The foreseeable impacts of climate change on the water resources of four major Mediterranean catchment basins

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The Mediterranean region will be particularly affected by climate change over the 21st century. Rising temperatures and more marked drought periods will affect spatial and temporal precipitation partition and hence of water resources. This, combined with human pressure on the environment and with water demand on a constant upward curve, will make it increasingly difficult to meet water demand in its various uses. Water demand doubled over the second half of the 20th century and could well grow by a further 20% by 2025. Thus, issues relating to water resource management are emerging more frequently.

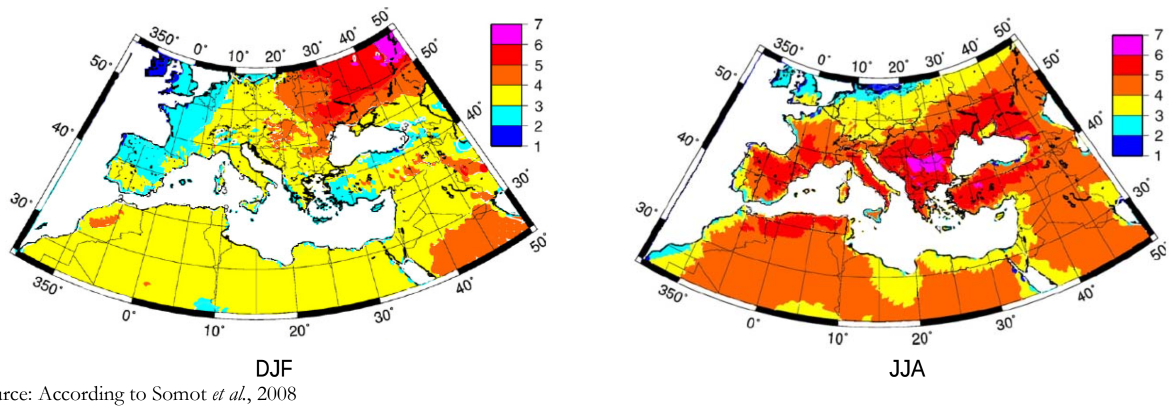
The use of a hydrological model at the catchment scale allows variations in water flow to be assessed. A decreasing trend in surface runoff has been identified in the Mediterranean region, more specifically in its southern countries. This initial assessment defines the hydrological risks the Mediterranean region might encounter shortly and underlies the need to promote adaptation policies to climate change based on improving integrated management of water resources and demand.

Water: a rare and vulnerable resource in the Mediterranean region

The renewable water resources of all the Mediterranean rim countries are estimated, on average, at 1 080 km^3/yr, in other words less than 3% of global resources for more than 7% of the global population. Moreover, these water resources are unevenly distributed as a result of the difference in climate between the northern countries and those to the south and east. Indeed, 68% of total water resources are concentrated in the northern Mediterranean countries, opposed to 23% in the northern African countries and 9% in the eastern Mediterranean ones (Plan Bleu, 2008). This major disparity in distribution, coupled with the many climatic phenomena and extreme weather events which affect the region, make the Mediterranean region one of the most vulnerable areas of the world as far as climate change is concerned.

