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THE RELATIONSHIP BETWEEN FLOW RATES AND LAND USE AT PLOT SCALE IN THE VOINESTI EXPERIMENTAL BASIN (ROMANIA)

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Abstract

The aim of this study is to investigate the role of land use in the dynamics of the water resources on a plot scale (water balance plot), following natural spring rainfalls and land use (grassland vs. bare soil). The study was primarily based on hydrometeorological data (e.g.: rainfall depths, rainfall intensities and flows), measured in the spring (IV-V) of 2014 at Voinesti Experimental Basin, part of the National Institute of Hydrology and Water Management - Romania. The water balance plots are situated at an altitude of 500 m a.s.l. in the Curvature Subcarpathians and have the following characteristics: 300 sq m area; type of soil: eutricambisol; average slope of 13% and N-S orientation; land use: a plot "grassland"(P1) and another plot "bare soil"(P2).
During the analyzed period, rainfall events, corroborated with previous conditions of soil humidity, have been quantitatively reflected in the flow parameters (depths, discharges) thus: the processed soil plot created heterogeneous conditions for the runoff surface, such as microdepressions, and thus flow rates have been reduced compared to those recorded on the grass plot; The interception of vegetation, in cases of previous humidity (last 3 days) caused by small depths (e.g. 0.6 and 19 mm), has been low and highlighted by high rates of overland flow (0.144 l/s on vs. 0.092 l/s on P1), and when antecedent conditions are marked by rainfalls, the interception has been reduced and thus the volumes of overland flows were amplified (4996 l on P2 vs. 2800 l on P1); soil infiltration rates were elevated in cases of previous rains and low when previous conditions were dry for both land use types; this is also confirmed by the partition of average flows volumes: 15% overland flow, 27% subsurface flow, 58% base flow.

***Key words**: plot scale, land use, flow, water balance plot, rainfall, Voinesti Experimental Basin.*

INTRODUCTION

Getting to know the anthropogenic effect on the liquid phase of water transport in its circuit plays a significant role in studying water balance. Vörösmarty & Sahagian (2000), Fohrer et al. (2001), Foley et al. (2005) have shown the consequences of land use on water resources at global, continental and regional scale.
Quantifying the hydrological consequences associated with land use represents a research method which directly contributes to our understanding of the spatial and temporal dynamics of water resources and indirectly helps in the process of choosing the right size of hydraulic works (e.g. dams, bridges, canals), managing extreme hydrological phenomena (e.g. floods). A useful scientific way of quickly assessing the influence of land use is the study of water balance at micro-scale (Hudson, 1993; Jencso et al., 2009; Sánchez, et al., 2012; Maetens et al., 2012; Popa et al., 2015).
Plot-scale experimental studies are designed to help understand interrelationships between the processes involving geomorphologic, hydrological and ecological factors (Bosch et al., 1982; Linsley, 2009; Zhang et al., 2015) and providing a basic description of the most relevant aspects, such as the influence of the land use on the water discharge (Joel et al., 2002).
Thus, many research studies on surface runoff have been made on experimental plots, which are easier to control and are better indicators of the factors that contribute to water balance, through rainfall spectrum, its timing, the surface and subsurface flow characteristics, and atmospheric processes (Bloschl et al., 1995). Furthermore, rainfall-runoff relationship in experimental plots is analysed at the centre of hydrologic research in studies concerning soil

macroporosity and erosion under different land use and land covers in northeast India (Shougrakpam et al., 2010).

The process of adopting different land uses is known to exhibit a significant effect on the rainfall - runoff responses that come from these watersheds' hydrological reaction to changes in the climatic system (Jakeman et al., 1993), macromodelling of the rivers (Bobinski et al., 1993), post-fire runoff and erosion (Benavides-Solorio & MacDonald, 2001), monitoring the obstructions emerging from the relationship land use - hydrological dynamics (Stanciu & Zlate-Podani, 1987; Brocca et al., 2004; Ionita et al., 2006; Dodocioiu et al., 2011), nutrient management in orchard productivity (Andrews, 2002; Durran-Zuazo et al., 2005). In this context, this paper present the results of a *hydrological investigation into the effects of land use on the dynamics of water resources at plot scale, following natural spring rainfalls and land use (grassland vs. bare), measured in spring (IV-V) of 2014 in the Voinesti Experimental Basin (Romania).*

MATERIALS AND METHODS

This study was conducted under field experiments on water balance plots from Voinesti Experimental Basin (VEB). This basin belongs to the National Institute of Hydrology and Water Management (NIHWM).

