EFFECT OF LAND USE ON THE RUNOFF REGIME IN THE SMALL DRAINAGE BASINS

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***Abstract*:** In this paper results are presented of studying the runoff regime in three small drainage basins in the hilly-mountainous region of the Western Serbia. The research was performed in the period 1980-1999 year. The watersheds are very similar in the sense of the natural conditions (climate, relief, geology, soils) but the land use is different. In the Lonjinski Potok drainage basin 70.35% of the total area is under well-stocked forests, in the Dubošnički Potok 48.52 % and in the Djurinovac Potok drainage basin 39.5%. Despite having the highest rainfall, the more forested Lonjinski Potok had the lowest average maximum annual discharge (0.1 vs 0.4 m^3s^{-1}) and a far greater sustained flow. Lonjinski Potok was dry for 12 days $year^{-1}$ on average compared to 121.4 and 192.4 for its less forested neighbours. Annual peak discharge were also far smaller in the more forested drainage basin (0.129 vs 0.612 $m^3s^{-1}km^{-2}$). The results show that the land use has a considerable effect on the runoff regime of the watersheds.
***Keywords*:** runoff regime, land use, drainage basin, forest cover.

EINFLUSS BODENSBENÜTZUNGWEISES AUF DAS REGIME WASSERABFLUSSES IN KLEINEN EINZUGSGEBIETEN

***Zusammenfassung*:** In dieser Zusammenfassung sind die Ergebnisse der Forschung über das Regime Wasserabflusses in drei kleinen Einzugsgebieten die befinden sich in West Serbien gezeigt. Die Forschung ist im Period 1980-1999 durchgeführt. Die Einzugsgebieten haben sehr ähnliche Naturseigenschaften (das Klima, die Landschaft, die Geologie, das Boden) aber haben unterschiedlich Bodensbenützung im Einzugsgebiet. Im Einzugsgebiet des Lonjin Bachs ist 70.35 % von gesamter Fläche unten Wald deckel, Dubosnicki 48.52, Djurinovac 39.5 . Trotzt dem großten Niederschlagen das Einzugsgebiet Lonjin als meist bewaldet hatte die kleinste durchschnitliche Maximum Jahresabflussmenge (0.1 bis 0.4 m^3s^{-1}) und den höchsten Oberflächenabfluss. Lonjin Bach ist durchschnitlich 12 Tage pro Jahr trocken gewesen im Vergleich mit Nachbarseinzugsgebieten die sind weniger bewaldet aber waren 121.4 und 192.4 Tage pro Jahr trocken. Spezifisches Jahresmaximalhochwasser ist auch viel weniger gewesen in meist bewaldenem Einzugsgebiet (0.129 gegen 0.612 $m^3s^{-1}km^{-2}$). Die Ergebnisse der Forschung zeigen dass Benützungsweise in einem Einzugsgebiet hat bedeutend Einfluss auf das Regime Wasserabflusses in kleinen Einzugsgebieten.
***Schlüsselworte*:** Wasserabflusses Regime, Bodensbenutzungsweises, Einzugsgebiet, Walddeckel.

1. Introduction

The runoff from a drainage basin is conditioned by a multitude of different factors entering a complex and unrepeatable combination for any site under consideration. Surface runoff, or overload flow, is formed when the soil is no longer capable of absorbing rainwater, nor it can be consumed in the processes of transpiration, infiltration and sub-surface runoff. The runoff regime depends on the simultaneous action of many factors which can be classified into the two groups:

1. Abiotic factors: relief and geomorphological characteristics, parent rock and soil composition, climate (first of all the intensity and amount of rainfall),

2. Biotic factors: vegetative cover of the slope, land use anthropogenic factors, etc. This group of factors is more interesting because they maintain the stabilizing effect of the forest cover as well as the economic activities (Nedyalkov, S., Raev, I., 1980).

The vegetational cover, and first of all the forest one, represents one of most powerful factors influencing the runoff regime, since by its effect it modifies and moderates the others.

