RAINFALL-RUNOFF MODELLING AND ALTERNATIVE SCENARIO IN A SMALL MEDITERRANEAN WATERSHED USING SWAT MODEL

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Abstract

The use of rainfall-runoff models in the decision making process of water resources planning and management has become increasingly indispensable. Such models are used, for example, in the design and operation of hydraulic structures, for flood forecasting and for evaluating possible changes taken place over the catchments due to urbanization. The transformation of rainfall into runoff is a complex, non-linear, time and spatial varying process. Accordingly, various models ranging from linear to non-linear, lumped to distributed, have been developed to describe the transformation of rainfall hyetograph to discharge hydrograph.

The nature of the catchment will influence the choice of modelling approach to use. Considerations include catchment size, location within a river basin (headwater, middle reach, lower reach), steepness and the influence of tides, backwater or river gate controls. In addition, it is important to consider whether the catchment is rural or urbanised.

Distributed hydrological models have the ability to mix rainfall-runoff and routing models in an integrated way to allow a unified transfer of information from gauged to ungauged sites using spatial datasets on terrain, soil, land use and geology to support model configuration.

The hydrological response of a catchment is the combination of several factors. Ambroise (1999) points out that climate forcing, background hydrological conditions and hydrological soil properties, in addition to topography and morphology and land use, determine the active processes in a catchment, as well as the intensities and interactions of these factors. The resulting combination of hydrological processes generates a response that is characteristic of the catchment, but also characteristic of every rainfall event.

In this work an evaluation of the importance of the different parameters as well as soil type, soil moisture and land use in the runoff processes has been evaluated.

The study area is Candelaro watershed, a small basin located in southern Italy, and the method selected for estimating surface runoff is the SCS Curve Number procedure (SCS, 1972).

The Candelaro river has a length of 67 km, the watershed area is about 1800 km^2 and it is characterised by a mean elevation of 300 m, with a maximum of 1150 m and a minimum of 0 m above the sea level. The superficial density of the hydrographic network is rather elevated: Celone, Salsola and Triolo are the main tributary; the final water body is the Adriatic Sea.

The main problems characterising the watershed are the scarcity of water resources, diffuse pollution from agricultural sources and flooding.

The climate is typically Mediterranean, it is characterized by low annual rainfall, mostly concentrated in autumn and winter, with very dry summers; furthermore, the rainfall has a very high variability in space and in time. This has a significant influence over peak discharge and river flow regime that, for this reason, results very variable, with periods without runoff and with extreme flush floods. The mean annual rainfall is about 550 mm and the temperature is high in summer period in the plain part of the basin where exceeds 40°C, while in winter snow falls only in the mountain part of the area.

The dominant land use category is the agriculture, which includes durum wheat (72%), olive (10%), and tomato, minor land use includes vineyard (5%), sugar beet (8%); also natural forest and pasture are present. The Land Use Map used in this work has been extracted by the Corine Land Cover Project 2003. The soils are related to the lithology and generally show a texture varying from sandy-clay-loam to clay-loam or clay. Depth and topsoil conditions are highly variable, the plain part of the basin is constitutes by deep soils (1.5-2.00 m) while the hill and the mountain part of the catchment is composed by soil moderately deep (1.00 m). Regarding the permeability of the soils, in general they have a moderate or slow infiltration and in some cases they are characterised by very slow infiltration. In according with the U.S. Natural Resource Conservation Service (NRCS) classification of soils, almost all profiles are grouped in the class C and in the class D.

There are two broad categories of factors that control runoff: meteorological factors and watershed physical conditions. Important rainfall characteristics include type of precipitation, duration, amount, intensity and distribution, antecedent precipitation. Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season.

Key watershed factors are: size, shape, topography, soils, landuse and hydrological condition.

