NON POINT SOURCE POLLUTION IN AN AGRICULTURAL CATCHMENT AND THE QUALITY OF RETURN FLOWS UNDER MEDITERRANEAN CONDITIONS

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ABSTRACT

Land-use, especially agricultural activities, change the natural functions of a watershed and affects both water quantity and quality through point and nonpoint sources, and impair aquatic ecosystems. The intensification of the agricultural activity, in particular the irrigated agriculture, increases the use of the agrochemical products, and the problems in the soil and water bodies. The study watershed is located within the Idanha Irrigation Scheme, Idanha-a-Nova, Portugal, and it covers an area of 189 ha. Climate is typically Mediterranean; the topography is slightly sloppy; the area of the catchment is well drained (12.2 m ha^{-1}); the predominant soil classes are *Cambisols* and *Luvisols*. The agricultural activity is developed in two different seasons; the winter season where the farmers produce especially winter cereals, and the irrigation season where they produce typical crops in this region (corn, sorghum, tobacco and pasture). A hydrological station was installed at the outlet of the watershed. At the beginning of this study, the water samples were collected almost once a day; now, we have a multiparameter probe to collect data continually. Computer simulation models provide an efficient and effective alternative for evaluating the effects of agricultural practices on soil and water quality at basin level, and provide alternatives to avoid or reduce the degradation of the environment. AnnAGNPS model was selected as the simulation tool to be used in this study. Some conclusions were possible to take from this study, by analyzing the collected data and the results of simulation output: the water derived to the basin study to be used in irrigation has a good quality, and also the water returned to the natural drainage meets largely the quality standards (nitrogen, salinity and sediments) not compromising its use downstream; the nitrate load depends, all time, on the availability in the soil and the runoff volume, due to its solubility; the total daily load of sediments not shows a direct relation with the runoff volume, except when it has a sufficient energy to detach and carry out, as in the extreme events.

KEYWORDS: non-point source, water pollution, rain fed and irrigated agriculture, catchment level, simulation models

1. INTRODUCTION

Soil, water and production systems constitute the most important natural resources of a watershed in the rain-fed and irrigated agro-ecosystem. For sustainability of the production systems, they need to be in harmony with the environment. Agricultural activities, as part of the natural resource management practice, impact soil and water quality at the watershed level [1, 2]. Soil and water conservation practices also help in reducing the loss of chemicals in runoff, and in maintaining water quality [3, 4]. The increases in nutrient losses and riverine nutrient loads have caused the eutrophication of many coastal and freshwater ecosystems [5-7]. Non-point source (NPS) pollution is an important environmental and water quality management problem, closely related with hydrologic behaviour of the territorial unit. NPS pollution occurs when rainfall, snowmelt, or irrigation water run over land or through the ground, pick up pollutants and deposit them into rivers, lakes, and coastal waters, or introduce them into ground water [8], but due to its distributed nature, it cannot be monitored directly in the same manner as point sources [9]. The non-point source (NPS) pollution has grown into a global environmental issue and has been the most talk about environmental degradation caused in recent years [10]. In this context, watershed is the basic unit of all research, development and policy-making activities related to water at present. However, a watershed is a geographically dynamic unit, and its behaviour varies both spatially and temporarily. Intensive study of individual watersheds is, therefore, necessary to develop management strategies for abating the agricultural NPS pollution [11]. To solve the NPS pollution problem, one approach is to identify critical areas of a watershed responsible for disproportionate amount of the pollution and to implement best management practices (BMPs), such as conservation tillage, improved fertilizer and animal waste management in the critical sub-watersheds [12-14]. Field monitoring is often used to evaluate and acquire knowledge of the impacts of management practices on productivity and environment. However, field research can be prohibitively costly and time consuming to perform across all possible landscape, climate, management practice, and cropping system combinations [15, 16]. Monitoring studies conducted at a watershed scale are difficult to replicate in the way that traditional plot-scale research is designed, in order to compare responses of alternative management practices using only field observations [17]. However, computer simulation models provide an efficient and effective alternative for evaluating the effects of agricultural practices on soil and water quality at the watershed level [18]. Several hydrological and water quality models have been developed to assist in understanding hydrologic systems and pollutant loadings. These models range from simple screening and planning models, such as USLE [19], to complex hydrological assessment models, such as CREAMS [20], ANSWERS [21], EPIC [22], WEPP [23], AGNPS [24], and its annualized version AnnAGNPS [25], SWAT [26].

The main objective is to study the dynamic of the nitrogen, salts and sediments in a typical Mediterranean agricultural watershed, under different agricultural conditions (irrigated and rain-fed agricultural systems), and the quality of water before and after its use in the crop irrigation.

2. MATERIALS AND METHODS

The studied watershed is located within the Idanha Irrigation Scheme, Idanha-a-Nova county, Portugal, near the border with Spain and just north of the Tagus river (Fig. 1). The study catchment covers an area of 189 ha and a perimeter of 6510 m, and presents a 3rd order hierarchy stream.

