Estuarine, Coastal and Shelf Science 167 (2015) 138–146

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Integrating operational watershed and coastal models for the Iberian Coast: Watershed model implementation – A first approach

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ARTICLE INFO

Article history:
Received 6 October 2014
Received in revised form
20 October 2015
Accepted 27 October 2015
Available online 31 October 2015

Keywords:
Western Iberia
Numerical modelling
Mohid land
Catchment
Nutrient budget
Iberian Peninsula

ABSTRACT

River discharges and loads are essential inputs to coastal seas, and thus for coastal seas modelling, and their properties are the result of all activities and policies carried inland. For these reasons main rivers were object of intense monitoring programs having been generated some important amount of historical data. Due to the decline in the Portuguese hydrometric network and in order to quantify and forecast surface water streamflow and nutrients to coastal areas, the MOHID Land model was applied to the Western Iberia Region with a 2 km horizontal resolution and to the Iberian Peninsula with 10 km horizontal resolution. The domains were populated with land use and soil properties and forced with existing meteorological models. This approach also permits to understand how the flows and loads are generated and to forecast their values which are of utmost importance to perform coastal ocean and estuarine forecasts. The final purpose of the implementation is to obtain fresh water quantity and quality that could be used to support management decisions in the watershed, reservoirs and also to estuaries and coastal areas.

A process oriented model as MOHID Land is essential to perform this type of simulations, as the model is independent of the number of river catchments. In this work, the Mohid Land model equations and parameterisations were described and an innovative methodology for watershed modelling is presented and validated for a large international river, the Tagus River, and the largest national river of Portugal, the Mondego River. Precipitation, streamflow and nutrients modelling results for these two rivers were compared with observations near their coastal outlet in order to evaluate the model capacity to represent the main watershed trends. Finally, an annual budget of fresh water and nutrient transported by the main twenty five rivers discharging in the Portuguese coast is presented.

1. Introduction

In recent decades, the population increase in urban areas led to a spatial concentration of water demand for production and irrigation. This demand was generally compensated by using surface water, which in the Iberian Peninsula present a high inter-annual variation, constraining water management decisions. In addition, population concentration in alluvial plain areas increased the need of appropriate flood risk policies and action plans in order to prevent and mitigate flooding episodes.

In order to obtain the appropriate information for water resources planning and management, river monitoring networks were designed and implemented. The hydrometric network in Portugal was observing streamflow and precipitation until the 90's or 00's while water quality monitoring started in the 00's. Due to economic constraints, the amount of active stations and the data reliability from the Portuguese hydro-meteorological network has been declining as a result of the maintenance interruption of the automatic monitoring stations since the beginning of the 2010's and field data collection in Portugal is nowadays quite sparse. The Portuguese case is part of a more general trend in hydrometric networks decline observed in many countries around the world (Mishra and Coulibaly, 2009).

A way to reduce the uncertainty of the quality and quantity of the fresh water resources is through mathematical models. Numerical models, once validated, could fill data gaps and link sources of pressure to the observed state in the catchment and allow scenario testing. Watershed models first appeared in the 50's – 60′s making the focus on water - the called rainfall-runoff modelling – (Donigian and Imhoff, 2002), and not until the 70′s did water

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http://dx.doi.org/10.1016/j.ecss.2015.10.022
0272-7714/

quality begin to gain notice, with models focusing in the soil loss and nutrient and pesticide export to rivers (Horn et al., 2004).

In the next decades the need for management-oriented process integration led to the development of watershed models with detailed land management such as the SWAT model (Neitsch et al., 2005) which is a semi-distributed watershed model with a strong semi-empirical component that reduces running time over large basins, but strongly increases the need for field data prior to model implementation.

In last decade, distributed physically-based models developed with the increasing computation capacity reducing the number of model empirical parameters and thus increasing model applicability in systems lacking data. Two examples are the MIKE SHE model (Refsgaard and Storm, 1995) and the SHETRAN model (Ewen et al., 2000) which were both originated from the SHE model (*Système Hydrologique Européen*) and are a reference in the generation of physically-based, integrated, distributed watershed models. Conceptually, these models and MOHID (Neves, 2013) are very close; nevertheless the former use finite-differences as the numerical method while MOHID Land uses finite-elements and the equations are solved for volumes ensuring, by default, mass conservation.

In this work, we present the tools, methodologies and a preliminary validation as the base to obtain accurate forecasts of fresh water quantity and quality that could be used to support modellers and managers targeting large regions at different scales, such as watersheds, reservoirs, estuaries, and coastal areas.

