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Watershed Modeling to Assess Resource Use in a Small Catchment in Northern Syria

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Résumé
Les modèles de simulation peuvent fournir des informations valables pour évaluer l'écoulement de l'eau et l'utilisation des ressources naturelles dans des bassins versants. Le SWAT (Outil d'Evaluation de l'Eau de Sol), un modèle continu-basé sur les aspects physiques, a été appliqué dans un bassin versant aride de 28 km^2, non jaugé, en Syrie du nord pour évaluer l'effet de différentes utilisations du terroir et procédures de gestion à long terme. La moyenne des pluies annuelles dans le bassin versant est de 220 mm, avec l'orge et les olives comme cultures principales. Des modifications du modèle ont été faites pour simuler les processus qui sont typiques pour les environnements méditerranéens arides. Les simulations ont indiqué que les techniques de conservation des eaux dans les vergers d'oliviers sur les pentes avait un effet mineur sur les rendements en olives, mais augmentent l'écoulement latéral dans le sol et de la recharge de la nappe souterraine. La distribution saisonnière et la précipitation annuelle influencent fortement les processus au niveau des bassins versants. Ceci souligne l'importance des études à long terme de surveillance et de simulation.

Introduction
Watershed models are valuable tools for assessing the different hydrologic processes that occur in watersheds and their relations in time and space. In the dry areas, evapotranspiration is the main use of the precipitation that drives the system. Therefore, accurate simulation of crop growth and evapotranspiration is critical. With groundwater often the only source of water supply for rural communities in arid areas, groundwater recharge is another important water balance component. Surface runoff records are often used to evaluate the performance of watershed models. However, the rarity and immensity of wadi floods in arid environments makes runoff monitoring a difficult and costly venture. Without data records for evaluation, the judicious use of models and model results is especially critical.

The Soil Water Assessment Tool (SWAT) was developed by Arnold et al. (1998) to predict the long-term impact of land management practices on water, sediment, and chemical movement in large complex watersheds with varying soils and land use conditions. The model has been used for a wide range of applications in various environments. The SWAT was selected for an assessment of resource flows in a 28 km^2 arid watershed in northern Syria, because (i) the model's mathematical representation allows long-term simulation of arid environments; (ii) it includes full water balance processes, such as crop growth, which allows the assessment of water productivity; (iii) it has a GIS-interface that facilitates the preparation of highly variable spatial watershed data; (iv) it is freely available, including documentation and source code; and (v) it has an active user and development community.

The objective of the here presented study was to evaluate the effect of different land uses and management practices on the water flow and productivity in the Habs-Harbakiyah watershed in northern Syria. This study focused on surface and soil water flow; erosion and nutrient processes are not evaluated.

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Materials and Methods

Model Description. The model version used in this study is SWAT2000 (Neitsch et al., 2002). The input data were prepared with the help of the SWAT ArcView interface (Di Luzio at al., 2002). The SWAT simulates the entire process of the hydrologic cycle, including rainfall, evapotranspiration, crop growth, water withdrawals, and groundwater recharge (Fig 4.1). The model uses the concept of Hydrologic Response Units (HRUs) to represent unique combinations of soil and land use properties within sub-watersheds. The model requires daily climate data. These can be generated from climate statistics, using the imbedded weather generator. Runoff is predicted from the daily rainfall with the curve number method. Flow in the soil profile occurs when the field capacity of a soil layer is exceeded. A kinematic storage model is used to simulate the lateral subsurface flow component. The flow rates are determined by the saturated hydraulic conductivity of the soil layers. The runoff and lateral flow volumes of all HRUs flow out of the sub-watershed and are routed downstream through the channel network.

The SWAT has four options for computing potential or reference evapotranspiration. The Hargreaves equation was used for this application. The potential plant transpiration is a function of the Hargreaves evapotranspiration and the Leave Area Index (LAI). Potential soil evaporation is computed as a function of the ET and the surface cover, and adjusted when evapotranspiration is high. Actual evapotranspiration is a function of the potential evapotranspiration and the amount of water available in the soil.

Plant growth and biomass production is simulated with a simplified form of the crop model of the Erosion Productivity Impact Calculator (Williams et al., 1995). Daily increase in leaf area is computed as a function of the fraction of the potential heat units of the crop. Biomass production is computed from the crop's radiation use efficiency (RUE), the intercepted photosynthetically active radiation (PAR), and the LAI. Water, temperature, and nutrient stress factors are computed to adjust biomass production and leaf growth for stress.

During the modeling of the Habs-Harbakiyah watershed by Van der Meijden (2004) the need to modify SWAT to better simulate the processes in this typical arid Mediterranean environment was identified. These changes include the modification of the irrigation-from-reach option to apply surface runoff generated by upstream HRUs to downstream HRUs within the same sub-watershed. Other modifications were related to the growth and dormancy of olives and winter crops, the effect of grazing on leaf area index, the indexing system for crop management operations and the change of the curve number during the growing season.

Study Area. The main agricultural activities in the Habs-Harbakiyah watershed are rain-fed barley and small ruminant production. In spring, the sheep graze the stony limestone hill-slopes that border the watershed. The hill-slopes are dissected by gullies, which carry runoff water down the steep, stony slopes. The runoff often disperses on the flat, deep soils of the crop land on the valley floor before it reaches the main *wadi* system. Farmers plough over these gullies, but they have not built diversions for spreading the runoff water on their land. A number of olive orchards have been established during the last six years. The trees are planted both on the stony slopes and on the flatter valley soils. Some farmers prepare v-shaped or semi-circular earth bunds in their orchards to harvest runoff water for the trees. The Government has recently constructed a small reservoir, just south of Harbakiyah village, which diverts the flow from the main wadi. This is considered the outlet of the watershed.

