Science of the Total Environment 461–462 (2013) 528–540

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Integrated modelling to assess long-term water supply capacity of a meso-scale Mediterranean catchment

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HIGHLIGHTS

- A model integrating water resources and demands is proposed on a meso-scale basin.
- An indicator that complies with stakeholder's needs assesses water supply capacity.
- Climate change impacted water resources availability and agricultural water demand.
- Anthropogenic changes have led to an increase in domestic water demand.
- Water supply capacity has worsened over the last 50years notably downstream.

ARTICLE INFO

Article history:
Received 29 March 2013
Received in revised form 13 May 2013
Accepted 14 May 2013
Available online 10 June 2013

Editor: Damia Barcelo

Keywords:
Climate variability
Integrated modelling
River Hérault
Water demand
Water resources
Water supply assessment

ABSTRACT

Assessing water supply capacity is crucial to meet stakeholders' needs, notably in the Mediterranean region. This region has been identified as a climate change hot spot, and as a region where water demand is continuously increasing due to population growth and the expansion of irrigated areas. The Hérault River catchment (2500 km^2, France) is a typical example and a negative trend in discharge has been observed since the 1960s. In this context, local stakeholders need first to understand the processes controlling the evolution of water resources and demands in the past to latter evaluate future water supply capacity and anticipate the tensions users could be confronted to in the future. A modelling framework is proposed at a 10-day time step to assess whether water resources have been able to meet water demands over the last 50 years. Water supply was evaluated using hydrological modelling and a dam management model. Water demand dynamics were estimated for the domestic and agricultural sectors. A water supply capacity index is computed to assess the extent and the frequency to which water demand has been satisfied at the sub-basin scale. Simulated runoff dynamics were in good agreement with observations over the calibration and validation periods. Domestic water demand has increased considerably since the 1980s and is characterized by a seasonal peak in summer. Agricultural demand has increased in the downstream sub-basins and decreased upstream where irrigated areas have decreased. As a result, although most water demands were satisfied between 1961 and 1980, irrigation requirements in summer have sometimes not been satisfied since the 1980s. This work is the first step toward evaluating possible future changes in water allocation capacity in the catchment, using future climate change, dam management and water use scenarios.

1. Introduction

In the context of climate change and population growth, the ability of water resources to satisfy different demands is essential (Vörösmarty et al., 2000), particularly in Mediterranean regions where difficulties in meeting water needs have already resulted in increasing social tensions (Margat and Treyer, 2004). The Mediterranean region has been identified as a climate change hot-spot (Giorgi, 2006), and as a region where population growth is strong (+30% over the last 20 years) (Abis, 2006). As a result, mean water resources around the Mediterranean basin could decrease between 30% and 50% by 2050, leading to increasing water stress (Milano et al., 2012, 2013a).

The worrying situation in this region highlights the need to develop methodological approaches to face such issues. Integrated studies, which investigate changes in water availability and water demand

Abbreviations: AWD, Agricultural Water Demand; DWD, Domestic Water Demand; F_{agg}, Aggregation Function; NSE, Nash–Sutcliffe efficiency criteria; NSE_{lf}, Nash–Sutcliffe efficiency criteria during low-flows; VE, Volume Error; VE_m, mean Volume Error; WD, Water Demand; WRA, Water Resources Availability; WSCI, Water Supply Capacity Index.

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http://dx.doi.org/10.1016/j.scitotenv.2013.05.036

should thus be undertaken to assess the impacts of climatic and human pressures on water supply capacity. Arnold (2013) underlined the difficulties involved in developing integrated approaches to bring together fragmented knowledge from different disciplines. Integrated impact studies must also compare water resources and demands at the scale at which water resources are managed to reduce the gap between scientific studies and efforts undertaken by water management stakeholders (Koutsoyiannis and Kundzewicz, 2007). In mainland France, catchments in the 1000–10,000 km^2 range are generally managed through water development and management plans. At this scale, stakeholders need to know where problems in water supply capacity could emerge in the future. Estimating climatic and anthropogenic pressures on water resources within a catchment implies dividing it into areas with similar water issues. In addition, the temporal scale of these approaches must be sufficiently representative of the hydro-climatic variability as well as of changes in human pressure over periods of time that are long enough to test their robustness with respect to their possible future use. The main difficulty lies in the need to accurately represent the dynamics of both water supply and water demand over long periods of time.

