THE EBRO RIVER:

SAME BASIN, DIFFERENT SYSTEM.

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The Ebro basin

Largest Mediterranean river of Spain.

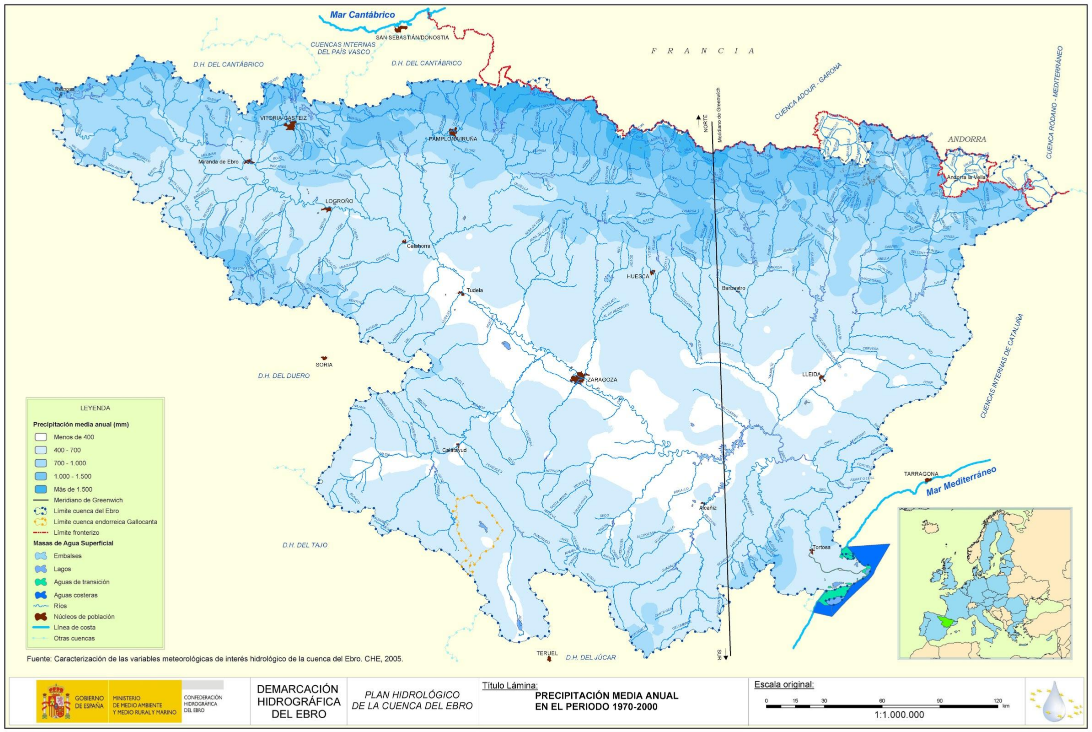
- ~86.000 km^2

Iberian river with highest mean flow.

- ~14.000 hm^3/y (natural flow)

River managed by the "Hydrographic Confederacy of the Ebro" (CHE, in Spanish).

Precipitation

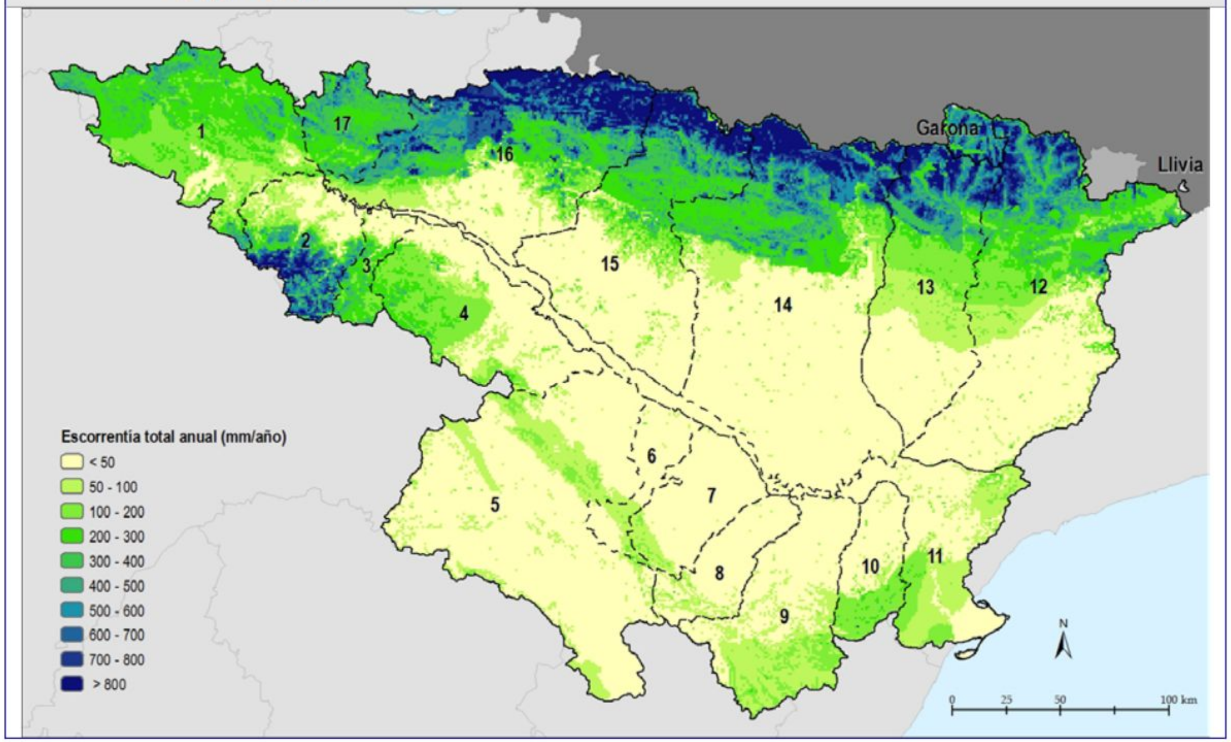


- Uneven distribution of precipitation
- Very dry central valley (~200 mm/y).

Precipitation is concentrated on the relief (> 1500 mm/y on the Pyrenees) and the northwestern part of the basin.

Runoff generation

Figura 30. Distribución espacial de la escorrentía total anual según el modelo SIMPA (mm/año), periodo 1980/81-2005/06

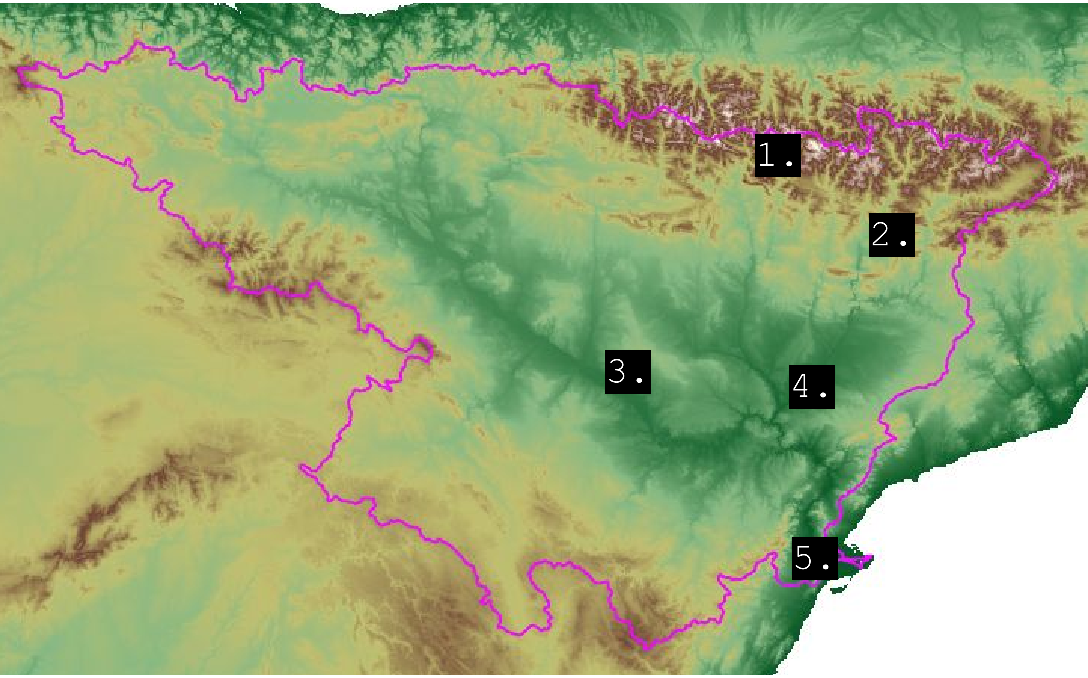


Water resources are mostly generated on the northern relief.