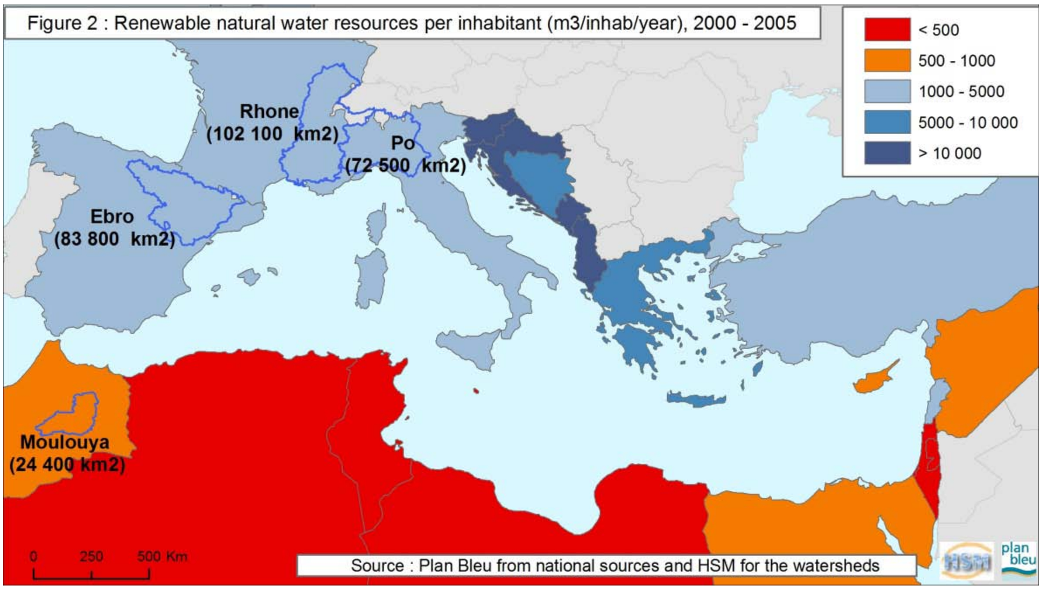
In its fourth report - published in 2007 - the Intergovernmental Panel on Climate Change (IPCC) combines twenty five global climate models in order to assess the impact of climate change for *2050* and *2100*. According to their work, temperatures are expected to rise by +2 to +3°C in the Mediterranean region by 2050, then by +3 to 5°C by 2100 (Figure 1). This rise in temperature is likely to reduce relative air humidity and increase the atmosphere's capacitive moisture load. The air will therefore have a higher saturation rate, leading to less cloud cover and hence decreased precipitation. Precipitation will be less frequent but more intense, whilst periods of drought will be longer and more frequent. Thus spatial and temporal precipitation patterns will be altered.

Figure 1 - Seasonal temperature variations by 2100 compared with the period from 1961-1990



Source: According to Somot *et al.*, 2008

The regional effects of global climate change on the water cycle therefore risk impoverishing water resources, accentuating their variability and undermining their exploitability. The water-poor countries are likely to be the most affected since, according to Giorgi and Lionello (2008), by *2100* rainfall is likely to have decreased by 20 to 30% in the countries to the south, opposed to a mere 10% in those to the north. The « water-poor » Mediterranean population, in other words those people living in countries with less than 1 000 m^3/capita/yr, could therefore rise from 180 to 250 million in 2025. The population living in « shortage », in other words with less than 500 m^3/capita/yr (in 2005: Palestinian Territories, Libya, Malta, Israel, Tunisia, Algeria), could rise over the same period from 60 to 80 million inhabitants (Figure 2; Blinda and Thivet, 2009).



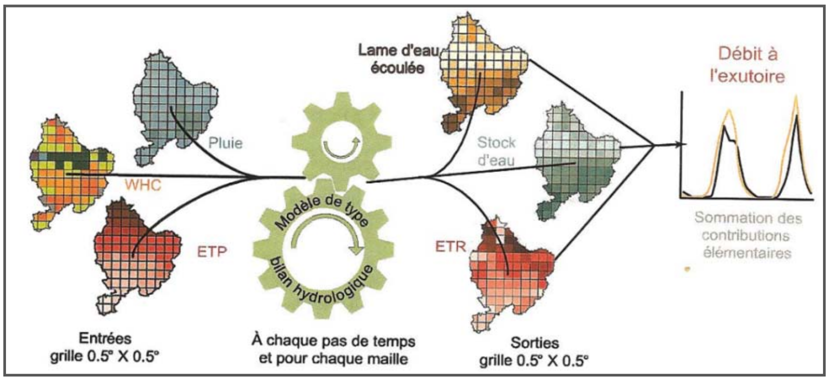
The Mediterranean basin is thus particularly sensitive to climate change. It is essential to have effective digital modeling tools if climate change in the Mediterranean and its impact on water resources is to be better understood.

