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Streamflow Characteristics of Two Forested Catchments in the Sopron Hills

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Abstract – One of the central issues in hydrology is today to establish a relationship between the hydrological and biological processes in ecosystems. One question of this theme is the vegetation impact on the water budget of the catchment. Water use by vegetation can closely be linked to streamflow patterns on a variety of time scales. At present many details of these connections are poorly understood.

Investigation on small catchments is the best way of studying hydrological processes in headwater, forested watersheds. In this paper drainage basin morphology and streamflow characteristics (base flow and quick flow) have been analysed under conditions of forest management in two neighbouring small forested catchments (the Farkas Valley and Vadkan Valley located in the prealpine hills bordering to Austria) on the basis of streamflow data collected during 2001.

streamflow characteristics / small catchment / forest vegetation

Kivonat – A Soproni-hegység két erdősült vízgyűjtőjének lefolyási jellemzői. Napjainkban a hidrológia egyik központi kérdése az ökoszisztéma hidrológiai és biológiai folyamatai közötti kapcsolat megfogalmazása. Ennek a témának az egyik kérdése a vegetáció hatása a kisvízgyűjtők vízmérlegére. A vegetáció vízfelhasználása különböző időskálákon szoros kapcsolatban lehet a lefolyás mintázatával. Manapság azonban még ennek a kapcsolatnak a részletei tisztázatlanok.

A kisvízgyűjtők vizsgálata az egyik legjobb módszer a hidrológiai folyamatok tanulmányozására a felső, erdővel fedett vízgyűjtőkön. Ebben a cikkben két párba állított szomszédos kisvízgyűjtő (a Vadkan-árok és a Farkas-árok) morfológiáját és lefolyási jellemzőit (alapvízhozam és árhullámok szintjén) elemezzük az erdőgazdálkodási tevékenység hatásai alatt a 2001-es év lefolyási adatai alapján.

lefolyási jellemzők / kisvízgyűjtő / erdő vegetáció

1 INTRODUCTION

Rainfall concentration and runoff causing discharge fluctuations, is one of the central issues of hydrology. Another important question in hydrology is the impact of vegetation on the water budget of the catchment. Water use by vegetation can closely be linked to streamflow patterns on a variety of time scales (Bond et al. 2002). Several social-economic demands have a strong connection with small or bigger streamsregarding both quantity and quality of the water. Meeting or consideration of these demands is substantially complicated because knowledge about streamflow regimes is still insufficient.

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1.1 The experimental catchment

Physical and statistical features of hydrological processes have already been analysed in experimental catchments for a century. The most famous forestry projects, Hubbard Brook (Bormann – Likens, 1979) and the Coweeta Experimental Forest (Swank et al. 1988) in the USA, have been analysed using several forested watershed ecosystems. In Hungary establishment of experimental and regionally representative catchments in a wider scale and the development of their network was begun in the 1950s and 1960s , but unfortunately some of them had already been terminated in the 1970s (Szesztay 1965, Domokos 1980).

In 1954 the first forested experimental catchment was chosen and equipped with recording instruments in the Dolina Valley near the village of Kisnána by the Forest Research Institute. The main purpose of this research was to study erosion and sediment movement processes. Not far from this catchment (also in the Mátra Hills) a forest hydrological research catchment was founded in the Szárazkesző Catchment (Bánky 1959, Szőnyi 1966, Újvári 1981). Later on the Forest Research Institute commenced to study the third generation of experimental catchments in the Mátra Hills, mainly from the point of view of environmental protection. This site was established at Nyírjes (Sitkey 1994).

The Faculty of Forestry has been studying the hydrological role of forests over a century. These research activities were generally intermittent, but some of them were based on long term data collection (Firbás 1963, Führer 1979). At the end of the 1970s, on the basis of earlier studies, József Rácz established an experimental catchment area in the Sopron Hills (Rácz, 1981). The location available for establishing a hydrological experimental catchment was the totally forest covered upper watershed of the Rák Stream (Hidegvíz Valley). The extension of the whole catchment is 6 km^2 and it has several favourable features (e.g. ephemeral streams, undisturbed environment, diverse forest vegetation types, easy accessibility etc.).