Large scale models often have a crude description of the relief.

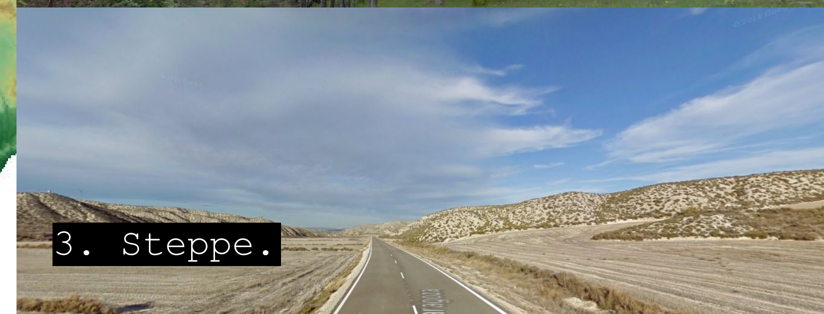
Agricultural areas are located in the valleys, far from where the water resources are generated.

Landscapes



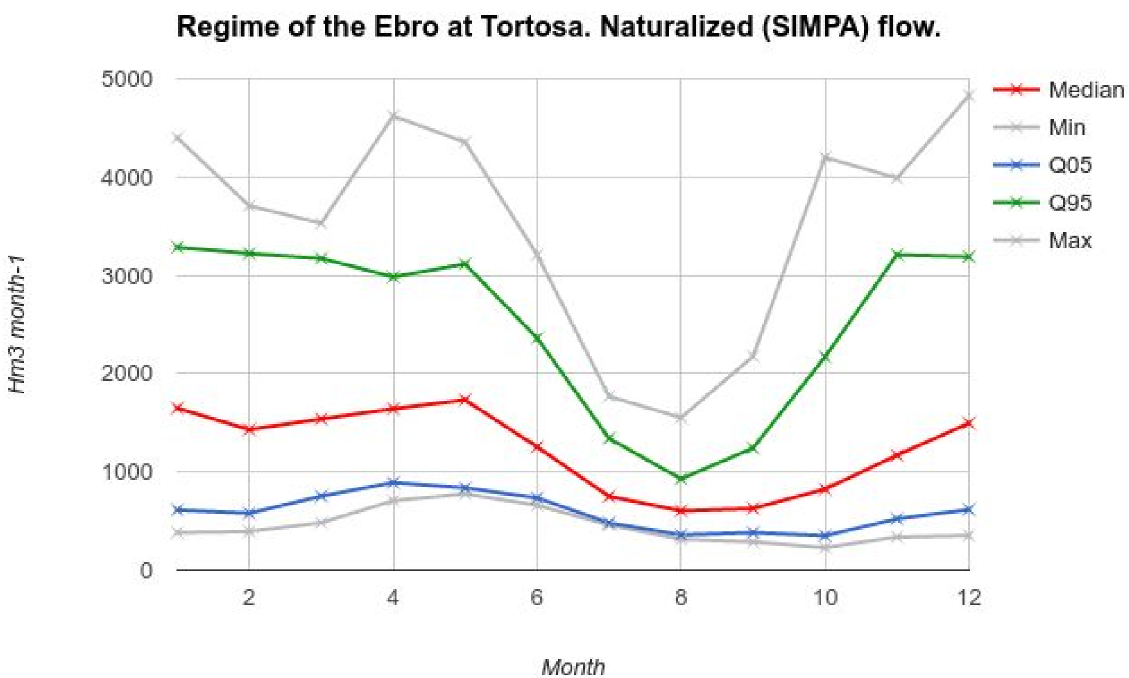
High diversity of landscapes and, thus, of hydrological processes.

Models must be able to correctly simulate processes in semi-arid areas, forests, high mountains, agricultural plains, etc.



Photos from Google Street-View

The natural regime at Tortosa (outlet)



- Mediterranean regime.
- High inter-annual variability.
- Low flows in summer.
- High flows in autumn-winter (ONDJ) and spring (AM).
- Spring flow includes melting.

The high variability makes water management challenging.

The Mediterranean influence, means that models must be able to simulate small scale intense events.

Current water demands and uses

- Water Exploitation Index:
  - its consumptive use of water being more than **34%** of the average long term renewable resources of the basin.
- Water resources are mainly managed using dams.
  - ~97% of the supply comes from surface waters.
  - Underground water represents ~3% of the supply.
  - The total dam capacity: 7600 hm3 (**54%** of the outlet's annual mean flow, ~14.000 hm3).
- Total demand is 58% of the annual mean flow.
- Demand is currently not satisfied in 875 hm3/y.
  - Not enough resources available (south), lack of regulation (north).

Ebro basin - Water demand (excluding transfers)

Sector	Demand (hm3/y)	%
Agriculture	7680,6	94%
Industry	147,3	2%
Urban	357,6	4%
TOTAL	8185,5	

source: CHE

Agriculture

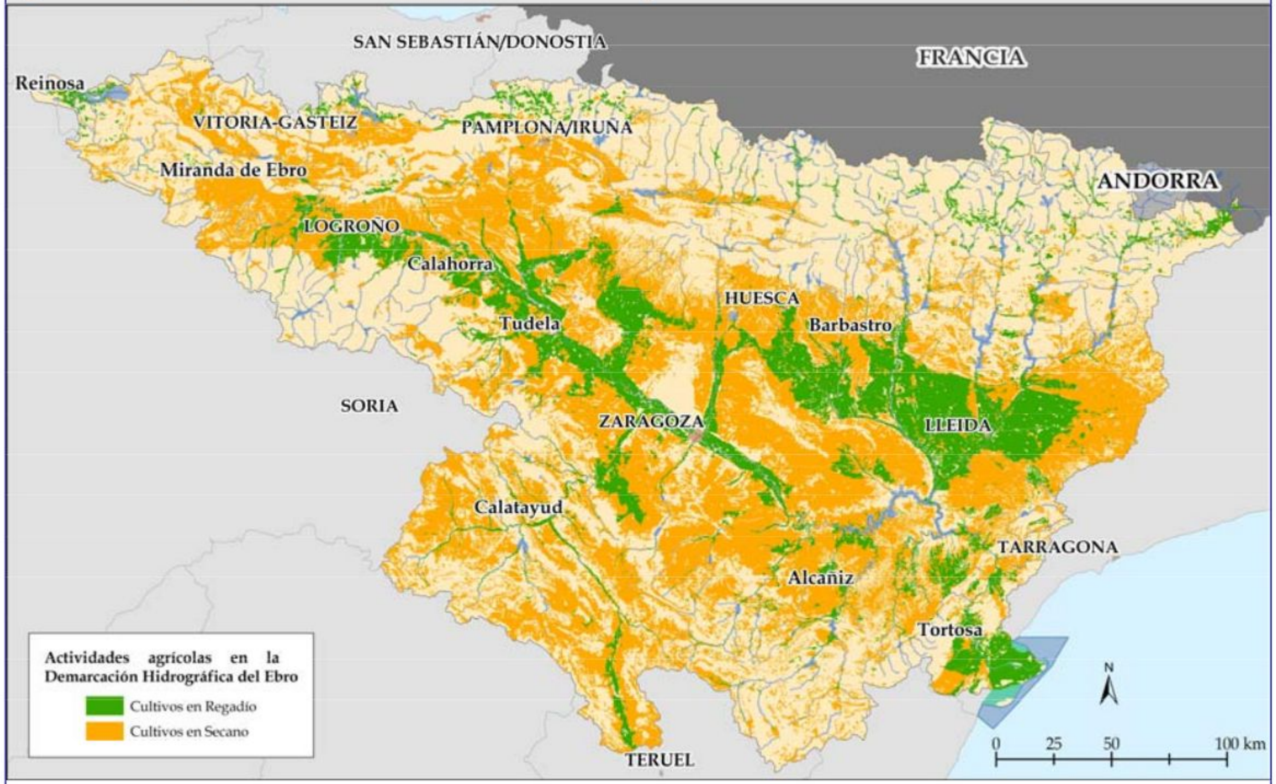
Agriculture is concentrated in the valleys.