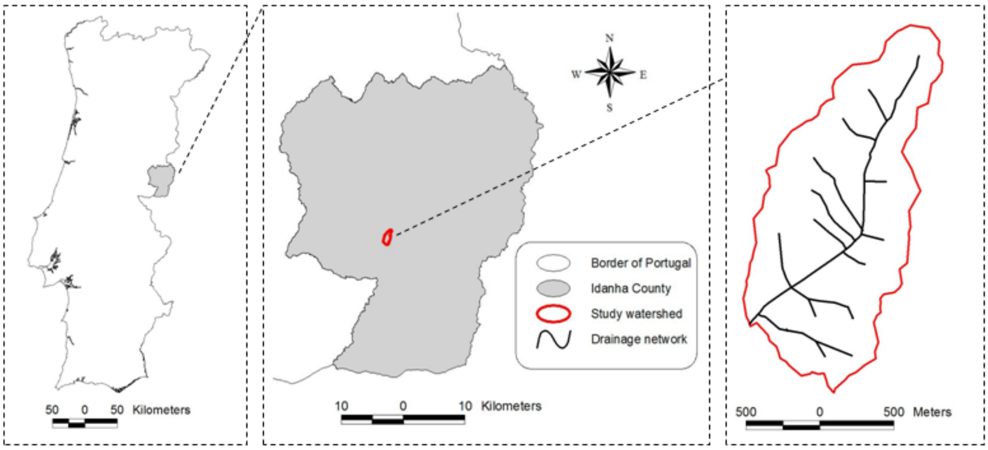

FIGURE 1 - Location of the study watershed.

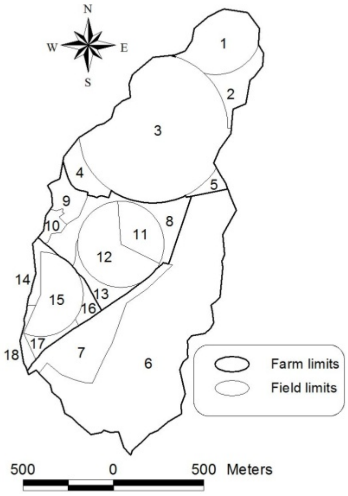

FIGURE 2 - Farms and fields (with field codes) in the studied catchment.

The basin is divided into 18 fields belonging to four farmers (Fig. 2) [27]. About one third (31%) of the catchment is not irrigable, and is now devoted to a young oak and cork tree forest (field code 6). The study site has in some areas an intensive agricultural use, such as tobacco (this area is one of the largest in Portugal in the production of this crop). Since the 2004 irrigation season, it has been verified a decrease in the irrigated area by changing in crop pattern.

Maximum cropping intensity in the irrigation season was 0.81 in the first year of analysis, whereas that year showed the second largest cropping intensity in the rain-fed season at 0.23, which was only exceeded by the cropping intensity in the rain-fed season that followed the irrigation season with lowest cropping intensity (2009) (Table 1). Oats and wheat are the main crops grown during the rain-fed season. Nowadays, the largest portion of the irrigable

TABLE 1 - Area (ha) per crop and cropping intensity (CI) in the 6 irrigation and 5 rain-fed seasons during the period of analysis in the studied catchment.

Croping Season	Year	Oak and cork trees	Fallow	Maize	Sorghum	Tobacco	Soybean	Grass	Oat	Wheat	*CI*
Irrigation	2004	(58.62)	25.40	72.99	10.27	21.73	0	0	0	0	0.81
	2005		79.35	17.19	12.12	21.73	0	0	0	0	0.39
	2006		81.20	21.73	16.26	11.20	0	0	0	0	0.38
	2007		99.11	11.20	10.27	0	0	9.81	0	0	0.24
	2008		47.06	21.01	10.27	0	52.05	0	0	0	0.64
	2009		109.30	11.20	0.00	0	0	9.81	0	0	0.16
Rain-fed	2004-05	(58.62)	99.77	0	0	0	0	0	30.62	0	0.23
	2005-06		112.31	0	0	0	0	0	18.08	0	0.14
	2006-07		112.12	0	0	0	0	9.81	8.46	0	0.14
	2007-08		121.93	0	0	0	0	0	8.46	0	0.06
	2008-09		110.01	0	0	0	0	0	8.46	11.92	0.16

area in the catchment is left fallow and is often grazed by sheep.

The climate is typically Mediterranean continental (Fig. 3). Average annual rainfall at Cabeço Monteiro dam (10 km north-west of the catchment) is 638 mm, with a rainless summer [28]; the average temperature varies from 8.1 ºC in January to 25.3 ºC in August [29]; the average reference evapotranspiration (*ETo*) ranges from 0.7 mm day^{-1} in January to 7.1 mm day^{-1} in July [27].

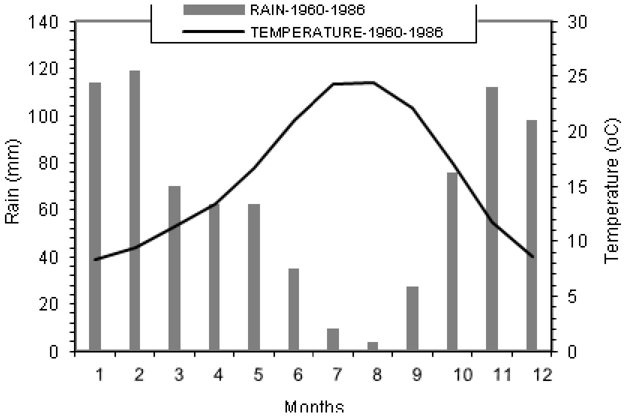

FIGURE 3 - Climatic characterization of the region where the study basin is located (climatic station of Castelo Branco; Portuguese Meteorological Institute; not published data).

