Hydrologic behaviour and dynamics of sediments in a small agro-forested basin in Portugal

A. C. Duarte, J. L. M. P. de Lima and L. Mateos

Hydrologische Eigenschaften und Sedimentdynamik in einem kleinen land- und forstwirtschaftlich genutzten Einzugsgebiet in Portugal

1 Introduction

The non-point source pollution is closely related to the hydrologic behaviour of basins and has grown into a global environmental issue and a first cause of soil and water degradation in many parts of the world. In this context hydrologic basins are, at present, the basic units of research, development and policy-making activities related to water. However, being hydrologic basins, their behaviour varies strongly both in space and time. This approach provides a framework to explore the coupled relationships between land use, sediment, and aquatic ecosystems within a certain basin (Grant, 1998). Land use activities change the natural functions of a basin, impacting the flow of water and water quality, and impair aquatic ecosystems (Randhir and Hawes, 2009).

Erosion of soil by water is caused by the simultaneous effect of the processes of disaggregating soil aggregates by the impact of rain drops and runoff, and then the transport of these aggregates by runoff, and has long been studied at different scales (e.g. Römkens et al., 1997; de Lima et al., 2003, 2008; Ferreira et al., 2011; Montenegro et al., 2013).

The main purpose of this study was the analysis of the hydrologic behaviour of a small agro-forested experimental basin, located in Idanha-a-Nova, Portugal during rainy

Zusammenfassung

Ziel dieser Untersuchungen war die Erforschung der hydrologische Eigenschaften und Sedimentdynamik in einem kleinen land- und forstwirtschaftlich genutzten Einzugsgebiet in der Regenzeit und in trockenen Perioden mit Bewässerungsbedarf. Das Einzugsgebiet liegt in Idanha-a-Nova (Portugal). Die Größe der Sedimentfracht in der Regenperiode ist hauptsächlich durch Extremniederschlagsereignisse bestimmt, insbesondere in trockenen Jahren in denen der Niederschlag auf wenige Einzelereignisse konzentriert ist. Die Abflussbeiwerte sind in der trockenen Beregnungszeit um vieles geringer.

Schlagwörter: Hydrologische Eigenschaften, Sedimentdynamik, kleine Einzugsgebiete, bewässerte und niederschlagsbeeinflusste Landwirtschaft.

Summary

The objective of this research was to study the hydrologic behaviour and dynamics of sediments of a small agro-forested experimental basin both in the rainy and irrigation seasons (dry period with mainly centre-pivot irrigation). The basin is located within the Idanha Irrigation Scheme, Idanha-a-Nova (Portugal). The hydrological behaviour of the basin was analysed and the differences between the rainy and irrigation seasons were highlighted. The amount of sediment load along the rainy season is mainly associated with extreme rainfall-runoff events, especially in dry years where rainfall is concentrated in a few events with high capacity to generate runoff. Runoff coefficients were much lower in the irrigation season.

Key words: Hydrologic behaviour, dynamics of sediments, small basin, irrigated and rainfed agriculture.

(wet) and irrigation (dry) seasons. Special attention was given to the dynamic of sediments. It is a follow up of the work done by DUARTE (2006).

2 The small experimental basin

The studied basin is located within the Idanha Irrigation Scheme, Idanha-a-Nova, mainland Portugal, near the border with Spain and just north of the river Tagus (Figure 1).

The basin covers an area of 189 ha, has a perimeter of 6510 meters and presents a 3rd order hierarchy stream. The climate is typically Mediterranean with usually rainless summers and an average annual rainfall of 638 mm (DUARTE, 2006). The main natural stream is 2300 m long and runs north-southwest. The drainage density of the perennial streams is 12.2 m ha^{-1}. Altitude varies from 212 m at the outlet of the basin to 248 m, and the slopes range from 0 to 4 %; thus, the topography is flat to gently undulating. The predominant soil classes are Cambisols and Luvisols, originated from deposits of the tributaries of the river Tagus. A hydrometric station was constructed and installed at the outlet of the basin (39º50'48" N, 7º10'00" W).

