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Hydrological and water quality impact assessment of a Mediterranean limno-reservoir under climate change and land use management scenarios

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SUMMARY

Water scarcity and water pollution constitute a big challenge for water managers in the Mediterranean region today and will exacerbate in a projected future warmer world, making a holistic approach for water resources management at the catchment scale essential. We expanded the Soil and Water Assessment Tool (SWAT) model developed for a small Mediterranean catchment to quantify the potential effects of various climate and land use change scenarios on catchment hydrology as well as the trophic state of a new kind of waterbody, a limno-reservoir (Pareja Limno-reservoir), created for environmental and recreational purposes. We also checked for the possible synergistic effects of changes in climate and land use on water flow and nutrient exports from the catchment. Simulations showed a noticeable impact of climate change in the river flow regime and consequently the water level of the limno-reservoir, especially during summer, complicating the fulfillment of its purposes. Most of the scenarios also predicted a deterioration of trophic conditions in the limno-reservoir. Fertilization and soil erosion were the main factors affecting nitrate and total phosphorus concentrations. Combined climate and land use change scenarios showed noticeable synergistic effects on nutrients exports, relative to running the scenarios individually. While the impact of fertilization on nitrate export is projected to be reduced with warming in most cases, an additional 13% increase in the total phosphorus export is expected in the worst-case combined scenario compared to the sum of individual scenarios. Our model framework may help water managers to assess and manage how these multiple environmental stressors interact and ultimately affect aquatic ecosystems.

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1. Introduction

Water pollution and water scarcity are affecting Europe's water resources and overexploitation of water, in particular, has led to complete dry-out or shrinking of natural water bodies in western and southern Europe. To maintain and improve the essential functions of freshwater ecosystems, a holistic management approach is required, based on insight into both river basin water and nutrient cycles and freshwater ecosystem functioning. The main aim of the EU water policy is to ensure that a sufficient quantity of good-quality water is available for people's needs and for the environment (EEA, 2012). The European Water Framework Directive adopted in 2000 (hereafter, WFD (OJEU num. 327, 2000)) established a new framework for water management: EU Member States should achieve a good status in all bodies of surface water by 2015. Achieving a good status involves meeting certain standards for quality and quantity of waters.

The continuing presence of a range of pollutants (e.g., excessive nutrient levels) in Europés waters threatens aquatic ecosystems. Excessive nutrient levels may render water bodies aesthetically unpleasant and unsafe for recreational activities, for example by stimulating the growth of bloom forming and potentially toxin producing blue–green algae. Hence, nutrient enrichment caused by agriculture can create eutrophication problems and agriculture is the largest contributor of nitrogen pollution in Europe (EEA, 2012). The effects of changes in land use and landscape management, in particular the expansion of agriculture, on water quality have been reported worldwide (e.g. Arbuckle and Downing, 2001). There is thus an urgent need at the European level to devel-

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op tools that will help Member States in both addressing water quality issues and evaluating the impact of management practices, and a recent EU project has demonstrated that catchment scale modeling approaches may be useful for these purposes (Schoumans et al., 2009).

Water flow regime and water level fluctuations are also major determinants of ecosystem functioning and services in river and lake ecosystems. Even though there can be high natural variation in flow regimes, many European rivers have their seasonal or daily flow regimes changed for various uses, with a significant impact on ecosystems (EEA, 2012). Accounting for climate change effects is one of the main challenges for water administrations in Europe (EEA, 2012), as it affects the availability of freshwater for ecosystems (IPCC, 2007). In spite of the extensive research on climate change, publications that use downscaling methods to examine seasonal hydrological impacts are still not abundant (Raposo et al., 2013) not least for the Mediterranean region, and existing studies often use simple average annual climate data to infer changes in water availability (e.g. Kalogeropoulos and Chalkias, 2013). The Mediterranean region, already subjected to water scarcity and drought today (MMA, 2007), will be particularly vulnerable in the future. Regional climate model simulations have given a collective picture of substantial drying and warming in this region (Giorgi and Lionello, 2008). For central Spain, several reports have predicted a reduction in water resources of 20–40% by the end of the 21st century (e.g. IPCC, 2007; van Vliet et al., 2013). Water quantity and water quality are closely linked (EEA, 2012) and some investigations have predicted that climate change may have profound effects on nutrient loading and eutrophication (Jeppesen et al., 2009; Jeppesen et al., 2011; Trolle et al., 2011). Thus, holistic management tools, accounting for multiple environmental stressors such as land use management and climatic forcing, are needed to assess how stressors interact and ultimately affect the aquatic ecosystems.

