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Observed trends in river flow rates in France

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Selecting a reference network and analysing temporal trends in regimes over the last 40 years

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Water shortages (increasingly severe low flows in rivers, lasting drops in water tables) have received growing attention, notably because of observed increases in imbalances between water resources and their multiple uses in several regions. These deficits, made even more visible by the recent dry periods despite the continued occurrence of wet years, may be worsened by future climate change and, more generally, by global changes (population, agricultural and energy-production needs, urbanisation, etc.).

The French network for measuring river flow rates is exceptional in terms of both its size and its age. It was possible, using rigorous mathematical tools, to analyse trends over the past 40 years in fundamental hydrological parameters, such as low, mean and high flows. The analysis revealed significant changes in certain regions and in certain factors, tending generally toward a reduction in water resources and a worsening of low flows.

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General situation

Until now, the idea that climate change could impact hydrological regimes has remained an unproven scientific hypothesis. Increases in temperatures and, to a lesser extent, changes in precipitation regimes [IPCC, 2007][1] may be seen as indicative of changes in hydrological regimes, but the modifications detected to date in hydrological data series have not revealed a consistent, overall signal. This conclusion may be drawn from studies by Kundzewicz et al. [2005][2] and Svensson et al. [2005][3], using data from hydrometric stations spread over the entire planet, and the study by Renard [2006][4] on France. This absence of a consistent, overall signal led Svensson et al. [2006][5] to raise the question as to "Why is there no clear signal in observations?".

In France, the question of possible future drops in available water resources has been raised. Given the small number of significant changes observed in the previous study (Renard, 2006, in which the diagnosis was limited by the number and duration of the data series), it was decided to take advantage of the more recent and better documented data series in the HYDRO[6] database in order to reanalyse the low, interannual mean and high-flow data in the hope of detecting more robust signals.

Statistically significant trends, if observed, will contribute to current work on the role of climate change and of variability, and on the necessary adaptation. In addition, a set of undisturbed stations devoted to long-term monitoring offers the double advantage of monitoring the possible effects of climate change and of constituting a "reference" sub-network providing data for WFD (Water framework directive) reports.

Selecting stations for the reference network

It is difficult to detect trends caused by climate in hydrological data series because:

- the variability of hydrological phenomena is naturally very high, which can mask trends;
- hydrometric data series are occasionally affected by metrological errors (uncertainty concerning measurement devices, rating curves, operational conditions, etc.) that may create artificial trends;
- many river basins are influenced by non-climatic factors, such as abstractions, various hydraulic installations, etc.

Because the impact of these factors cannot always be precisely quantified, it may be difficult to distinguish between their effects and those of climatic factors. The study presented here therefore collected a set of data that was extensively reviewed and consisted of long data series on river basins considered to be undisturbed or only slightly disturbed by human activities. The data were selected in two main steps [reports in 2008, 2009 and 2010][7]:

- station pre-selection based on meta-data from the HYDRO database, i.e. 1) stations in operation for at least 40 years, 2) those considered undisturbed or virtually undisturbed during low-flow periods and 3) those where the quality of measurements is considered "good" during low-flow periods;
- a second selection cycle in conjunction with data producers to discuss, among other topics, the causes of breaks in hydrological data series, e.g. moving stations to different locations, construction of a weir, new installations, etc.

The resulting selection of stations from the HYDRO database thus represents a sub-network called RRSE (Reference network for low-flow monitoring). It includes a total of 236 hydrometric stations in continental France and 14 in the overseas departments (see Figure 1).

Virtually all the hydrometric data series cover the entire period after 1968 and some range much farther back in time. The network, on the whole, reflects the hydrological diversity found in France in terms of flow regimes, climatic influences and river-basin sizes. A few additional "candidate" stations have been identified, i.e. those with slightly shorter data series but located in small river basins and others whose data series will soon be long enough.