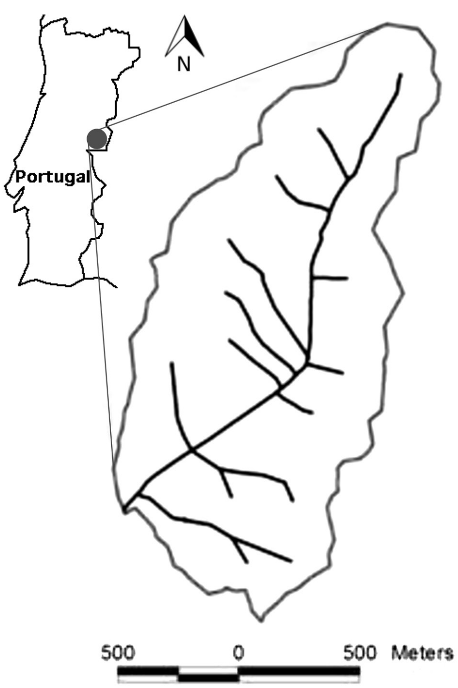

Figure 1: Shape and perennial streams of the small experimental basin located in Portugal

Abbildung 1: Netz der ganzjährigen Gewässer des experimentellen Einzugsgebiets in Portugal

Of the total area of the catchment, 130.4 ha are under irrigation and the remaining (58.6 ha) are used for cork and oak trees plantation. The centre-pivot irrigation system is the main water supply method employed in the agricultural scheme (90 %); the rest is irrigated with stationary sprinklers. During the last decades, the cropping intensity has been decreasing, both in the rainfed and irrigated areas.

3 Applied observation techniques

A hydrometric station was constructed and installed at the outlet of the basin (39º50'48" N, 7º10'00" W). The station consisted of i) a long-throated flume, with a triangular control section for small water depths and a triangular/trapezoidal section for larger discharges, and ii) an ultrasonic sensor connected to a datalogger continuously measured and recorded the water level at the flume every 15 minutes. The concentration of the pollutants and sediments in the water was evaluated with a multiparameter probe for monitoring water quality and recorded at the same time intervals. In fact, the sediments concentration was evaluated with an optical sensor (turbidity), and applied a specific formula evaluated in laboratory tests.

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

4 Results and discussion

4.1 Hydrologic behaviour and dynamics of sediments in the irrigation season

Figure 2 shows the evolution of accumulated water irrigation and runoff in the study basin, throughout the 2004 and 2005 irrigation seasons. They reflect the agricultural practices namely the behaviour of farmers regarding to the water application schedules. Even in efficient systems drainage losses are inevitable (lower lines in Figure 2).

In 2004, the total water consumption in irrigation was 651539 m^3, with a volume of runoff of 68008 m^3. This corresponds to a runoff coefficient of 10.4 %, and a global irrigation efficiency of 89.6 % (which can be considered a good value; MATEOS et al., 1996). In 2005, the irrigated area was reduced significantly (51.9 %) with clear impact on runoff (drainage from the area). The total water consumption in this irrigation season was 237997 m^3, and the volume of runoff was 10420 m^3. The correspondent runoff