The natural drainage network was surveyed in 2004 with the aid of a GPS (GeoExplorer3, Trimble Navigation Ltd., California) and a reference station that allowed post-processing differential correction. The main natural creek is 2300 m long and runs north-southwest. The drainage density of the natural permanent channels is 12.2 m ha^{-1}. The limits and topography of the catchment were determined from a digital elevation model with a 1-m resolution. Altitude varies from 212 m at the outlet of the catchment to 248 m at a plateau located towards the northeast. The slopes range from 0 to 4%; thus, the topography is flat to gently undulating (Fig. 4).

The predominant soil classes are *Cambisols* and *Luvisols* [30], originating from deposits of the tributaries of the Tagus River. Another soil class in the watershed is

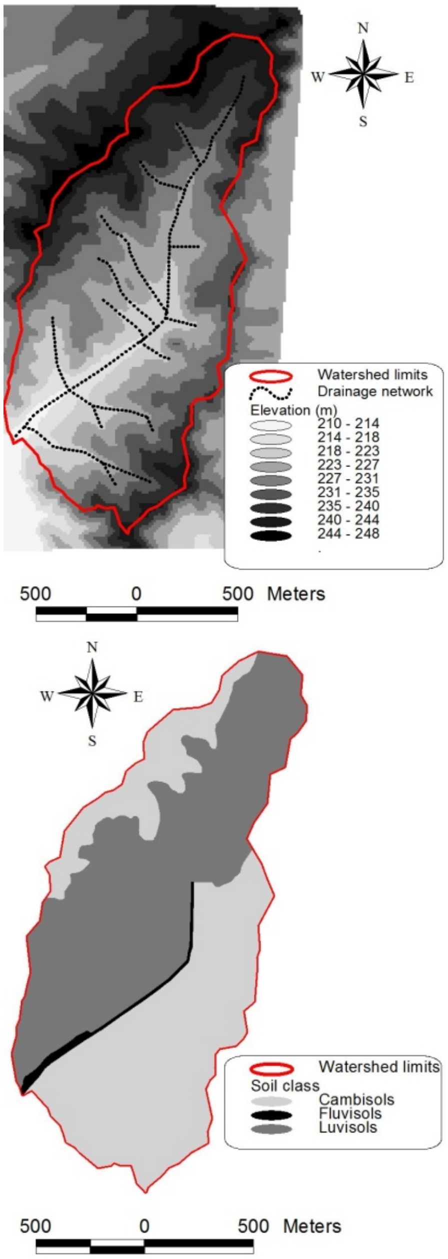

FIGURE 4 – Topography and natural drainage network and soil classes in the studied watershed (FAO nomenclature).

Fluvisols [30], originated by alluvial deposits of the main creak that crosses the watershed (Fig. 4). An impermeable soil layer underlies the three soil classes at approximately 0.4 m in depth, which greatly determines the hydrology of the watershed. Soils in the catchment were mapped from pre-existing unpublished studies, field inspections, photo-interpretation techniques, and detailed characterization of one soil profile per soil group.

A hydrological station was constructed and installed in 2004, at the outlet of the catchment (39º50'48'' N, 7º10'00'' W) (Fig. 5). 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 [31], and ii) an ultrasonic sensor ("The Probe", manufactured by Milltronics, Siemens Milltronics Process Instruments Inc., Ontario, Canada) connected to a datalogger continuously measuring and recording the water level at the flume. 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, nitrogen (in its three mineral forms: ammonium, nitrate and nitrite) and total dissolved solids. We assumed that the pollutant concentration was constant along the day, thus knowing the runoff rate. Therefore, we could estimate sediment and nitrogen losses [27]. Agricultural practices were recorded by the farmers and verified by direct observations during visits to the watershed. Actually, the same pollutants are evaluated with a multiparameter probe for monitoring and logging the water quality (TROLL 9500 Water Quality Instruments, manufactured by In-Situ Inc., Fort Collins, Colorado, USA).

FIGURE 5 – Hydrological station installed at the outlet of the study catchment.