Water resources can be evaluated using conceptual hydrological models (e.g. see Fujihara et al., 2008; Senatore et al., 2011; Ruelland et al., 2012; Belgiorno et al., 2013), which simulate the dynamics of the hydrological cycle. Among different approaches, these models can be used being constrained by hydro-climatic data for long periods of time, and thus enabling studies of the impact of climate change over a period of at least 30 years, as recommended by the Intergovernmental Panel for Climate Change (IPCC, 2007). However to date, few integrated studies have been conducted over such long periods, mainly due to the difficulty in accessing data (Hannah et al., 2011). A historical reconstruction of water uses can be required for long-term studies as well as it is essential to represent the hydro-climatic processes, which, in the Mediterranean context, may result from extreme events. Although many impact studies are constrained by data availability to use a monthly time step (Bronster et al., 2000; Quilbé and Rousseau, 2007; Varela-Ortega et al., 2011), a shorter time step (e.g. a daily time step, see Oxley et al., 2004; Bangash et al., 2012) may be recommended to catch the temporal variability of rainfall events and simulate Mediterranean hydrological processes (Moussa et al., 2007). On the other hand, water use data, whose variables are significant indicators of changes in water demand, are generally available at coarser time steps (usually acquired during irregular surveys). Moreover, the crop growth processes are subjected to seasonal dynamics that need to be accounted for to grasp the fluctuations in the need for irrigation water over the year depending on climate conditions. Thus, a 10-day time step appeared to be an acceptable compromise to represent hydro-climatic processes as well as anthropogenic and crop dynamics over meso-scale Mediterranean catchments to assess long-term changes in water supply capacity.

Some recent integrated models like the Water Evaluation And Planning (WEAP) model (Yates et al., 2005) or GIBSI model (Quilbé and Rousseau, 2007) are designed to investigate water supply capacity issues. However, they are based on a general water management approach (delineation of the catchment, interactions between resources and demands, storage-dam modelling, etc.) which may make it difficult to adapt them to the local context of the hydrosystem concerned. Moreover, their user-friendly interface makes it difficult to access detailed equations: for instance, the calibration methods are sometimes not suited to the modelling objectives, i.e., other data sources or criteria could be more appropriate in the specific context under study. Finally, efforts are still needed to be able to compare water supply and water demand using indicators that would also be useful for water management stakeholders.

A number of existing indicators can be used to compare water resources and water demand. Sullivan et al. (2003) defined a water poverty index that assesses the impact of the lack of water on human communities, and which accounts for, among others, available water resources, access to these resources, and the ability of the population to manage their resources. Another index is the water stress index, defined as the ratio of annual total withdrawals to annual available water resources (Menzel and Matovelle, 2010). The water demand satisfaction rate is also used (e.g. Rosenzweig et al., 2004; Sun et al., 2008; Milano et al., 2013b). This index states whether water demand has been satisfied, and has the advantage of being easily understood by both scientists and stakeholders. However, these indicators do not completely answer stakeholders' needs when they design future water management plans. The water volumes that can be withdrawn in the future are indeed based on the frequency at which water resources can supply water demand. This point should be taken into account to facilitate dialogue between research and water management.

This paper deals with all these issues. It presents an integrated approach to evaluate long-term changes in the water supply capacity of a Mediterranean meso-scale catchment. It aims to propose an interdisciplinary approach to assess how climatic and water uses changes impacted the ability of water resources in supplying water demands. In line with the local stakeholder's attempts, the frequency of the ability in supplying water demands was analyzed through its evolution over the last 50 years.

2. Study area

The Hérault catchment is located in the south of France and drains an area of approximately 2500 km^2 (Fig. 1). The river rises in the Mont

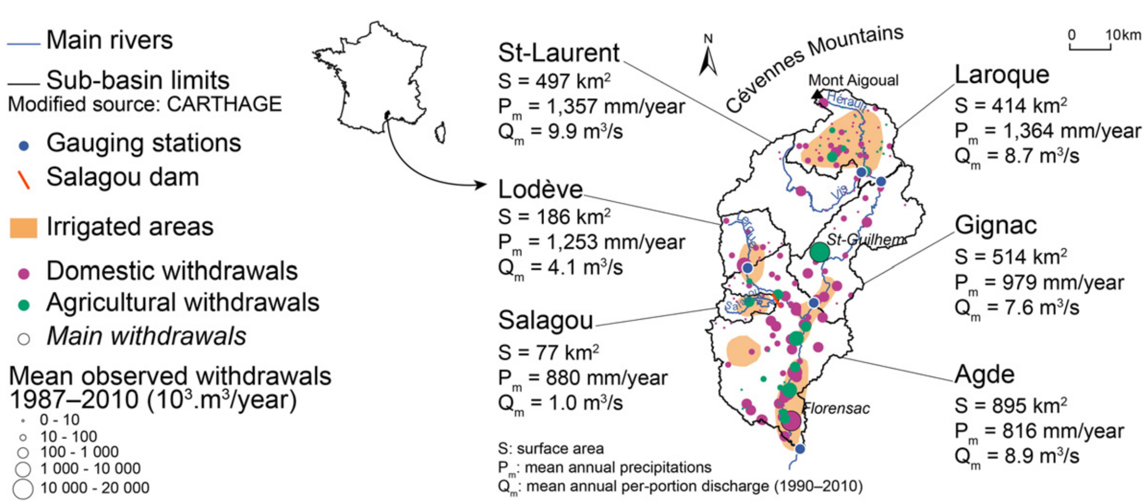

Fig. 1. The Hérault catchment.