In this article we present streamflow patterns of two small catchments of the Hidegvíz Valley on the basis of one year's data. Both catchments are of a similar magnitude: 0.6 and 0.9 km2. We have analysed in detail some hydrological elements: Patterns of rainfall, discharge, rainfall-induced flood waves, and basic discharge in drought periods. Variances of these parameters have been analysed in relation to the surface of the catchments, vegetation coverage and forest management.

2 MATERIAL AND METHODS

2.1 Study area

The model catchments are placed in the Hidegvíz Valley, at the foothills of the Alps, (*Figure 1*) at following geographical coordinates:

ρ (latitude) = 47-40-24;
λ (longitude) = 16-27-49.

Figure 1. Location of model catchments

2.2 History of measurements of discharge and other parameters

Discharge measuring was started in 1992 in the the Farkas Valley stream (Kucsara – Vig 1993). The volumetric method was adopted. This measurement period was continued in 1993 and 1994 in both catchments. In these years we made expedition measurements when we tried to measure flood wave shapes on rainy days. Soon it became obvious that only continuous measuring can provide enough data for analysis of these phenomena.

In 1995 gauging stations were established at the catchment outlets (*Figure 2*). In the beginning the water level was measured by a float. These instruments operated with frequent mechanical breakdowns, resulting in a lot of missing periods.

In the year 2000, the water level measuring instruments were changed. We chose sensors functioning on the principle of water pressure. These sensors provided more reliable discharge time series data since 2001.

Figure 2. Gauging station

A data logger records water level values every second minute. In order to convert the water stages into discharge values we used an empirical stage-discharge relation (Kucsara et. al. 2000).

Besides the water gauge at catchment outlets, meteorological data (e.g. rainfall with 0.1 mm precision, air and soil temperature, air humidity, net radiation, wind direction, gusts, speed) and other hydrological parameters (e.g. interception) have been measured in an opening and in different forest sites in the catchments.

2.3 Morphology

Drainage basin morphology data (characteristic physical parameters calculated on the basis of works of Lee (1980) and Hewlett (1982)) are presented in *Table 1*.

Table 1. Characteristic physical parameters of the two catchments

Physical parameters	Farkas Valley	Vadkan Valley
Area of catchment (A) (km^2)	0.62	0.92
Length of catchment (L) (m)	1320	1340
Perimeter of catchment (m)	4680	5140
Shape		
Form factor [catchment area]/[catchment length]^2	0.36	0.51
Mean width (A/L) (m)	470	690
Greatest width (m)	602	880
Average length of overland flow (A/L*1/2) (m)	235	343
Mean height (m.a.s)	489.83	484.51
Lowest point (m.a.s.)	401.88	403.25
Highest point (m.a.s.)	549.00	555.80
Total relief (m)	147.12	152.55
Slope steepness (° and %)	20.3° (34.7%)	18.6° (31.9%)
Stream channel length [sum{main channel}] (m)	1170 {1170}	1685 {1418}
Channel slope (° and %)	4.4° (7.7%)	3.2° (5.5%)
Drainage density (length of cannel/surface area [km/km^2])	1.89	1.83
Average exposure of catchments	W-NW	N-NW

The table shows that the physical parameters of the two catchments are similar, but the Farkas Valley is a narrower watershed and has a steeper hillside than Vadkan Valley.

2.4 Geology and Soils

The geology of the two investigated catchments is crystalline bedrock deposited in the Tertiary (Miocene) period, and fluvial sediment, which is strongly unclassified. The fluvial sediment was deposited in five layers. The lowest layer is called the Brennberg Lignite Formation. Above it there is a thick fluvial sandy-gravel layer called the Ligeterdő Gravel Formation.

The lower beds (with prevailing metamorphic pebbles and conglomerates), are distinguished as the Alsóligeterdő Formation while the subsequent bundles of beds as the Felsőligeterdő Formation. The middle part of the formation with lignite strings and Congeria-bearing beds is called the Magasbérc Sand Formation. The letter formation is capped with gravel and conglomerate beds of the Felsőtödl Gravel formation. These formations of the Ottnangian and Carpathian ages are up to 500 meters thick.

Only the two upper layers appear on the surface. On the hilltop and hill-slope the Felsőtödl Gravel Formation can be found. The thickness is 10 - 50 meters. This contains coarser gravels and finest loam, and is therefore strongly unclassified. On the valley bottom, the finer material of the Magasbérc Sand Formation appears everywhere. These layers are a good aquifer, so both valleys have a perennial streamflow. Streams never dry out, not even in driest periods (Kisházi – Ivancsics 1981-85).