Land-cover change is an important factor for nearly all components of water balance everywhere. However, in mountainous areas it is usually the most apparent and essential for two reasons: precipitation is usually abundant and effects of superfluous water more adverse in a steep terrain. (Buchtele,J., et al., 1998). Annual value of specific discharge is a very important indicator of the runoff regime in a watershed, necessary in research and projects aiming at reclamation, water supply, power supply, etc. Also, maximum discharge and maximum specific discharge are significant indicators of the runoff regime in a drainage basin.

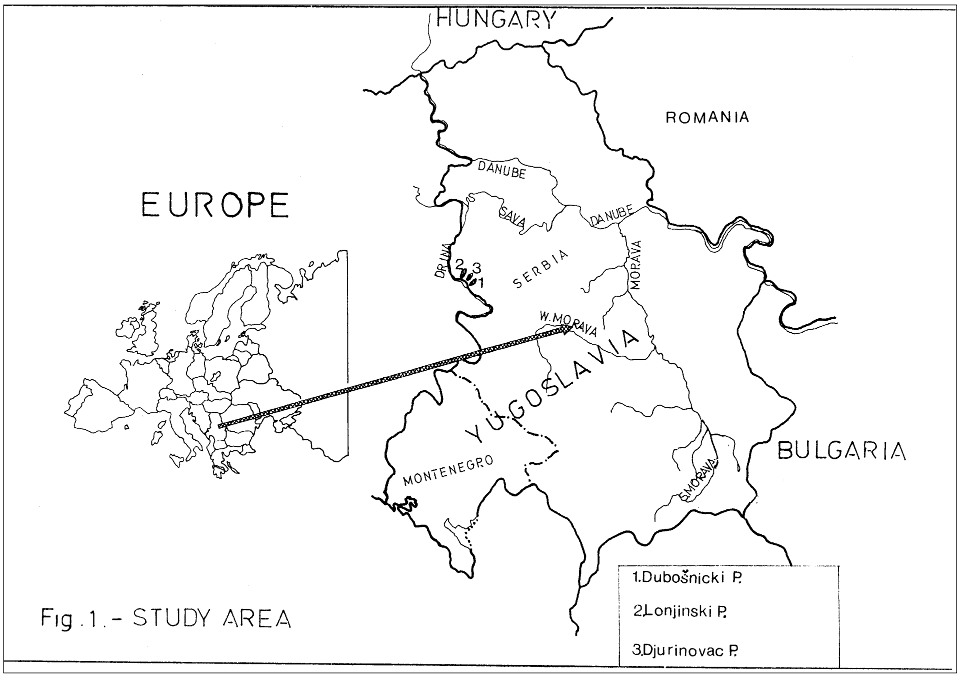

Figure 1. Study area

In this paper the results are presented of studying the runoff regime in three small drainage basins in the hilly-mountainous region of the Western Serbia. They are different only according the land use, as the consequence of different volume of erosion control works in the period 1969- 1980.

2. Subject and method of reserearch

2.1. Study Area

The researchs were caried out in three small experimental drainage basins in West Serbia: Dubošnički Potok, Lonjinski Potok and Đurinovac Potok. The drainage basins of the streams have a typical torrential characteristcs. All the three experimental drainage basins are the right tributaries of the river Drina. They are situated on the territory of the community Ljubovija in West Serbia (Fig. 1). They are in a hilly mountainous region, which can be seen from their main topographic features given in Table 1 (Kostadinov S., 1996).

Parent rock is the same in all the threedrainage basins, i.e. a sandy-schistose series consisting of metamorphosed sandstones, phylites, agrilloschists and more rarely sericites, green schists, quartz breccias, quartzites and marbles.

The soil in the is acid brown soil on schists (skeletoid).