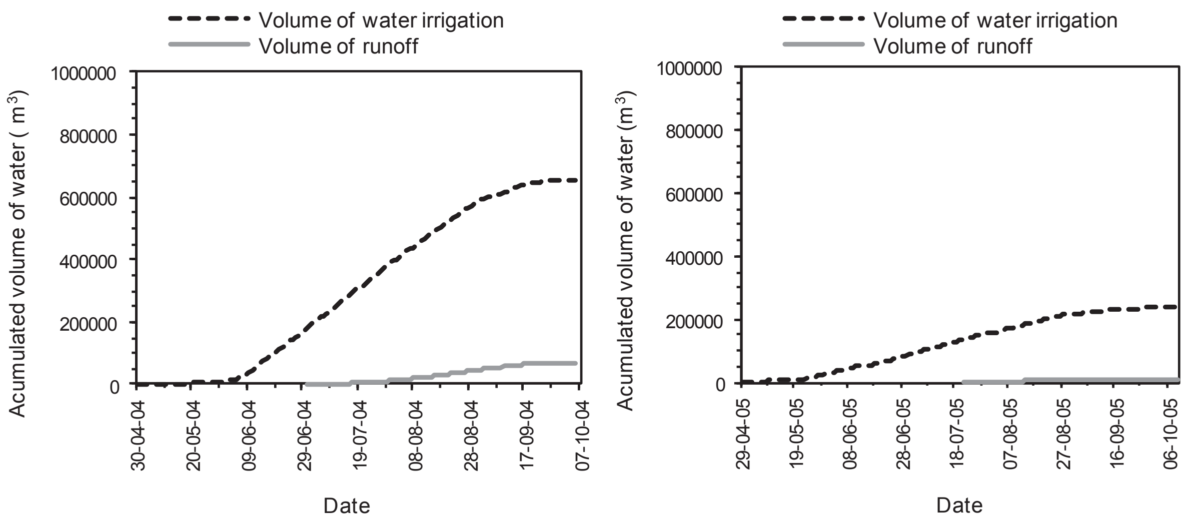

Figure 2: Evolution of accumulated irrigation water and runoff in the basin, throughout the irrigation seasons of 2004 (left) and 2005 (right)
Abbildung 2: Akkumuliertes Beregnungswasser und Abflussentwicklung im Einzugsgebiet während der Beregnungsperiode 2004 (links) und 2005 (rechts)

coefficient is 4.4 %, and the global irrigation efficiency is 95.6 %.

With respect to the sediment transport from the irrigated agricultural areas, Figure 3 clearly shows the dynamic behaviour (as an example the year of 2008 was chosen), resulting of farmers irrigation activities. In the year of 2008 the irrigation efficiency was moderate (64.0 %) mainly because all the existing pivots were used and runoff was generated mainly in areas near the natural drainage network. Higher sediment concentrations could be observed for higher discharges, despite the discharges are lower than in the rainfall season. This is due mainly because of unprotected sloping soil surfaces and the relatively high flow rate at the end of the pivots machines.

4.2 Hydrologic behaviour and dynamics of sediments in the rainfall season

Figure 4 presents the evolution of accumulated rainfall and runoff in the study basin, throughout two rainfall seasons. A delay between the rainfall cumulative curve and the run-

