NON POINT SOURCE POLLUTION AND RUNOFF SIMULATION WITH *AnnAGNPS* MODEL, IN A SMALL IRRIGATED WATERSHED IN PORTUGAL

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ABSTRACT. The main objective of this study was the application of the hydrologic, non point source pollution model *AnnAGNPS* to a small watershed (189 ha) that has irrigated agriculture as major use. The study watershed is located in the *Idanha Irrigation Scheme* (Portugal). The main irrigated crops are barley, corn and sorghum. Oat are cultivated rainfed and a young non-irrigated oak forest occupies one third of the watershed. Climate is Mediterranean; topography slightly sloppy; the natural drainage network is dense; and the soils are heterogeneous with an impermeable layer at depth varying between 0.35 and 0.45 m. We measured runoff at the outlet of the watershed in a long-throated flume were water depth was recorded continuously. Water samples were collected almost daily for determining sediment and nitrogen concentrations. The study was carried out during the hydrologic years 2004/2005 and 2005/2006, including periods in which rain or irrigation were the dominant water precipitation sources. *AnnAGNPS* simulated runoff reasonably well. The main trends in sediment transport were captured by the model well. However, our analysis pointed to poor simulation of the nitrogen fate in the study environment, although we could not draw definitive conclusions because the sampling method of the observed data was not completely satisfactory. The spatial distribution of runoff and soil losses indicated where in the watershed especial care is needed for assuring sustainable management at the watershed scale.

Keywords: non source pollution, *AnnAGNPS* model, water quality, agricultural watershed, hydrology.

1.- Introduction

In agricultural research, modelling-based on physical models, empirical models, or a combination of both has become an important methodology to assess tactic and strategic alternatives of resources management in general and of soil and water management in particular (Kite y Droogers, 2000; Lorite *et al*., 2004). Moreover, good management practices can be identified for specific environments with the aid of models that are properly calibrated. A further step on the application of models came with the development of geographical information systems (GIS) that allowed spatially distributed analysis. Non-point processes such as agricultural pollution require this kind of analysis (Novotny, 2003). As many authors have highlighted (i.e., Berry *et al*., 2003), soil and water conservation, and sustainable agricultural management in general, will rely on the development and application of appropriate computer tools oriented to site specific management. The complexity of the interaction between the hydrological characteristics of agricultural watersheds, the agricultural practices, and the fate of chemicals and water make difficult measuring and controlling the flows of these substances (*FAO*, 1997). This complexity lead to the development of the model *AnnAGNPS* (*Annualized Agricultural Non Point Source Pollution*) (Cronshey y Theurer, 1998), which approach tries to balance accuracy in the simulations and applicability. The model simulates water flow and transport of sediments, nutrients and pesticides at daily time steps and at the scale of the agricultural watershed. Runoff is simulated based on the curve number method (USDA-SCS, 1972; USDA-NRCS, 1986), erosion on the *RUSLE* method (Renard *et al*., 1997), and evapotranspiration on the Penman equation (FAO, 1984). Spatial analysis in *AnnAGNPS* is performed through a GIS interface in an *ArcView* environment.

This study presents an application of *AnnAGNPS* to an irrigated watershed in Portugal aiming to understand the interactions between rainfall/irrigation and the occurrence of runoff and sediment and nitrogen losses.

2.- Description of the study watershed

The study watershed is located within the *Idanha Irrigation Scheme*, Idanha-a-Nova, Portugal, near the border with Spain and just north of the Tejo river (Fig. 1).