Diversity of crops.

Water is needed mainly in spring and summer.

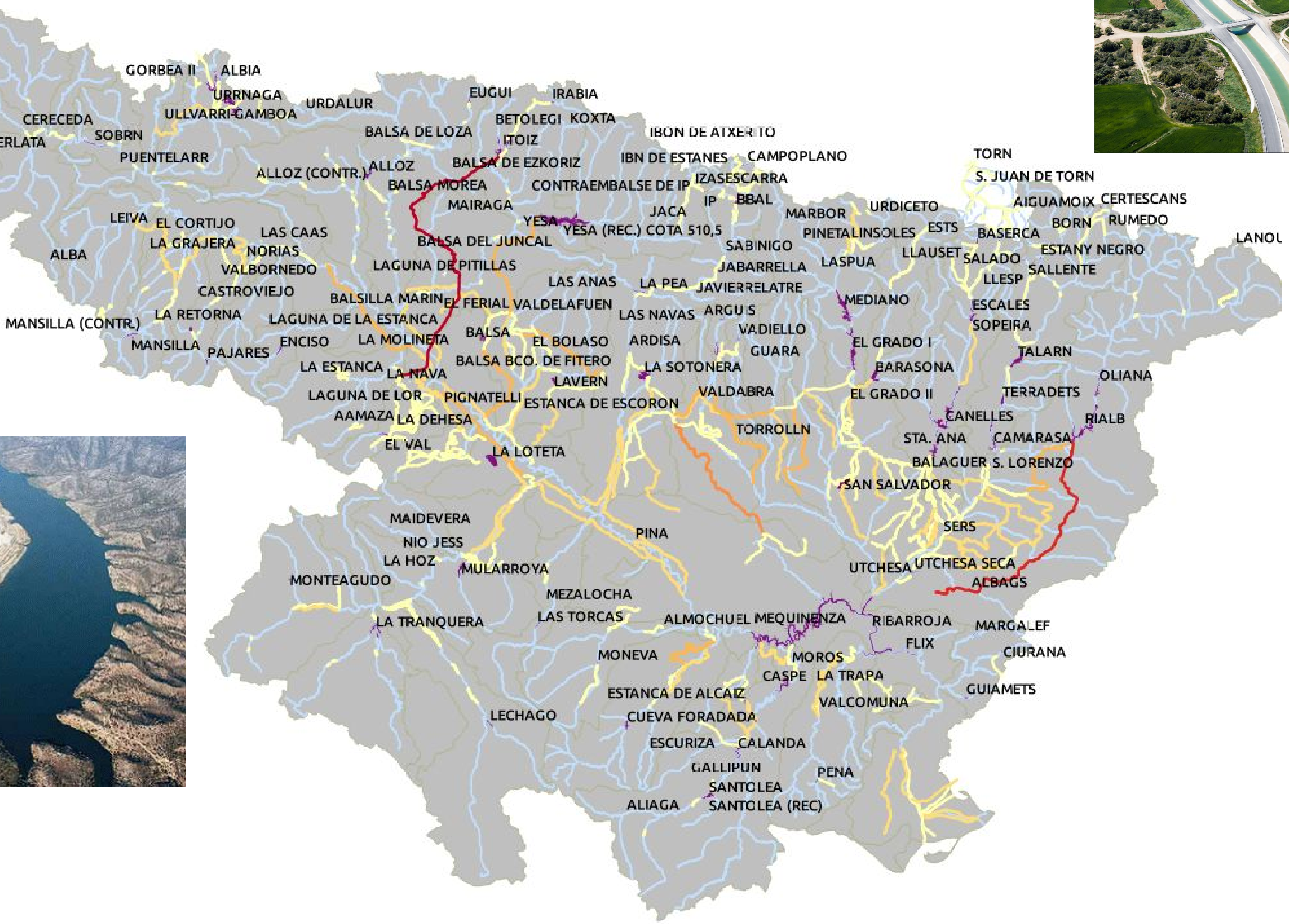
Water is stocked in dams and transported through the river and canal networks.

Figura 51. Tipos de cultivos en la Demarcación Hidrográfica del Ebro



Fuente: CORINE

Current infrastructure



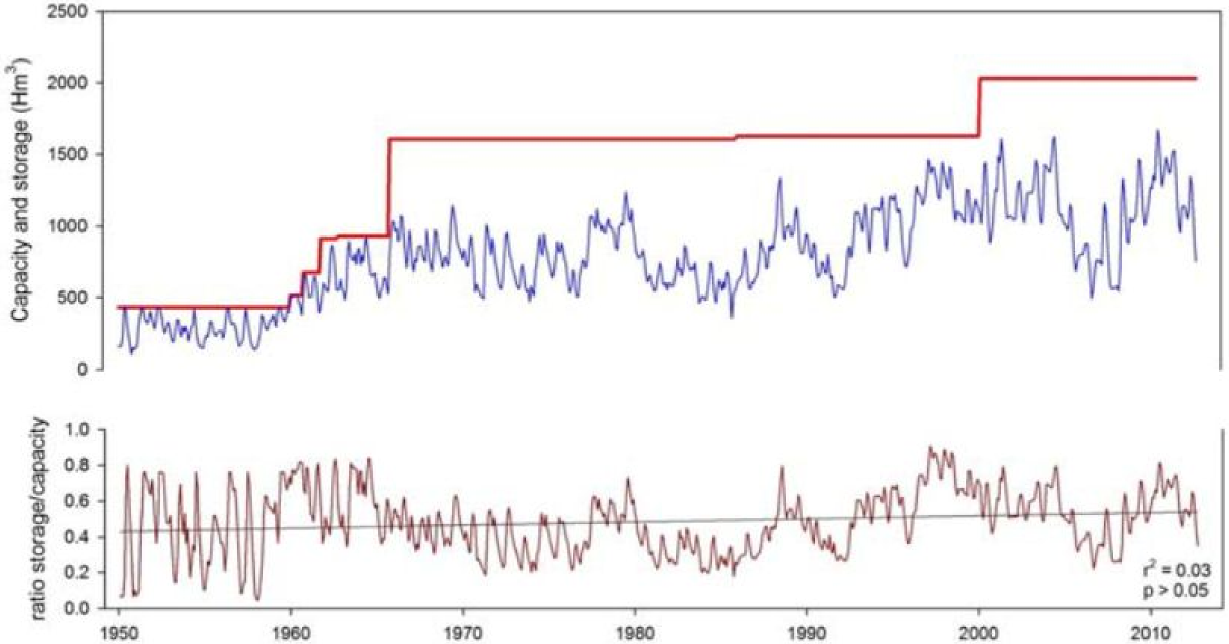
Large infrastructures have been built in order to guarantee the supply of water for irrigation.

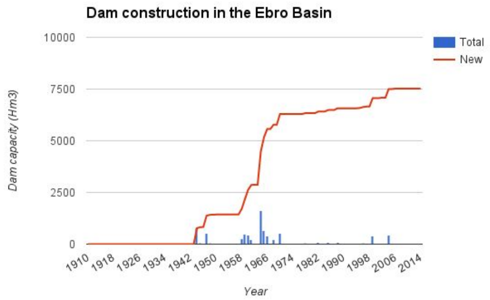
Timeline of infraestructure building

Dam construction starts after the Spanish Civil War, in the 1940s. Major dams were constructed in the 1960s.

Timeline of infraestructure building

Evolution of total dam capacity and volume
(Vicente-Serrano et al., 2016).





Actual water storage in dams is lower than dam capacity.

It depends on climate, management, etc.