The vegetative cover, i.e. land use, is different in the three experimental drainage basins. Table 2 is a survey of land use. As it can be seen, in the Lonjinski Potok drainage basin 70.35% area is under well-stockted forests, in the Dubošnički Potok 48.52%, and in the Đurinovac Potok drainage basin 39.5%. The vegetative cover in all the three drainage basins has the same characteristics. Significant areas are covered by very degraded forests transformed into very thin brushwood of eastern hornbeam, ash and oak, where very strong rill erosion occurs.

Table 1. Parameters of the Drainage Basins

PARAMETERS	SYMBOL	Dubošnočki Potok	Lonjinski Potok	Đurinovac Potok
Area	F - km^2	1.2464	0.7656	0.544
Drainage basin perimetre	O - km	5.25	3.60	3.55
Length	L_{gl} - km	2.48	1.40	1.40
Drainage density	G – $km\ km^{-2}$	3.26	2.38	4.04
Mean elevation of the drainage basin area	N_{sr} - m	487.90	363.90	299.70
Mean slope of the drainage basin area	I_{sr} - %	47.24	38.87	43.59
Stream-bed slope	I_t - %	18.37	18.94	12.63
Erosion coefficient	Z	0.56	0.34	0.49

Table 2. Land Use in the Drainage Basins (vegetative cover)

CULTURE	Dubošnočki Potok		Lonjinski Potok		Đurinovac Potok	
	km^2	%	km^2	%	km^2	%
Pasture	0.0224	1.80	0.014	1.83	-	-
Meadov	0.1768	14.18	0.07	9.14	0.0764	14.04
Plowland	0.0256	2.05	0.03	3.92	0.0136	2.50
Farm yard	0.0304	2.44	0.012	1.57	0.057	10.48
Orchard	0.0784	6.29	0.023	3.00	0.0168	3.10
Degraded forest	0.2848	22.86	0.078	10.19	0.1456	26.76
Well stocked forests	0.6048	48.52	0.5386	70.35	0.2149	39.50
Bare land	0.0232	1.86	-	-	0.0197	3.62
Total	1.2464	100	0.7656	100	0.544	100

2.2. Study Methods

The complete research includes the following stages:

- collection and study of the existing documentation on the experimntal darinage basins: Project of erosion control works (ECW), documentation of implemented ECW;
- the study of natural characteristics and the analysis of physical-geographicall factors of sediment formation (state of soil erosion processes in thedrainage basins);
- measurement of water disharge and precipitation;
- survey of the type and scope of ECW.

Natural characteristics of the draianage basins were studied based on reference data (climate, geology, soil) and the direct reconnaissance (vegetation and erosion processes). The analysis of phisical-geographical factors of runoff and sediment formation was carried out after Gavrilović (1972). Rainfall was measured by rain gauge. Disharge was measured on equipped cross sections according to the method adapted for torrential flows *(Kostadinov S. 1996).*

Precipitation was measured in a classical way by rain gauges. The data of diurnal, monthly and annual values were collected. Discharge was measured at gauging site by staff gauge and limnigraph by recording water level permanently. Based on the relation $Q=f(h)$ daily, monthly and annual discharges were calculated for each watershed. The subject of the study were the values of annual discharge specific (from a watershed) M_Q ($L \cdot s^{-1} \cdot km^{-2}$), and aiming at easier comparison, values of maximum specific discharges in each year Q_{sp} ($m^3 \cdot s^{-1} \cdot km^{-2}$). In addition, the numbers of days in a year were registered, when the stream went dry, i.e. when there was no water. This datum is a significant indicator, together with the discharges maximum, of the regime of runoff in a drainage basin.

3. Results of research

3.1. Soil erosion in the watersheds before erosion control works

In the late sixties and early seventies, according to the state of erosion in the drainage basins all of the three watercourses were typical torrents. Owing to the natural conditions in the watersheds and, first of all due to inadequate soil management, the processes of intensive erosion dominated with the coefficient of erosion after Gavrilović Z=0.95 (Dubošnički Potok), Z=0.91 (Lonjinski Potok) and Z=0.80 (Đurinovac Potok). Maximum value of Z=1.50 (Gavrilović, S., 1972). As the result of intensive erosion processes in the drainage basins, the runof regime was unbalanced which was reflected in frequent torrential floods, followed by periods without any water in stream channel (when the streams went dry).