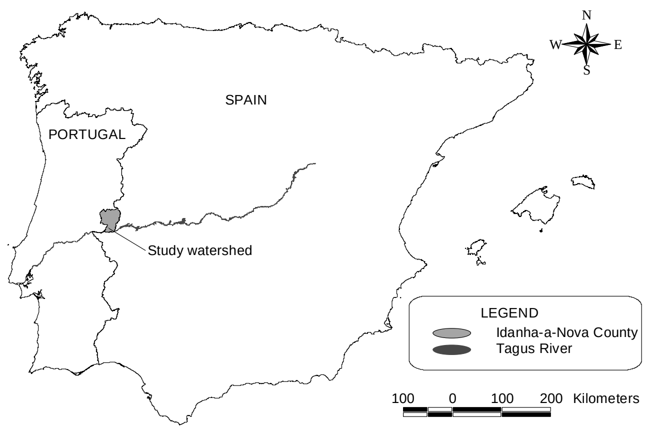

Fig. 1- Location of the study watershed.

The watershed has 189 ha and 28 natural channels with density 12.2 m ha^{-1} and fluvial hierarchy of three levels (Fig. 2). Altitude varies from 248 m, in a plateau north east, to 212 m at the control section. The slopes are in the interval 0 and 4%, thus the topography is flat to slightly sloppy (Fig. 2).

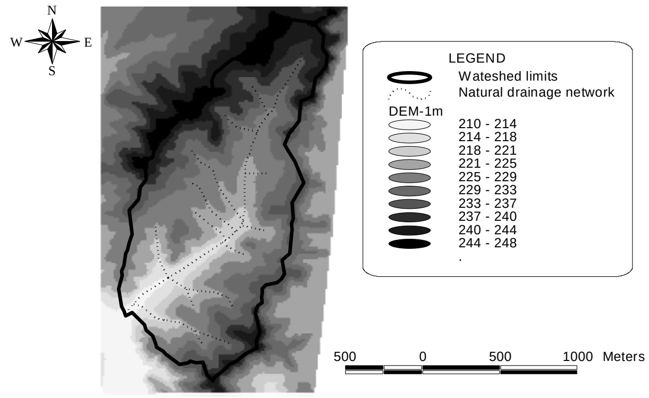

Fig. 2- Topography and natural drainage network of the study watershed.

The predominat soil classes are *Cambisols* and *Luvisols*, originated from deposits of the tributaries of the Tejo river (Fig. 3). Other soil class in the watershed is *Fluvisols*, originated by alluvial deposits of the main creak that crosses the watershed. An impermeable soil layer underlies the three soil classes at approximately 0.4 m in depth, which greatly determines the hydrology of the watershed.

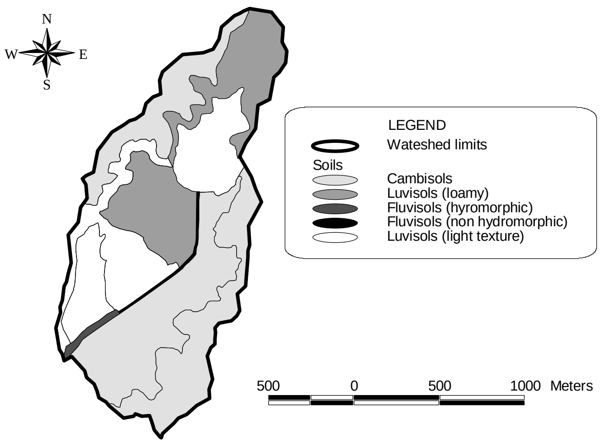

Fig. 3- Soil classes in the study watershed (FAO nomenclature).

Climate is Mediterranean continental, with average annual rainfall 624 mm, and average temperatura varying from 8.3 ºC in January to 24.5 ºC in August (INAG, 2007).

Land use can be differentiated in three areas (Figs. 4 and 5): forest (oaks), intensive agricultural use (mostly corn in year 2003/04 and fallow in year 2004/05), and marginal agricultural use.

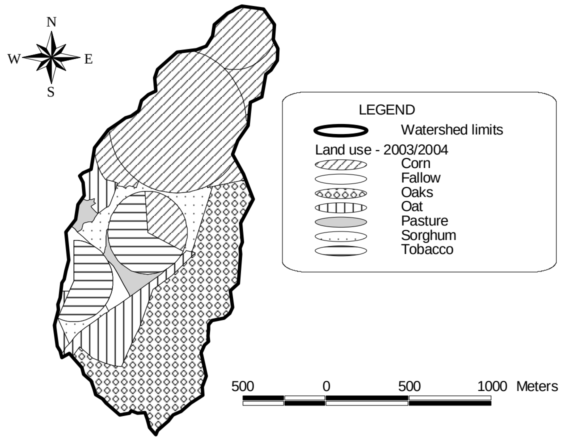

Fig. 4- Land use in the study watershed, year 2003/2004.