On the basis of fluvial sediment, podzolic brown forest soils, highly acidic non-podzolic brown forest soils and lessivated brown forest soils have evolved. To a small extent eroded skeletal soils and on the bottom of the slopes also colluvial soils can be found. All soils have a 70-80 cm deep and water retaining loamy layer producing subsurface flow.

2.5 Characteristics of the Vegetation Cover

Both catchments and their surroundings have been totally covered by forest for hundreds of years.

The catchments are basically similar from the point of view of forest coverage, but show some small differences:

In the Vadkan Valley 59.6% of the catchment's area is deciduous (mainly beech and oak) 37.7% coniferous (mainly spruce) forest in contrast to Farkas Valley, where 40.7% is deciduous, and 53.1% is coniferous forest. The main conifer species is spruce (*Picea abies*) and the main deciduous is beech (*Fagus sylvatica*). These species have different hydrological behaviours. Spruce has a higher interception capacity (more than 40% of the yearly precipitation), and a higher transpiration constant, and has therefore a dryer impact. Beech has more favourable features, smaller interception (20-25%) and is directing its streamflow along the root systems into the soil. These species also have different forest floor cover. In the bottom of the valleys another species, alder (*Alnus glutinosa*) is the dominant species.

For the last few years a lot of clear-cutting took place in this area. In the year 2001 clear-cutting areas were bigger and closer to the stream system in the Farkas Valley therefore it probably had an effect on the runoff.

There is a difference between the shares of road areas within the two catchments. The road area is more than twice as big in the Farkas Valley (6.2 %) than in the Vadkan Valley (2.7%). These roads can modify runoff processes: e.g. they can separate or even detach areas from the catchment and they can slow or accelerate surface runoff.

3 RESULTS AND DISCUSSION

3.1 Water Yield

In 2001 the annual runoff patterns of two small catchments showed both similarities and differences As a first comparison let us have a look at the daily water yield time series, mm/day. *Figure 4* shows unequivocally the similarity of the streamflow patterns. There is a similar tendency of the time series of base flow, and the impact of rainfall is similar to the two smaller catchments' runoff. Direct runoff values vary differently in the two catchments, but the base flow is always higher at the Vadkan Valley.

