A quantitative approach of the morphological changes in the middle Garonne river (South-west France) during the last 150 years

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Fig 1. Location of the Garonne river

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Introduction

The Garonne is the fourth longest river of France (522 km length and 56,000 km² catchment) and flows from south to north-west from the Pyrenees to the Atlantic Ocean (Fig. 1).

The Garonne river has evolved under a state of hydro-geomorphological crisis since the 70s, reflected in :

1) a decrease in the lateral riverbed mobility ;
2) a general trend to channel incision and deepening ;
3) a loss and reduction of riparian environment diversity.

Previous studies have correlated these phenomena to human activity intensification and transformation during the 20th century : reforestation of upper watershed slope, in channel gravel dredge and gravel pit on riverbank/floodplain, sediment retention by hydropower dam, channel fixing by artificial levee or jetty to facilitate fluvial navigation and riverbank protection by embankment to reduce flooding.
However, studies documenting this evolution are sparse and have focused on short time evolution (< 50 years) and man-induce changes. The potential role of recent climate change (shift from Little Ice Age to present Global Warming) has no so far been studied.

The aim of this study is to periodize the geomorphological evolution of the Middle Garonne river, from Toulouse to the Tarn junction from middle 19th century to Present, in order to highlight the respective role of climate vs anthropization as driving force.

Method

The geomorphological evolution of the Garonne river was analysed using four groups of historical maps : 1868 (anonymous author, 1:10000) ; 1941-50 (National Institute of Geography (IGN), 1:5000 to 1:25000) ; 1970-78 (IGN, 1:25000) and 2002-06 (IGN, 1:25000).
These maps were coregistrered with precision depending of the quality of the initial documents (RMSE ranging from 0,5 to 6 m). The channel, the vegetalized islands and the no vegetalized central or lateral bars were then digitized and described using morphometrical measurements.
The 65 km length valley was split into 1 km length units and nine descriptors were retained and computed (Fig.2). Six of these descriptors relate to isands and bars and were computed into each 1 km length unit : vegetalized surface, no vegetalized surface, mean surface, mean perimeter, mean near distance to the bank and mean compactness Gravelius coefficient. The three other descriptors related to the channel are computed on a transect in the middle of each 1 km length unit : number of channel, sum of channels widths and width of the active belt.
For each date, statistical analysis of the data set was performed : 1) PCA in order to evaluate the weight of each descriptor and 2) HCA based on the two first PCs from PCA, in order to cluster units. The different groups of units formed for each date, have been then associated according to the discriminating variables.

