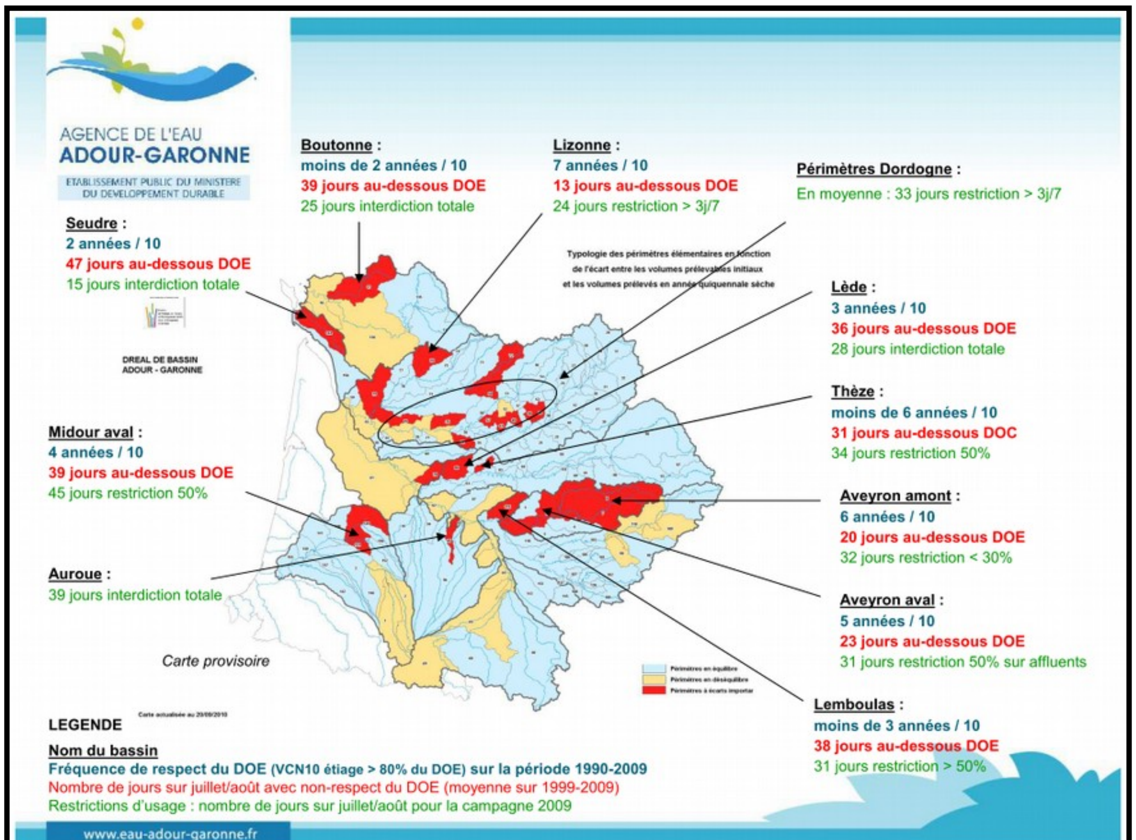
Water crises

Minimum flows are imposed to guarantee a normal functionning of aquatic ecosystems (EU Water framework directive).

In Summer, crisis occur when river flows are measured under the official threshold.



Watersheds with recurrent river flow < the regulatory threshold

Water crisis management

- Water release possibilities and efficiency depend on characteristics of dams (e.g. min and max flow, possible period of release)

Water use restrictions are set up for specific locations (some districts) and durations (at least one week) and may cause significant crop yield reductions

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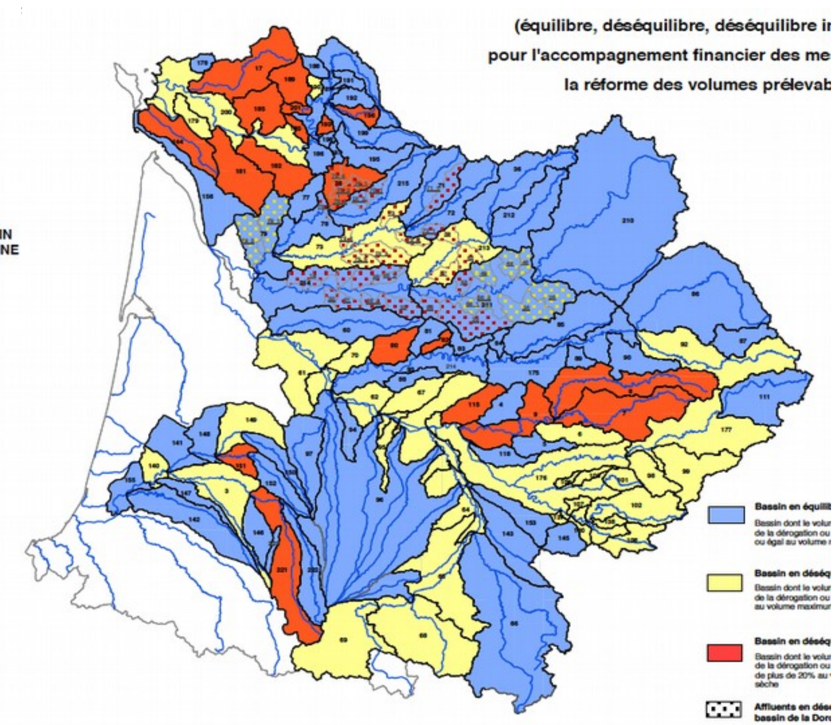
Evolution of the water management gouvernance

Since 2009, to avoid regular water crisis French government is instituting a new regulation of agricultural water withdrawals

Determination of new water volumes available for agriculture at watershed level

Allocation rules between farmers



Yellow watersheds: VAA < water withdrawn in driest year
Red watersheds: VAA << water withdrawn in driest year

In main irrigated watersheds new authorized volumes are (much) under the water volume currently withdrawn
➔vehement protests of farmers that claims the need to account for socio-economic impacts

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Building a socio-hydrological system over the Garonne