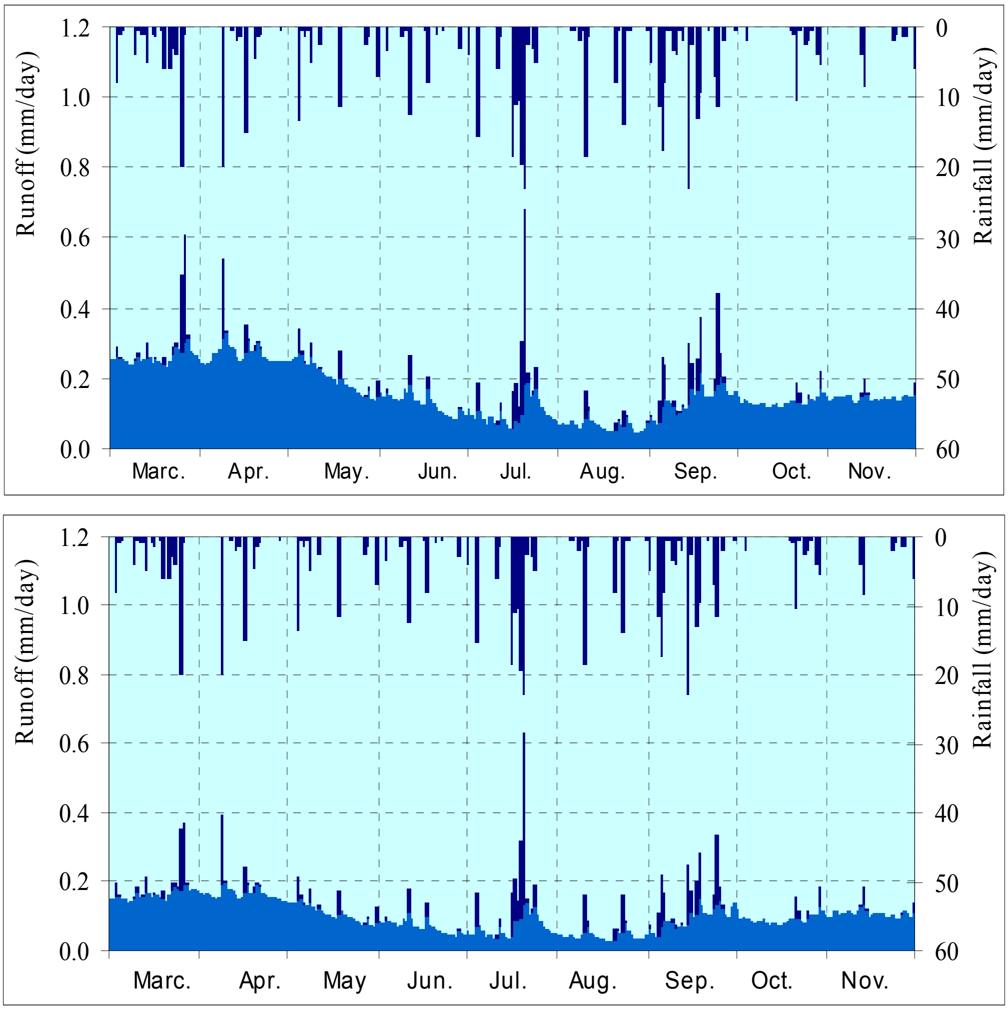


Figure 3. Streamflow patterns of Vadkan Valley (above) and Farkas Valley (below) in 2001

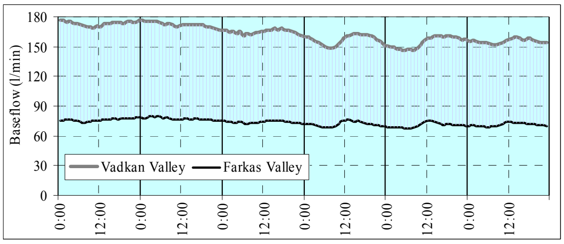
3.2 Base Flow

Originating from groundwater outflow the resultant base flow patterns show a characteristic annual rhythm. This rhythm is mainly influenced by longer rainfall periods filling up pores in the soil and seeping out.

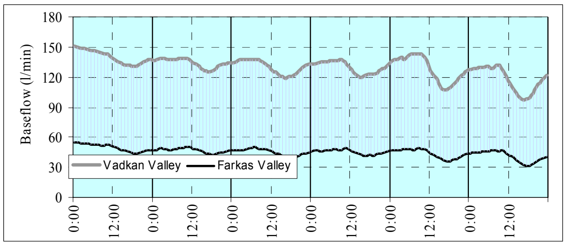
Forested catchments have their own base flow diurnal fluctuation (Pörtge 1996, Bond et al. 2002, Gribovszki 2002), which reflects the daily rhythm of other hydrological parameters.

Diurnal fluctuation has different typical forms at different periods of the year. Four characteristic periods have been identified (*Figure 4*):

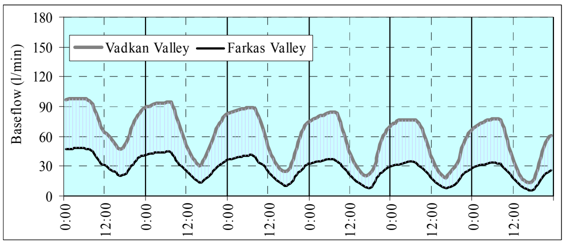
- Normally at the end of winter (2001 in March and at the beginning of April), when soil surface temperatures fluctuate around zero, streamflow discharge has its minimum in the early morning and its maximum early afternoon (*Figure 4 a*).
- After freezing stops (from May in 2001) the transpiration impact of vegetation becomes more and more relevant. Maximum discharge appears in the morning and the minimum in the afternoon (*Figure 4 b*).
- As the summer becomes warmer, water consumption of vegetation and its impact on the hydrological regime intensifies and the amplitude of the streamflow's daily increases significantly (*Figure 4 b-c*). This amplitude, in terms of per cent of base flow starts from 2-3% in early May and rises to 45-50% in July (*Figure 4 b-c*). The daily rhythm amplitude of temperature in winter is commonly much smaller than transpiration amplitude.
- In October the transpiration- (summer) and temperature- (winter) induced diurnal rhythms overlap (*Figure 4 d*). The transpiration-caused rhythm can be detected even at the end of October.