When rain falls on a surface covered by a thick mantle of plants, its velocity and erosive power are reduced and most of the water either quickly percolates through the soil or moves over the surface with non-erosive velocity. Areas not protected with thick cover of plants are unable to absorb water effectively, because the dashing rains shatter the soil surface, the fine soil particles go into suspension and the thick mixture of water and soil quickly fills and closes the tiny interstices in the soil, reducing infiltration and consequently increasing run-off and soil loss.

Among the different hydrological parameters, soil moisture is a key factor determining runoff response to a given precipitation event (Phillips, 1992). Thus, the spatial pattern of soil moisture may be used to identify areas with a different hydrological response and to identify critical wetness thresholds to runoff and erosion in a watershed. The spatial distribution of soil water content in the top horizon tends to be the result of complex processes depending on relief, top-soil characteristics (such as water retention capacity, soil sealing and crust) and their links to the climate. The Mediterranean climate shows a complex pattern of spatial and seasonal variability, with wide and unpredictable rainfall fluctuations from year to year. Extreme rainfall events of high intensity are frequent phenomena in this region, together with long dry periods that are disruptive for natural and human systems. Recently, many works have reported the main factors governing the spatial and temporal variability of soil water content in the top layer under different vegetation types (Calvo-Cases *et al.*, 2003).

The watershed model used in this study is Soil and Water Assessment Tool (SWAT). SWAT is a semi-distributed model, which makes use of a digital elevation model (DEM) to delineate a watershed into subbasins, which are spatially defined areas. Further subdivision of subbasins into Hydrologic Response Units (HRUs) can be performed using specification of unique land use and soil combinations. However, the HRUs are spatially undefined units within in the subbasin and watershed parameters such as land uses and their associated management practices, soil types, geomorphic parameters, and weather are considered to be homogeneous at the HRU scale. Numerous physical and chemical processes are modelled by SWAT and the major ones are hydrology, nutrient transport, plant growth, and management practices. The hydrologic processes include surface runoff, estimated by SCS Curve Number procedure or by the Green Ampt infiltration method; potential evapotranspiration, estimated by Penman-Monteith, Hargreaves or Priestley method; percolation, simulated by a combination of a layered routing technique with a crack flow model; lateral subsurface flow or interflow, simulated by a kinematic storage model; and ground water flow. In this work, the study area has been divided in 34 subbasins and 195 HRU. SCS Curve Number has been selected to calculate surface runoff and Hargraves method has been chosen to evaluate evapotranspiration. The Curve Numbers for the condition II has been assigned considering the soil type, land use, slope and hydrological condition, for each HRU.

The model has been run from 1989 to 2001. Sensitivity analysis procedure pointed out the most important parameters that influence flow discharge: Curve Number, soil available content and soil depth. The calibration has been done working on these parameter and on groundwater parameter. Simulated flow and observed flow has been compared in three different station located on tributaries: Celone, Salsola and Triolo. SWAT modelling performance was evaluated by Nash and Sutcliffe coefficient (NSE).

SWAT model provides, for each subbasins and for each Hydrologic Response Units, the amount of the surface runoff, potential and actual evapotranspiration, percolate and water in soil profile at the end of simulation time step (day, month, year).

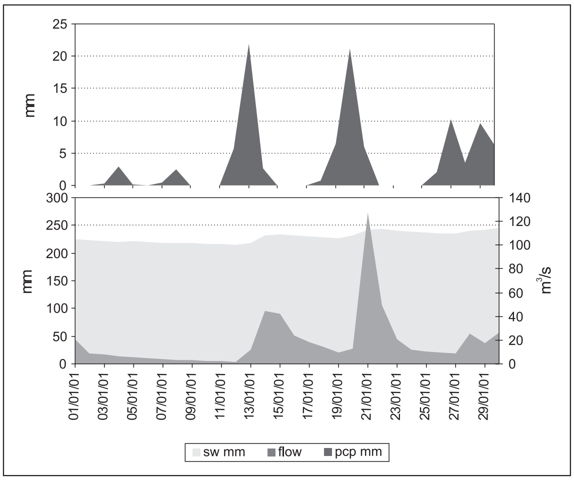

Figure 1. Measured daily rainfall flow and simulated daily discharge and mean soil water content