Torrential floods brought great damage to the town Ljubovia (Đurinovac Potok) and villages Bačevci (Dubošnički Potok) and Lonjin (Lonjinski Potok). Also, floods brought great damages to the National road Belgrade- Užice (all the three torrents). The damages were as follow: burying the buildings in the settlements, ploughland and the road, with vast amounts of erosive sediment. In this period, there were no measurements of the discharge.

3.2. Erosion control works and their effects

Erosion control works (ECW) started in 1969 (Dubošnočki Potok) and 1973 (Lonjinski and Đurinovac Potok) and they were continued till 1980. Details of type and scope of ECW in all three drainage basins are given in Table 3.

Table 3. Erosion Control Works in the Drainage Basins

Observed values		Dubošnočki Potok	Lonjinski Potok	Đurinovac Potok
1	Regulation of the lower course …. [m]	640.00	400.00	350.00
2	Stone masonry check dams … [units]	1.00	1.00	1.00
3	Gabion check dams …. [units]	/	1.00	/
4	Afforestation of bare land and degraded pastures with Austrian pine (Pinus nigra Arn.) …. [ha]	20.84	24.12	8.33
5	Afforestation with Black locust (Robinia Pseudoacacia) ….. [ha]	8.00	3.00	2.50
6	Afforestation with spruce (Picea excelsa) ….. [ha]	15.50	8.00	2.00
7	Restocking by pits and patches of the thinned and degraded forests of oak with Austrian pine …. [ha]	/	18.74	/
8	Grassing (mixture of grasses) … [ha]	21.79	/	28.75
9	Establishment of orchards on the steep slopes ….. [ha]	22.00	/	10.26

As the result of ECW, land use (vegetative cover) in the drainage basins changed significantly in comparison with the land use before works, but different between the drainage basins, depending on the volume of ECW in each draiange basin (Table 2).

As the result of different land use (different degrees of forest cover), erosion processes of different intensities develop in the watersheds. The most intensive processes of erosion occur in the Dubošnički Potok (*Z*=0.56, medium erosion) then in the Đurinovac Potok (*Z*=0.49, medium erosion), whereas the weakest processes of erosion occur in the Lonjinski

Potok (Z=0.34, weak erosion), Z - denotes the coeficient of erosion in a drainage basin or in erosive area, according to S. Gavrilović (Gavrilović, S., 1972).

The results of the research show that erosion control works i.e. change of land use in the watersheds (by a significant increase of the share of well stocked forest area especially in the Lonjinski Potok watershed) had very positive effect reflected in:

- decreased of erosion intensity in the watersheds,
- a significant reduction of sediment yield and transport.

The most significant decreasing of intensity of soil erosion is in the Lonjiski Potok watershed, because of the fact that about 70% of the watershed area was treated by ECW.

Very important effect of ECW, i.e. changing of land use, is on the runoff regime, which is different in the drainage basins depending on the volume of ECW i.e. of percentage of forests.

3.3. Precipitation and runoff

Table 4 presents the average annual and maximum values of rainfall and runoff.

Table 4. Annual Characteristics of Runoff

Observed values	Dubošnički Potok		Lonjinski Potok		Đurinovac Potok	
	Max. Value	Av. value	Max. value	Av. value	Max. value	Av. value
Annual precipitation P [mm]	1020.3	764.7	1054.7	801.6	1011.2	769.5
Annual specific discharge M_Q [$L{\cdot}s^{-1}{\cdot}km^{-2}$]	13.74	6.25	14.58	8.59	14.82	7.51
Maximum discharge Q_{max} [$m^3{\cdot}s^{-1}$]	1.050	0.406	0.428	0.099	0.980	0.333
Maximum specific discharge Q_{sp} [$m^3{\cdot}s^{-1}{\cdot}km^{-2}$]	0.842	0.326	0.559	0.129	1.801	0.612
Number of days in a year without water [n]	205	121.4	99	12	257	194.2
Period of Research	1980-1989		1980-1999		1981-1999	

Max. value – maximum value in the period of research

Av. value – average value in the period of research.