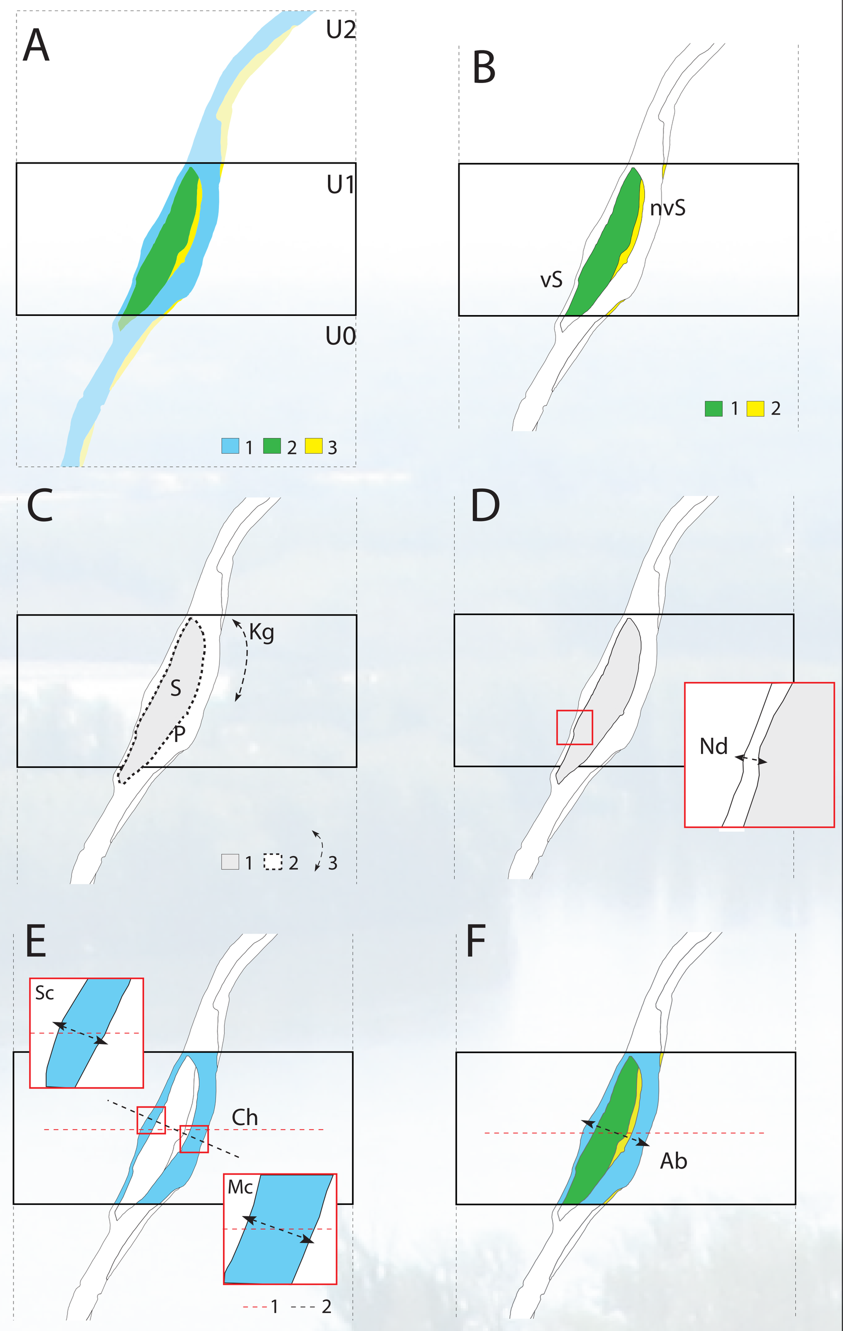

Fig. 2 : Method for morphometrical descriptors computation. **A.** U0, U1, U2 : 1km length units ; 1 : channel ; 2 : vegetalized islands ; 3 : no vegetalized bars. **B.** 1 : vegetalizedsurface (vS, m²) ; 2 : no vegetalized surface (nvS, m²). **C.** 1 : mean surface of islands and bars (S, m²) ; 2 : mean perimeter of islands and bars (P, m) ; 3 : mean compactness Gravelius coefficient (Kg). **D.** Near distance between islands or bars and the bank (Nd, m). **E.** Channels width (Ch, m) : sum of main channel width (Mc, m) and secondary channels widths (Sc, m). **F.** Active belt width (Ab, m)