1

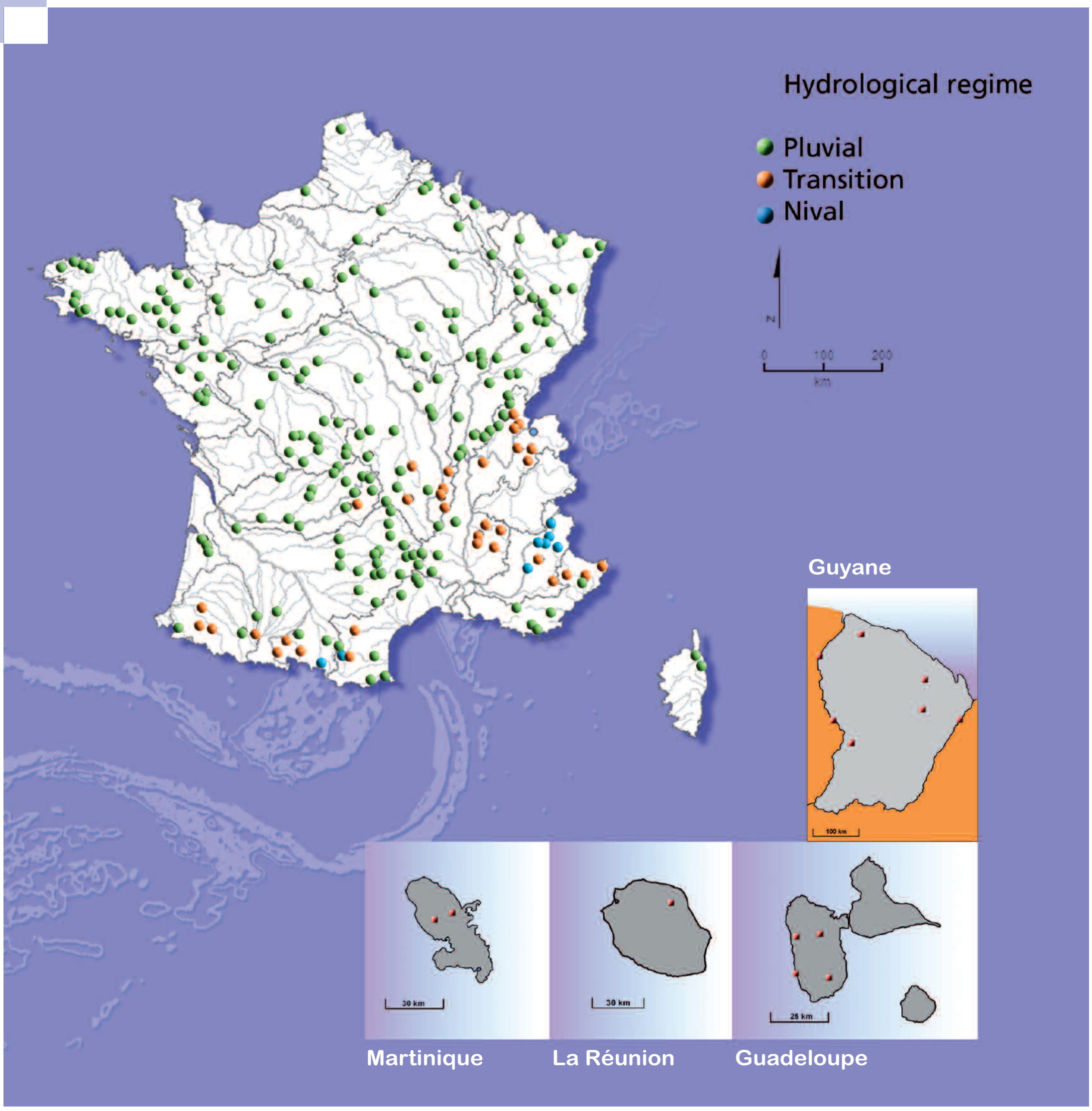

Figure 1. Hydrometric stations in the reference network to monitor climatic influence on low flows in France.

Analysed hydrological indices

A limited number of indices were defined [2009 report][7] to provide an integrated description of low, mean and high flows. They are calculated using daily flow-rate data series. The main indices (see Figure 2) concern:

- **low flows,** i.e. indices on severity (volume deficit, duration, annual minimum) and seasonality (start, middle and end of low-flow period).
- **mean flows,** i.e. the interannual mean flow, averaged over a long interannual period;
- **high flows,** i.e. indices on severity (maximum annual flow rate, volume above a threshold) and seasonality (date of annual maximum, middle of high-flow period).