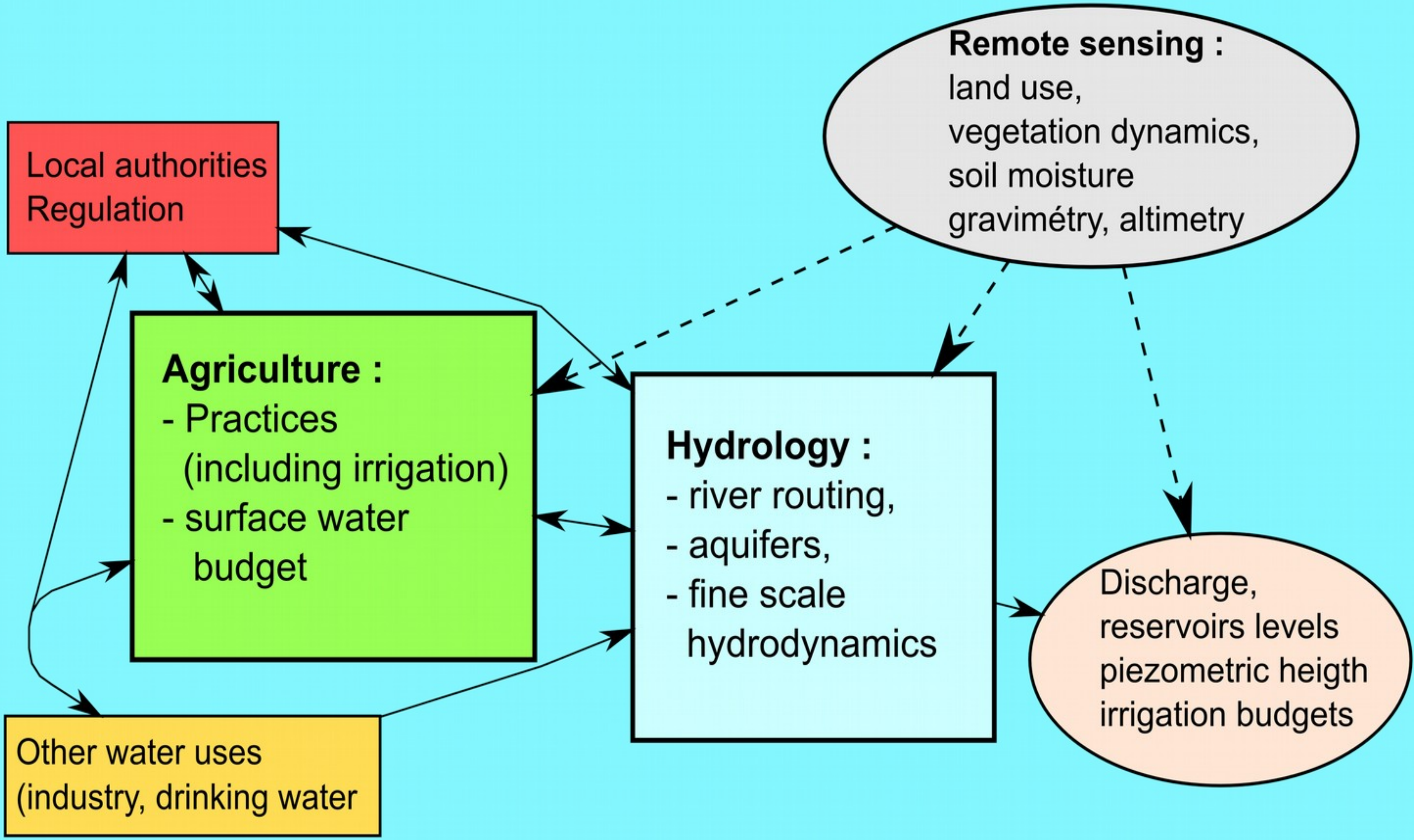
Motivations and questions :

- Are we abled to simulate the real water cycle (that can be compared to observations !)
- What are the modifications of the « natural » system ?
- What are the impacts of the agricultural practices, regulation, crisis management on the system ?
- How can we combine models and in situ and (future) fine scale remote sensing ?
- What is the appropriate level of spatial and temporal aggregation ?

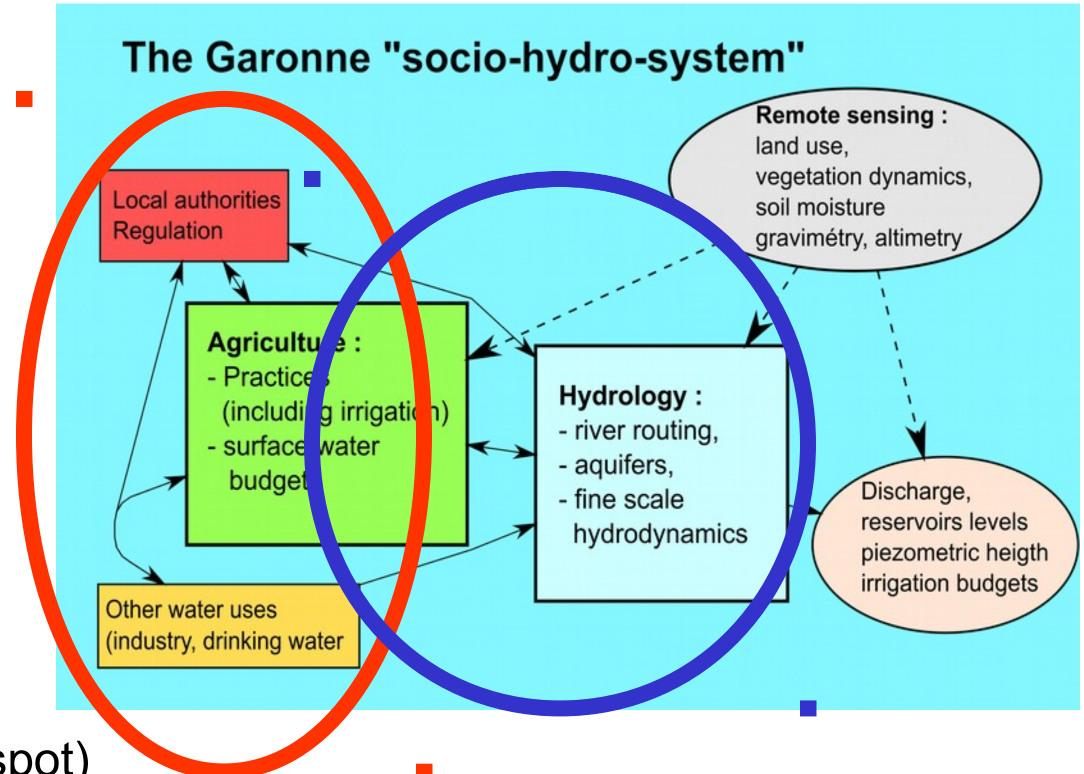
Testing of scenarios :

- Re-analysis of the past
- Alternative scenarios (changes in crops)
- Climate change

The Garonne "socio-hydro-system"



The models of the project

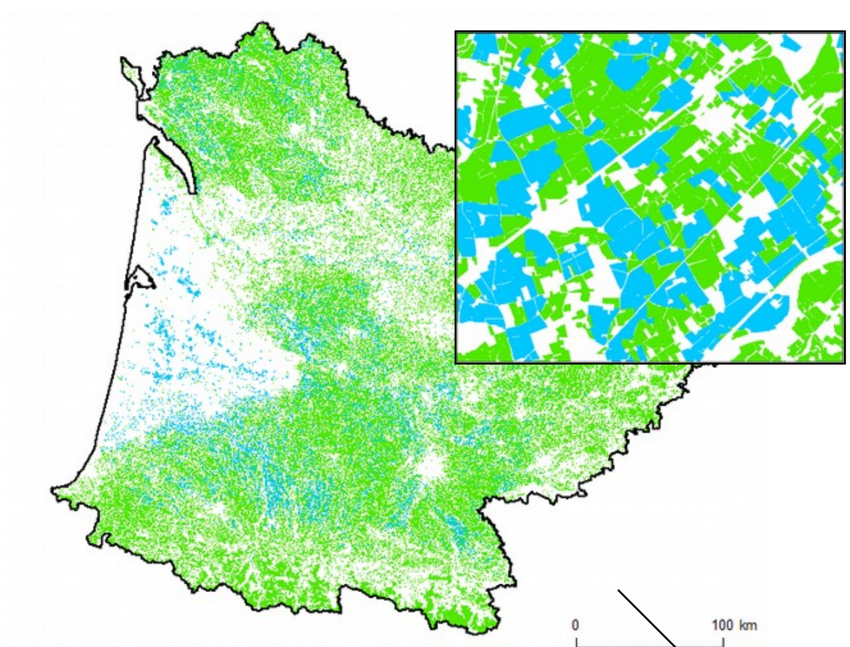


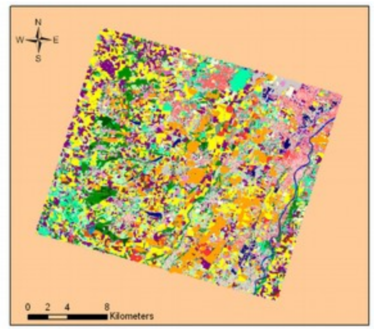
MAELIA :
Multi agent system
Generic formalism to simulate human activities
Include databases of hydraulic relations and between crops and water resources