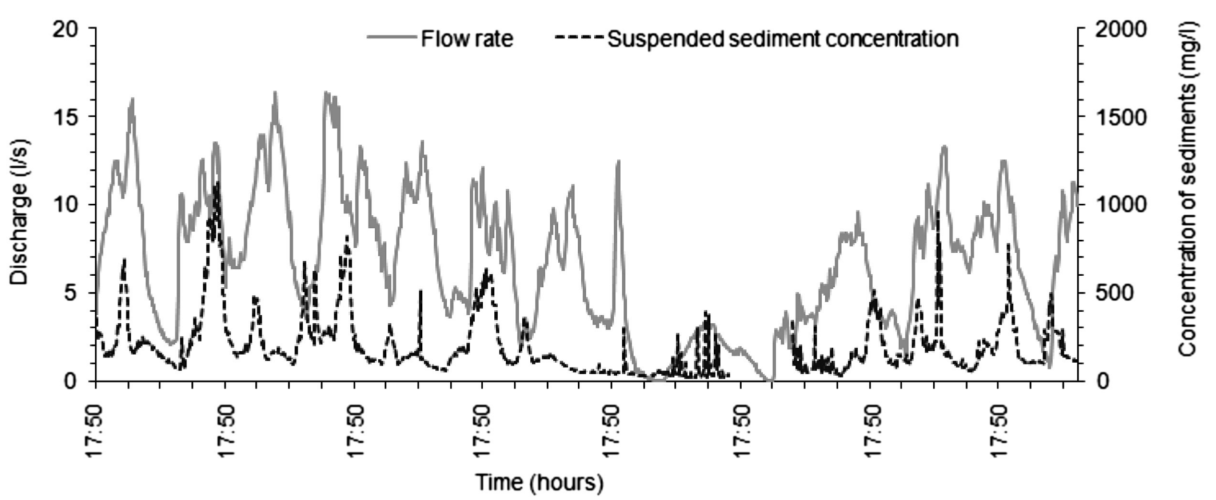

Figure 3: Discharge and suspended sediment concentration observed between 31/07/2008 and 07/08/2008 at the outlet of the basin
Abbildung 3: Beobachteter Abfluss und Schwebstoffkonzentration am Gebietsauslass zwischen 31/07/2008 und 07/08/2008

off cumulative curve is due to losses in the process of transformation of rainfall into runoff caused by vegetation (e.g. crops) and soil.

The hydrologic year of 2004/2005 (starting in the 1st October) was one of the driest years of the last decades, with only 287 mm (INAG, 2006) when the average is around 640 mm (Figure 4 – left). Being a small basin, not so permeable, isolated intense storms produce runoff hydrographs with high peaks not far away from the centre of gravity of the corresponding precipitation event (WARD, 1995). The runoff coefficient of 2004/2005 was therefore very high (36.5 %) with 542430 m^3 of rainfall (287 mm) and 198132 m^3 of runoff. Despite de fact that this year was relatively dry there was a high runoff coefficient, because there were six extreme events, with a favorable antecedent soil moisture conditions, which generated large volumes of runoff. Available soil moisture also plays an important role and, in an average year, runoff coefficient would be certainly lower, as been observed by other authors in similar small basins (CEBALLOS and SCHNABEL, 1998). This is what happened with the hydrologic year of 2005/2006 where the runoff coefficient dropped to 20.9 %. Also, the year 2005/2006 (Figure 4 – right) had twice the number of rainfall events than 2004/2005 and approximately twice the volume of rainfall (2005/2006: 1002571 m^3), although the runoff volume was similar: 197771 m^3 in 2004/2005 and 209815 m^3 in 2005/2006.

Figure 5 shows the close relation between the hydrograph peaks and the sediment concentration observed in the outlet of the small basin (4–12 December, 2010), specially in the rising limb. In the descending limb the observed deviations have also been appointed by other authors (WILLIAMS, 1989).

It is interesting to further study the sediment dynamics which can be done plotting of the sediment concentration against runoff (Figure 6). Most runoff events (events 1 and 5) showed clearly a clockwise sediment graphs (positive hysteresis), indicating that the sediments arrive fast to the hydrometric station and are originated mainly from the nearby sites (e.g. SOLER et al., 2008). A negative hysteresis would be indicative that the sediments have originated in more remote locations in the basin (e.g. GARCÍA-RUIZ et al., 2000). On the other hand, the pollution load of sediments does not seem dependent on the total runoff volume of a certain event, except when flow has enough power to detach and transport the particles outside of the drainage network (e.g. transport resulting from sheet and rill erosion on the slopes); therefore, the amount of sediment load along the rainy season was mainly associated with extremes rainfall-runoff events (e.g. Figure 6–1).

5 Conclusions

The hydrological behaviour of the catchment was quite different in the rainy and dry (irrigation) seasons. The runoff coefficient was much greater in the rainy season where the dependence of this coefficient on the antecedent soil mois-