The highest average annual precipitation value was observed in the Lonjinski Potok drainage basin (801.6 *mm*), and the lowest in the Dubošnički Potok (764.7 *mm*). Also in the Lonjinski Potok drainage basin the highest annual specific discharge was recorded (8.59 $L{\cdot}s^{-1}{\cdot}km^{-2}$), whereas in the Dubošnički Potok the smallest annual specific discharge (6.25 $L{\cdot}s^{-1}{\cdot}km^{-2}$) was observed.

The highest average annual maximum discharge were recorded in Dubošnički Potok (0.406 $m^3{\cdot}s^{-1}$), and the lowest in Lonjinski Potok (0.099 $m^3{\cdot}s^{-1}$). This is drastically expressed in the case of maximum specific discharge observed in a year - Q_{sp}. The highest average annual values were recorded in the Đurinovac Potok watershed (0.612 $m^3{\cdot}s^{-1}{\cdot}km^{-2}$), and the lowest in Lonjinski Potok (0.129 $m^3{\cdot}s^{-1}{\cdot}km^{-2}$).

Lonjinski Potok dried up rarely (on a few occasions - average annual 12 days), whereas Dubošnički Potok, and Đurinovac Potok were very often without water. This was particularly true for the Đurinovac Potok watershed, for which it can be said that during the greater part of the year there was no stream flow (average annual number days without water was in Dubošnički Potok 121.4 and in Đurinovac Potok 192.4).

3.4. Discussion of the results

The results of the research show that runoff regime in the Lonjinski Potok was balanced, without high peaks. Runoff in the Dubošnički Potok and Đurinovac Potok was discontinuous with large intervals of drought and the discharge was mainly in the form of flood waves. Unbalanced regimes of runoff in the Dubošnički Potok and Đurinovac Potok drainage basins were manifested, first of all in the fact that during a large part of the year they are dry. This is also confirmed by the data of maximum annual discharge (Q_{max} and Q_{sp}). Average annual height of maximum specific discharge in Lonjinski Potok was 4.74 times lower than that in the Đurinovac Potok and 2.53 times lower than in the Dubošnički Potok drainage basin.

Bearing in mind that climate, parent rock, and soil are the same in all the three watersheds, some other characteristics of the drainage basins had to be analyzed.

According to topographic characteristics the Dubošnički Potok and Đurinovac Potok have a higher mean slope of the drainage basin, but, on the other hand, the Lonjinski Potok has the highest stream-bed slope which means the highest transport capacity of the flow. Therefore, as for the slope, it can be said that it is similar in all the three drainage basins.

Consequently, the vegetative covering, i.e. the forest in this case (as the consequence of ECW) was the modifier of erosion and runoff regimes. The Lonjinski Potok, after the ECW, has the highest percentage of area under well-stocked forests.

Favorable effects of forests are multiple. Forests prevent sudden surface runoff of water, so that even in the heaviest showers they can decrease the peak flow. This effect of the forest is the result of the impact of the crown of trees and the forest litter. Forest litter, owing to its high permeability and high water capacity enables the quick infiltration of rainfall. Forest litter is capable of absorbing 2-5 times more water than its weight in air-dry state. According to the data by Gadziev (Zaslavsky, M.N., 1983), the highest water capacity of forest litter reaches 400% its dry weight. It was shown that, with the removal of forest litter, the runoff increased for 5-10 times. The impact of the forest on runoff regime depends on the choice of species, density of planting, age, grass cover, and forest litter (Zaslavsky, M.N., 1983).