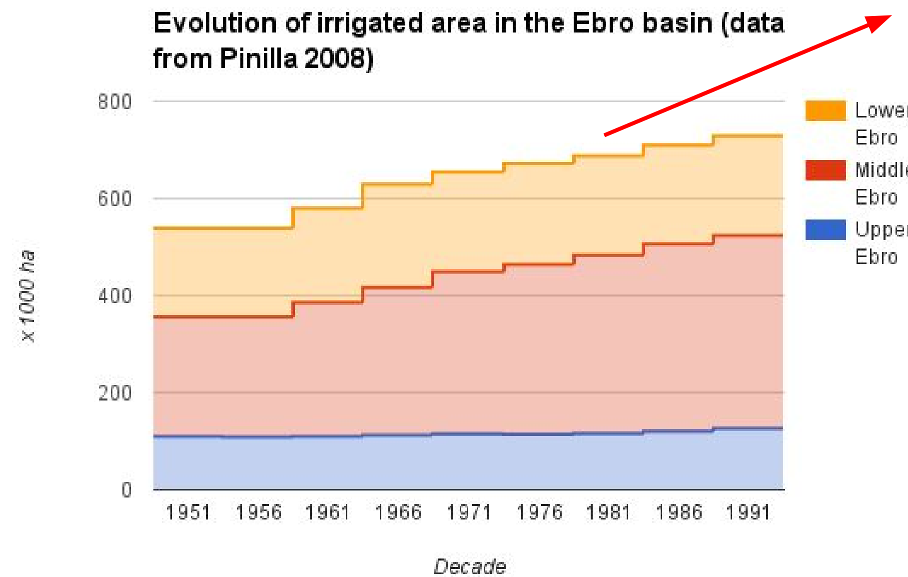
Evolution of irrigation

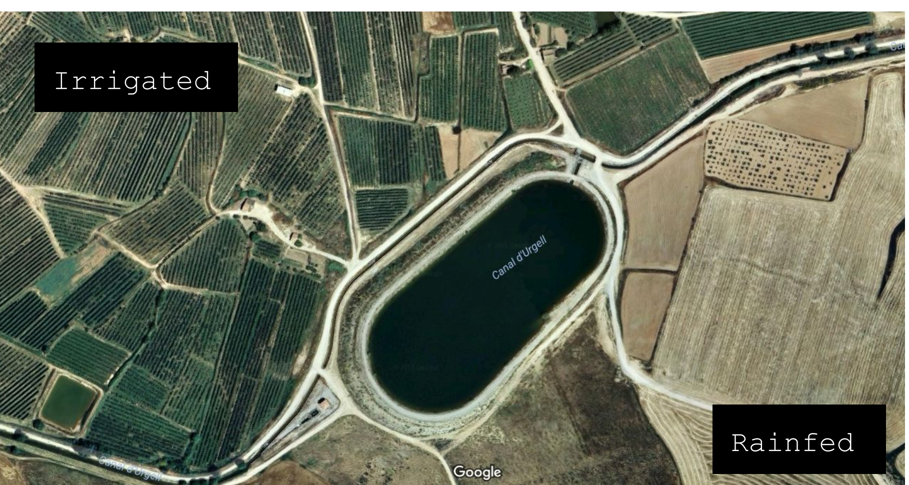
New offer and increased demand go hand in hand.

Increased demand can be explained by:

- Increased irrigated area.
- Intensification and increased productivity.
  - New crops.
  - New technologies.

Currently irrigated surface is 966.000 ha. (source CHE)





	Change between 1990 and 1950 (1950 is 100).
Production	348
Surface	160
Prod/ha	217

Source: Pinilla (2006)

Impacts of modern irrigation systems

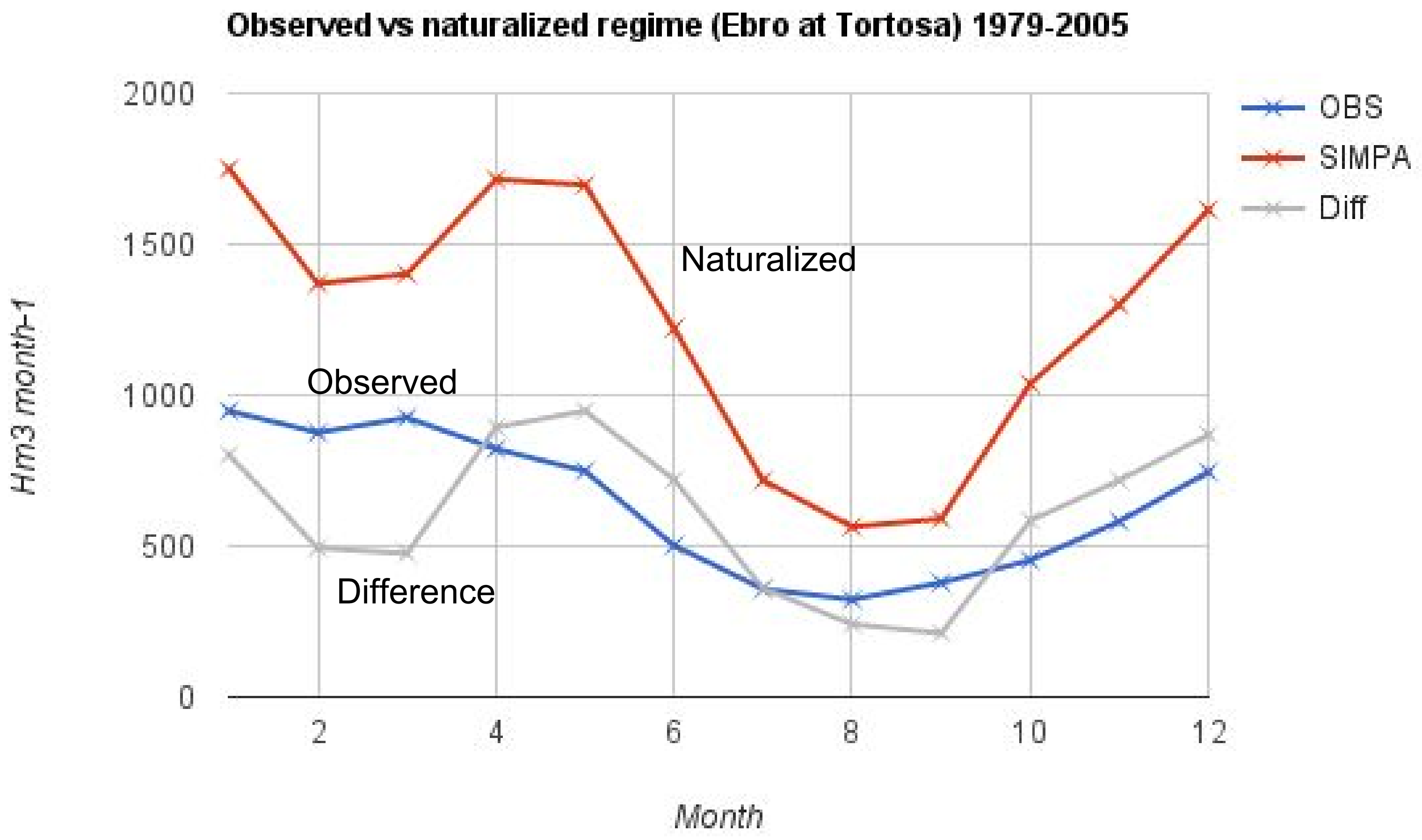
Different methods, different impacts on the water balance.