The main data types used in the current experimental investigation (e.g.: rainfalls depths; volumes of overland flow, subsurface flow called intermediate or hypodermic flow and base flow; soil moisture) have been measured, processed and corrected in the Experimental Hydrology Section of NIHWM. Rainfalls measurements have been carried out continuously with a pluviograph, and runoff rates on the tow water balance plot (300 sq m) were determined with the help of devices that continuously measure and record (Valdai limnigraph) attached to the collector tanks.

The conversion of the water volumes (V) collected in the tanks was achieved through the volumetric method V=f(H) and/or the spillway method Q=f(H).

Data on flows on subsurface flow were collected from a depth of 40 cm and base flow was measured at a depth of 1.20 m.

Soil moisture was measured daily, by probing soil profiles next to the water balance plots at 6 depths 0-10, 20, 30, 40, 60 and 100 cm, with a capacity sensor.

The volumetric water content expressed in terms of the volume of water per volume of soil (m^3 of water/m^3 of soil) was converted in a mean equivalent water depth.

The main method used when investigating the effects associated with land use was based on the water balance equation. Lvovich (1965, 1980) formulated the general expression of a mean water balance equation, and Sokolov & Chapman (1974) particularized and detailed this equation depending on the time interval and water bodies (e.g. river basins; forest and forested basins, drained land etc).

Among the forms of these equations for investigations on a micro-scale of water balance plots, we adopted and adapted the following form (Eq. 1):

$$P - Q - E - \Delta S - \Delta M - \eta = 0 \tag{1}$$

where:

P = precipitation;

Q = total flow (overland flow, subsurface flow and base flow);

E = evaporation (incorporates evaporation; precipitation intercepted by the grasses;

ΔS = water storage on the soil surface in endorheic micro- depression;

ΔM = water storage in the upper 1 m soil layer;

η = water balance discrepancy.

All statistical analysis and graphical of hydro-meteorological data were performed using OriginPro version 8.5, and mapping was made with ArcGIS Version 9.3.

Geographical background

The Voinesti Experimental Basin is located in the Curvature Subcarpathians, on the left bank of Dambovita River, at 28 kilometers away from the Targoviste city (Figure 1).

VEB was created in 1963, though the first material on the research of runoff formation processes started in 1964.

The goal of its creation was to establish relations between runoff and its genetic and conditional factors, to design rainfall-runoff mathematical models, to quantify the way different topographical and cultivated surfaces participate in the flow processes and to study the water balance in the soil (Minea & Morosanu, 2014).

The climate of the region is moderate temperate-continental and the area of the VEB was characterized in the 1980-2014 period by an average multiannual rainfall depth of 806 mm. Most rainfalls occurred in the warm semester (63%), and the highest number of rainfalls was recorded in June (12.6%) and July (12.4%).

The lowest amount of precipitation was registered in the cold semester (October-March), with the fewest precipitations measured in January (5.21%) and February (5.7%).

The average air temperature was 9.7 °C, and July was the month of the maximum temperature (17.9 °C, with absolute maximum of 37.3 °C in 2000 - a dry year) and January, the month of the minimum temperature (-2.2 °C, with the absolute minimum of -22.6 °C in 1979).

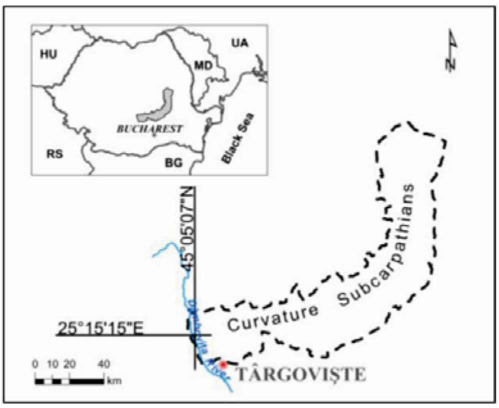

Figure 1. Geographical location of the experimental site

Water balance plots design

The water balance plots (Figure 1) are situated at an altitude of 500 m a.s.l. (45°05'07.27"N latitude and 25°15'15.43"E longitude - cartographic projections Stereo 70) and have the following characteristics:

- 300 sq m area (10x30 m);
- eutricambisol a type of soil with *"28% clay, 21% silt, 51% sand"* (Maftei et al., 2002);
- average slope of 13%;
- N-S aspect;
- land use: a plot covered by permanent *"grassland"* (P1) and second plot (P2) *"bare soil"* had its soil processed through the digging of the first horizon (20 cm), without crops or natural vegetation (Figure 2).

Figure 2. Water balance plot *"bare soil"* (P2)

In this sense, the technical equipment of the balance plot allowed a wide range of hydrological (tank collectors, water-level recorder) and meteorological (e.g.: recording rain gauge) measurements.