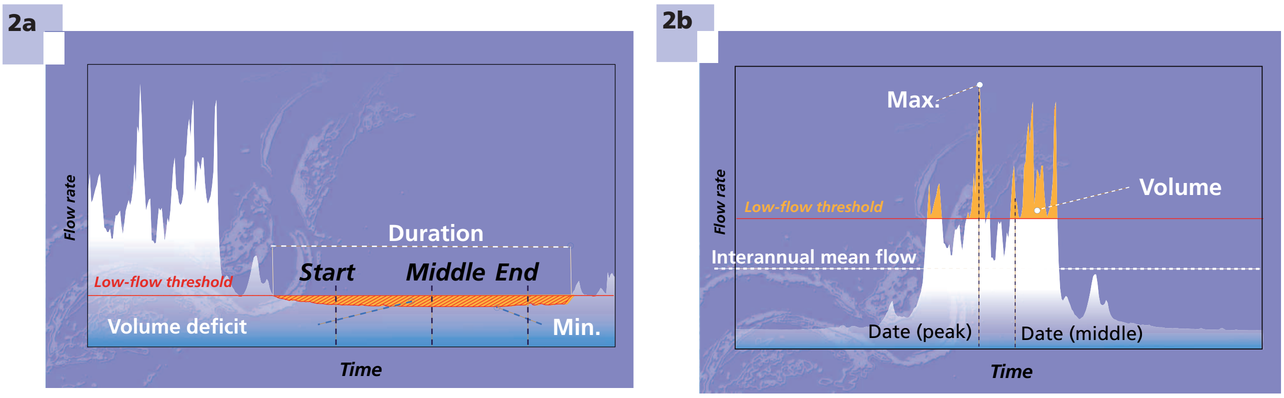

Figure 2. Diagrams of hydrological indices showing a) low flows, where the duration is the total time below the threshold and the start, middle and end correspond respectively to 10%, 50% and 90% of the duration, and b) mean and high flows..

Trends observed in hydrological regimes

Trend-detection analysis was carried out for all the indices over the 1968 to 2007 period [2010 report]. All of France was analysed but, given the more divergent results in the overseas departments, only the main results for continental France and Corsica are discussed below (see Figure 3).

Severity of low flows (deficit in volume)

There is clearly a North-South divide with trends toward increasing severity of low flows in several regions in southern France, notably the Pyrenees, the Massif Central and the Jura region, as well as in Aquitaine and around the Mediterranean. Rivers with strictly nival regimes (Alps and Pyrenees) are not affected. The number of significant changes in the severity of low flows is much smaller in the northern part of the country.

Seasonality of low flows (start of low flows)

Contrary to the severity, there are no geographic distinctions for seasonality. Taking France as a whole, the clearest trend concerns the start of the low-flow period, which would seem to occur a bit earlier in the south-eastern half of the country and in a few rivers in Brittany. This shift is less clear for the middle of the period and fairly insignificant for the end.

Interannual mean flow

No significant trends were detected in northern France. On the other hand, a large number of trends down were noted in the South, more precisely in the Pyrenees, Cevennes and the Massif Central. It should be noted that no significant changes were observed in rivers with strictly nival regimes in the Pyrenees and Alps.

High flows (annual maximum flow)

Similar to the indices for low and mean flows, there is a North-South divide. In the North, trends are generally upward, but are often not significant. However, a number of consistent upward trends may be observed in the North-East part of the country. Conversely, trends are generally down in the South, with consistent sets of downward trends in the Pyrenees and the Massif Central.