The case of the Alto Aragon (Lecina et al., 2010)

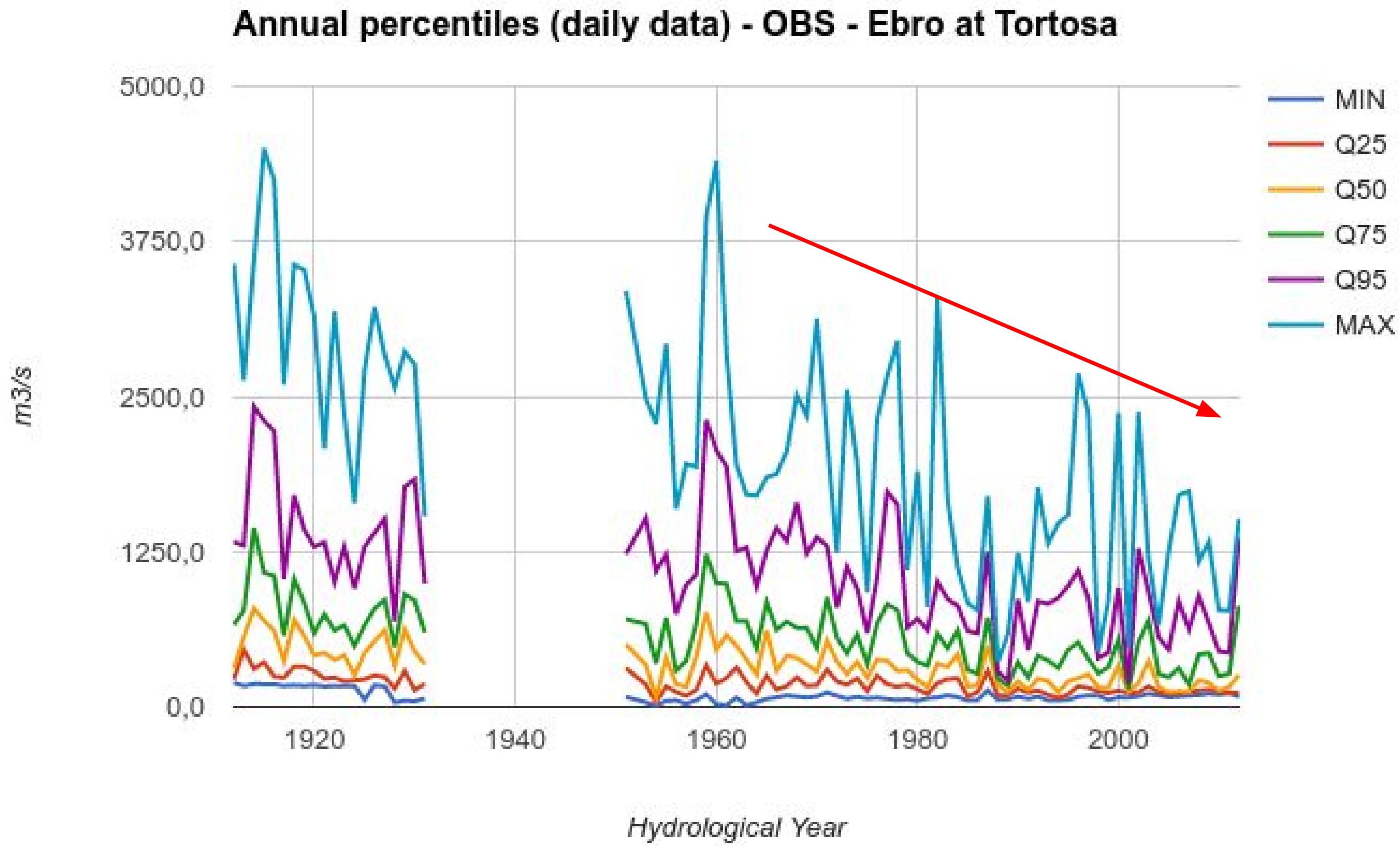
- Traditional irrigation (73%) and sprinkler systems (27%).
- Farmers are switching to sprinkler systems which:
  - increase crop yields
  - cause more intense cropping patterns.
  - increase crop evapotranspiration and non-beneficial evapotranspiration per unit area!
- As a consequence:
  - Increased water depletion and water use.
  - Higher productivity.
  - Lower return flows: improvements in the quality of the receiving water bodies.
  - **Water productivity computed over water depletion will not vary with irrigation modernization.**

Anthropic impacts on the river flow

Current management practices have altered the river regime.



Negative trends in river flow



- Negative trends in almost all percentiles.
- Decreased variability.
- Lower peak flows, decreased floods.
- Low flows depend on environmental flow regulation.

Anthropic impacts on river flow

The decrease of flow is not so pronounced in the Pyrenees.

The basin is becoming more dependant on the Pyrenean runoff.

This is a problem under climate change:

- Decreased snowfall.
- Increased evapotranspiration in the headwaters.

López-Moreno et al., 2011.

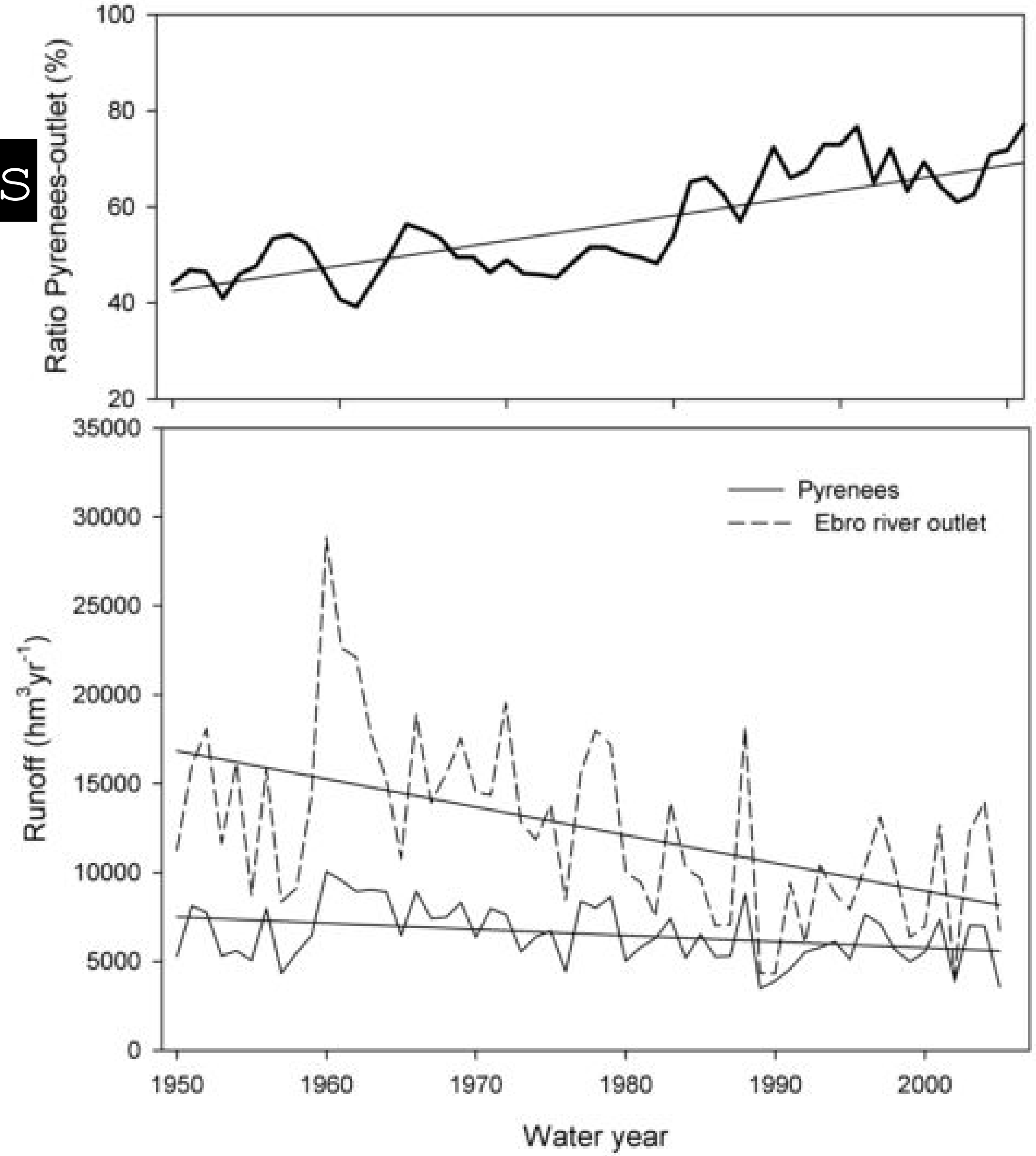


Fig. 7. Annual runoff from Pyrenean headwaters and the discharge of the Ebro River in its lower reaches (lower panel). Evolution of the ratio between the series (upper panel).

Land-use and land-cover (LULC) change

Photo source.

- Abandonment of agricultural areas in the headwaters is causing an increase in forested area, which increases evapotranspiration and decreases runoff generation in the Pyrenees.
- Revegetation is far to conclude.

López-Moreno et al., 2011.