Soil use varied significantly from year 2003/04 to year 2004/05 (Fig. 5) due to a 52% reduction of the irrigated area and to a crop intensification in the upper and lower part of the watershed, respectively.

The irrigation methods used in the study watershed are sprinkler centre pivot and stationary sprinkler (in the areas not covered by the pivot machines).

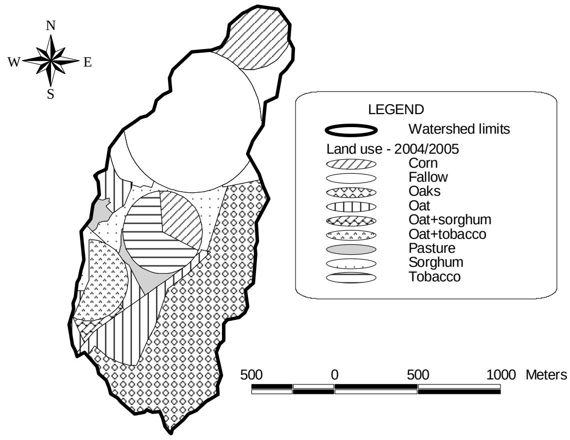

Fig. 5- Land use in the study watershed, year 2004/2005.

3.- Methods

A hydrological station was installed at the outlet of the watershed. The station consisted of i) a long-throated flume, with control section triangular for small water depths and triangular/trapezoidal for large water depths, designed and calibrated following the procedure in Bos *et al*. (1991), and ii) an ultrasonic sensor connected to a datalogger for measuring and recording water depth.

Water samples were collected at the hydrological station almost once a day. The samples were transported to the laboratory in a cold environment to determine the concentration of sediments and nitrogen (in its three mineral forms: ammonium, nitrate and nitrite). We assumed the pollutant concentration constant along the day, thus knowing the runoff rate we could determinate sediment and nitrogen losses.

Agricultural practices were recorded by the farmers and verified by direct observations during visits to the watershed.

The application of *AnnAGNPS* required creating files containing the meteorological data, the topographical and fluvial configurations, soils and land use information, and data on crops and agricultural practices.

Two vertical resolutions (1 and 5 m) of the digital elevation model were tested. An *AnnAGNPS* module, called *FlowNet Generator*, produced the watershed limits, the natural channels network, the cell divisions, the *LS* factor in the *RUSLE* equation, the classification of the cells in slope or channel categories, the length and slope of the water flow in each cell, and the classification of flow in each cell into laminar or concentrated (Bingner y Theurer, 2001). The natural channels network produced by *FlowNet Generator* was compared with that obtained using a precision GPS (Figs. 6 and 7). We considered that 5 m resolution (Fig. 6) was insufficient for satisfactory simulation of the hydrological and topographical configuration of the watershed while 1 m resolution (Fig. 7) was satisfactory.

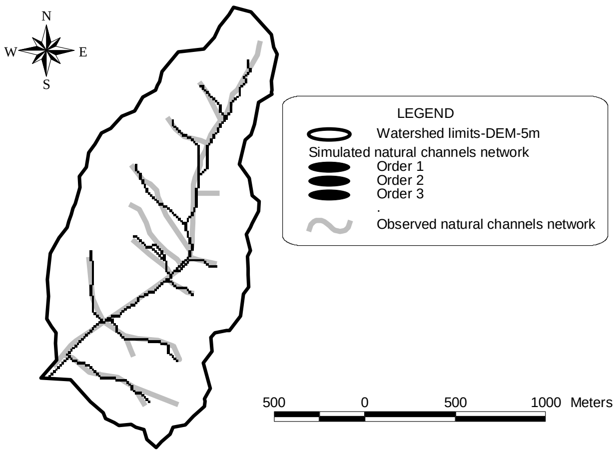

Fig. 6- Natural channels network observed and generated by *FlowNet Generator* using a digital elevation model with 5m of vertical resolution.