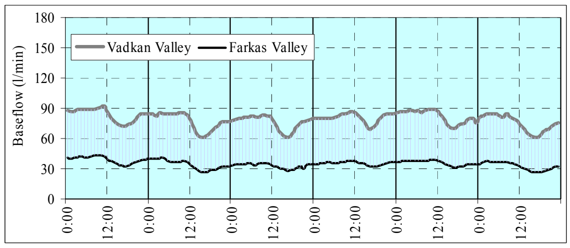
a) March 29. – April 3.



b) May 12 – 17.



c) July 26 – 31.



d) October 10 - 15

Figure 4. Typical shapes of the diurnal fluctuation in 2001

Table 2 shows some characteristic values (time of minimum, time of maximum, amplitude) of base flow diurnal rhythms in 2001 (Gribovszki et al. 2004). The data show the time of the minimum and maximum discharge and amplitude of the base flow through the year modified by the impact of vegetation and the effect of frost.

Table 2. Diurnal fluctuation features of the Vadkan Valley base flow in 2001

Date	Time of base flow minimum value (h)	Time of base flow maximum value (h)	Amplitude of diurnal fluctuation (l/min)
Mar. 14 – 20	8:00	14:00	19
Apr. 10 – 16	5:00	14:30	26
Jun. 03 – 09	15:00	5:30	50
Jul. 25 – 31	15:30	5:30	113
Aug. 13 – 19	16:00	7:00	110
Sep. 07 – 13	15:00	7:00	54
Oct. 10 – 16	15:00	8:30	38
Nov. 03 – 09	23:30	14:30	12

3.3 Stormflow

The runoff of catchments depended mainly on the various rainfall events during the year 2001:

- Even modest rainfalls increased the streamflow discharges. After rain begins, the discharge immediately rises. The reason for this phenomenon is that the less permeable surfaces have less infiltration and more overland flow (*Figure 5 d*).
- Short, high intensity rainfall (shower) causes significant surface runoff (*Figure 5 c*). Water concentration is very quick and peak discharge manifests itself in a few minutes in these small catchments.
- Longer, protracted rainfall causes a protracted flood wave, where the shape perfectly follows rainfall characteristics (*Figure 5 a and b)*
- In spring and autumn flood waves settle onto a non-periodic base flow. Separation of flood waves is simple (*Figure 5 d*). But on hot summer days, a shower-caused flood wave cannot be separated without taking the diurnal fluctuations into consideration (*Figure 5 b*).