Results

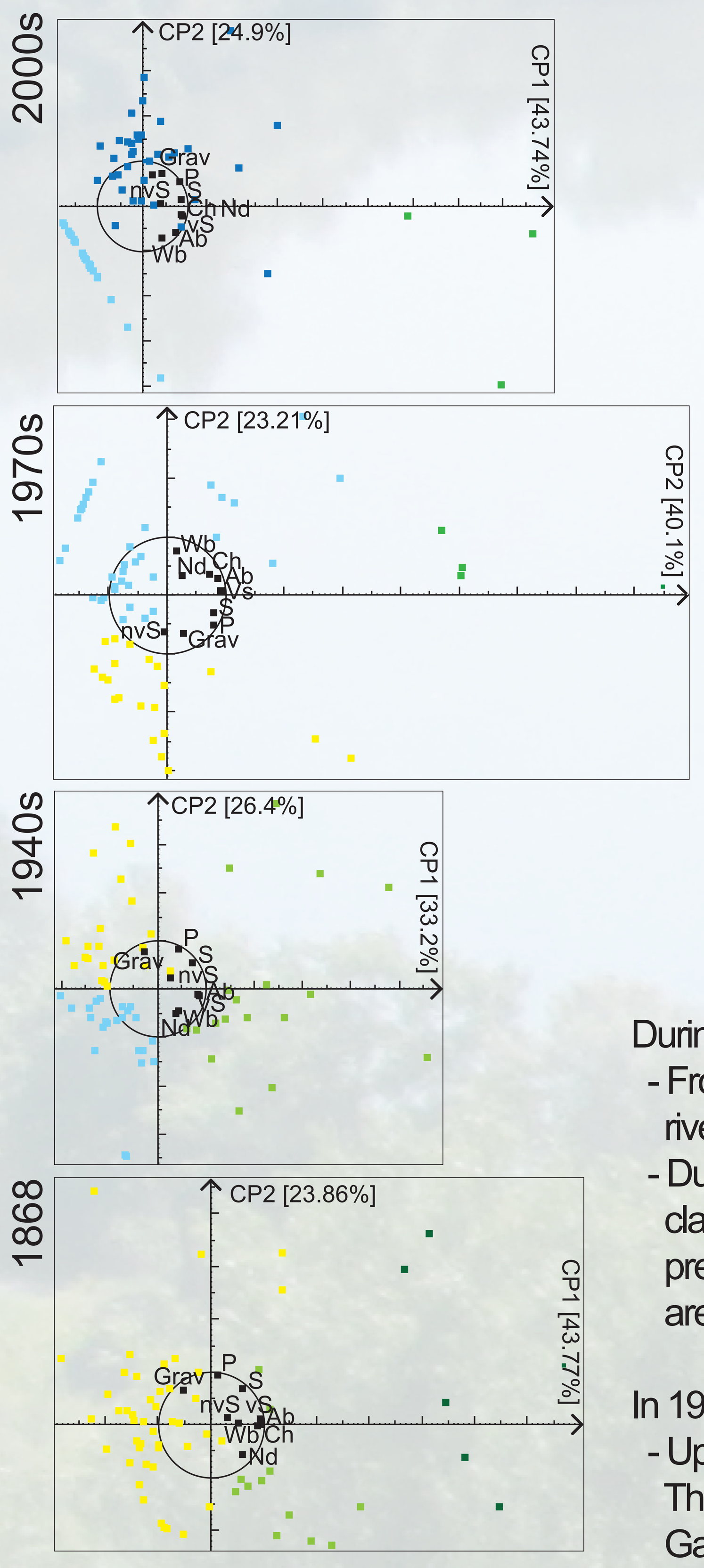

Fig. 3 : Results of PCA / HCA analysis. Circles of correlation and projection of points on the factorial axes (PCA). The colours show clusters from HCA.