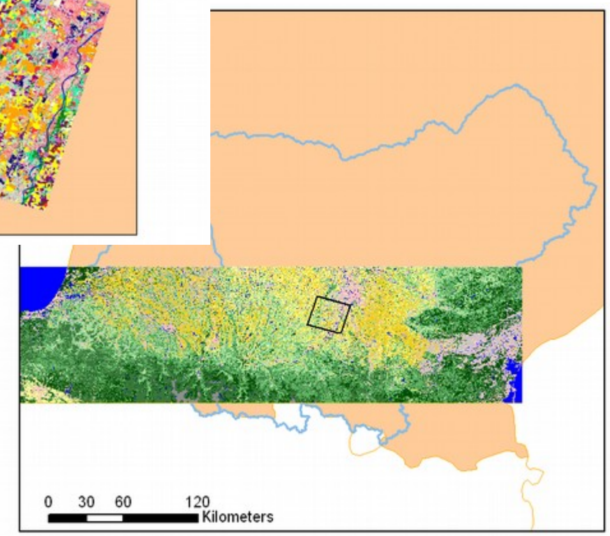
Remote sensing :
-Land cover (landsat, formosat, spot)
LAI (+MODIS)
-snow (MODIS)
-Soil moisture (SMOS)
-Water level elevation (Jason, ENVISAT, Altika, AirSWOT)
-TWS (GRACE)

Hydrological models :
ISBA /MODCOU(RAPID) : coupled land surface and distributed hydrological model
SWAT : semi distributed hydro-agronomic model
MARTHE : Groundwater model
IMFT : 1D hydrodynamic model

Impact of soil usage, vegetation evolution and irrigation on fluxes







What is the level of coherence of the two informations ?

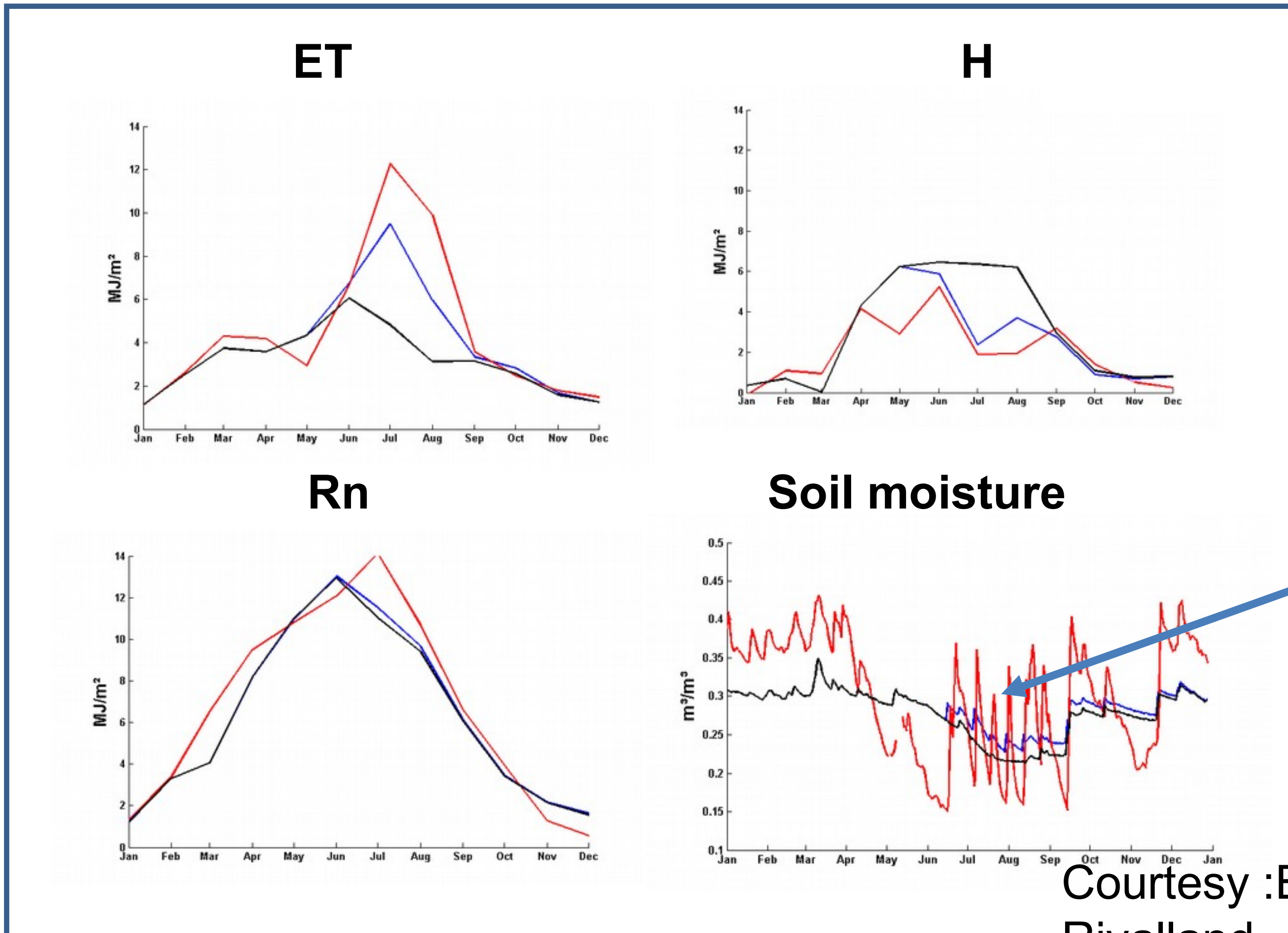
Soil data : cadastre + satellite : landsat, modis, formosat

Courtesy :Therond,Gascoin, Rivalland et al.

Impact of irrigation on surface fluxes

Lamasquère : evolution of the surface fluxes over maize

(LAI from Formosat)



Légend :
- **with irrig**
- **without irrig**
- **obs in situ**

Oscillation linked to irrigation

Courtesy :Bellot, Gascoin, Rivalland

Reservoirs and impacts on discharge

Context :