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

Several available hydrologic models were evaluated, and the AnnAGNPS model [25] was selected as the simulation tool to be used in this study. This model is well suited to evaluate best management practices (BMPs) because of its ability to concurrently simulate water quantity and quality in different parts of a watershed [32]. AnnAGNPS uses major hydrologic concepts of the single event model AGNPS [24], widely applied around the world [32-34]; AnnAGNPS improves and expands by the continuous simulation modelling of physical processes governing routing of sediment and pollutants associated with runoff events [35]. Previous studies support AnnAGNPS application under Mediterranean conditions [27, 36, 37]. AGNPS is a joint Agricultural Research Service (ARS) and Natural Resources Conservation Service (NRCS) suite of computer models developed to predict non-point source pollutant loadings within agricultural watersheds. Within AGNPS, AnnAGNPS is a continuous-simulation, mixed-land use, watershed-scale computer model designed to predict the origin and movement of water, sediment, and chemicals at any location in agricultural watersheds. The model estimates erosion caused by different processes, such as sheet and rill, tillage induced gullies, classical gullies, and stream-bed and bank sources [38]. The input data set for AnnAGNPS consists of 33 sections. AnnAGNPS catchment area is divided into individual slopes (so-called cells), which are directly connected to the river network by potential flow paths. The cells and any potential flow paths are defined automatically based on the digital elevation model (DEM). Each cell has homogeneous vegetation and soil characteristics allocated by the GIS interface based on the prevailing soil type and vegetation [39]. AnnAGNPS input accepts five types of land-use identifiers (cropland, pasture, forest, rangeland and urban), and only the predominant land-use and management are used to represent each AnnAGNPS cell. The potential evapotranspiration was computed using the Penman equation. Percolation was estimated using the Brooks–Corey equation based on the soil hydraulic conductivity corresponding to the soil moisture content. Output parameters, such as runoff, sediment, nutrients and pesticides, are selected by the user for the desired watershed source locations (specific cells, reaches, feedlots, gullies and point sources) for simulation duration source accounting.

3. RESULTS AND DISCUSSION

3.1. Quality of return flows

The results that we present in this section, concern to the comparison between water quality derived to the watershed study to be used in crops irrigation, and the quality that is returned to the natural drainage network, with respect to the pollutants salts, nitrates and ammonium. The origin of salts loaded with generated runoff, is related to the leaching process (carbonates, sulfates, nitrates, and others), the natural weathering of rocks and their use as mineral fertilizers in agricultural activity [40]. An obvious observation that allows the analysis of Fig. 6 is the very low mineralization of the water derived to the watershed study, with little variation over the 2004 and 2005 irrigation seasons, and with values of electrical conductivity rarely exceeding 100 S cm^{-1}. Also the quality of return flows, despite some deterioration on this parameter, presents a quality that not compromises its use downstream; the majority of points in the following pictures shows values between 200 and 300 S cm^{-1}. The peak of observed salinity, in 2005 irrigation season, occurred in final of July 2005, and was due to significant nitrate fertilization occurring in maize and tobacco. The same may have happened in the 2004 irrigation season where there was no opportunity to confirm this assumption [27].

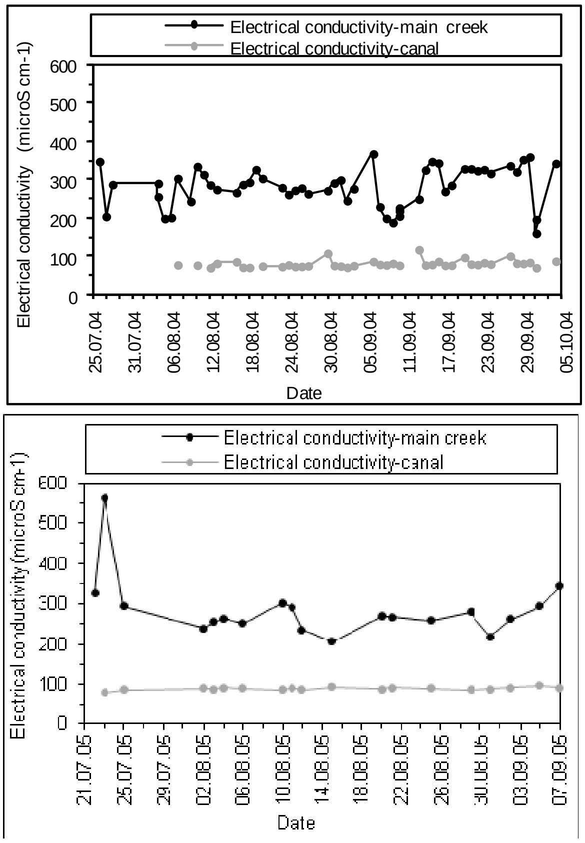

FIGURE 6 – Electrical conductivity observed at the irrigation canal and at the outlet of the study catchment, during the 2004 and 2005 irrigation seasons.

Nitrogen, especially the more oxidized forms which are very soluble, is one of the most problematic water contaminants, due its multiple negative effects in aquatic ecosystems [41]. The highest values of nitrate concentrations, recorded between final of July and middle of August in return flows (Fig. 7), were due to fertirrigations in nitrate form during this period, also reflecting in water salinity. In 2005 irrigation season, where there was a large reduction in irrigated area, with impact more than proportional in the volume of return flows, were recorded always higher values of nitrate concentrations, given the solubility characteristics of this contaminant. In the 2004 irrigation season, only two values, from a set of 53 values, were above to 3.0 mg L^{-1}, whereas in the 2005 irrigation season, eight values, from a set of 19 values, were above that value. Also, it is important to remark that, especially to the end of the irrigation season, the values of nitrate concentrations in return flows and in the water delivered from the channel will be approaching, while there are some situations where the water quality increased with respect to this contaminant.