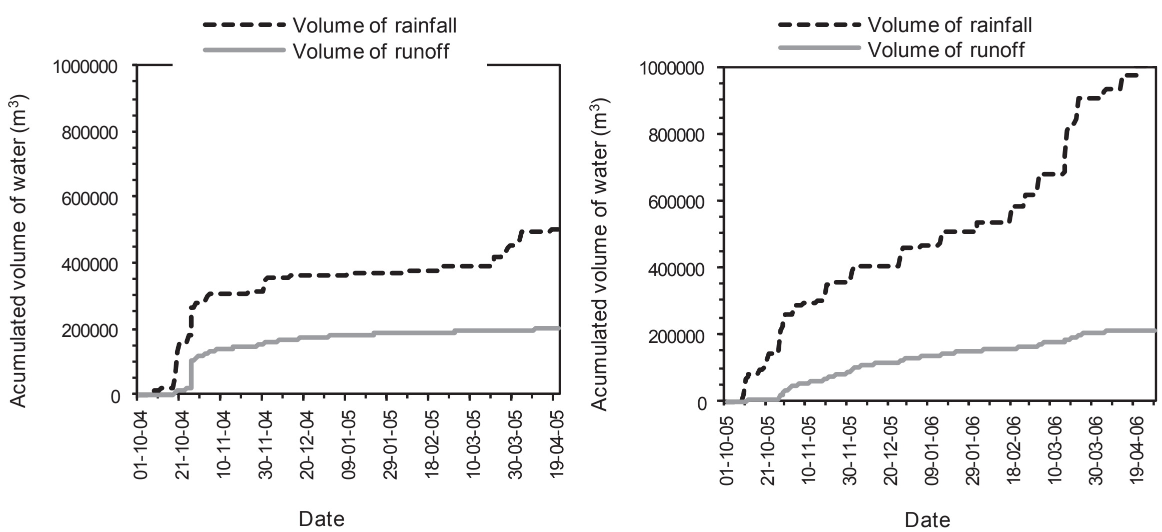

Figure 4: Evolution of accumulated rainfall and runoff in the study basin, throughout the 2004/2005 and 2005/2006 rainfall seasons
Abbildung 4: Akkumulierter Niederschlag und Abflussentwicklung im Einzugsgebiet während der Niederschlagsperiode 2004/2005 und 2005/2006

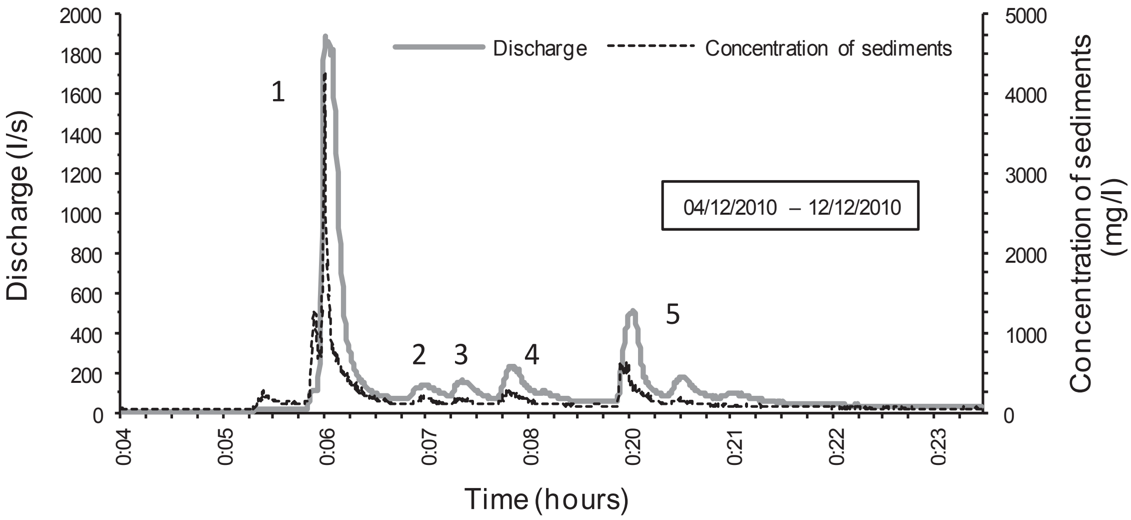

Figure 5: Discharge and suspended sediment concentration verified between 04/12/2010 and 12/12/2010 at the outlet of the study basin
Abbildung 5: Beobachteter Abfluss und Schwebstoffkonzentration am Gebietsauslass zwischen 04/12/2010 und 12/12/2010