Need water in the dams in summer for irrigation

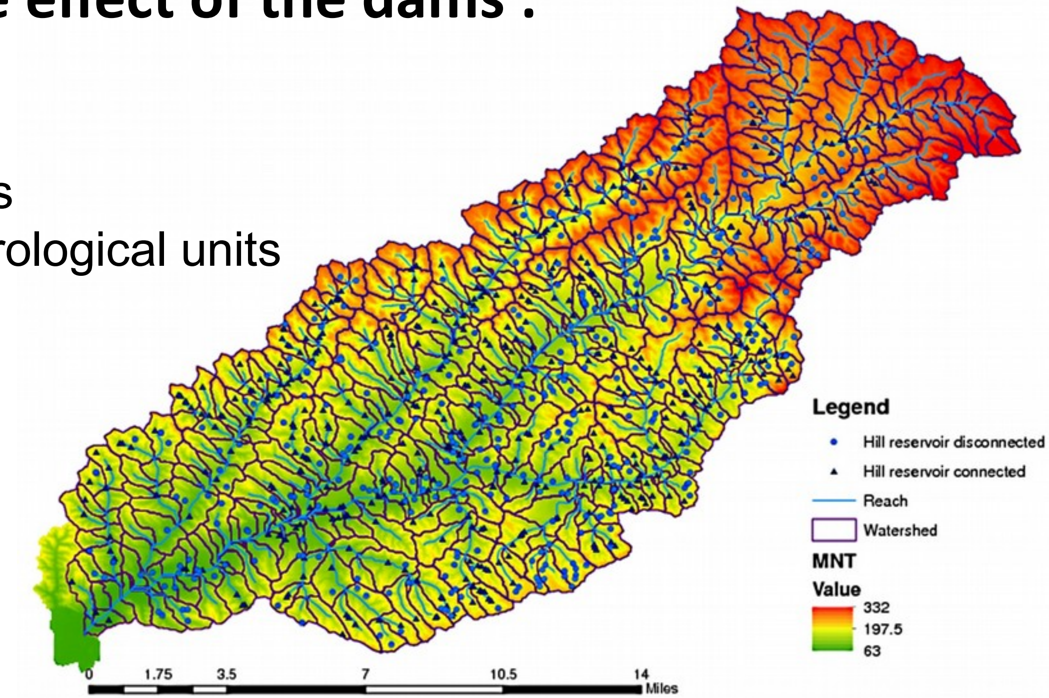
Need water in river in summer <u>and</u> winter (high flows)

Questions :

- What is the maximum water volume that can be stored in the irrigation dams while keeping a reduced impact on the flow ?
- Is there a need to modify the law with regards to the functioning of these dams, especially, to the authorized filling period ?
- How to be sure that the decisions taken nowadays will be economically and environmentally sustainable, especially in a context of climate change ?
- Does the dams storage is coherent with the needs ?

Evaluation with SWAT of the effect of the dams : Lemboulas sub-basin

875 dams
(535 hydrological units

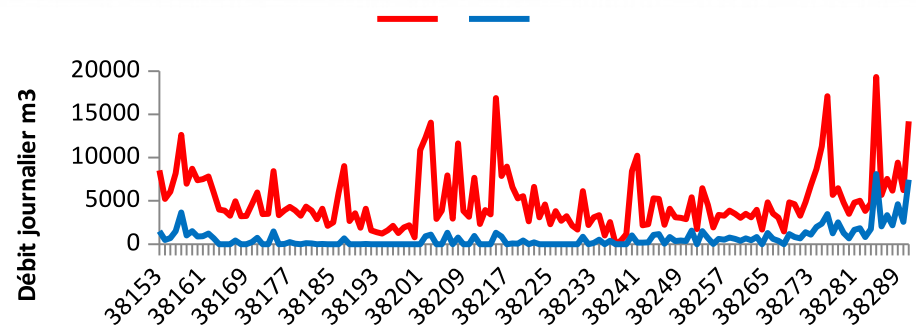


- 403 km²
- Precipitation : 650 mm/year
- Mean discharge : 2,2 m³/s

No regulation :

10 years average effect :
March-April : -0.5 %
June-August : -80 %

Annual average 3%



Summer 2002

Courtesy :Pailloux, Sauvage, Sanchez Perez

Alternative filling strategy for the dams

Fill the dams in winter only while preserving some high discharge periods (for environmental reasons) :

Limit the filling period (5 month ? 3 month?)

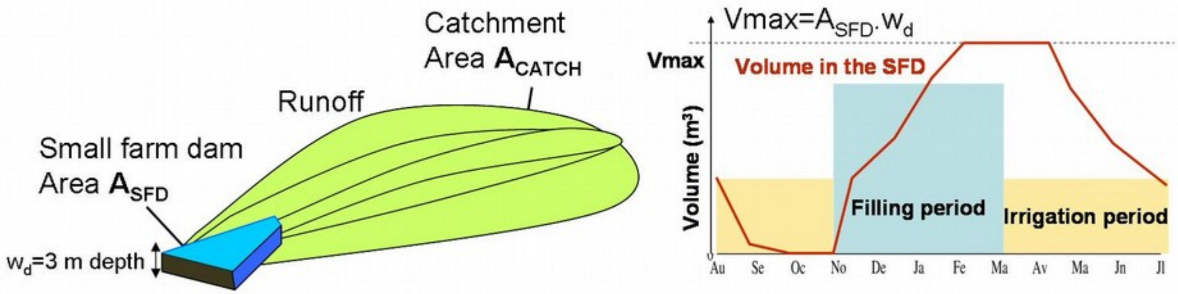
Questions :

•Can the dams be filled ?

•Impact on discharge ?

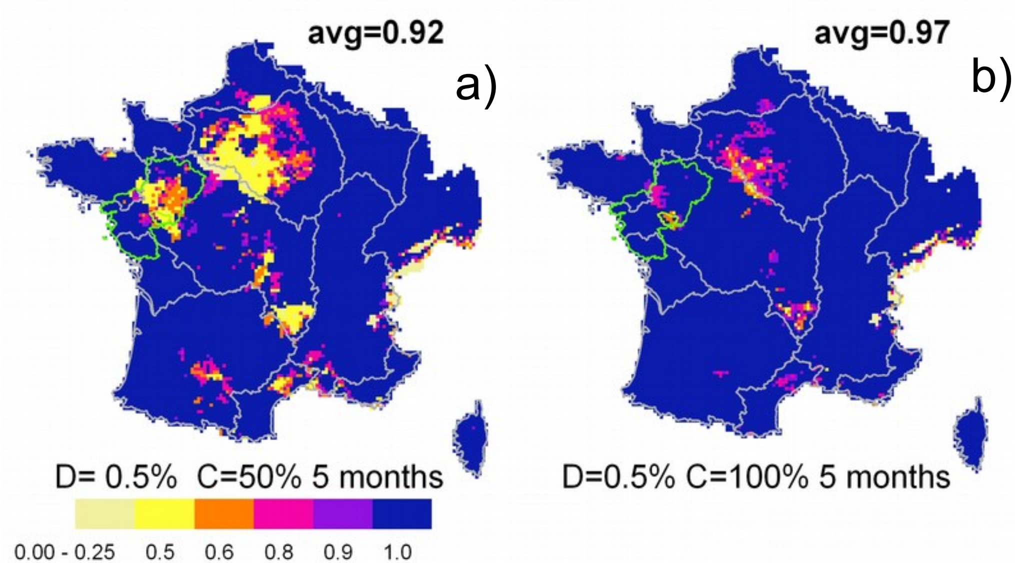
•Future climate ?