Climate Change vs direct impacts.

It is already possible to estimate the contribution of climate change.

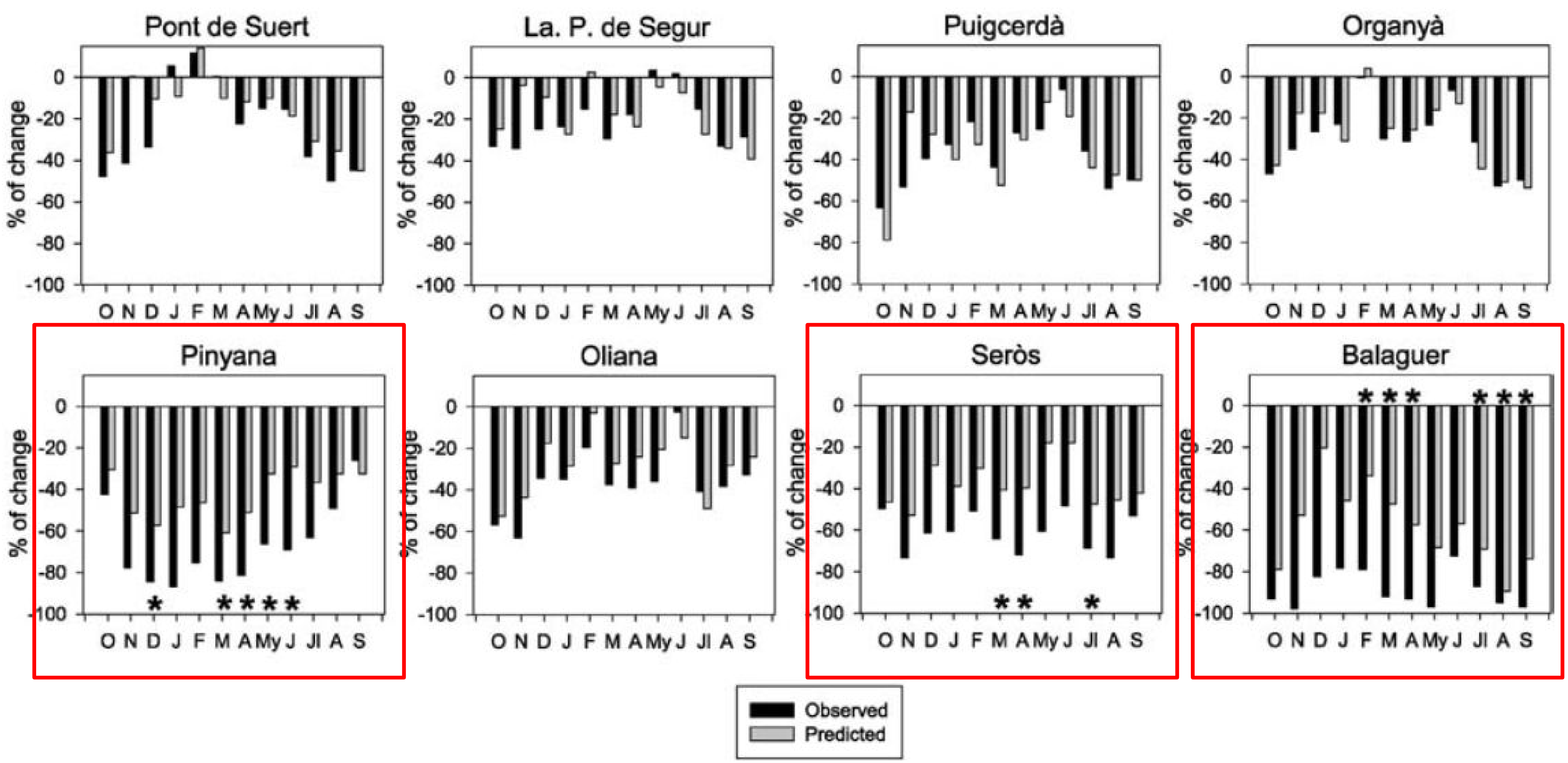


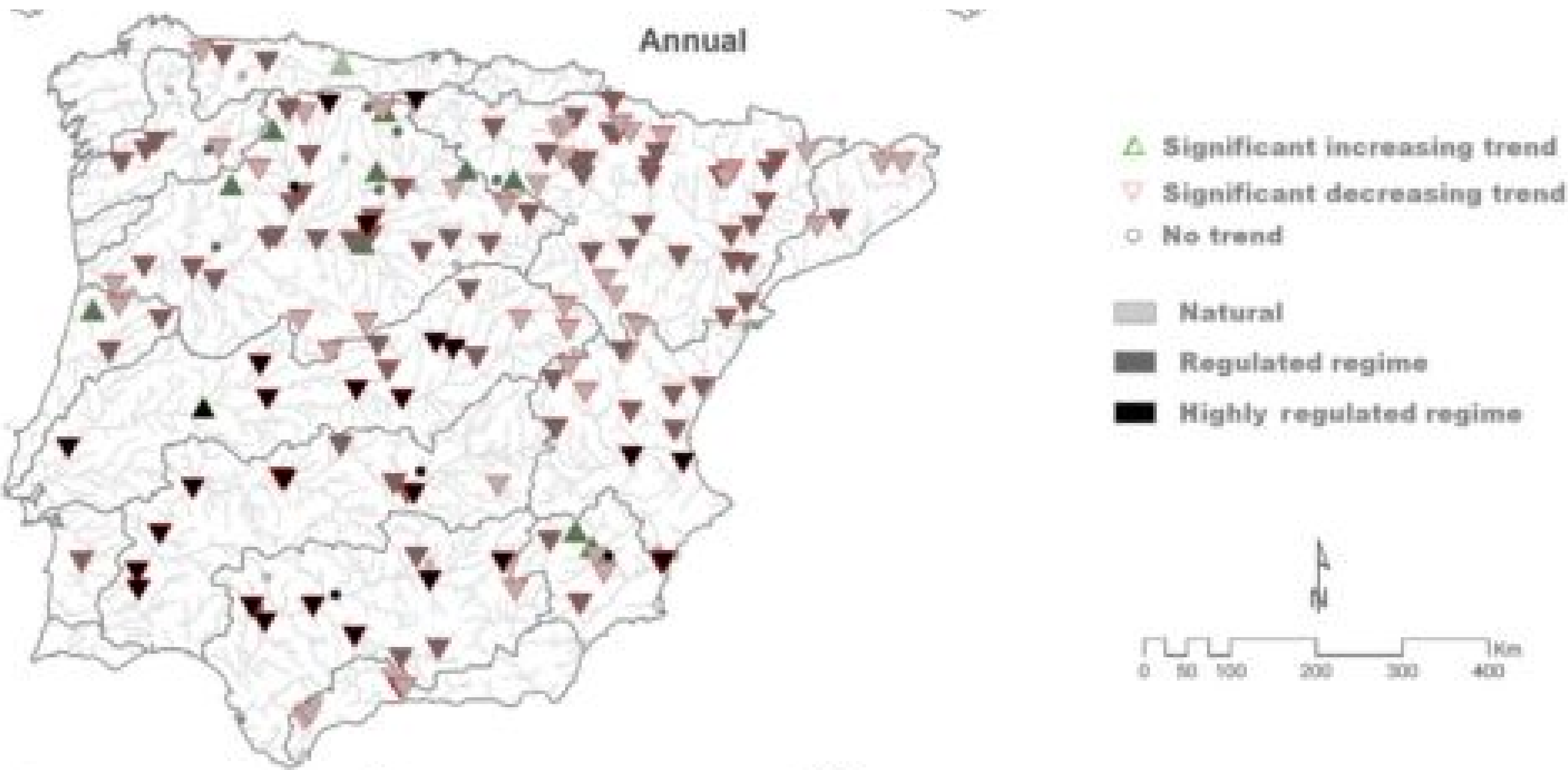
Fig. 12. Observed percentage change in monthly streamflow from 1951 to 2013, and predicted percentage change according to climatic changes alone. Asterisk indicates a statistically significant difference ($p < 0.05$) between observed and predicted changes.

Vicente-Serrano et al. (2016) CATENA

Observed river flow trends

Observed trends in monthly river flows are caused by:

- Water management.
- LULC.
- Climate change.



