INFLUENCED RUNOFF IN THE UPPER AND MIDDLE BASIN OF THE OLT RIVER

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Summary. Influenced runoff in the upper and middle basin of the Olt River. Olt River represents one of the most complex hydrographic system, both in terms of the natural factors of the flow and the uses that influence the natural flow. Hydrometric stations on the main course provide good monitoring of the runoff. The most important uses are water supplies and reservoirs. The analysis refers to the degree of runoff influence and the type of influenced runoff. The degree of runoff influence is analysed at all seven hydrometric stations in absolute and relative values. The type of flow affected indicates relative constancy and does not change along the main course.

Keywords. Natural flow, influenced runoff, natural runoff factors, water uses, water influence degree, influenced runoff types, Olt River

1. INTRODUCTION

Today, there are practically no more rivers with natural runoff. Society's water needs have multiplied to such an extent that water resources, especially surface ones, are very intensively exploited. This intensive use is sometimes disturbed by the surplus of water, at other times by the scarcity of resources. It is not by chance that our century is associated with the generic name of *the water century*. The natural variation of the runoff and the multitude of water uses that influence it, require a more accurate knowledge of the degree of influence and the establishment of some types of influenced runoff.

Olt River, after the rivers Siret and Mureș, represents Romania's third hydrographic basin, with an area of 24,300 km^2. Among the inland rivers, it has the longest length (699 km). Regarding the multiannual average flow, the Olt River ranks second-third (165 m^3/s), together with its brother - Mureș, after the Siret River.

The source of the hydrographic system is located near the limestone massif of Hășmașul Mare in the Eastern Carpathians. It crosses a whole range of very varied landforms. After leaving the mountain area, it crosses the Ciuc Depression and enters the Brașov Depression through the Tușnad Gorge. Here the flow increases substantially due to the catchment accumulating character of

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the depression. Due to some local subsidence areas, it changes its course direction by 180°, heading north, between the Baraolt and Perșani Mountains. It pierces the neo-volcanic area of the Persian Mountains, cutting the Racoș Gorge (Ghinea, 2002), turns sharply again to the southwest, and after entering the Făgăraș Depression, it heads west. The tributaries with rich waters from the Făgăraș Mountains contribute to a significant new increase in flow. It heads south again and makes the only breakthrough in the Carpathian Range through the Turnu Roșu – Cozia Gorge, after which it flows towards the Danube River.

The present study analyses the phenomenon of the influenced runoff on the Transylvanian sector of the Olt River from its spring to Turnu Roșu.

2. NATURAL RUNOFF FACTORS

The natural factors of the discharge can be differentiated into genetic factors and influenced factors. The inequality of the energetic premises determines the spatio-temporal variation of the genetic and influencing factors of the discharge. Depending on this, the degree of humidity and water reserves, which generate the runoff in a watershed, vary.

Among the climatic factors, precipitation and temperature have the predominant role, along with evaporation, winter phenomena, etc. The most important factors influencing runoff are the geological substrate and relief, followed by soils and vegetation.

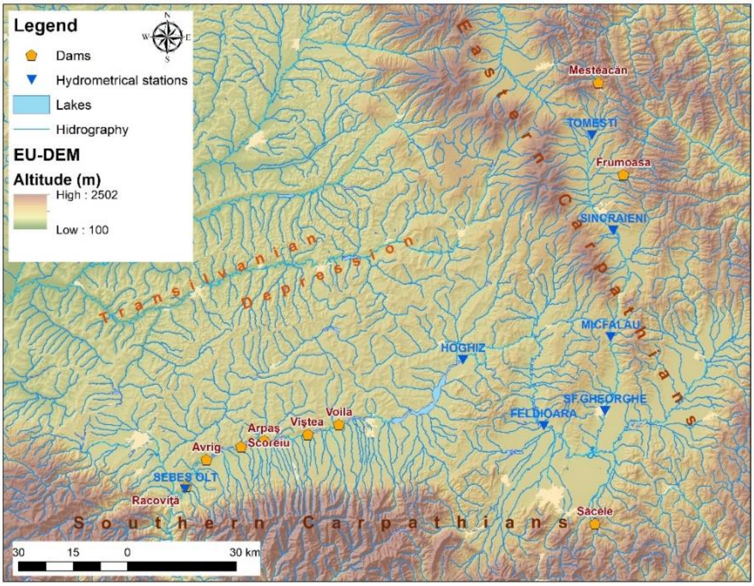

Fig. 1. Location of hydrometric stations and reservoirs within the relief units

The average annual precipitation has maximum values of over 1200 mm in the high mountain areas of the Eastern Carpathians and the Făgăraş Mountains. The lowest precipitation values are recorded in the Ciuc and Braşov Depression, below 600 mm. The months with maximum precipitation are between May and June, when the runoff is very rich, while the months of January and February are the lowest in precipitation.