Hydrologic modeling: a high performance tool for assessing the impact of climate change on water resources

An initial assessment of climatic and hydrological variations at the *2050* and *2100* horizons was conducted by the Plan Bleu in conjunction with the Montpellier Hydrosciences laboratory, which carries out research in water sciences. To conduct this study, catchment basins representative of the Mediterranean area were selected on the following basis: one basin per Mediterranean shore, the surface area of which is over 1 500 km² and which outlet is in a coastal region. Four catchment basins were thus chosen according to the availability of hydrological data: the Ebro in Spain (83,800 km²), the Rhone in France (102,100 km²), the Po in Italy (72,500 km²) and the Moulouya in Morocco (24,400 km²). These catchment basins have a so-called Mediterranean climate and hydrological system: mild and wet winters, with the possibility of heavy rains sometimes triggering devastating floods, and long, hot and dry summers, with runoff at their lowest level.

The GR2M (Génie Rural à 2 paramètres au pas de temps Mensuel) global conceptual hydrological model at monthly time-step, developed by the CEMAGREF, was used to study the impact of climate change on water resources in these four catchment basins (Figure 3). This model divides up each catchment basin into a regular grid (0.5° x 0.5°). On each cell of the network and for each time interval, a fraction of rainfall contributes to direct runoff. The level of the reservoir changes depending on the remaining portion of rain and on potential evapotranspiration (PET). The maximum capacity of the « soil » reservoir corresponds to the soil's water capacity, which data was estimated using the FAO's soil map (Dieulin, 2005). No account is taken of the human impact on soil. Runoff at the outlet of the catchment basin is established by adding together the contributions of the various network cells (Ardoin-Bardin *et al.*, 2009).

Figure 3 - Diagram of the workings of a semi-global modeling chain for rainfall/runoff relationships



Source: Ardoin-Bardin, 2004

In order to simulate runoff rates for the *2050* and *2100* horizons, the model was first optimized over periods for which rates are known, to ensure that the model best reproduces the way in which the basin behaves. To this end, monthly rainfall data over the period 1901-2002, available from the University of East Anglia's Climatic Research Unit (CRU), was used along with monthly PET grids calculated according to Thornthwaite's formula (Réméniéras, 1986). The monthly hydrological data comes from the « Global Runoff Distribution Centre » (GRDC) and the Hydro Bank, hydrological data collection centers.

Once the model has been optimized and the rainfall/runoff relationship established for each catchment basin, it is then possible to simulate surface runoff for the *2050* and *2100* horizons. The study based itself to this end on the use of variables produced by three coupled ocean-atmosphere global climate models according to the IPCC's 2007 A1B greenhouse gas emission scenario. This scenario evokes a world which is undergoing very rapid economic development, major demographic growth with almost 9 billion people by *2050*, and where a balance has been struck between the various sources of energy.

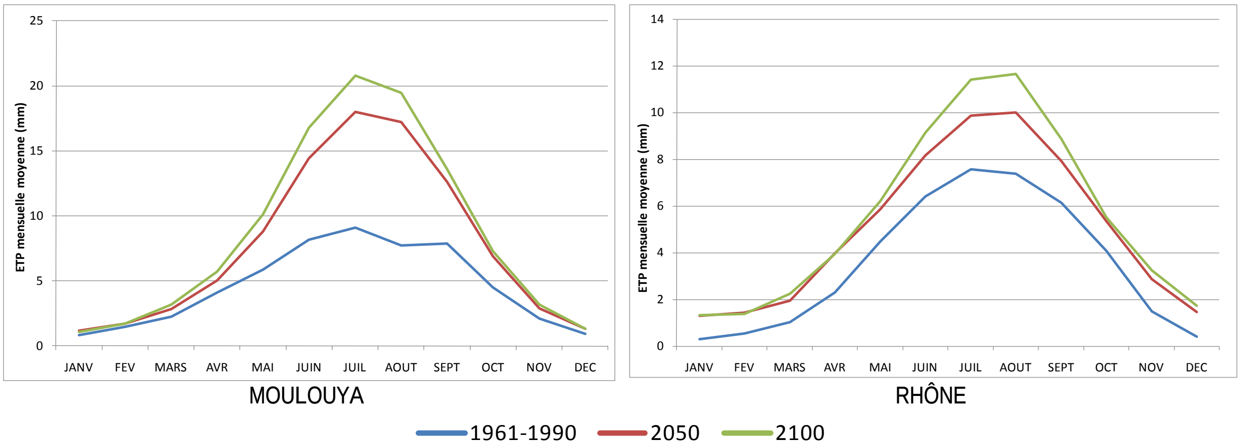
Towards a severe drainage of the Mediterranean basin