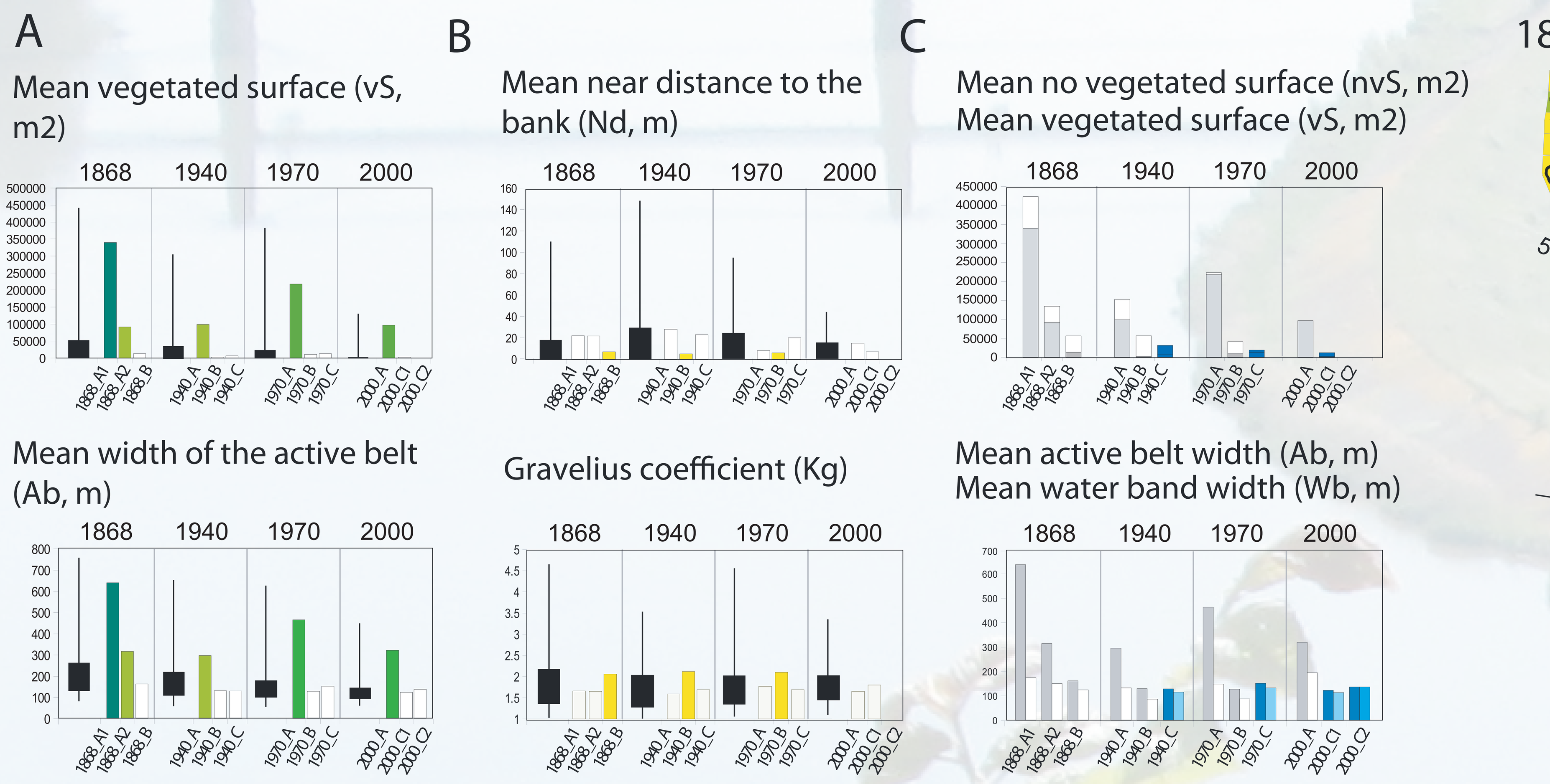

Fig. 4 : Description of PCA / HCA units groups, defined according to discriminating variables. A. Green indicates groups are characterized by variables related to vegetalized islands. B. Yellow indicates groups are characterized by variables related to lateral elongated bars. C. Blue indicates groups are characterized by variables related to single channel.

During 1868 to 1940s, the fluvial reach can be divided into three sectors (Fig. 5) :

- From Toulouse to Grenade-sur-Garonne (units 1 to ~20) and downstream to Mas-Grenier (units ~40 to 63), the Garonne river is characterized by elongated lateral bars, low vegetalized islands surface and a reduced active belt (fig 3 and 4, class B).
- During 1868 to 1940s, in channel riparian vegetation increases as the surface of the lateral bars decreases (fig 3 and 4, classes A and C). From Grenade-sur-Garonne to Mas-Grenier (units ~20 to ~40) in channel riparian vegetation is more present and the active belt larger in 1868 (classes A1 and A2).Vegetation decreases during 1868 to 1940s, while reaches are characterized by elongated lateral bars or single channel morphology (classes B and C).

In 1970s, the fluvial pattern is simpler (Fig. 5) :

- Upstream to Mas-Grenier (units ~20 to ~40) single channel morphology is dominant and islands and bars are scarce. The channels width is then equal to the active belt (Fig 3 and 4, class C). However a subset appears near Grenade-sur-Garonne (units 17 to 25) characterized by elongated lateral bars (class B) and a spot of large vegetalized islands (class A).
- Downstream to Mas-Grenier (units ~40 to 63), the river is dominated by multiple elongated lateral bars and low vegetalized islands (Fig 3 and 4, class B).