Average annual temperatures oscillate between 0°C on the peaks of Făgăraş and 10°C in the Făgăraş Depression. In January, the average temperatures are between -8 and -4°C, which contributes to a low runoff and in July between 14 and 22°C.

The Upper Olt collects its waters from the volcanic mountains in the west and the Cretaceous deposits in the east. Both formations facilitate a rich surface runoff. The middle basin consists of the metamorphic of the Făgăraş Mountains and the Miocene of the Hârtibaci Plateau. In the depressions, it drains soft, friable formations of the Quaternary age, which facilitates the loading of water with alluvium.

The relief of the basin is determined by its petrographic structure. In the mountains made of hard rocks, the altitudes are high, and the slopes are steep, generating torrential flows. In the depressionary areas, the slopes decrease a lot, the main course and some tributaries presenting a lazy, sometimes meandering flow.

Overall, among the most important factors that determine the runoff can be mentioned the isolation of the depressions in the upper basin from the dominant atmospheric circulation, the abundance of input in the Braşov Depression and the exposure to the western circulations of the northern slope of the Făgăraş Mountains. Due to the multitude and different factors, the hydrological regime of the Olt River is a diversified one (Ujvari, 1972).

3. ANTHROPIC WATER USES THAT INFLUENCE THE NATURAL RUNOFF

Through different uses, society modifies the natural runoff and the distribution of water resources in time and space and thus changes the natural flow regime of the rivers. This is achieved by means of some infrastructures in the riverbed or near it.

The effects of hydro-technical facilities on the hydrological regime downstream can be very important: attenuation of flood waves, increase of minimum flows and modification of the runoff regime. These effects can have beneficial or detrimental consequences relative to the natural runoff regime. Their quantification helps to evaluate the economic, social and ecological impact of the developments (Ionescu, 2001).

In the hydrographic basin of Olt River, there is great complexity and variety of users that make use of the surface water resources. They are found both on the main course of the river and on the tributaries. Depending on the capacity of the uses, only a part of them significantly affects the river flow. Of the 24 major uses, the most important are reservoirs and the surface impoundments. Their distribution is uneven, depending on water needs. Thus, six are in Harghita County, three in Covasna County, eleven in Brașov County and four in Sibiu County. The total captured flow amounts to 2023 l/s, with which more than one million inhabitants are served (Cioranu, 2009).

Reservoirs retain part of the runoff and redistribute it over time, thereby exerting the most important influence on natural runoff. Of the nine accumulations, seven are located on the main course of the river, and two are on tributaries.

On the upper course of the Olt River, upstream from the town of Bălan, a rock dam was built in 1966, which controls 65 km^2 of the hydrographic basin. The lake, with a total volume of 0.8 mil. m^3, is intended to serve the locality with drinking water and the industrial water. In 1985, the Frumoasa reservoir was put into use, on the tributary of the same name. It has a total volume of 10.6 mil. m^3 and is located upstream of Miercurea Ciuc. The main function is the water supply of the city. The dam is made of ballast, with a clay core. In the Brașov area, the Săcele reservoir was put into use in 1975, on the Târlung River. It has a double function: supplying water to neighbouring towns, including Brașov, and producing electricity. The dam was made of earth filled with a clay core. Due to the recent raising of the dam, it became the reservoir with the largest volume in the analysed area (28 mil. m^3).

Table 1. The volumes of reservoirs

Name of reservoirs	River	Volume (mil.m^3)
Mesteacăn	Olt	0.8
Frumoasa	Frumoasa	10.6
Săcele	Târlung	28.0
Voila	Olt	12.3
Viștea	Olt	4.3
Arpașu	Olt	7.3
Scoreiu	Olt	5.2
Avrig	Olt	10.1
Racoviță	Olt	14.8

The most important reservoirs are located on the middle course of Olt River, in the Făgăraș Depression. The development of this sector began in 1984 and includes a group of five units: Voila, Viștea, Arpaș, Scoreiu, Avrig reservoirs (Pop, 1996). They are part of the "Olt Superior Hydropower Development”, on the Făgăraș - Avrig sector, put into operation in 1989 - 1990. The reservoirs have a small retention capacity, ensuring only daily regularization of the tributary flows (5.2 - 12.3 mil. m^3). The dams are of the spillway type with lateral dikes that outline the accumulations. Each dam is equipped with a hydroelectric plant on the water line, with a small drop.