Hydrological model : ISBA/MODCOU (at the scale of France



a) **Schematic representation of a small farm dam (SFD)**

Present climate



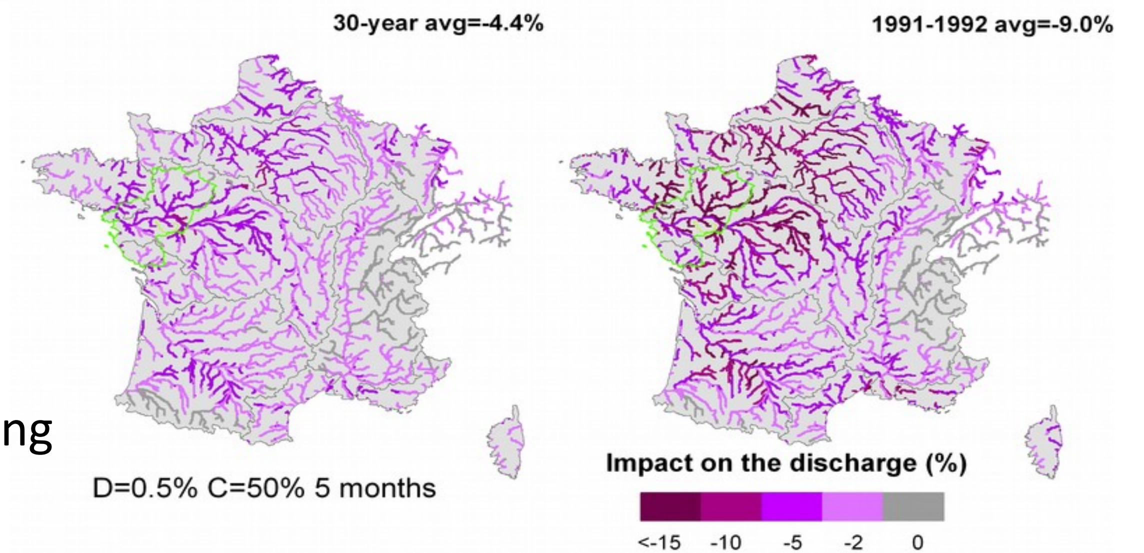
a) dams catchments = 50 % of the area

b) dams catchments = 100 % of the area

Impact on the average discharge : -4%

-9% in 1991/1992

Difficulties to fill the dams during dry winters !



Habets et al., in press

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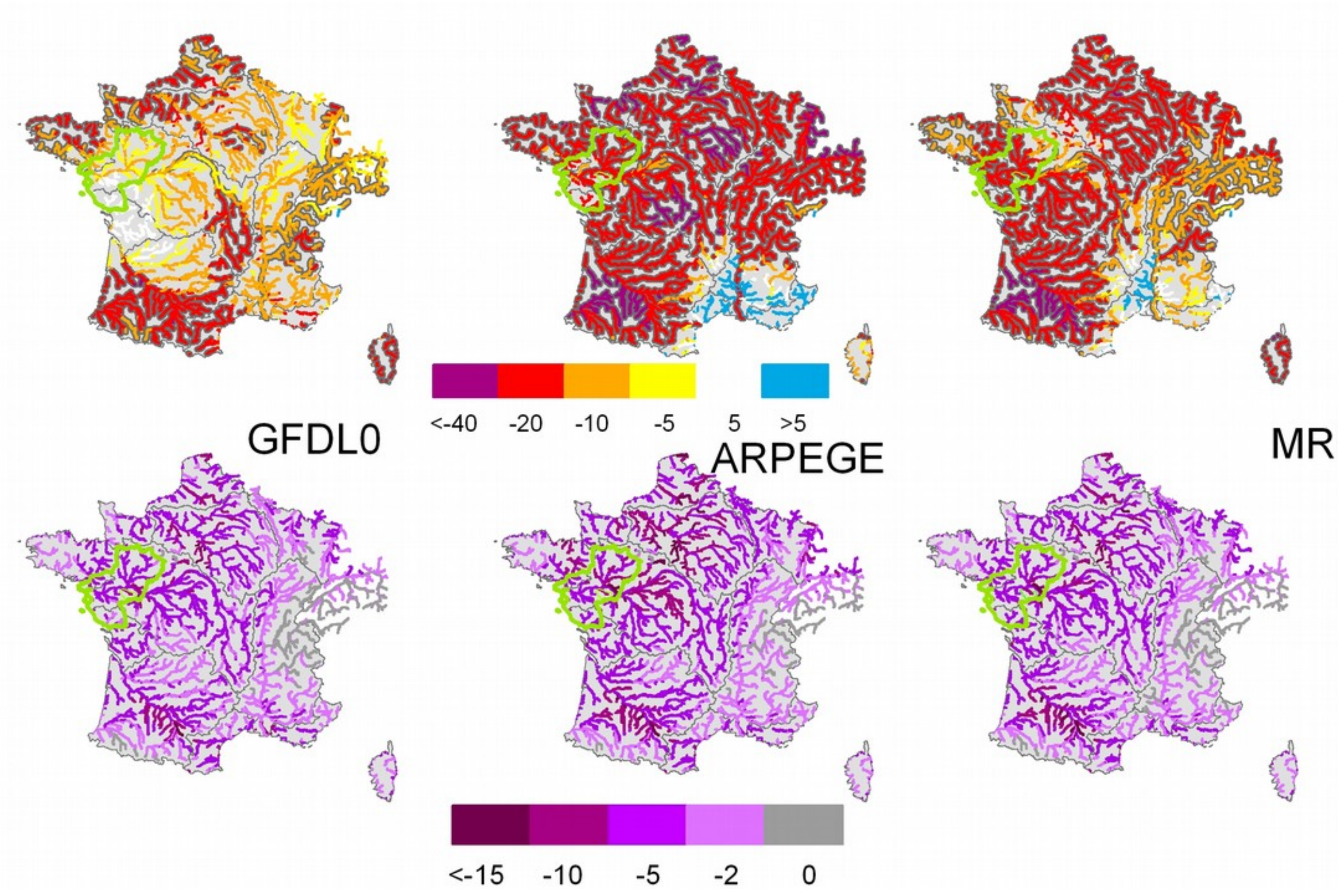
Impact of climate change (A1B – 2050)



3 contrasted scenarios for 2050 :

Impact on discharge : up to –40%

Additional effect of dams

~-5%

(Evaporation from dams not taken into account)

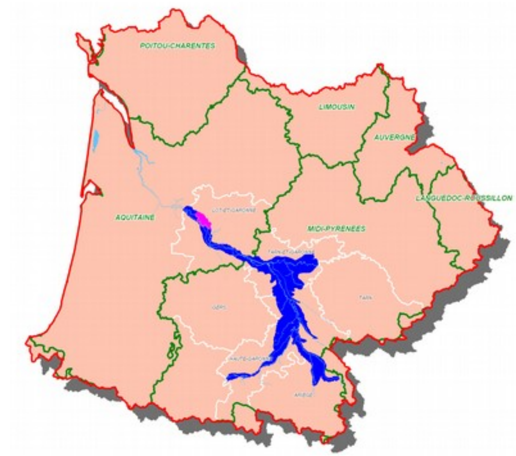
Habets et al., in press

Aquifers

Aquifers are part of whole systems and provide a part of the water used for irrigation

The aquifers are fed by rain and sustain the river discharge in (nearly) all seasons

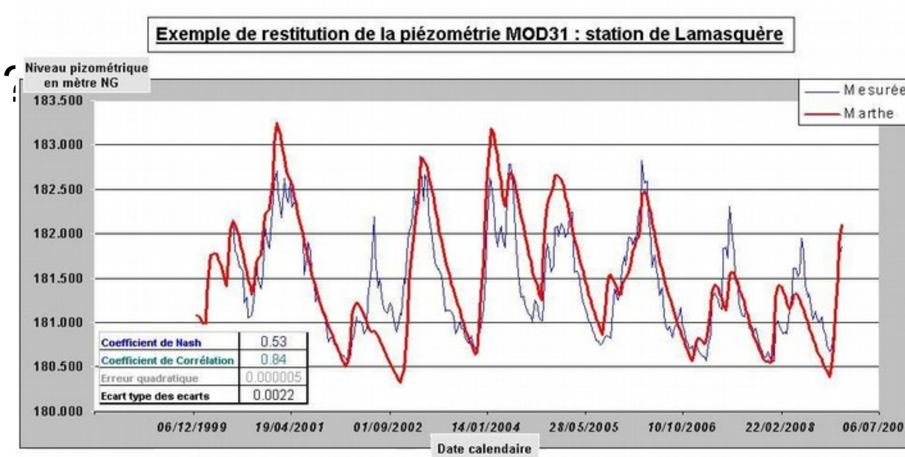
Aquifer model : MARTHE



At present the model is used operationnally to test pumping scenarios to determine the maximum available water

Can the model results be improved with a more accurate surface budget ?