RESULTS AND DISCUSSIONS

Hydrological investigation of genetic (natural rainfalls) and control (initial soil humidity; land use; soil texture; slope) factors of the elements that make up the water balance allowed us to identify the following particularities:

i.) Rainfall events:

- depths > 15 mm and durations >3 ÷ 13 h (e.g.: 180 min. on 25.V.2014; 680 min. on 18.IV.2014; 650 min. on 19.IV.2014; 790 min. on 24.IV.2014 - Figure 3) and have produced abundant flows;
- the maximum intensities of rainfalls have been low, such as: 0.190 mm/min. – 18.IV.2014; 0.100 mm/min. on 19.IV.2014; 0.140 mm/min. on 24.IV.2014 (Figure 3) and a maximum of 0.280 mm/min. on 25.V.2014;
- rainfalls with small depths and low intensities, after periods without any precipitations, even if they are not capable of producing overland flows and/or significant events, have contributed to restoring the soil's humidity reserve.

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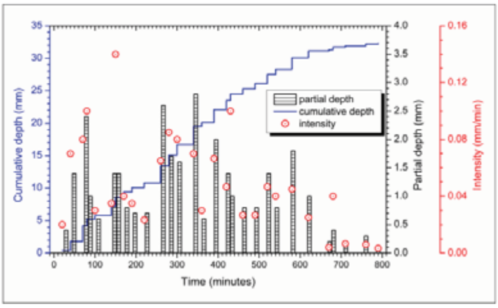

Figure 3. Elements of the rainfall event of 24.IV.2014

ii.) Previous soil humidity conditions, in strong correlation with precipitations, represent a factor that has a variable influence on flow rates;

- in terms of the soil's moisture regime, it is of a percolation type - rates of infiltration have exceeded those of evapotranspiration and a gravitational water current was formed, which ensured a strong supply of groundwater; previous mean values of soil water content (3 days) underwent a growing trend; in the 17-18.IV.2014 interval, the average stored water volume was the equivalent of a 4.79 mm depth and for the 22-24.V.2014 interval, it was the equivalent of a depth 4.10 mm thick (Figure 4);

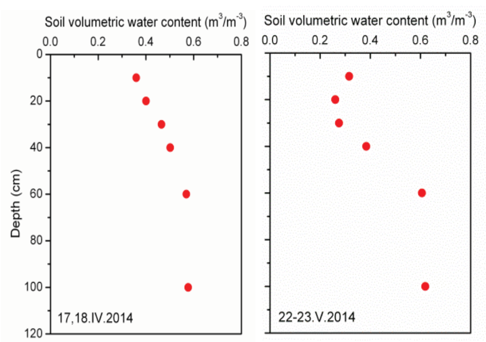

Figure 4. Antecedent soil water contents (depths of 10, 20, 30, 40, 60 and 100 cm) near plots

iii.) Hydrologic investigation at micro-scale on the relation between the genetic factor rain (hp) and the main control factor of flow - land use highlighted differences between flow parameters in the two plots (Table 1):

- maximum discharges of overland flow were influenced by the land use in conjunction with the antecedent moisture; in terms of insignificant previous rainfall (Table 1), maximum discharges were high on P1 (e.g. 0.144 l/s) and low on P2 (0.091 l/s), (Figure 5);
- significant depths of water have been involved in overland flow (5.47 mm/sq m on P2 and 6.88 mm/sq m on P1) and base flow (6.5 mm/sq m on P1 and 18.6 mm/sq m on P2), and the lowest of subsurface flow (1.7 mm/sq m on P2 and 2.37 mm/sq m on P1);

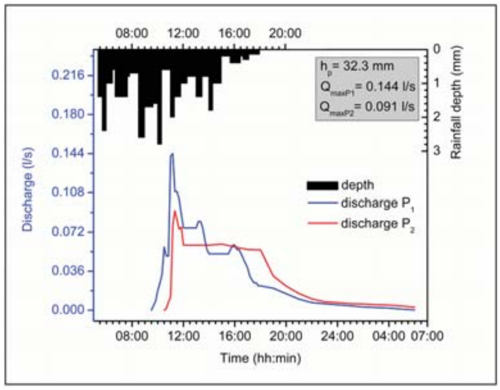

Figure 5. Hydrograph of overland flow from water balance plots grass covered (P1) and bare soil (P2) from 24/25.IV. 2014