Downstream of Avrig, the Racoviță accumulation was completed (2013), with a total volume of 14.8 mil. m^3. The type of dam is identical to the previous ones, including the side dams and here there is a hydroelectric plant with a small drop.

4. DATA AND METHOD

From its spring in the Hășmaș Mountains to the confluence in the Southern Carpathians at Turnu Roșu, the Olt River discharge is controlled by seven hydrometric stations. They are well distributed, so that they ensure adequate control of the water flow. The stations cover 379 km of the river's length, over a surface area of 10776 km^2, with average altitudes decreasing from 1070 m to 748 m. From these stations, the monthly runoff series representing mesured and reconstructed discharge data over a period of 20 years were used for analysis.

Table 2. The morphometric elements of the basin at the stations

Hydrometric station	Distance am. (km)	Basin surface (km^2)	Average altitude (m)
Tomesti	25	214	1070
Sancraieni	58	902	937
Micfalau	91	1424	912
Sf.Gheorghe	117	4198	843
Feldioara	159	5678	797
Hoghiz	241	7225	805
Sebes Olt	379	10990	748

To express the degree of influence of the natural runoff and the typification of the influenced runoff, it is necessary to reconstruct the series of flow rates. This operation is carried out based on monitoring the flow of rivers and the operation of utilities. Most often, average monthly flows are reconstructed. Calculation is carried out at the hydrological stations, based on the data from the hydrometric stations and from the uses that significantly influence the natural runoff.

The influence degree on the natural flow can be expressed in absolute values and/or in relative values, using the formulas from the literature (Pandi, Stoica, 2015):

$$\Delta Q = Q_{nat} - Q_{infl} \qquad (mc/s) \qquad [formula\ 1]$$

$$\varepsilon = (Q_{nat} - Q_{infl}) / Q_{nat} * 100 \qquad (\%) \qquad [formula\ 2]$$

The graphs $\Delta Q = f(T)$ and $\varepsilon = f(T)$ expresses the deviations of the reconstituted / natural multiannual average monthly flows compared to the influenced / measured ones. Of course, the deviations of the respective annual average values can also be expressed on their basis.

The first graphs express the deviations calculated based on the runoff from all seven hydrometric stations. Next, to illustrate the evolution of the phenomenon along the Olt River, the ΔQ and ε values were calculated for the first and last hydrometric station (Tomești and Sebeș Olt, respectively). Finally, the graphs were drawn up for the multi-year average values from each station.

The types of influenced runoff regime are established according to the natural runoff, through the Qinf / Qnat ratio (Pandi, 2011).

5. RESULTS

Degree of runoff influence

Multiannual monthly average deviations are not too significant. For absolute deviations, the value of 1 m^3/s is exceeded only in April. The other two spring months follow with exceeding the value of 0.7 m^3/s. All other months are below 0.6 m^3/s. The smallest absolute deviations are in January and February, below 0.4 m^3/s. The relative constancy of the absolute deviation values between June and December is observed.