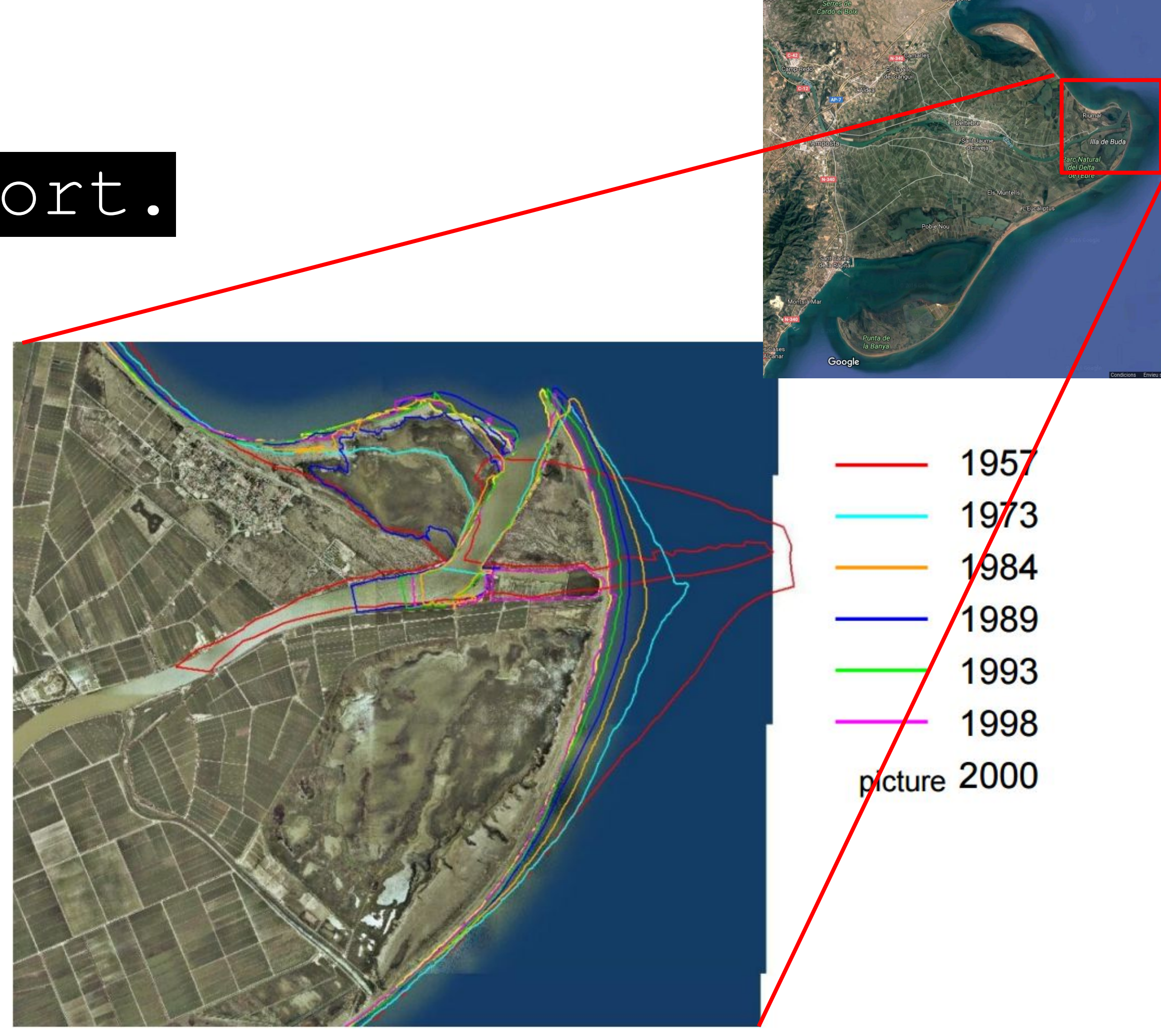
Lorenzo-Lacruz et al., 2012.

Sediment transport.

Dams are causing changes in sediment transport.

The sediment load of the lower Ebro was reduced by 95-99% (Rovira and Ibàñez, 2007; Tena and Batalla, 2013).

Sediments are need to compensate for subsidence and sea-level rise.



Source: C. Ibáñez.

Operational and structural changes are needed in order to manage sediment flow (Rovira and Ibàñez, 2007).

CEDEX (2010, 2012)

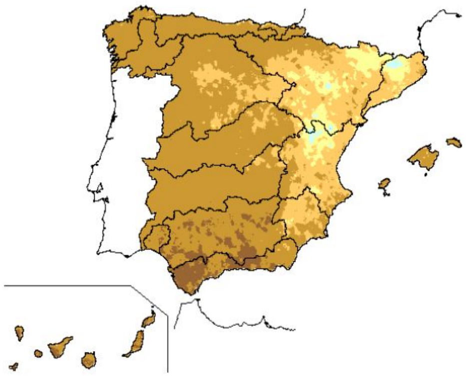
A2 emissions scenario; 2071-2100.

Precipitation ↓

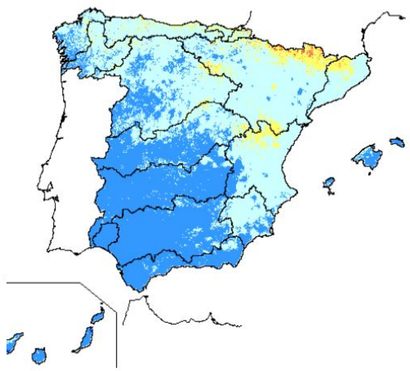
Evapotranspiration: ↑ Pyrenees, ↓ Valley

River-flow ↓

Climate Change.



Delta of annual precipitation (%)



Delta of real evapotranspiration (%)

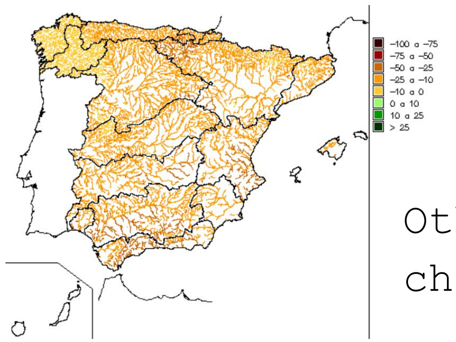


Figura 148. Δ APN (%) en la red hidrográfica. 2071-2100, B2

Delta of natural river flow (%)

Other expected changes:

- Possible increase in extreme events.
- Decreased snowfall.
- Longer summer dry spells.

Change in the available water resources (%) in comparison to 1961-1990.

		Escenario de Emisiones A2							Escenario de Emisiones B2						
		CGCM2-FIC	ECHAM4-FIC	HadAM3-FIC	HadCM3-SDSM	HadCM3-PROMES	ECHAM4-RCAO	Media	CGCM2-FIC	ECHAM4-FIC	HadAM3-FIC	HadCM3-SDSM	HadCM3-PROMES	ECHAM4-RCAO	Media
	2011-2040	-7	-13		-12			-11	-8	-14		-9			-10
Ebro	2041-2070	-11	-18		-18			-16	-12	-21		-17			-17
	2071-2100	-17	-21	-12	-40	-26	-37	-26	-5	-18	-10	-17	-23	-22	-16

Water resources will decrease.

Is current and planned irrigation sustainable?