Forest cover also reduces the factors affecting overland flow by increased roughness of slopes increased infiltration of water in the soil, etc. By increasing infiltration, forest cover minimizes overland flow and transforming potential surface runoff into ground water. This underground water moves to springs and the stream bed, and thus the stream does not go dry even in the warmest periods of the year. Consequently, in the Đurinovac Potok and Dubošnički Potok streams the total annual runoff occurs in several events in April, May and October whereas in Lonjinski Potok drainage basin, there mainly is a constant stream flow throughout the year (with some exception as a result of long period of drought preceded by high temperatures in the previous months). Also, by preventing rapid overland flow, forests increase the time of water concentration, which directly reduces the risk of flood peaks.

The indirect effect of the forest reflects itself in the good structure of the soil under permanent vegetation, which increases soil resistance. The increased infiltration capacity of such soils leads to the reduced quantity and velocity of water movement down the slopes. Also, the specific fauna gas the beneficial impact and it improves the structure and the infiltration capacity of the soil.

The results of research confirm that good forest cover in a drainage basin produces a balanced regime of stream flow without larger floods of dry periods. This is very important as dry streams adversely affect bad ecological conditions as well as life and economic activities of the local population. The significance of forest cover should be emphasized in control of soil erosion. Namely, after forest degradation occurs there follow, a more intense erosion process whereby the soil is removed. Erosion loss of the spongey forest surface soil causes the deterioration of the runoff regime from the watershed, as rainfall cannot be infiltrated so it runs down the bare, slopes and consequently augments the flood peak. Therefore, forests also affect the regime of runoff by controlling soil erosion.