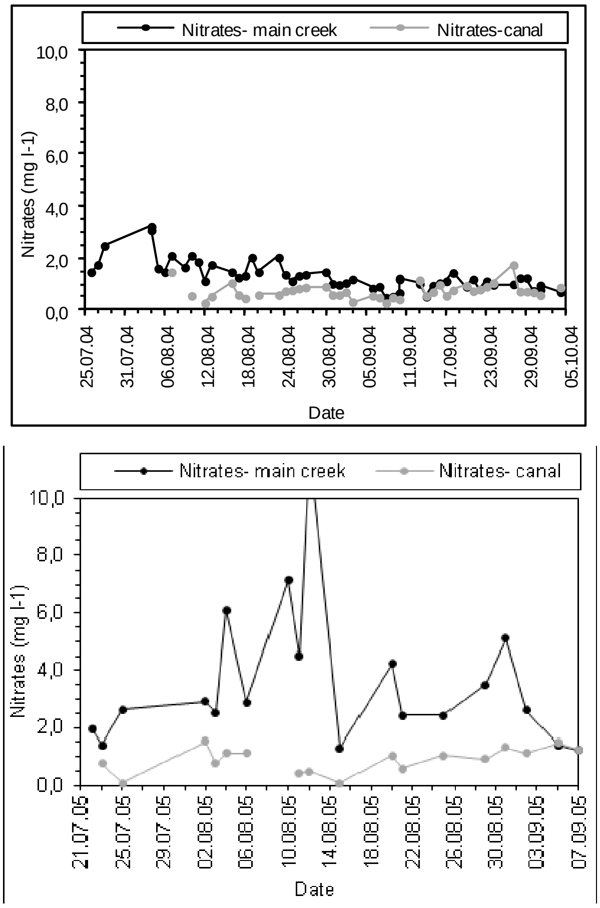

FIGURE 7 – Nitrate concentrations observed at the irrigation canal and at the outlet of the study catchment, during the 2004 and 2005 irrigation seasons.

The ammonia nitrogen present in the soil results mainly from fertilizations verified at seeding/planting of crops (typically winter cereals), or from degradation of animal or vegetal materials. This pollutant has a lower solubility than nitrates and, therefore, with less chance to be loaded in solution with runoff; in the ionic form, and given the nature of its electrical charge, it can be loaded with the colloidal particles of soil [42]. In Fig. 8, we can observe that, along much time of the two irrigation seasons, the values of ammonia nitrogen concentration in water remain similar before and after passing in the basin. The higher values of this contaminant in the return flows at beginning of August are probably due to direct grazing sheep near the natural drainage network of the basin.

3.1. Dynamics of pollutants in the basin

The resolution of the DEM affects the delineation of watersheds which, in turn, would influence models' pre-

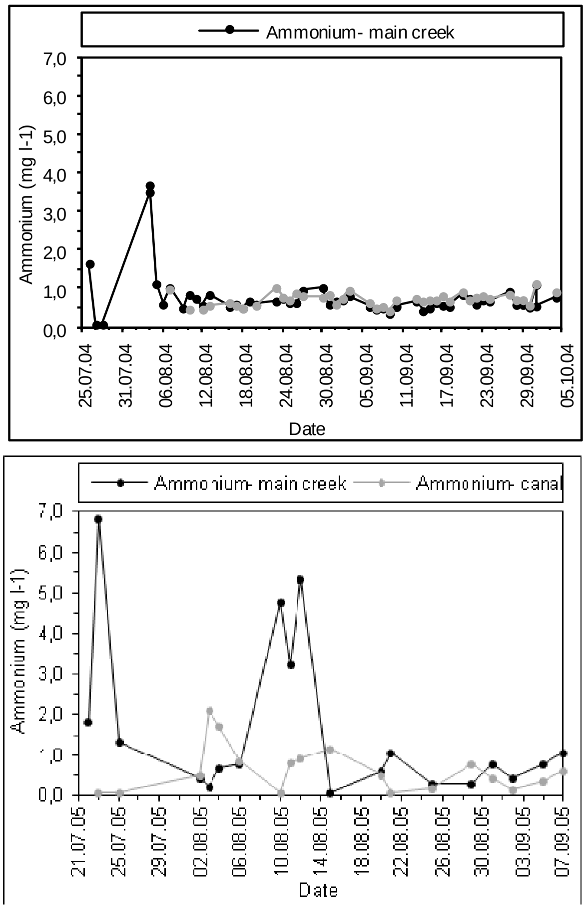

FIGURE 8 – Ammonium concentration observed at the irrigation canal and at the outlet of the study catchment, during the 2004 and 2005 irrigation seasons.

diction quality [43]. Two DEMs with resolutions of 1 and 5 m were generated by digitizing existing cartographic information at 1:2500. Critical source area (CSA) and minimum source channel length (MSCL) are the input parameters to TOPOAGNPS, which is a subset of the topographic parameterization (TOPAZ) computer program [44]. The selection of CSA and MSCL values controls the number and size of sub-watersheds (referred to as AnnANGPS cells) and extent of the channel network, respectively. CSA is the minimum upstream drainage area below which a source channel can be initiated and maintained. MSCL is the minimum acceptable length for a source channel [9]. The selection of the combination of CSA/MSCL values, that best represented the observed watershed characteristics, were obtained by a trial-and-error process and the values adopted were 3.0 ha and 80.0 m for CSA and MSCL, respectively. Using these values, the study basin was subdivided into 28 sub-watersheds, 67 cells, and 28 reaches [45]. For a basin of 130.8 ha and with similar characteristics, 41 cells and 17 reaches, using CSA of 4 ha and MSCL of 50 m, were obtained [46]. Similarly, other researchers used values of 1.25 ha for CSA and 100 m for MSCL for another watershed located in the Mediterranean environment [47].