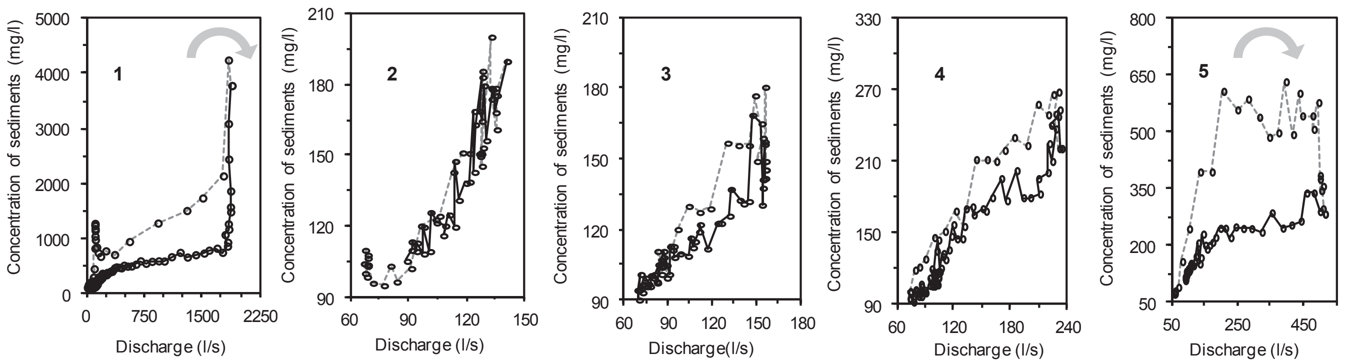

Figure 6: Discharge against suspended sediment concentration during five single hydrologic events, between 04/12/2010 and 12/12/2010, at the outlet of the basin (dashed line- increasing limb of sedigram; solid line- decreasing limb of sedigram). Notice that the vertical and horizontal axes are not the same
Abbildung 6: Abfluss und Schwebstoffkonzentration während fünf Einzelereignisse zwischen 04/12/2010 und 12/12/2010. Strichlierte Linien zeigen den ansteigenden Ast des Sedigramms, durchgezogene Linien den abfallenden Ast. Die Achsenskalierung der Bilder ist unterschiedlich

ture content was evident. However, such dependence was masked during the irrigation seasons by the regular application of water with a constant intensity mainly from the centre-pivot irrigation system. The pollution load of sediments does not seem dependent on the total runoff volume of a certain event, except when flow has enough power to detach and load the particles outside of the basin (e.g. sheet and rill erosion on the slopes); therefore, the amount of sediment load along the rainy season is mainly associated with extremes rainfall-runoff events. As was possible to observe in the study catchment, the sediments concentration during the irrigation season is sometimes higher than the rainy season. But, the total sediments load is greater in the rainy season because the volume of runoff.

References

CEBALLOS, A. & SCHNABEL, S. (1998): Hydrological behaviour of a small catchment in the dehesa landuse system (Extremadura, SW Spain). Journal of Hydrology, 210, 146–160.

DE LIMA, J. L. M. P., SOUZA, C. S. & SINGH, V. P. (2008): Granulometric characterization of sediments transported by surface runoff generated by moving storms. Nonlinear Processes in Geophysics, 15, 999–1011.

DE LIMA, J. L. M. P., SINGH, V. P. & DE LIMA, M. I. P. (2003): The influence of storm movement on water erosion: Storm direction and velocity effects. CATENA, 52, 39–56.

DE LIMA, J. L. M. P., CARVALHO, S. C. P. & DE LIMA, M. I. P. (2013): Rainfall simulator experiments on the importance of when rainfall burst occurs during storm events on runoff and soil loss. Zeitschrift für Geomorphologie, 57(1), 91–109. http://dx.doi.org/10.1127/0372-8854/2012/ S-00096.