- previous rainfalls, which have not generated rich overland flow rates, have significantly raised the soil's moisture and thus, they have also raised base flow rates (e.g. 10.4 mm/sq m. on P1 and P2 - 19.IV.2014), compared to overland flow rates (1.64 mm/sq m. on P1 and 3.60 mm/sq m on P2 – 19.IV.2014);
- water infiltration in the upper soil horizons (40 cm), plays an important role in subsurface flow rates dynamics:
  - high infiltration: 5.91 mm/sq m. on P1 - 19.IV.2014 and 4.4 mm/sq m. on P1 - 18.IV.2014,
  - low infiltration: 1.70 mm/sq m. on P2 - 24.IV.2014 and 1.75 mm/sq m. on P2 25.V.2014);
- in case of rainfalls with reduced depth (hp = 15.6 mm), overland flow depths have been substantially reduced on the processed plot, which has no plant retention (e.g. 2.94 mm/sq m. on P2 - 25.V.2014);

Table 1. Flow characteristics on the water balance plots with different land use

Data	hp (mm)	hs_1 (mm)	$q_{max.hs1*}$ (l/s. km^2)	hs_2 (mm)	$q_{max.hs2*}$ (l/s. km^2)	α_{P1}	α_{P2}	S (mm)	A_{hp} (mm)
18.IV.2014	32.3	9.3	295	16.7	250	0.29	0.52	4.79	26
19.IV.2014	25.8	10.4	273	18	117	0.40	0.70		57
24.IV.2014	32.3	15.7	480	25.8	306	0.49	0.80	4.50	0.6
25.V.2014	15.6	6.9	3556	11.7	64	0.44	0.75	4.10	19

hp = rainfall depth (mm); hs_1 = flow depth on the grassland plot; $q_{max.hs1}$ = specific maximum discharge of the grassland plot; hs_2 = flow depth on the bare soil plot; $q_{max.hs2}$ = specific maximum discharge of the bare soil plot; α_{P1} = discharge coefficient for the grassland plot; α_{P2} = discharge coefficient for the bare soil plot; S = average previous depth (3 days) of the equivalent amount of water in the soil (0 - 100 cm depth); A_{hp} = total rainfall depth for 3 days.

- runoff coefficients (Table 1), for grass plot (α_{P1}) have average values reduced by 0.28 compared to processed plots (α_{P2});
- total water volumes that have passed through the three types of runoff have varied both between each runoff type and between each plot, e.g. 2063 l on P1 vs. 1642 l on P2, in case of overland flow; 712 l on P1 vs. 508 l on P2 on subsurface flow; 1590 l on P1 vs. 5590 l on P2, in case of base flow on 24.IV.2014 (Figure 6); at the total runoff volume level per rainfall event (18.IV.2014), the effect of land use was best exhibited: 4996 l on P2 vs. 2800 l on P1.

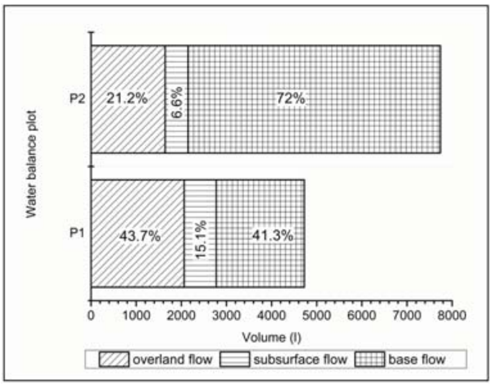

Figure 6. Total water volumes from water balance plots of grass covered (P1) and bare soil (P2) from 24/25.IV.2014

CONCLUSIONS

Investigations of flow from different land use (grassland vs. bare soil), under natural rainfall allowed us to determine the following particularities:

a) rainfall events, corroborated with previous conditions of soil humidity, have been quantitatively reflected in the flow parameters (discharges, depths, volumes);
b) the water balance plot with processed soil *"bare soil"* creates heterogeneous conditions for the runoff surface, such as micro-depressions, and thus flow rates have been reduced compared to those recorded on the grassland water balance plot;
c) the interception of vegetation, in cases of previous humidity (last 3 days) caused by small depths (e.g. 0.6 and 19 mm), has been low and highlighted by high rates of overland flow, and when antecedent conditions are marked by rainfalls, the interception has been reduced and thus the volumes of overland flows were amplified;
d) soil infiltration rates were elevated in cases of previous rainfalls and low when previous conditions were dry for both land use types; this is also confirmed by the repartition of average water flows volumes:
   - overland flow (15%),
   - subsurface flow (27%);
   - base flow (58%).

Future Research Directions

For a correct calculation of water balance, it will be necessary to explore water residence time from natural rainfall in areas covered by vegetation (grassland) by using lysimeter method and the hydraulic properties of soil.

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