The hydrologic behaviour of the basin during the rainfall season is different from the irrigation season. Generally, the irrigation season is the period of higher agricultural activity and, therefore, is the period with intensive application of fertilizers and other agro-chemicals accompanied by increased soil moisture. Rainfall season is, therefore, a period of lower agricultural intensification; with growing of winter cereals for livestock feed. The fertilization is basically made at sowing, incorporating the fertilizer nitrogen in form of being less oxidized. During this period, also some soil nutrients from the irrigated crop fertilizations, which could have not been absorbed by plants or have not been transported with runoff events, were observed.

The superficial runoff dominates the hydrological response of this basin during the most significant events. In Fig. 9, we can observe this type of response, verified mainly in small watersheds, and known as hortonian behaviour [48]. The same behaviour is observed in the irrigation season, when the runoff generated in the basin showed a strong dependence from the superficial runoff, especially the proximity of the pivot machines to the natural drainage network; the second picture in Fig. 9 shows this situation relatively to two pivots with different rain intensity.

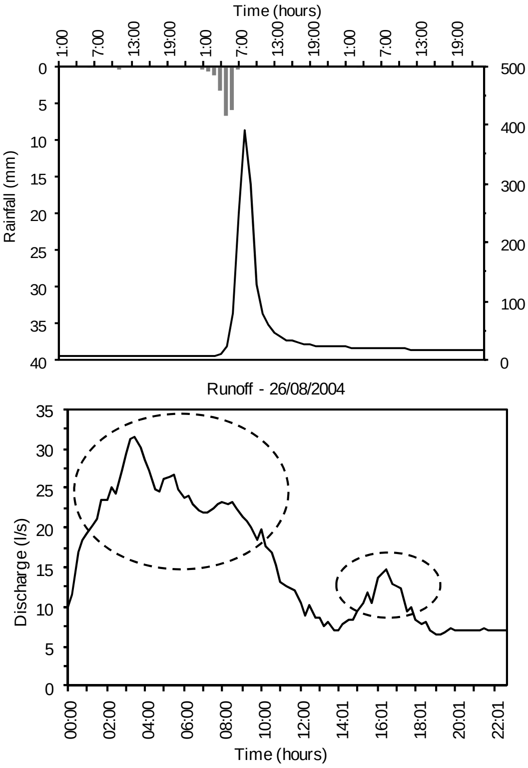

FIGURE 9 – Histogram and hydrograph, recorded between 30-Nov-2004 and 02-Dec-2004, and increase of runoff in the basin, due the favourable position of two pivots with different rain intensity.

In this study, we have opportunity to conclude about the strong influence that has the soil cover in the magnitude of the runoff events, and its effect on soil erosion.

For this purpose, we related the flow-rate and sediment concentration for two erosion events occurring on 22/10/2005 and 15/01/2006, with different amplitudes and different conditions in the basin. It should be noted the small number of data supporting the following analysis and, thus, reserving a space for uncertainty. In October 2005, the winter cereal crop management left soil unprotected and with high levels of nitrogen related to fertilizations. In the erosion event occurring in January, the soil was well protected from the aggressive effect of rain, and had lower availability for all salts, as they were transported from the soil by runoff occurring to this date. The mobility and transport of sediments in the basin have a greater linearity between the respective processes and what happened at the outlet of the basin, which makes the understanding of its dynamics more immediate than for other pollutants do (salts, nitrogen). In Fig. 10, the two erosion events are plotted. The more accentuated slope of event 1 can be associated with lower degree of soil cover protection in October than in January, which partly explains a flow-rate of 30 L s^{-1} load and sediment concentration nearly to 1000 mg L^{-1}. In January, a similar flow-rate carried in suspension just over 100 mg L^{-1} of sediments. This reinforces the idea that it is unwise to dissociate this type of relationship, that is established based on data evaluated in a section of the stream, to the conditions into the basin that have allowed the observed data. However, we can generalize the idea, found in similar studies [49], that, in terms of surface runoff occurrence, the sediment concentration in the flow increases linearly with increasing to the respective flow-rate. The amplitude of this positive proportionality depends on the conditions in the basin.