DUARTE, A. C. (2006): Non source point pollution caused by agricultural activity, at watershed scale. PhD Thesis, University of Córdoba, Spain. (in Spanish).

FERREIRA, C. S. S., FERREIRA, A. J. D., DE LIMA, J. L. M. P. & NUNES, J. P. (2011): Assessment of surface hydrologic properties on a small urbanized mediterranean basin: experimental design and first results (Messung oberflächenhydrologischer Eigenschaften eines städtischen, mediterranen Einzugsgebiets) Die Bodenkultur – Journal for Land Management, Food and Environment, 62 (1–4), 59–64.

GARCÍA-RUIZ, J. M., MARTÍ, C., ARNÁEZ, J., BEGUERÁ, S., LORENTE, A. & SEEGER, M. (2000): Las cuencas experimentales de Arnás y San Salvador en el Pirineo central español: escorrentía y transporte de sedimento. Cuadernos de Investigación Geográfica, 26, 23–40 (in Spanish).

GRANT, W. E. (1998): Ecology and natural resource management: reflections from a systems perspective. Ecological Modeling, 108 (1–3), 67–76.

INAG (2006): Boletim de precipitação anual – Estação do Ladoeiro-14N/02U. Serviço Nacional de Informação de Recursos Hídricos (SNIRH), Retrieved January 25, 2006: http://snirh.inag.pt/snirhwww.php?main_id=18item=4.3. (in Portuguese).

MATEOS, L., FERERES, E. & LOSADA, A. (1996): Eficiencia del riego y modernización de los regadíos. XIV Congreso Nacional de Riegos, AERYD, Almeria, Spain (in Spanish).

MONTENEGRO, A. A. A., ABRANTES, J. R. C. B., DE LIMA, J. L. M. P., SINGH V. P. & SANTOS, T. E. M. (2013): Impact of Mulching on Soil and Water Dynamics under Intermittent Simulated Rainfall. CATENA, 109: 139–149. http://dx.doi.org/10.1016/j.catena.2013.03.018.

RANGHIR, T. O. & HAWES, A. G. (2009): Watershed land use and aquatic ecosystem response: Ecohydrologic approach to conservation policy. Journal of Hydrology 364 (2009) 182–199.

ROMKENS, M. J. M., PRASAD, S. N. & GERITS, J. J. P. (1997): Soil erosion modes of sealing soils: a phenomenological study, Soil Technology, 11, 31–41.

SOLER, M., LATRON, J. & GALLART, F. (2008): Relationships between suspended sediment concentrations and discharge in two small research basins in a mountainous Mediterranean area (Vallcebre, Eastern Pyrenees). Geomorphology, 98, 143–152.

WARD, A. D. (1995): Surface Runoff and Subsurface Drainage. In: Environmental Hydrology, A. D. Ward, W. J. Elliot, Ed., CRC Press LLC, Boca Raton.

WILLIAMS, G. P. (1989): Sediment concentration versus water discharge during single hydrologic events in rivers. Journal of Hydrology, 111(1989), 89–106.

Address of authors

António C. Duarte, CEER-Centre of Biosystems Engineering**,** Escola Superior Agrária, Instituto Politécnico de Castelo Branco (IPCB), Portugal (corresponding author) acduarte@ipcb.pt

João L. M. P. de Lima, Institute of Marine Research (IMAR) and Marine and Environmental Sciences Centre (MARE), Department of Civil Engineering, Faculty of Science and Technology of the University of Coimbra (FCTUC), Rua Luís Reis Santos, Campus II – University of Coimbra, 3030-788 Coimbra, Portugal. plima@dec.uc.pt

Luciano Mateos, Instituto de Agricultura Sostenible (IAS), Consejo Superior de Investigaciones Científicas (CSIC), Córdoba, España. ag1mainl@uco.pt