In 2000s (Fig 5), the entire channel shows few or no islands and bars (Fig 3 and 4, classes C1 and C2) except for three 1 km length units characterized by vegetalized islands.

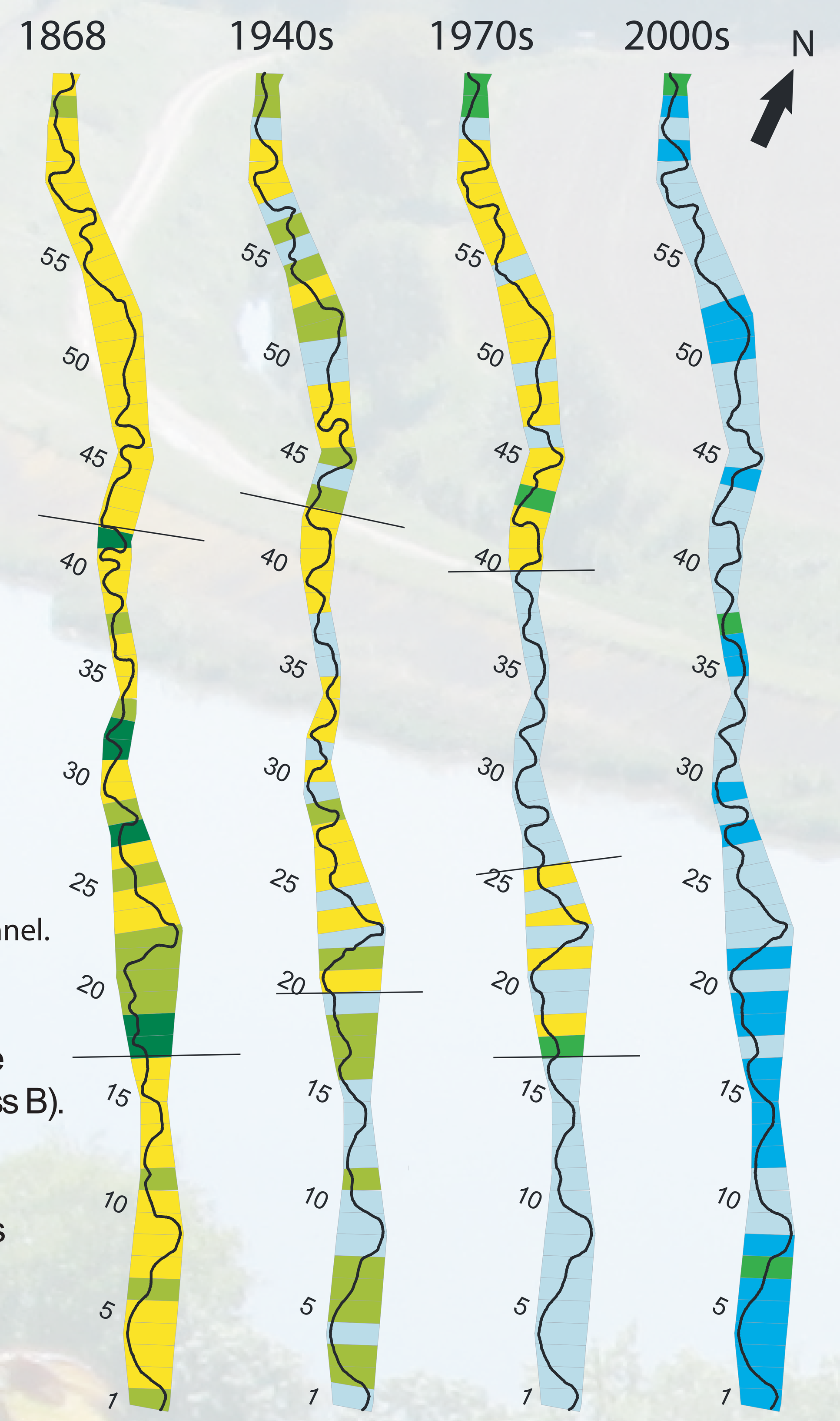

Fig. 5 : Sectorization of the middle Garonne river according to PCA / HCA units groups. Colors refer to Fig. 3 and Fig. 4.