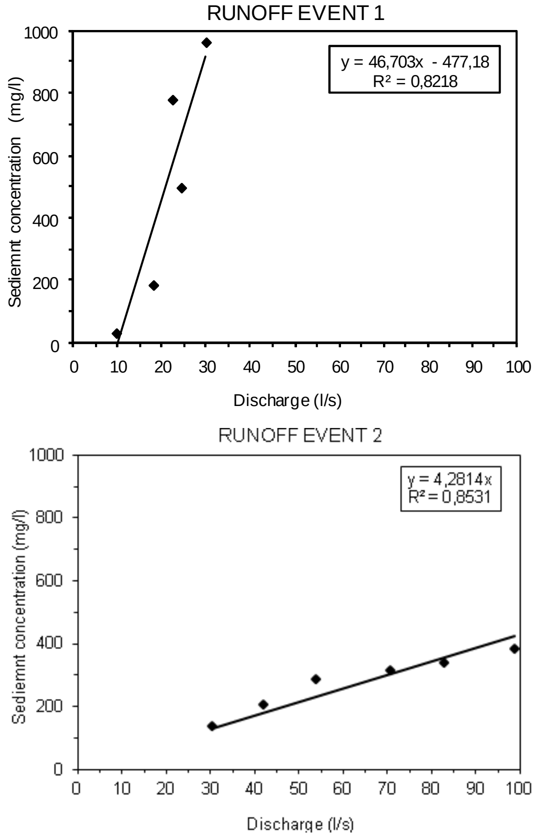

FIGURE 10 – Relation between flow-rate and sediment concentration at the basin outlet, in two runoff events, in the 2005/2006 rainfall season (runoff event 1 – 22/10/2005; runoff event 2 – 15/01/2006).

About spatial distribution of runoff volume and ratio of erosion in the basin, based on observations of the results (Fig. 11), it seems that there is a distinction between the two runoff-producing areas in the basin: one that generates little runoff (0-40 m^3 ha^{-1} yr^{-1}) which corresponds to the uncultivated area in the basin (58.6 ha), and another, which is the remaining area of the watershed (130.4 ha) occupied by various crops, which produces a higher runoff (41-140 m^3 ha^{-1} yr^{-1}). The variation of runoff in the cultivated part of the basin depends on the topography, the type of soil covering, and their intrinsic characteristics. The part of the basin with higher altitude, located to the north, is the part that has higher production of runoff, as it is an area of intensive agriculture and where higher slopes are found, except for the cells located in the plateau areas. In the middle part of the cultivated area, some cells also have high runoff per unit area and time. Land-use is similar to the northern part of the basin, and it is a gently sloped area; so, the simulated runoff can be attributed to soil characteristics, which are finer textured and, consequently, have slower infiltration.

A global overview of the average production of sediments in the studied basin suggests that the generality of the basin is almost exposed to water erosion processes, except for a small number of cells (Fig. 11). In these, one of the main uses is winter crops (oats), where, during the months of abundant rainfall, the soil is exposed to the rain aggressiveness. The comparison of the two pictures in Fig. 11, allows concluding that there is no correlation between average of sediment production and average of runoff volume in most of the cells in the basin. Although it has influence on the erosion process, the average volume of runoff is not the determining factor, but other factors, such as land cover throughout the year, especially during the concentration of rainfall, or the occurrence of more or less erosive storms.

Regarding the non-point source pollution of nitrates, from the comparison of the two pictures in Fig. 12 can be deduced clearly the following: the process occurs when it has significant runoff, given the solubility of nitrates, and when it has availability of this nutrient in the soil, in sequence of more or less intense fertilization. Considering this, the areas of greatest nitrate loads were those having significant runoff; in the same time, more intensive farming with higher levels of nitrogen fertilization occurred [50]. The intense nitrogen fertilization, mainly in the more oxidized forms, with the consequent availability of this nutrient in the soil, combined with the existence of runoff, superficial and subsuperficial, are the favourable conditions to expand the process of non-point source pollution and the consequences in water-bodies downstream. To mitigate this process, a greater number of nitrogenous

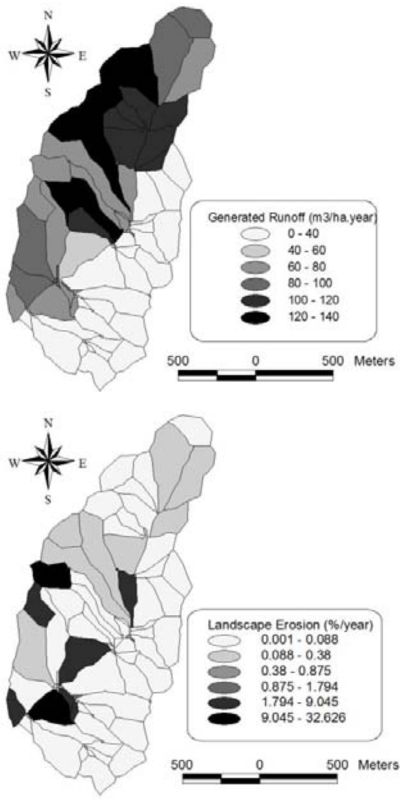

FIGURE 11 – Average simulated runoff and erosion rate, generated in each cell and sub-catchment, by AnnAGNPS model (period 2003-2005).