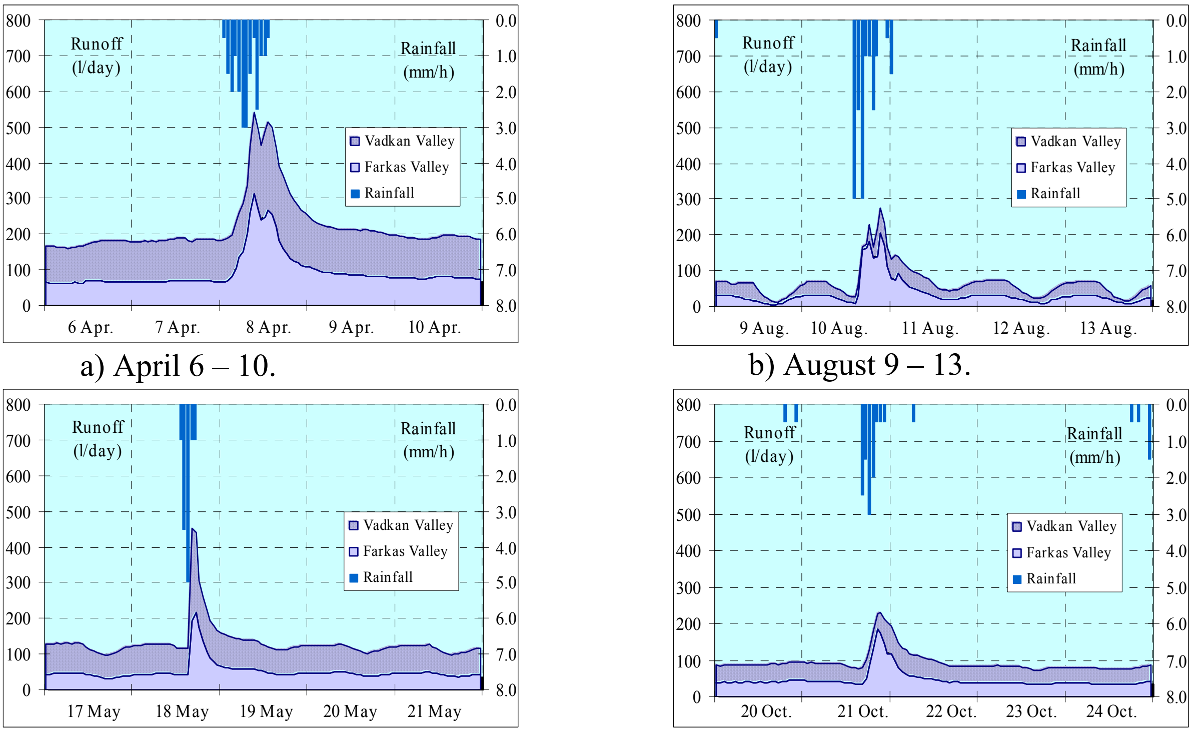


Figure 5. Typical shapes of characteristics hydrographs in 2001

Table 3 shows characteristic rainfall-induced flood wave features. The data of *Table 3* show that only a small part of the big storm's rainfall was transformed into direct runoff. Hydrologic response variability is fairly big, because it depends on continuously changing environmental parameters. The first three rows show a seasonal tendency. At the end of the dormancy season, the runoff was bigger, because the soil's pore capacity was filled and sometimes frost appeared on the surface. As the weather became warmer and vegetation transpiration began, water storage capacity of catchments was reduced and not only the base flow but the same magnitude of rainfall-induced stormflows also decreased in volume (by July hydrologic response was reduced to less than one fifth of the original value in March).

Table 3. Some features of characteristic flood waves

Period	P Precipitation (mm)	Vadkan Valley (93.3 ha) Volume of flood wave (m^3)	Q_s Storm discharge (mm)	$\alpha = Q_s/P$ Runoff coeff.	Farkas Valley (62.2 ha) Volume of flood wave (m^3)	Q_s Storm discharge (mm)	$\alpha = Q_s/P$ Runoff coeff.
Mar. 25-26.	20.0	488	0.52	0.026	221	0.36	0.018
Apr. 08-09.	20.0	212	0.23	0.012	129	0.21	0.010
Aug. 10-11.	20.0	86	0.09	0.005	82	0.13	0.007
Jul. 19-20 .	40.0	654	0.70	0.018	447	0.72	0.018
Sep. 24-25.	11.5	309	0.33	0.029	151	0.24	0.021

Besides the drainage basin's morphology and instantaneous (actual) hydrological conditions (e.g. saturation, vegetation cover), the amount and intensity of rainfall has a dominant effect on runoff processes. In July 40 mm of rainfall recharged the subsurface storage capacity of catchments, and produced a significant stormflow. However a smaller rainfall had the biggest runoff coefficient in 2001. It was the 11.5 mm of precipitation (last row of Table 3.), which had induced a fairly big stormflow, because earlier rainfalls (until this time in September 108.5 mm) recharged the storage capacities of the catchments. Under these conditions the runoff coefficient in these forest covered catchments had not even reached 0.03 (3%) value.

Comparing the two catchments we can generally say that the volume of stormflows in the Farkas valley was generally smaller than in the Vadkan Valley (Table 3), but water concentration is faster and falling limbs of flood waves are steeper in the Farkas Valley. The reason for this must be that there is a bigger area of less permeable surfaces and steeper slopes of the Farkas Valley.

During the summer period both peak discharges and the volume of flood waves of the Farkas valley stream gradually reached and sometimes exceeded the same values in the Vadkan Valley stream (Table 3 and Figure 5). The reason for this change could be a clear cutting, which had been done along the stream banks, very close to the Farkas Valley outlet. This activity significantly increased the area of surface runoff.