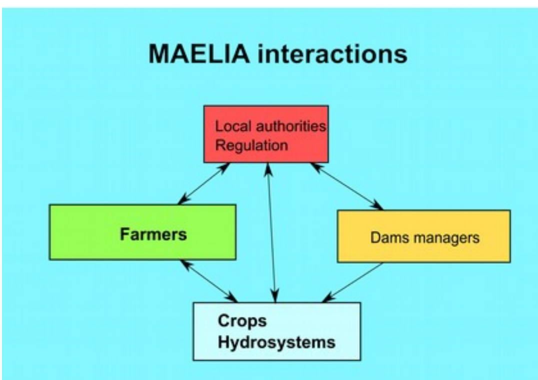
What is the impact of aquifers on discharge, especially during low flows ?

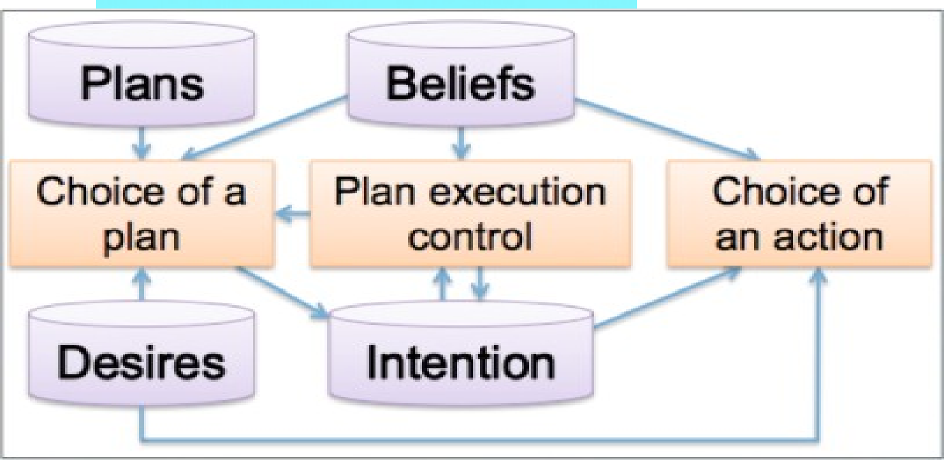


Courtesy Bardeau et al.

The multi-agent system MAELIA

- Processes interact in space (field, farm, sub-watershed) and time (day)
- MAELIA includes a coupling of social and ecological processes





A Belief-Desire-Intention architecture to represent the farmer's:

- multi-criteria choice of the cropping plan according the belief theory on 4 criteria : profit, variability of profit, workload and similarity to the last cropping plan
- Memorize yields, prices, water available, workload

Courtesy: Therond et al.

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Example of decisions and actions

Human activities (Decision process)

- **Farmer decision**
  - crop allocation plan
  - crop management
- **Local authorities decision:**
  - Water-use restrictions (severity & spatial extension)
- **Dam Manager decision:**
  - water releases

Different operations (some just for workload constraints) :

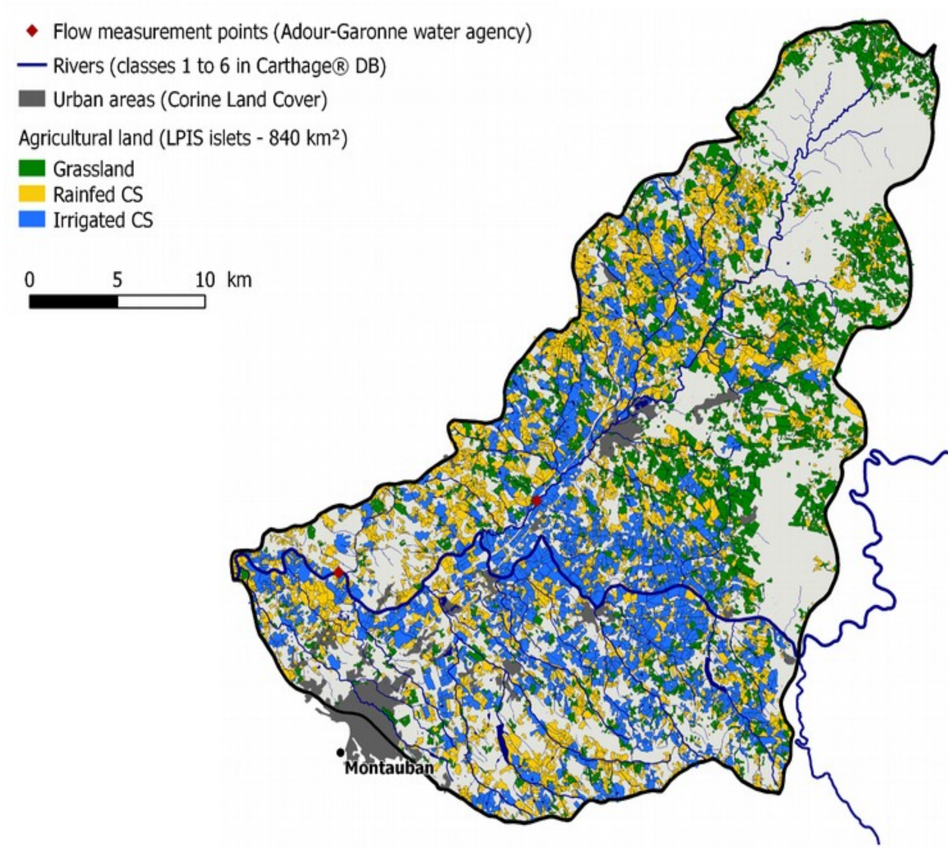
- Tillage
- Sowing a field
- Protect cultures
- Surface tilling
- Fertilise a filed
- Irrigation of a field
- Harvesting of a field

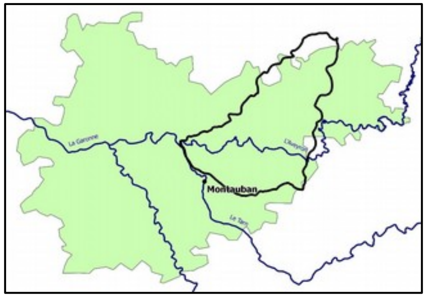
Courtesy: Therond et al.