A first evaluation of hydroclimatic variations for *2050* and *2100* was established using hydrologic modeling. Despite the strong assumption that the rainfall/runoff relationship will stay stable in the future, trends were identified for the four catchment basins studied.

Changes in evapotranspiration. The higher temperatures forecast for the Mediterranean region are likely to prompt an increase in PET of between 30 and 50% by *2050*, with a further 15% by *2100*. The highest growth rates are likely to be seen from June to September, with an average increase of 3 to 8 mm/month by *2050* and a further 2 to 5 mm/month by *2100*. The summers are likely by then to be much hotter and dryer. For the rest of the year, the PET is likely to increase by 0.6 to 0.8 mm/month, thus rendering winter conditions more like spring or autumn ones (Figure 4).

These increases will have repercussions on the water cycle. The rise in temperature, coupled with increased PET, is likely to cause snows to melt earlier and precipitation (snow and rain combined) to decrease, leading to a drop in surface runoff. Water stocks will therefore be increasingly unavailable, particularly over the summer, when water demand is at its highest as a result of the Mediterranean coasts' growing pull on tourists.

Figure 4 - Monthly PET changes in the Moulouya and Rhône catchment basins for *2050* and *2100* compared with the reference period; simulation according to the ECHAM5 global climatic model



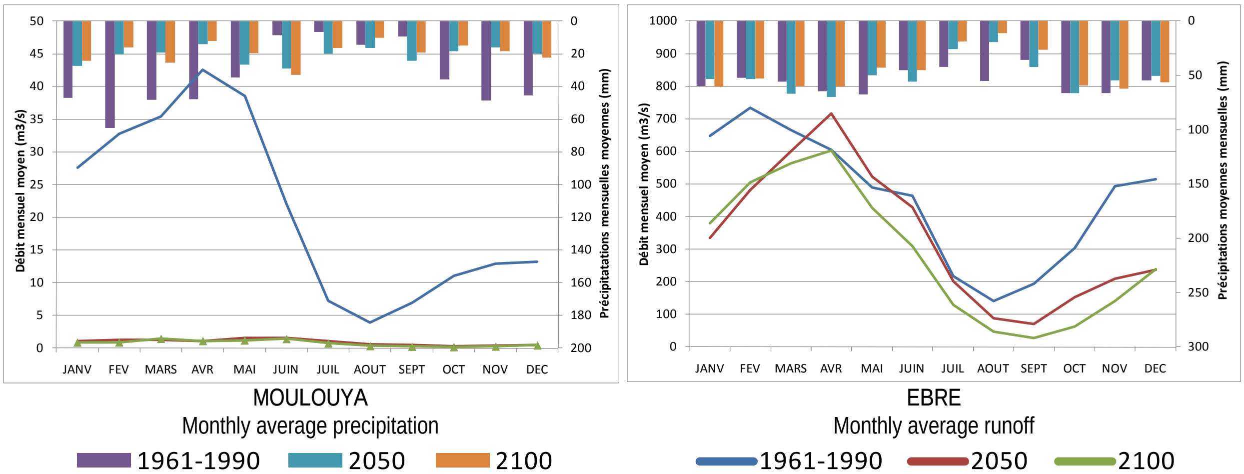
Precipitation Changes. All the climate models used forecast a progressive decrease in precipitation by *2050* and *2100*. In the northern region of the Mediterranean area, this decrease will be marked by particularly dry summers, with a precipitation drop between 20 and 30% compared to the levels observed over the 1961-1990 reference period. During the winter, however, the levels observed will probably tend to hold up if not increase by some ten millimeters. However, at the same dates the Moulouya catchment basin will on the contrary be marked by virtually constant precipitation levels throughout the year - between 20 and 25 mm/month on average. The winter rains would thus be more than halved and summers would be wetter, with an additional 15 mm/month of rain (Figure 5).