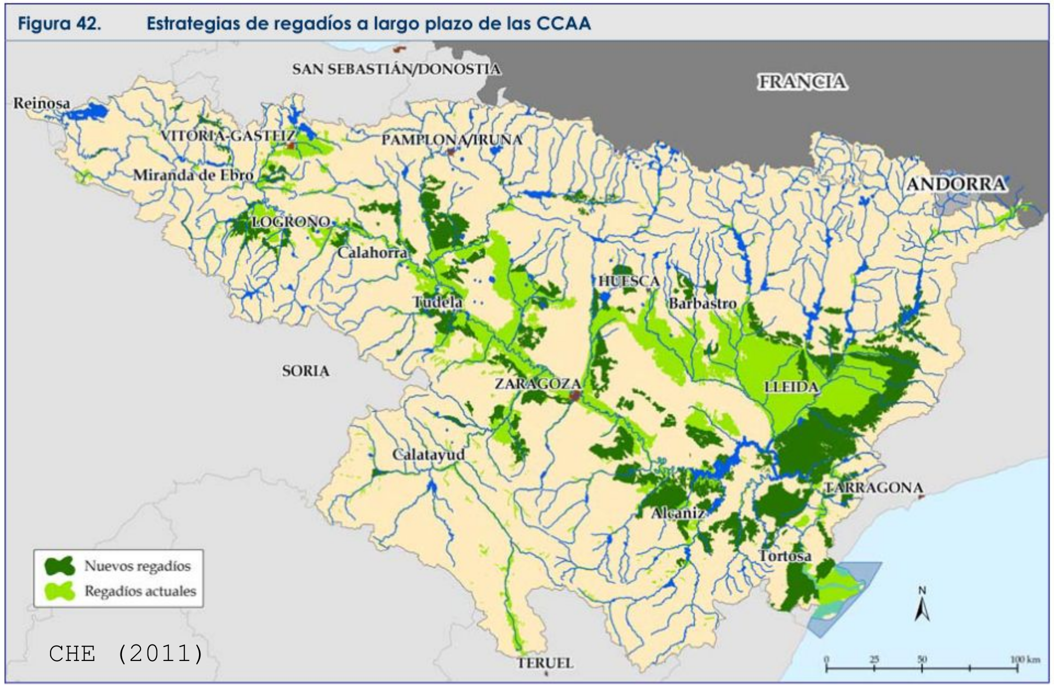
Milano et al. (2013):

- In 2050, water resources are projected to decrease by 15-35% during spring and summer.
- Growing competition among users and severe water shortages for irrigated agriculture.

Current policies stipulate that demand should increase from 7700 hm3/y (2013) to 9800 hm3/y (2033) +27%!

New dams are not expected.

Planned expansion of irrigation in the basin.



Expansion of irrigation demand does not seem realistic according to climate scenarios.

Simulation of the real Ebro basin.

Modeling the Ebro in natural conditions is a challenging task.

- Rich basin hydrological behaviour.
- Importance of relief.
- Snowpack.

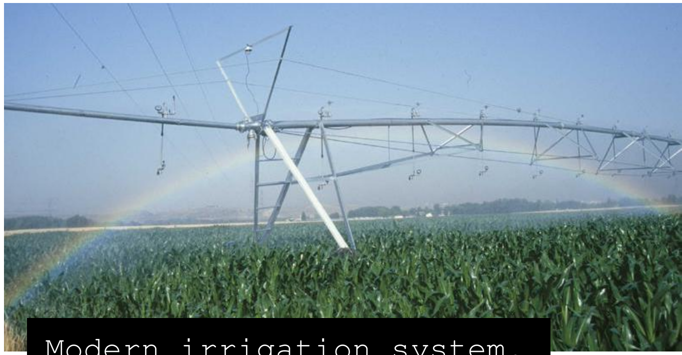
(relief and snow are challenging for global models)

It is a regulated river:

- Humans are part of the system (feedbacks).
- Modified water balance.
- Modified mean and extreme flows.
- Changed regime.

Very sensitive to the impacts of climate change.

Pyrenees.



Modern irrigation system.

Riba-roja dam.

Simulation of the real basin.

Main direct human influences:

- Dams, canals, irrigation and land-use.
- Climate Change.

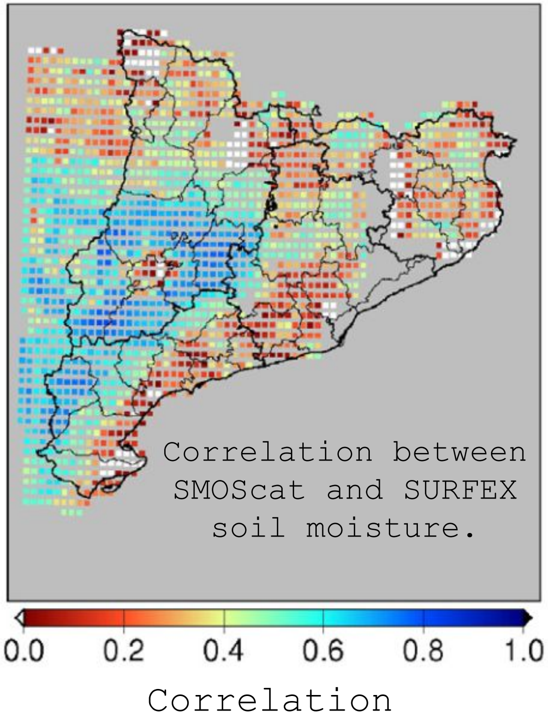
These change in time.

Dams and canals can be simulated by means of management rules or forcing them with observed data.

In order to simulate the impact of **irrigation**, it is necessary to take into account the wide variety of crops and irrigation methods.

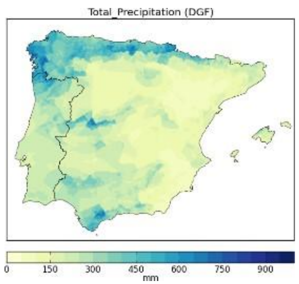
Remote sensing can provide information on land-use change, irrigation (Escorihuela and Quintana-Seguí, 2016), etc.

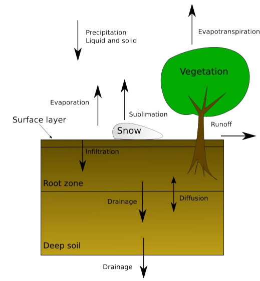
Segarra-Garrigues Canal.

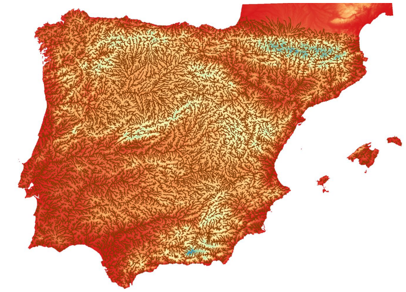


Correlation between SMOScat and SURFEX soil moisture.

The SAFRAN-SURFEX-RAPID model.







ATMOSPHERE *(SAFRAN)* → **LAND SURFACE (SURFEX)** → **RIVER SYSTEM (EAU-DYSSÉE RAPID)**

Based on **SURFEX** LSM (5 km) and similar to Météo-France's SIM (Habets et al., 2008).

SAFRAN meteorological forcing dataset (Quintana-Seguí et al 2016a, 2016b):

- all necessary variables to force a LSM (5 km, 35 years).
- Public dataset. (HyMeX database).

Currently the model simulates the natural system, however **the RAPID River routing scheme is able to simulate dams** (Cédric et al. 2011a, 2011b).

Next steps:

1. In depth **validation** and **improvement** of key processes.
2. Inclusion of **dams** and **irrigation**.

Opportunity for **collaboration:** Implementation, testing and comparison of different methodologies and models.

Conclusions.

- **Human impacts on the Ebro basin are large, have been increasing and are expected to increase even more.**
  - Dams, canals and irrigation.
  - Land-use and land-cover change.
  - Increased disassociation between climate and river-flow.
  - Declining river-flow (mean and extreme).
  - Modified water balance and river regime.

- **An understanding of the hydrology of this basin requires an understanding of human induced processes, their impacts and feedbacks.**
- **We can use the Ebro as a laboratory in order to improve our knowledge on these issues and also for improving, testing and comparing our models.**

The Ebro as a laboratory.

1. The Ebro is a representative Mediterranean basin.
2. Example of human influence in an hydrological system.
3. Data is available (dam inflow and outflow, etc.).
4. There is some momentum:
   a. Projects: HyMeX, E2O, MARCO, etc.
   b. Models: SURFEX, LEAFHYDRO, ORCHIDEE, ...

The following subjects could be studied in a project that could use the Ebro as a laboratory (maybe within a larger project):

1. Irrigation and dam schemes.
2. Land-use and land-cover changes.
3. Physical processes relevant in the Mediterranean: snow, semi-arid areas, extremes, etc.
4. Feedbacks between the human influence and the natural system.

This workshop offers an opportunity to discuss the science behind such a project and also funding options.

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Thank You!

Ebro river at Miravet (Catalonia).

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