3

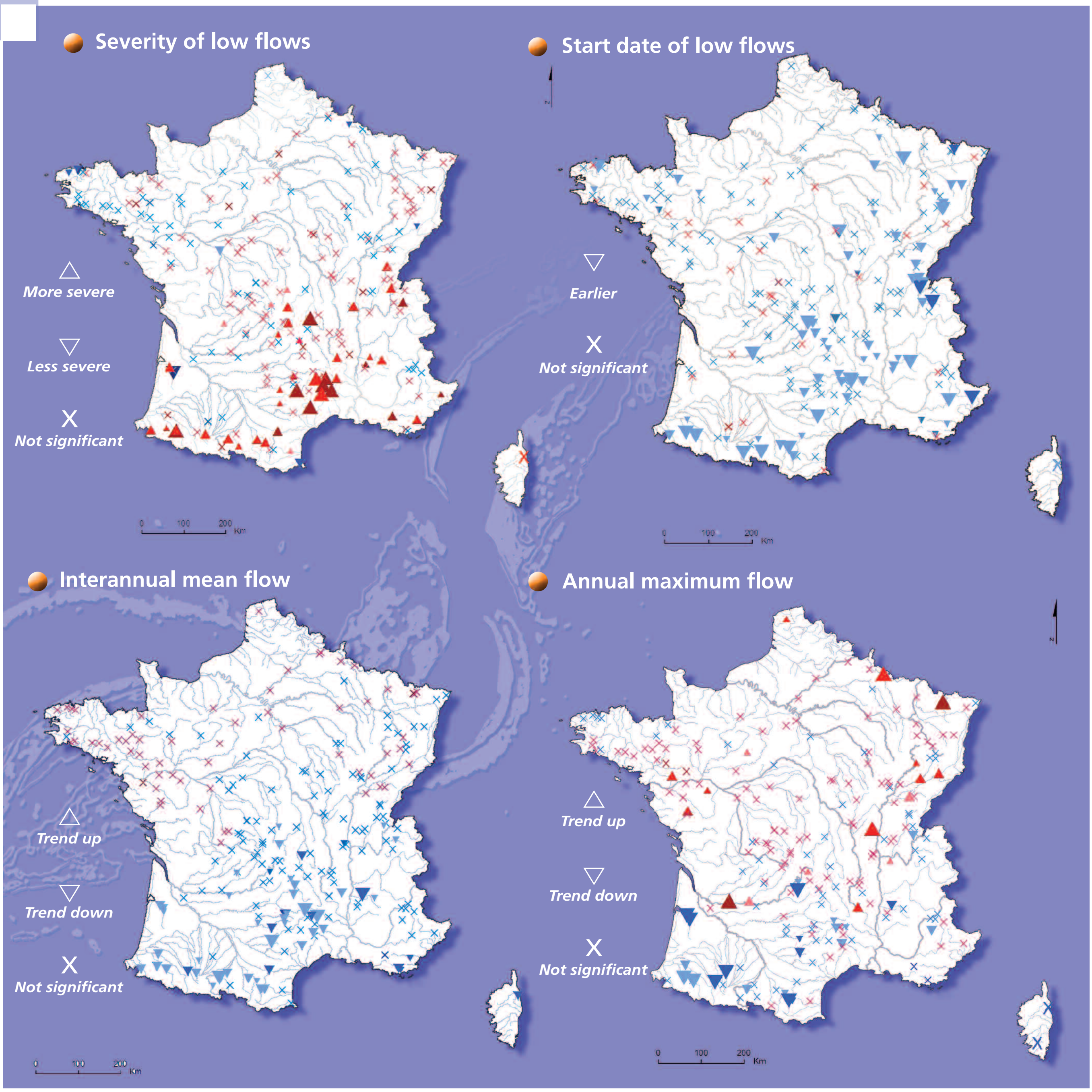

Figure 3. Trends detected for four indices, 1) Severity of low flows, 2) Start date of low flows, 3) Interannual mean flow and 4) Annual maximum flow.

Index confidence rating	*Chance that trend is real*
△ (small)	*90%*
△ (medium)	*95%*
△ (large)	*99%*

Rate of change in indices, down in blue and up in red		*% per decade*
		0 to 1.5%
		1.5 to 3%
		3 to 5%

Role of climatic oscillations

In spite of the significant trends discussed above, it is important to remember that trends in themselves do not constitute proof of an impact by global warming (correlation does not imply causation). The climate fluctuates naturally according to modes of variability that may last years or decades, e.g. the Atlantic Multi-decadal Oscillation (AMO), the North Atlantic Oscillation (NAO), etc. These natural oscillations may perhaps explain in part the trends observed over a period of approximately 40 years. We therefore carried out exploratory analysis to better understand the links between hydrological regimes and climatic oscillations [2011 report]8. The main results suggest that:

- concerning the severity of low flows, correlations with the AMO and the NAO were detected in southern France where the spatial distribution was similar to that observed for the temporal trends. It is therefore possible that at least some of the temporal trends detected are caused by climate oscillations;
- concerning the seasonality of low flows (start, middle, end, duration), correlation with the oscillations is much less clear. The trends observed, e.g. earlier starts of low flows, see Figure 3), cannot be positively linked to the climatic oscillations;
- the correlation is better with certain climatic indices (NAO, WP2 and WP8 during winter and spring) in terms of low-flow severity during the summer. These results suggest interesting possibilities in terms of seasonal low-flow predictions.