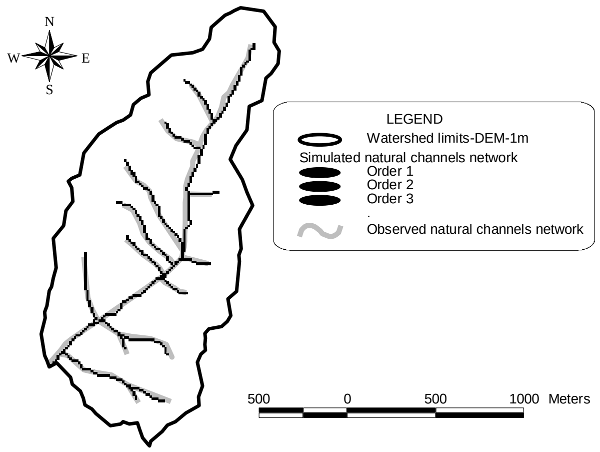

Fig. 7- Natural channels network observed and generated by *FlowNet Generator* using a digital elevation model with 1m of vertical resolution.

4.- Results

The results correspond to the irrigation season 2004 and hydrological years 2004/05 and 2005/06 (until 31 December 2005) and are discussed separating the irrigation and rain seasons.

Observed and simulated runoff for each of the four periods considered is in Table 1. Both values were close for the irrigation season, but differed significantly for the rain season. We think that this divergence is due mainly to the inability of the model to simulate base flow (Bingner y Theurer, 2005), a water balance component that seems to be important in the study watershed in view of the trend showed in Fig. 8.

Table 1- Simulated and observed runoff for the periods of analysis.

PERIODS OF ANALYSIS	RUNOFF (m^3)	
	Observed	Simulated
Irrigation/2004	68008	71108
Rain/2004-2005	198132	107504
Irrigation/2005	10420	10067
Rain/2005-2006	128105	73514
Total	**404665**	**262193**

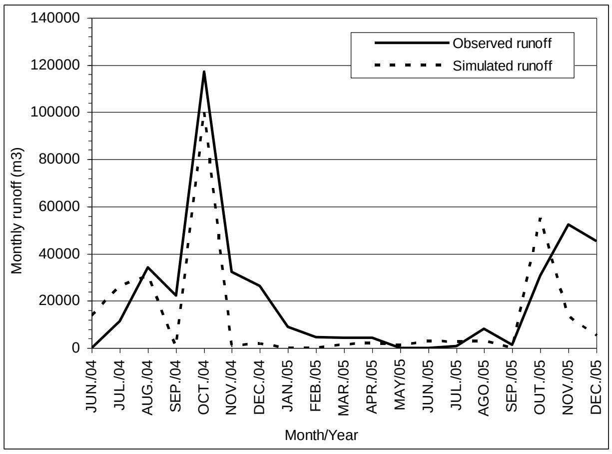

Fig. 8- Comparison between monthly simulated and observed runoff in the watershed study.

Sediment yield is closely dependent on runoff originated by events of intense precipitation (Lal *et al*., 1999). *AnnAGNPS* assumes that sprinkler irrigation events are not sufficiently intense to produce erosion (Bingner and Theurer, 2005). Therefore, the model did not simulate transport of sediments during the irrigation periods. However, we measured some sediment losses in the irrigation period of 2004/05 and insignificant losses in the irrigation period of 2005/06. The difference in sediment losses between the two irrigation periods was related to the much less runoff in the second season. Regarding the rain season, Table 2 shows that observed and simulated sediment losses were very close in the first year but diverged in the second, when simulated sediment losses were only 53% of those observed. We think that a part of this discrepancy may be due to our assumption of constant sediment concentration along the day because some samples were taken at peak runoff during rainfall events, when sediment concentration is expected to be higher. Note that there were days in which we did not collect samples, thus we made interpolations also between consecutive sampling days. A more detailed view of the sediment losses is in Fig. 9, where it can be appreciated that the greater divergence between the observed and measured sediment losses occurred in the descending limb of the sediment yield trend in the rain period of 2005/06.