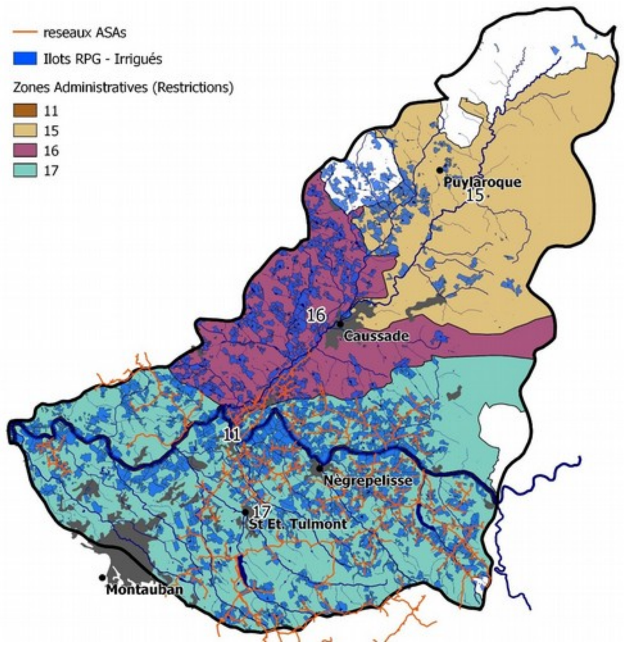
Application on the Aveyron sub-catchment

40 000 ha, 1150 farms

Maize : 12% of the surface



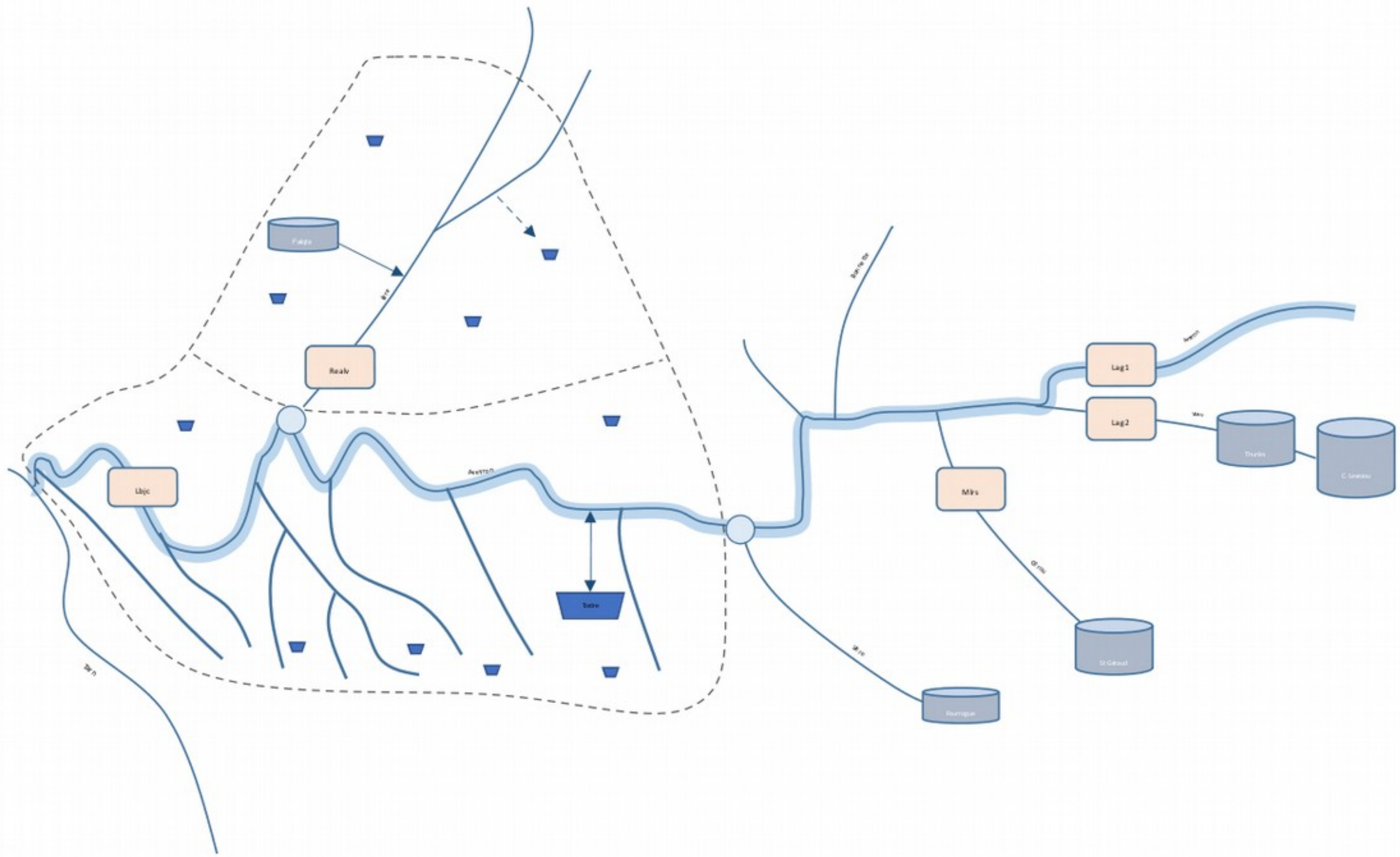




Courtesy: Therond et al.