Conclusion

The study revealed a clear trend toward a reduction in surface-water resources and a worsening of low flows over vast sections of the country, particularly, but not only in the South. Contrary to the previous study (Renard, 2006), the signal is now statistically significant.

Though the study results are, in some cases, mixed or even favourable and even though the role of climate change has not been firmly established, the results nonetheless signal pressures on resources, thus confirming numerous observations in the field. They also confirm the value of pro-active policies to preserve water resources and limit their use via balanced management ensuring sustainable, good operation of aquatic environments and the satisfaction of human and environmental needs.

It is clear that these results would be less robust if the French hydrometric network were not so exceptionally large and long-standing. The network constitutes a true scientific heritage that must be preserved if we wish to pursue this type of analysis in the future and set up effective climatic monitoring of hydrological regimes. Maintaining the RRSE (Reference network for low-flow monitoring) over the long term in an important step in that direction.

1- IPCC (2007), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 996 pp, Cambridge.

2- Kundzewicz, Z. W., D. Graczyk, T. Maurer, I. Pinskwar, M. Radziejewski, C. Svensson, and M. Szwed (2005), Trend detection in river flow series: 1. Annual maximum flow, Hydrol. Sci. J.-J. Sci. Hydrol., 50(5), 797-810.

3- Svensson, C., Z. W. Kundzewicz, and T. Maurer (2005), Trend detection in river flow series: 2. Flood and low-flow index series., Hydrol. Sci. J.-J. Sci. Hydrol., 50(5), 811-824.

4 - Renard, B. (2006), Evolution des extrêmes hydrométriques en France à partir de données observées, Houille Blanche, 6.

5 - Svensson, C., J. Hannaford, Z. W. Kundzewicz, and T. Marsh (2006), Trends in river floods: why is there no clear signal in observations?, paper presented at Frontiers in Flood Research, IAHS Publication, Paris.

6 - The hydrological database, called HYDRO, houses the data series on river flow rates, acquired by State services and other sources (e.g. EDF, CNR), as well as other information on data quality and acquisition. www.hydro.eaufrance.fr

7 - Renard, B., Lang, M., Sauquet, E. (2008). Identification des impacts hydrologiques du changement climatique, rapport Cemagref 2008.

- Giuntoli, I. et Renard, B. (2009). Identification des impacts hydrologiques du changement climatique : vers un réseau de référence pour la surveillance des étiages, rapport Cemagref 2009.

- Giuntoli, I. et Renard, B. (2010). Identification des impacts hydrologiques du changement climatique : constitution d'un réseau de référence pour la surveillance des étiages, rapport Cemagref (2010).

8 - Giuntoli, I., Renard, B. et Vidal, J.P. (2011). Rôle de la variabilité climatique dans l'évolution temporelle des régimes d'étiage en France, rapport Irstea 2011 (2012).

For more information...

List of stations in the network

On request from Benedicte Augeard (benedicte.augeard@onema.fr). The list will eventually be available on the EauFrance site.

Annual reports

http://www.documentation.eaufrance.fr/recherche-textuelle/

Scientific publications and presentations

Giuntoli, I., B. Renard, *and* A. Bard (2011), *Low flow trends in France: analysis of 236 undisturbed catchments over 40 years, poster presented at EGU General Assembly 2011, Vienna, Austria.*

Giuntoli, I., B. Renard, *and* M. Lang (2012), *Floods in France, in : Changes in flood risk in Europe. Edited by Z. W. Kundzewicz, IAHS Press. http://iahs.info/bluebooks/SP010.pdf*

Giuntoli, I., B. Renard, *and* J. P. Vidal (2012), *Low flows in France and their relationship to large scale climate indices, Journal of Hydrology. submitted.*

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