The results have been reassumed for the different soil classes (USDA classification): clay, clay-loam, loam, sandy-clay-loam, sandy-loam, silty-clay-loam and for the crops cultivated in the area. The results show that, for each class, play a very important role in partitioning the water budget tillage operation, slope, soil type and soil moisture. They clearly indicate that if the land is left undisturbed under a natural cover, the runoff and soil loss are the least; the soil loss and runoff increase steeply when the vegetation is removed and the land is cultivated. In particular the runoff is very high for vineyard, sugar beet and tomato cultivated on sandy-clay-loam soils, while is low for pasture and durum wheat. In addition it has been observed that deep soils, sandy loam and loam, have the lowest rate of run-off, alluvial soils, silty-clay-loam and sandy-clay-loam, have a very high rate of runoff and clay-loamy soils have an intermediate rate of runoff.

Analyzing the results of the simulations is evident that infiltration processes and runoff generation occur in a non-uniform way in space and time, due to local differences in soil infiltration capacity and preferential paths within the soil profile. In addition, soil thickness is a critical property determining the water-holding capacity of soil. In this respect, land surface changes and land transformations involving heavy land-levelling could have significant impacts on the hydrological properties, such as water infiltration and holding capacity, due not only to the different soil structure of the resulting soils, but also to the alteration of the soil thickness, which will certainly help to generate additional spatial differences in soil hydrological properties.

Antecedent soil moisture has great influence on flow peak discharge, as it can be observed in the Figure 1 the response of the basin in terms of flow discharge is more different after two rainfall events, which mean value is 21.96 mm and 21.25 mm respectively. The flow discharge is about 44 $m^3 \cdot s^{-1}$ in the first peak and about 127 $m^3 \cdot s^{-1}$ after the second event, this is due to the different antecedent soil water content.

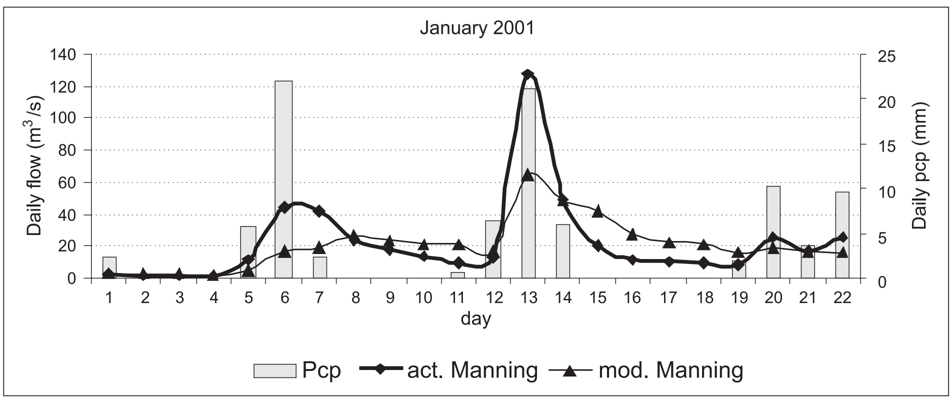

Figure 2. Simulated flow (actual and the modified Manning's coefficient)

Considering that roughness has a great influence on runoff, an alternative scenario has been simulated in order to reduce peak discharge. In particular, the overland Manning roughness has been changed by the actual values, ranging between 0.14-0.100, to the values: 0.300-0.400 and the Channel Manning roughness of tributary and main channel has been modified by the value: 0.014 to the value: 0.100.

As it can be observed in the Figure 2, the peak discharge simulated in the new scenario is less than the actual. On yearly basis, not substantial differences in the surface runoff have been simulated while a slight increase has been found in the baseflow.

This scenario implies the conservation of natural streamflow regime and reduction of overland flow with conservation tillage, therefore, Best Management Practices can reduce erosion and runoff and thereby provide greater infiltration opportunities at the soil surface.

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