C. Murgue

Hydrological scheme



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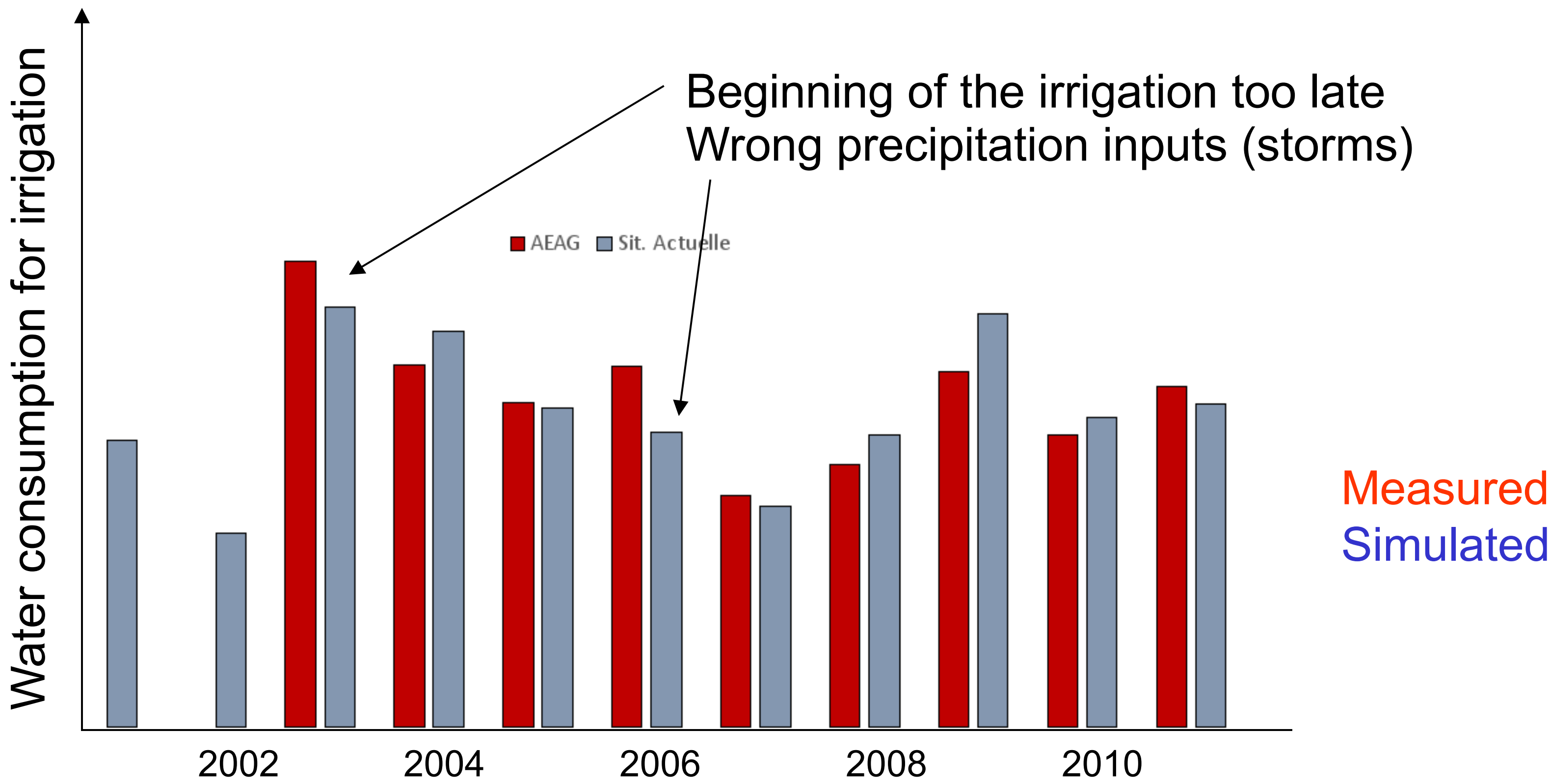
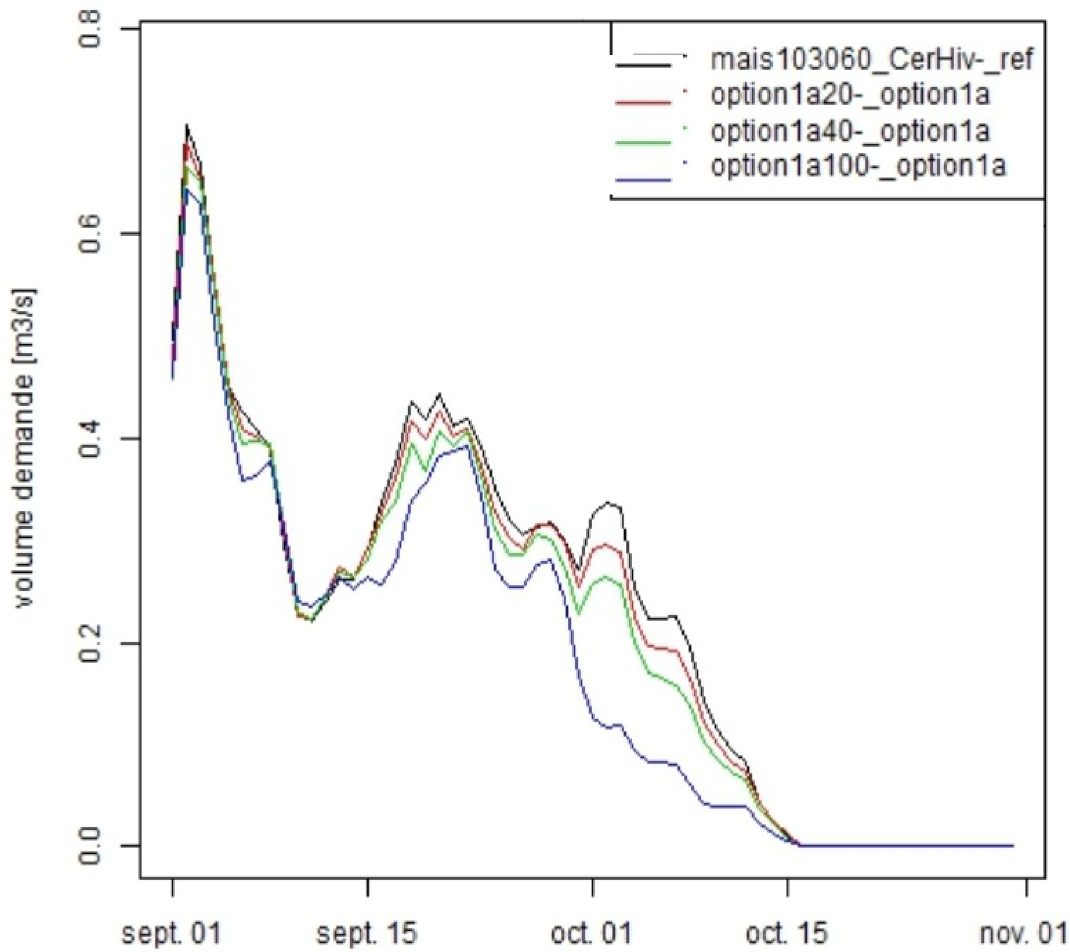
Validation with measured water consumptions



Scenario 1 : Moving to early maize

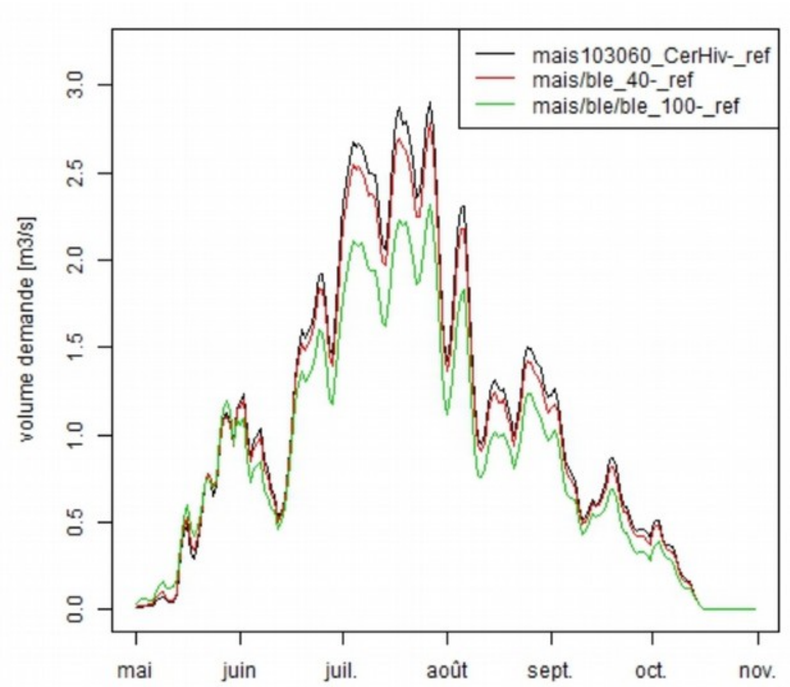
Replacement of current maize by early maize
Over 20, 40 and 100% of the Actual surfaces

Impact at the end of the season
If the change occurs for more than 40 % of the fields
Mainly for years with hot springs



Courtesy: Therond et al.

Scenario 2 : Impact of a replacement of maize by maize/wheat rotations



Irrigation volume
Mean year

Replacement over
-40% of the surface
-100% of the surface

Significant impact only for 100%

Courtesy: Therond et al.

Conclusion

- Fine scale modeling of highly anthropized basins need a huge amount of data due to the complexity of the systems
- Multi-agent systems may be a way to account for the many human factors (agriculture, environmental, …).
- The water budget is the result of the interaction of all components of the system
- Even if the system is not fully coupled now, the components are able to evaluate the feasibility of some management options.

- (Long) series of remotely sense data can help to constrain and validate the systems :
  - Land-use changes (incl. urbanisation)
  - Surface state (snow, soil moisture, incl. inundated areas)
  - Rivers and aquifers including their interactions.

- Fine scale models may help to better inform large scale modeling