2. Study area

The study area covers the entire Iberian Peninsula with a surface area around 580 000 km^2 and more specifically to the rivers discharging in the Portuguese coastal area. Iberia presents several largest rivers including the Douro River (area ca. 100 000 km^2), the Tagus and the Ebro rivers (area ca. 80 000 km^2), the Guadiana River (area ca. 70 000 km^2) and the Guadalquivir River (area ca. 60 000 km^2) that, with the exception of the Ebro River, have international character sharing their catchment between continental Spain and Portugal and discharging on the Atlantic Ocean draining on its way almost two thirds of the territory. For the scope of the validation of the presented methodology study, we will focus mainly on the Tagus River with a total length ca. 1000 km, the longest river of the Iberian Peninsula, and the Mondego River, the longest river located exclusively in Portuguese territory (Length 230 km, area 6.600 km^2).

The determination of the rainfall is of the utmost importance, as it is a primary variable in most hydrological models. The precipitation in the Iberian Peninsula is characterized by high spatial and temporal variability because of a complex orography and diverse atmospheric regimes. Mean annual precipitation varies between more than 2000 mm in the northwest coast and less than 200 mm in the south-eastern coast (AEMET and IM, 2011).

In Iberia most of the precipitation falls between October and May and is produced by large-scale atmospheric perturbations that originate in the Atlantic sector and move eastwards (Serrano et al., 1999; Santos et al., 2005). During winter, western Iberia is affected by westerly winds, influenced by the position of the Icelandic low, that carry moist air and produce rainfall events mainly in northern Portugal. The precipitation is intensified by the passage of cold fronts associated with families of transient depressions and more efficient when the Icelandic low is very deep and shifter southwards (Trigo et al., 2004). In addition to the seasonal character, the Iberian Peninsula is also characterized by a strong inter-annual precipitation variability presenting very wet and dry years occur with some frequency affecting the hydrological cycle and by consequence the river flow and water resources (Trigo et al., 2004; Paredes et al., 2006).

3. Materials and methods

3.1. Modelling grids

Two domains covering the Iberian Peninsula (IP domain) and the Western Iberia (WI domain), with 10 km and 2 km horizontal resolution respectively (Fig. 1), were populated using the NASA SRTM three arc-second digital terrain elevation, that in the studied area has a horizontal resolution of 70–90 m (Farr et al., 2007). The IP domain, with 80 × 130 cells in horizontal and 8 vertical layers, allows the reproduction of large trans-boundary rivers discharging in Western Iberia as the Tagus, Douro and Guadiana rivers at their natural state. The WI domain, 250 × 160 cells in horizontal and 8 vertical layers, provides high resolution results for Portugal and the Galicia region (Northwest Spain), encompassing watersheds up to 10 000 km^2.

Along with the topographic data, the model was provided with land use and soil properties. In order to have a common source for both modelling domains, the Corine Land Cover 2006 – CLC2006 (EEA, 2007) with a resolution of 100 m was used to derive crop types for the vegetation growth model, surface impermeabilisation and Manning resistance following Van der Sande et al. (2003) and Chow (1959) suggested correspondences.

The soil hydraulic permeability and retention capacity control the infiltration and groundwater movement and surface water quantity. Soil map distribution and hydraulic characteristics, necessary to specify the van Genuchten model parameters, were obtained from the Joint Research Centre database (http://eusoils.jrc.ec.europa.eu/) for both domains with a 900 m resolution.

In the absence of detailed information on agricultural practices in a wide area as the Iberia Peninsula, it was used the auto-fertilization concept from SWAT model. In practical terms, this means that agricultural practices are assumed to be optimal since the fertilization occurs according to the plant needs. Maximum values of 50 kg/ha.day and 200 kg/ha.year of fertilizer where considered based on the good agricultural practices guide for Portugal (DGADR, 1997).

The objective of this model implementation was to represent the large scale hydrological and water quality processes, including evapotranspiration and river discharges, and not the local processes associated for example with land use changes smaller than the cell size. More detailed approaches can however be implemented in areas of interest having the boundary conditions given by the Iberia Peninsula or Western Iberia model applications.

The atmospheric boundary conditions for the WI domain were obtained from the MM5 model (Grell et al., 1994) with a horizontal resolution of 9 km implemented by the IST meteorological group (http://meteo.ist.utl.pt). For the IP domain, results from a WRF model (Skamarock et al., 2005) application with 12 km resolution computed by Meteogalicia (http://www.meteogalicia.es) were used as atmospheric forcing. Both meteorological models results were interpolated to the MOHID Land grids.

3.2. MOHID land model

The MOHID Land model is the catchment component of the MOHID Modelling System (Neves, 2013; http://www.mohid.com). The MOHID land model is a 3D distributed, continuous, physically based, variable time step model using a finite-volume approach based on mass and momentum balance equations. The simulated processes include interception and evaporation in leafs, infiltration and evapotranspiration in soil/vegetation, vegetation growth,