Discussion

The morphometrical analysis of the middle Garonne river between 1868 and 2000s shows a progressive clearing of the sedimentary bedload from upstream to downstream as reflected by bars and vegetalized islands decreases. Close to the Hers tributary junction near Grenade-sur-Garonne, trend of evolution is rather different, may be in relation with local sediment supply. There, the rate of channel simplification and evolution is slowered.

The general channel standardization of the middle Garonne river from upstream to downstream, may be interpreted as the clearing of Little Ice Age (LIA) bedload, as the sedimentary supply was highly reduced by channel gravel extractions, dams construction and channel calibration of the second half of the 20th century (Fig. 6). Major floods period during 1932-40s, appears to briefly stop this evolution. Later evolution marks the return to downcutting and bedload outflow. Moreover, local bedload supply (i.e. Hers, Girou, …) decrease during the 1980s due to catchment lakes building and conduct to a similar evolution at river junctions. At least, the banning of in channel gravel extraction after 1980, does not revert geomorphological trend of evolution.

The Garonne river appears now as a closed system, incising the riverbed without significative regenerative bedload. The reversibility of this evolution remains uncertain.

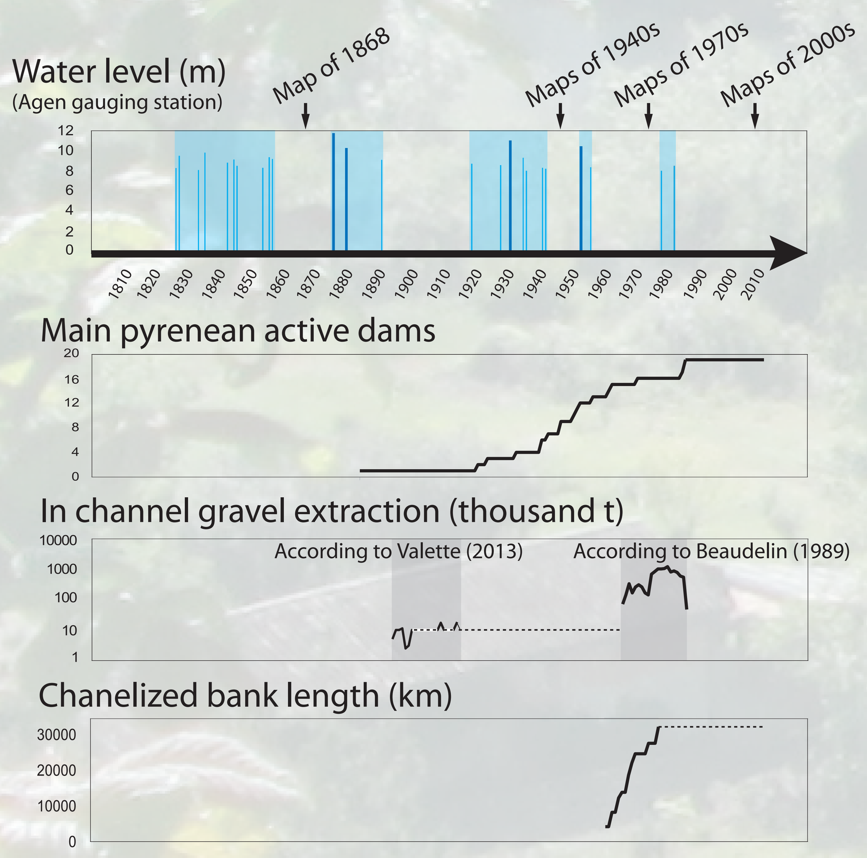

Fig. 6 : Driving forces of the Garonne river hydro-geomorphological system evolution

Conclusion

The human activities intensification during the 20th century acts as primary factor of the hydro-geomor-phological trend in the Garonne river.
However, the rate the fluvial system evolves, is under control of hydrological variation, e.i. the effectiveness of floods to evacuate the residual bedload. The future hydro-climatic evolution is then a key variable to predict future Garonne channel evolution.

This study was supported by the inter-region programm GaGiLau and the ANR programm Adapt'eau

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