Table 2- Comparison between simulated and observed sediment losses for the periods of analysis.

PERIODS OF ANALYSIS	SEDIMENTS (kg)	
	Observed	Simulated
Irrigation/2004	1245	0
Rain/2004-2005	8297	7598
Irrigation/2005	63	0
Rain/2005-2006	11512	6136
Total	**21117**	**13734**

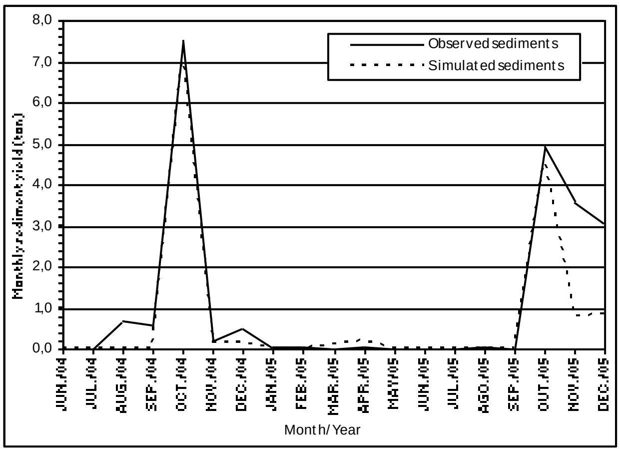

Fig. 9- Comparison between monthly simulated and observed sediment losses in the watershed study.

The dynamic of nitrogen in the watershed differed from that of the sediments because the most abundant forms of nitrogen are soluble in water, thus they are transported even by the base water flow, not considered in *AnnAGNPS*. This may be one of the explanations for the discrepancy between observed and simulated nitrogen losses presented in Table 3 and in Fig. 10. The one-sample-per-day method for collecting water is surely another reason for this disagreement. Finally, the procedures in *AnnAGNPS* for simulating the nitrogen fate may not be fully appropriate for the agricultural system and environment in the study watershed.

Table 3- Comparison between simulated and observed nitrogen losses for the periods of analysis.

PERIODS OF ANALYSIS	NITROGEN (kg)	
	Observed	Simulated
Irrigation/2004	98	733
Rain/2004-2005	331	437
Irrigation/2005	38	1436
Rain/2005-2006	195	874
Total	**662**	**3480**

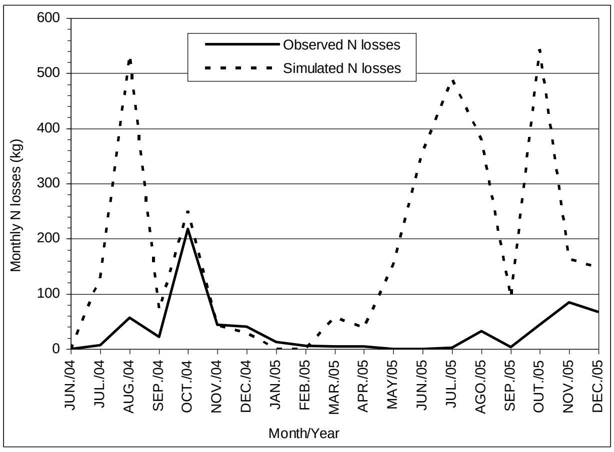

Fig. 10- Comparison between monthly simulated and observed nitrogen losses in the watershed study.

Finally, we proceeded to simulate the spatial distribution of some fluxes to investigate relationships between watershed characteristics or agricultural practices and some of the simulated fluxes. In view of the performance of *AnnAGNPS*, herein we present spatially distributed runoff and sediment losses only.