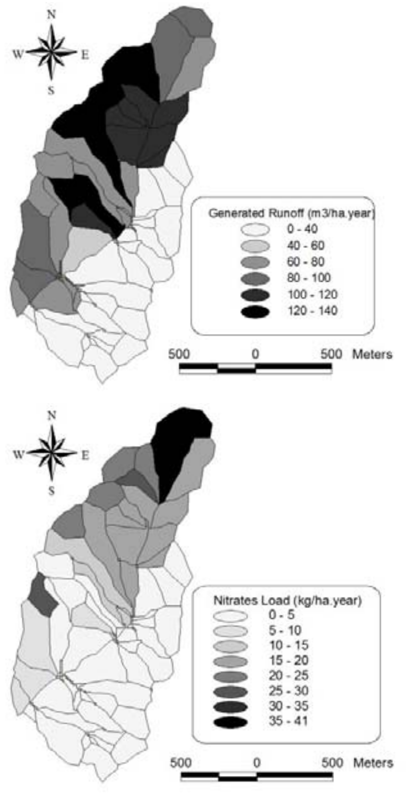

FIGURE 12 – Average simulated runoff and nitrate loads, generated in each cell and sub-catchment, by AnnAGNPS model (period 2003-2005).

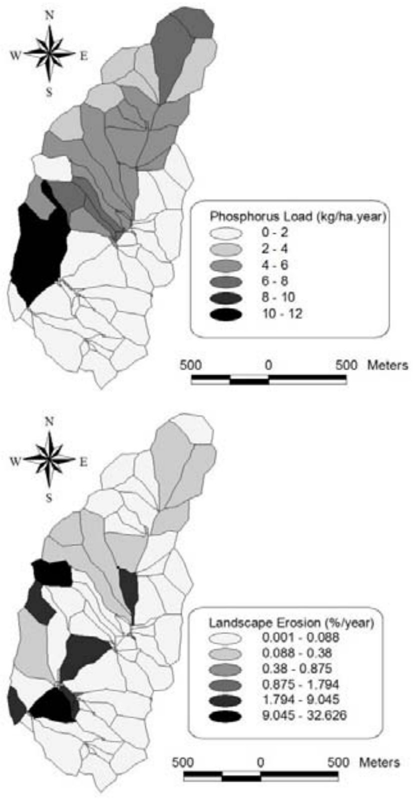

FIGURE 13 – Average simulation of phosphorus load by AnnAGNPS model, generated in each sub-catchment (period 2003-2005).

fertilization with lower doses in each application appears like a attitude of prudence.

Phosphorus is an element with a little mobility in the soil, and can be transferred from agricultural systems to water-bodies dissolved in the superficial runoff, or leaching to deeper soil layers, but the predominant losses occur in conjunction with mineral and organic sediment, in the water erosion process [51]. The transfer of phosphorus to superficial runoff is a process that occurs in the upper 1-5 cm of soil, and is controlled by physical and chemical processes, such as desorption, dissolution and diffusion [52]. The first evidence resulting from the analysis of the pictures in Fig. 13 is that phosphorus losses are less with regard to nitrate losses, due, as already mentioned above, to its lower water solubility and mobility in soil. Unlike the most bibliographies say about this theme [51], in this case, most of the phosphorus is lost in solution with the water and not with the soil colloidal particles loaded from the watershed. Therefore, there is a greater correspondence between the first picture in Fig. 13 and the first picture in Fig. 12, than with the second picture in Fig. 13; it is not in the cells/sub-basins where a greater erosion rate occurs as well as the greatest phosphorus losses. However, by analyzing the output file of AnnAGNPS, it appears that the cells/sub-basins where the phosphorus is mainly lost in adsorption with the soil particles, are the same cells/sub-basins where the erosion rates are higher. Analyzing the same output file resulting from the simulation performed by AnnAGNPS model, we find that the most particles of lost soil belong to the silt and fine sand size categories; in them, the physicochemical process is more difficult to occur whereby phosphorus is preferentially loaded.

4. CONCLUSIONS

This study, although conducted over a few years and, therefore, has some inheriting limitations, provides indications about the quality of return flows from a small watershed, and the dynamic of sediments in the same territorial unit. The water supplied by the Idanha Irrigation District has a good quality, and circulation in the study catchment not compromises its use downstream. The spatial distribution of runoff was primarily influenced by topography and management. Thus, the uncultivated part of the basin recorded low runoff volumes, while at the northern part of the basin higher values of runoff were estimated due to higher slopes and more intensive agricultural practices. The evolution of the nitrate pollution load depends on the volume of runoff and the availability of this nutrient in the soil, due to its solubility. So, the simulation of the spatial distribution of nitrate load shows a dependence of the spatial distribution of runoff, due to its high solubility, and of the location of the fields where the farming is more intensive with higher levels of nitrogen fertilization. The ammonium because having low solubility and forming a positive ionic form, is preferentially carried out with the sediments; thus, the pollution load of ammonium, being available in the soil, depends on the volume of runoff in the extreme hydrological events. The pollution load of sediments does not seem dependent on the volume of runoff, except when it has enough power to detach and load the particles outside of the basin; so, the amount of sediments load along the rainfall season is developed by levels, associated with extremes events. Thus, the simulation by AnnAGNPS of the spatial distribution of soil erosion by water, despite its close relation with runoff, indicates that the process not depends directly on it, being much more influenced by land-cover. The losses of phosphorus are less than that of nitrate, due to its lower water solubility and mobility in soil. When the majority of loaded soil particles belongs to the silt and sand categories, the phosphorus can be preferentially lost not attached, but in solution, from these areas when it has very runoff and availability of this pollutant in the soil.

The author has declared no conflict of interest.

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