Water level fluctuations due to water exploitation and climatic influences also cause some undesirable effects in large Mediterranean reservoirs. Besides having socioeconomic impacts, these negative effects include the development of an arid drawdown zone, which is a landscape impact and also leads to the loss of bank vegetation and nesting places for aquatic birds (MMA and CNEGP, 1996; Molina-Navarro et al., 2010). Water managers have taken some actions to mitigate these impacts in Spain. One such attempt is to construct small dams in the riverine zone of large reservoirs, generating small water bodies with rather constant water level independent of the management of the larger main reservoir. They have been termed "limno-reservoirs", since they rather resemble a lake than an ordinary reservoir (Molina-Navarro et al., 2010).

The Pareja Limno-reservoir (Guadalajara Province, central Spain) was built in 2006 and was the first Spanish limno-reservoir to serve environmental and recreational purposes (Molina-Navarro et al., 2012). However, some uncertainties about its environmental quality arose after its construction and for impact assessment a Soil and Water Assessment Tool (SWAT) model using its ArcGIS interface (Winchell et al., 2009) was developed for the Ompólveda River basin flowing into the Pareja Limno-reservoir. The main objective was to evaluate its usefulness as a tool to assess the hydrological viability of the Pareja Limno-reservoir, based on present land use and climate conditions (Molina-Navarro et al., in press).

SWAT applications in the Mediterranean region are limited, but has been successfully applied in a few catchments, for instance for the purpose of modeling nutrient exports (e.g. Panagopoulos et al., 2011a) and evaluating the effects of land use management on water and nutrient exports (e.g. De Girolamo and Lo Porto, 2012; Panagopoulos et al., 2011b; Pisinaras et al., 2010) or climate change (Kalogeropoulos and Chalkias, 2013; Varanou et al., 2002). In Spain, SWAT has recently been applied to evaluate the effects of best management practices on NO_3 export (Cerro et al., in press), the vulnerability of agriculture in a climate change context (Savé et al., 2012) and the potential impacts of climate change on groundwater recharge (Raposo et al., 2013).

We expanded the SWAT model already implemented in the study area to account for nutrient exports, and coupled it to the Vollenweider and Kerekes empirical model (OECD, 1982) with the objective of analyzing the potential effects of several climate change and land use management scenarios on water discharge and availability, nutrient loads and water quality of the Pareja Limno-reservoir.

2. Materials and methods

2.1. Study site

The Ompólveda River catchment is located in the upper Tagus River basin (South of Guadalajara Province, central Spain) (Fig. 1). It has an approximate area of 88 km^2 and altitude in the basin ranges between 718 and 1137 m.a.s.l. Climate in the basin has Mediterranean characteristics: annual average temperature is around 13.0 °C, with cold winters and warm summers. Average annual rainfall recorded at the Escamilla station (the closest to the study area, Fig. 1) is around 600 mm. Although the station is located in the southeast border, data from this station is considered representative for the whole catchment due to its small size.

The catchment has rural features and natural vegetation is the main land coverage. Thus, 37% of the catchment is covered by forests (pine and holm oak) and 36% by scrubland, occasionally combined with pasture. Twenty-five percent of the catchment is agricultivated, mainly including non-irrigated cereal crops (17%) and olives orchards (7%, many of them abandoned). There are about 300 inhabitants in the catchment, mostly living in the village of Pareja (Molina-Navarro et al., in press).

The Pareja Limno-reservoir was built in 2006 in the riverine zone of a sidearm of the much larger Entrepeñas Reservoir (Fig. 1), where the Ompólveda River discharges. The limno-reservoir has a capacity of 0.94 hm^3, a potential inundation area of 26 ha and an average depth around 4 m. More detailed features of the study site can be found in Molina-Navarro et al. (in press).

2.2. Model implementation and calibration

The Ompólveda River catchment model was previously calibrated and validated for streamflow with SWAT in Molina-Navarro et al. (in press) and further details on model setup and hydrological performance can be found there. In the present study, we expanded this SWAT application to account for nutrient export and to quantify potential climate and land use change impacts.

Nutrients are modeled by SWAT in the soil profile and in the shallow aquifer. They are introduced into the main channel through surface runoff and lateral subsurface flow, and transported downstream with channel flow. In the shallow aquifer, nitrogen enters in recharge from the soil profile and SWAT allows for fluctuations in loadings over time, while the concentration of soluble phosphorus in the shallow aquifer may be specified. Detailed information about nutrients cycling in SWAT can be found in Neitsch et al. (2005).

The expansion of the SWAT model to account for nutrients exports required some changes. Firstly, the expansion of the rainfall and temperature time series input. Nitrate ($N–NO_3$) and total phosphorus (TP) data for calibration were collected seasonally in the period Spring 2008–Summer 2011 (near monthly during hydrologic year 2009/2010) (Molina-Navarro et al., 2012). Samples were taken in the Ompólveda River just before its inflow in the Pareja

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