The weather generator was used to allow long-term simulation. For the rainfall distribution parameters, a 7-year record (1998-2005) from the tipping bucket rain gauge in the nearby Qurbatiyah station was used. The monthly data of this station were similar to the long-term monthly data from the manual rain gauge in Khanasser town (1929-2001).

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A Digital Elevation Model (DEM) of the watershed was made using data from the Shuttle Radar Topography Mission (USGS, 2005) an ortho-rectified Landsat 7 ETM+ image covering the whole area, an Ikonos image of part of the watershed, and field data of the gullies and *wadis,* collected with a handheld GPS. A land-use map of the Khanasser Valley was made based on a visual interpretation of an Aster image (August 28, 2001) and the ortho-rectified Landsat 7 ETM+ image (May 7, 2003), the DEM, a GPS-survey of the olive fields, and detailed knowledge of the study area. The main crop in the Habs-Harbakiyah watershed is rain-fed barley, while natural rangelands are covering the stony slopes. Olive orchards occupied almost 4% of the cultivated land in the watershed in 2003. Groundwater levels are at least 18 m below the surface.

The main soils in the Habs-Harbakiyah watershed are Calcisols in the valley floor, Calcaric Leptosols on the slopes, and both on the plateau (Ruysschaert, 2001). Soil textures are mainly clay loam and loam, and infiltration rates are high. The main differences in the physical characteristics of the different soil units are due to the soil depth and stoniness, which are related to the land form. Therefore, the soil map was adjusted with the help of the DEM into the following units: valley floor (0-3.5% slope), foot slopes and plateau slopes (3.5-10%), escarpment (10-44%). The soil physical characteristics were taken from soil samples collected by various ICARDA studies, complemented with properties computed by the soil water characteristics calculator from texture data (Saxton et al., 1986). The available water capacity and bulk density were adjusted for the stone content of the soil, with consideration of the retention properties of the calcareous stones (Cousin et al., 2003).

Results

The average annual precipitation for the 100-year simulation was 225 mm. The driest year in the record received 111 mm precipitation and the wettest year 388 mm. The crop production and water balance components for the main HRUs in the watershed are summarized in Table 1. The simulated yearly biomass and yields of the different crops fell within the range of data from local studies. The average water productivity of the barley grain yields in the valley was high, 1.0 kg m^{-3}. The minimum and maximum grain yields of the barley in the valley during the 100-year period were 0.3 and 2.0 ton ha^{-1}, respectively. The water productivity of the rangeland was very low due to the over-grazed, degraded plant cover and the shallow stony soils. The precipitation on the slopes was mainly lost to soil evaporation and runoff.

The percolation from the barley fields on the plateau was high but was affected by the distribution and amount of the rainfall, in 10 of the 100-years there was no percolation. The high percolation rate is due to the shallow depth (0.6 m) and the low water holding capacity of the soils (10%), which is caused by the high stone content. To explore the effect of the uncertainty in these parameters, the model was also run with minimum and maximum estimates. For the same available water capacity but a soil depth of 0.5 m, the average annual percolation would be 14% of the precipitation. Whereas for a soil depth of 0.7 m and an available water capacity of 14%, the long-term average annual percolation would be 4% of the precipitation.

The water productivity of the olives was high, because of their year-round cover. An average yield of 20 kg per tree was harvested. The differences in the yields for the olives with and without micro-catchment systems were small, ranging between 0.3 and 0.8 kg per tree for the 100-year period. The water harvesting systems reduced the surface runoff from the orchards, but because the soils of the olive fields were relatively shallow (1.0 m) part of the precipitation was lost to percolation.

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Table 1. Average annual crop production and water balance components, expressed as a percentage of the precipitation, for the main HRUs in the Habs-Harbakiyah watershed.

Land use	Soil unit	Total biomass[a]	Grain yield	Crop transpiration	Soil evaporation	Run-off	Perco-lation
		ton ha^{-1}	ton ha^{-1}	%	%	%	%
Barley	plateau	2.8	0.9	34	49	6	11
Barley	valley	3.1	1.0	43	57	0	0
Olive	footslopes	48.9	3.0	70	19	7	4
OliveWH[b]	footslopes	50.1	3.1	72	18	1	9
Rangeland	edges	0.5[c]	na	9	58	24	9

[a]Total above and below ground biomass before harvest; [b]Orchards with micro-catchment water harvesting; [c]Total above ground biomass grazed by the sheep.

Discussion and conclusions

Part of the percolation from the olive fields and the rangelands on the slopes and the escarpment does not recharge the groundwater but flows as quick lateral subsurface flow to the wadis. Similarly, on the plateau the actual recharge may be constrained by the characteristics of the underlying geologic formation. Currently, the model uses the one value for both the horizontal and vertical hydraulic conductivity of the soil to compute lateral flow and percolation. Additional collection and analysis of field data and model modifications will be made to allow a more detailed evaluation of the simulated process components.

The SWAT is a powerful tool for assessing the effect of different land uses and management practices on the water flows and productivity in watersheds. A good understanding of the hydrology of the watershed is needed to evaluate the processes simulated by the model. Modifications to the model code were made to simulate crop production, management, and runoff processes that are typical for dry Mediterranean environments. The watershed processes were highly depended not only on the variable total annual precipitation but also on the distribution of the precipitation over the season. This emphasizes the importance of long-term measurements and simulations.

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