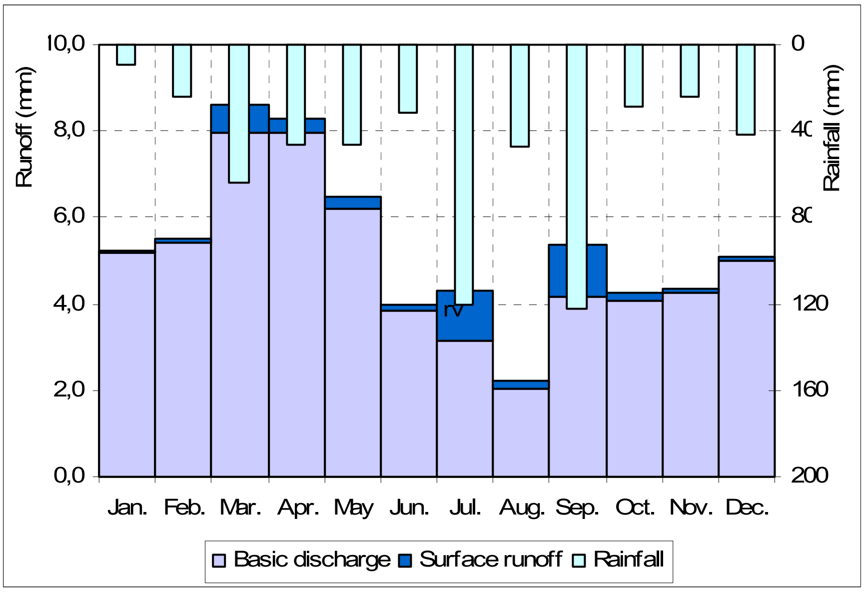
4 SUMMARY AND CONCLUSIONS

Because of their high sensitivity, small catchments are very useful to investigate hydrological elements, their interactions and the impact of different human interferences (e.g. clear cutting) on them.

In 2001 the annual total of precipitation (607 mm) was under the long term annual mean (917 mm/a). Figure 6 shows precipitation, stormflow and baseflow annual pattern as specific values (in mm) for each month,illustrating that:

- In 2001 the annual runoff volume of the Vadkan Valley and the Farkas Valley catchments were only 10% and 7% respectively of the annual precipitation total;
- Streamflow mainly got its supply from baseflow (groundwater outflow) and only a small part of the streamflow (Vadkan Valley 11.0% and Farkas Valley 7.2%) was produced by direct runoff (stormflow);

- Annual streamflow (with its dominant component baseflow) has a standard regime in our climate, which shows a spring maximum and a summer recession, but these regular patterns can be modified a little by rainfall e. g. a rainy period in summer can also raise the base flow but can not fundamentally change the seasonal rhythm.
- While there were only minor differences between the annual stormflow volumes of the two investigated catchments (Vadkan Valley 4.4 mm/a and Farkas Valley 4.3 mm/a), the differences between their annual base flow volumes (their average ratio being 3:2) were caused by the geological, pedological, vegetation, etc. characteristics of the two catchments.



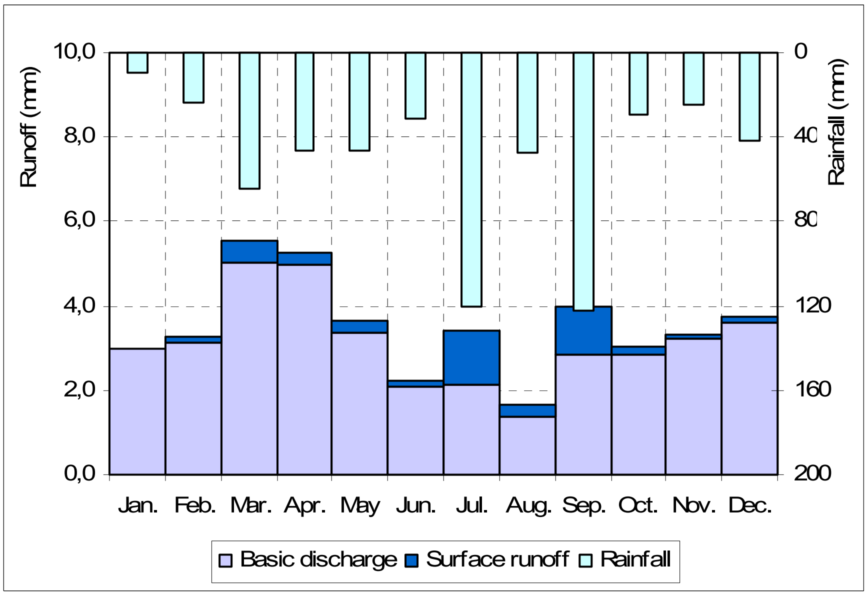


Figure 6. Monthly values of base flow and stormflow of Vadkan (above) and Farkas Valley (below)

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