Finally, it would appear to be moving towards the drying up of Mediterranean catchment basins, which will change soil properties and, consequently, most probably reduce surface runoff, seepage rates and groundwater replenishment.

Changes in surface runoff. The trend throughout the Mediterranean basin is towards a decrease in surface runoff. The northern Mediterranean catchment basins are likely to witness a 15-30% drop in runoff. It is during the summers that this decrease will be most drastic, with runoff falling by 30 to 40% and low water levels persisting for some 2 additional months. The lengthening of this period shall however be considered with care, since when the hydrological model was optimized it emerged that the model tended to extend the drying up periods by a month. Over the winters, the levels observed over the 1961-1990 reference period should hold up. However, the decreases are likely to be much smaller than in the southern Mediterranean region. According to the study on the Moulouya catchment basin's hydrological system, the drop in rainfall and rise in evapotranspiration is likely to be such that surface runoff would show low and constant levels. This worrying development is doubtless linked to the difficulty which the chosen climate models have in reproducing climate forcing in a semi-arid zone. It is essential that other catchment basins to the south of the Mediterranean be analyzed before any conclusions are drawn.

The fact remains that the increase in the PET rate and the decrease in precipitation forecasted for 2050 and 2100 will inevitably lead to less runoff in spite of the one-off hikes following heavy rains. The decrease will be particularly marked in the southern Mediterranean regions. Water resources will thus be less available.

Figure 5 - Variations in mean monthly precipitation and mean monthly runoff rates in the Moulouya and Ebro catchment basins for *2050* and *2100* compared with the mean monthly precipitation and mean monthly runoff observed over the period 1961-1990 ; simulation according to the HADCM3 global climate model.



Tools towards improving the integrated management of water resources and demand

It is still difficult to quantify the regional effects of climate change on the water cycle for any specific moment in time. However, this initial work on hydrologic modeling in four Mediterranean catchment basins has led to the identification of the main development trends for water resources in the Mediterranean area.

Over the next century, the Mediterranean region will witness a drop in water resources: more evapo-transpiration, less snow, less rain, therefore less surface runoff and less groundwater replenishment. This depletion of water resources will be particularly marked in the southern Mediterranean regions. A priori, the northern Mediterranean region is not likely to find itself in a water deficit situation overall and should be in a position to meet the needs of its people, although it may not be spared some tension at local levels (cf. the Catalonian basin in Spain, for example). The Moulouya basin, however, is highly likely to face a water shortage. The extension and worsening of water shortage situations would appear to be unavoidable, particularly to the South and East.

Given the increase in water-related issues, it is becoming increasingly necessary to move water management policies (i) towards more rational use (« water demand management »), (ii) towards an increase in exploitable potential through better water and soil conservation and (iii) by making greater use of artificial groundwater replenishment. There is considerable scope for progress, since better demand management would mean that a quarter of all demand could be saved, in other words some 85 km^3 in 2025 (Blinda and Thivet, 2009).

Improving the integrated management of water resources and demand requires a more in-depth analysis on a wider spatial scale - preferably regional - in order to have a more global vision of the effects of climate change on water resources. Moreover, the identification and regular monitoring of indicators of the impact of climate change, tailored to the Mediterranean region and allowing hydrological variations to be monitored and pre-empted, will be highly useful in defining and implementing pro-active water management policies.

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