Fig. 11 shows two distinctive runoff zones in the watershed, one with runoff in the range 0-40 m^3 ha^{-1} $year^{-1}$, which corresponds to the forest area (58.6 ha), and the other (130.4 ha), the cropped area, with runoff in the range 41-140 m^3 ha^{-1} $year^{-1}$. In the later zone runoff varies mainly according to the slope and land use.

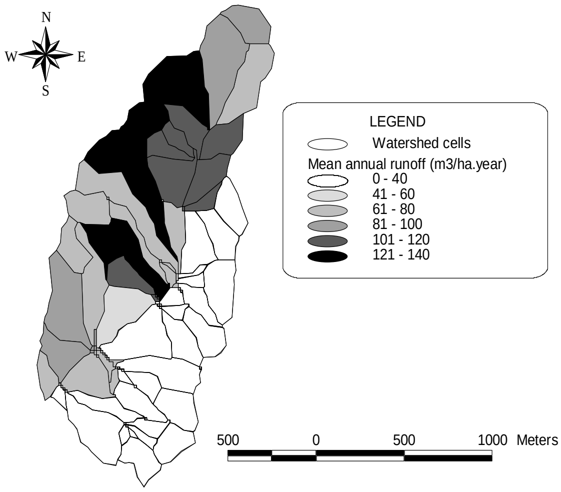

Fig. 11- Spatial distribution of the average runoff in the study watershed.

Regarding the sediment losses, Fig. 12 shows that the watershed is not exposed to significant soil losses. Soil losses are noticeable only fields with winter cereals where the soil is bare or partially covered during autumn. A comparison between Figs. 11 and 12 indicates that the role of runoff on the soil losses is not sufficient to establish a clear relationship between both of them, meaning that other factors or the interaction of many factors needs to be considered (as *AnnAGNPS* does) to analyse cause-effect relationships (Duarte, 2006).

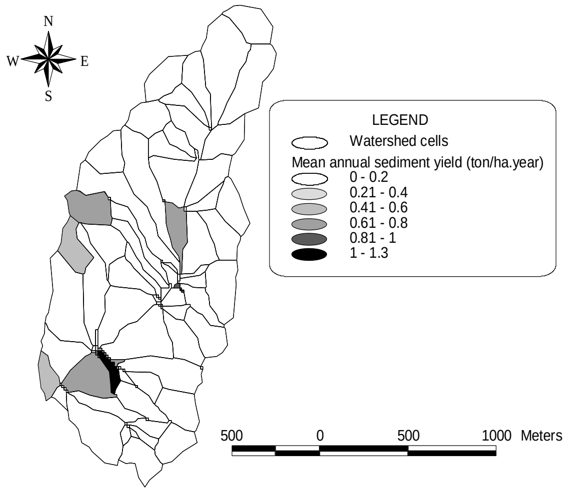

Fig. 12- Spatial distribution of the average sediment losses in the study watershed.

5.- Conclusions

The model *AnnAGNPS* appears to be a suitable tool for predicting non-point pollution due to some biogeochemical fluxes in irrigated agricultural watersheds. The experience on applying *AnnAGNPS* makes us think that the principles that support the model keep balance between complexity and applicability. Runoff could be simulated in the study watershed reasonably well. Likely, a calibration of the parameters of the runoff sub-model would improve the performance of the model, but its inability to simulate base flow is a limitation inherent in the model. The main trends in sediment transport also seem to be simulated well. Again, a calibration of the parameters of the erosion and sediment transport sub-model could improve the simulations. However, our analysis points to poor simulation of the nitrogen fate in the study environment, although we cannot draw definitive conclusions because the sampling method of the observed data requires improvement. The spatial analysis that can be done with the assistance of *AnnAGNPS* has great potential for developing technically-sound on-site management practices. The spatial analysis of runoff and soil losses indicated where in the watershed especial care is needed for assuring sustainable management at the watershed scale.

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