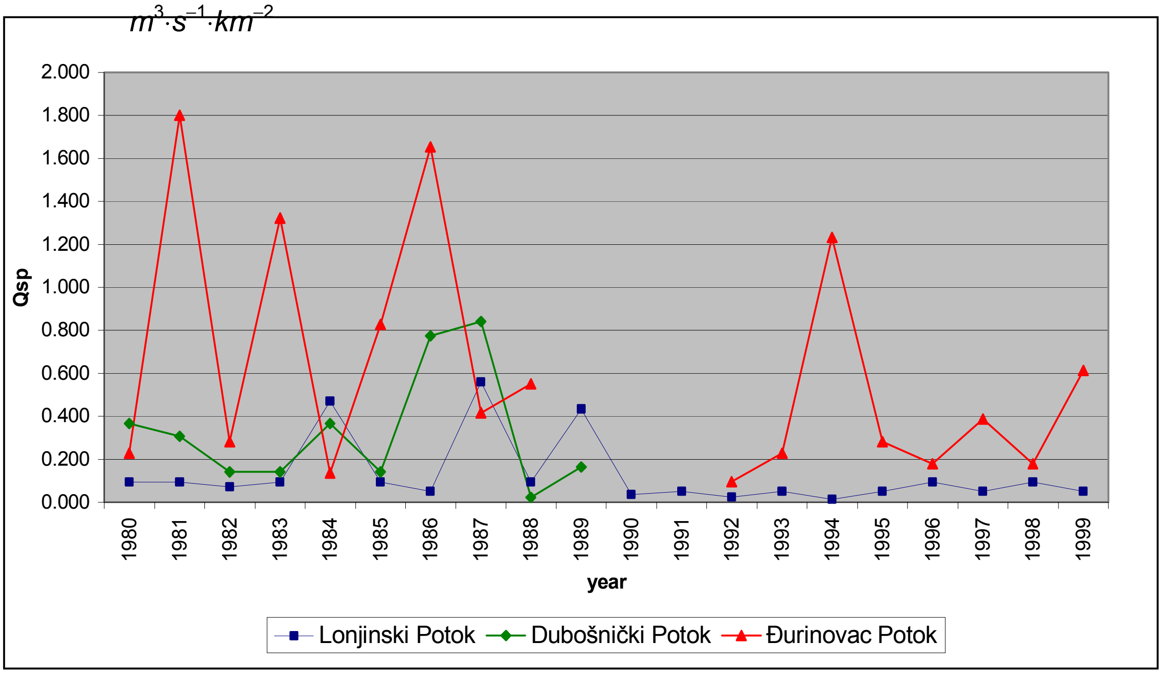

Figure 2. Maximum specific discharge observed in a year

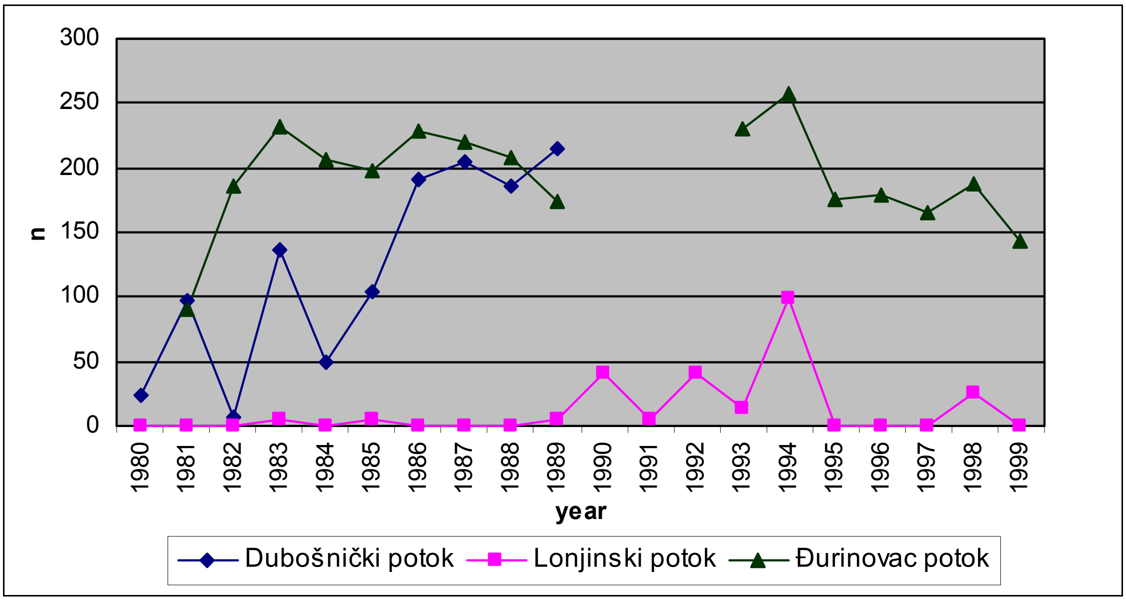

Figure 3. Number of days in a year, when the stream went dry

4. Conclusion

The results of the research show that adequate land use, as the consequence of erosion control works in the case of three experimental drainage basins, has a significant hydrologic effect. In addition to rainfall, forest cover has a decisive role in the process of runoff formation in the drainage basin as well as on the total runoff regime.

With all the other conditions being equal or similar (rainfall, relief, parent rock, soil) in Lonjinski Potok (70% of the drainage basin area under well-stocked forest) there is a balanced regime of runoff whereas the torrents Đurinovac Potok (39.5% of drainage basin under forest) and Dubošnički Potok (48.5% under forest) have unbalanced regime of runoff. Runoff in those two drainage basins was discontinuous with large intervals of drought and the discharge was mainly in the form of flood waves.

The unbalanced regime is also confirmed by the data on maximum discharge (Q_{max} and Q_{sp}). Average annual height of maximum specific discharge in Lonjinski Potok was 4.74 times lower than that in the Đurinovac Potok and 2.53 times lower than in the Dubošnički Potok drainage basin. Lonjinski Potok dried up rarely (average annual 12 days) whereas average annual number days without water was in Dubošnički Potok 121.4 and in Đurinovac Potok 192.4.

All the above proves that land use and, first of all, forest cover natural or established after erosion control works, is a powerful means of flood peaks control in the small mountainous drainage basins.

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