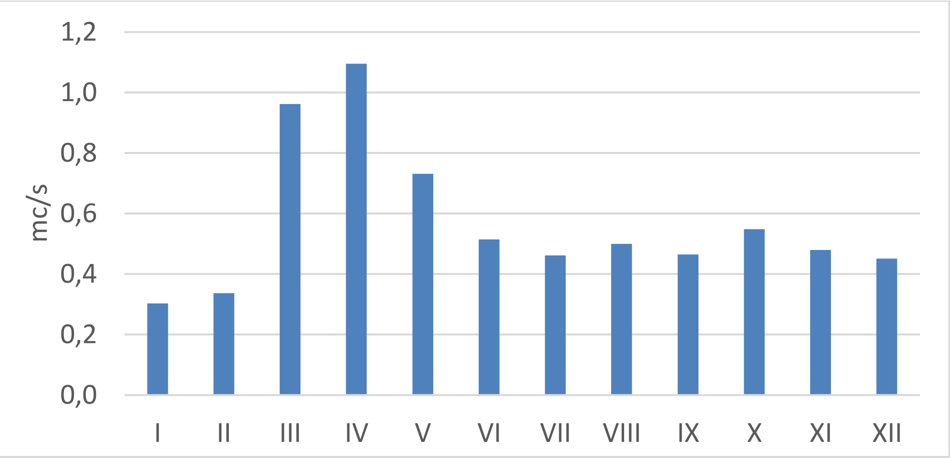

Fig. 2. The absolute deviations of the average monthly flows from all stations

The relative deviations show similarities, but also some differences compared to the absolute ones. So, they have maximum values in the last three months of the year to which March is added. The highest value of the relative deviation was recorded in October (2.88%). In January and February, the relative deviations, like the absolute ones, are small, to which June and July are added. These deviations are around 1.5%. The lowest value is recorded in July, 1.45%.

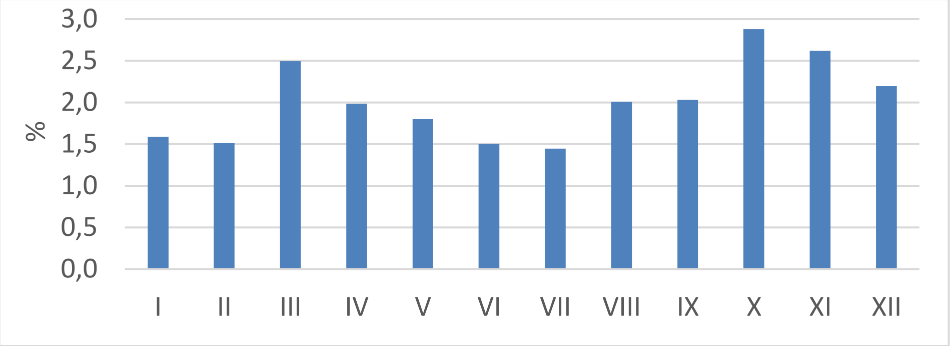

Fig. 3. The relative deviation of the average monthly flows from all stations

The two types of deviations indicate interesting variations if the first and the last hydrometric station on the Olt River course are analysed. The absolute deviations are very large in Sebeș Olt compared to Tomești. The cause is the progressive increase in flow downstream. The shape of the graph at Sebeș Olt resembles that of the absolute deviations of all stations (Fig. 2): maximum values in March – May and minimum values in January – February. The highest value is in April (2.38 m^3/s) and the lowest in January (0.55 m^3/s). At the first station, Tomești, the absolute deviations do not exceed 0.25 m^3/s, and in May we have a negative deviation. Values above 0.1 mc/s are found in the months of January - March, July - August and October - November.

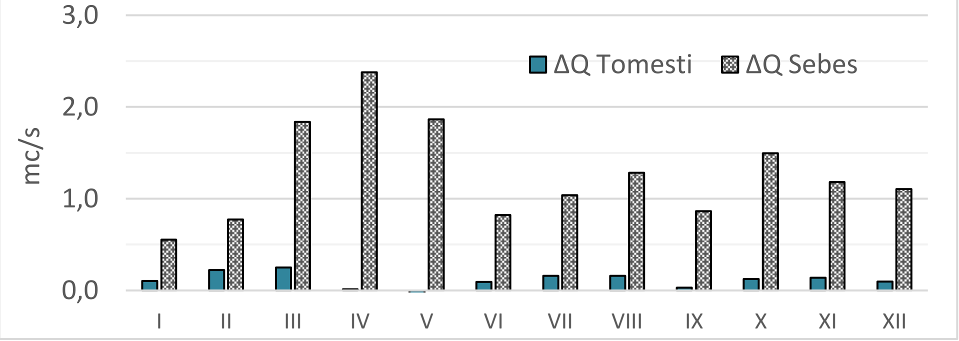

Fig. 4. Absolute deviations at Tomești and Sebeș Olt stations

The relative deviations from the two stations have a completely different form. At Tomești they are significantly higher than at Sebeș Olt because the flows are small on the upper course of the river. The highest values are recorded in the first and last three months of the year. By far the highest deviation is in February, 20.9%. The deviation of June is very small (0.40%), and in May the relative deviation is still negative, like the absolute one. It is a naturally recurring phenomenon. At the Sebeș Olt station, these deviations do not exceed 3%. The maximum is in October (2.68 %), and the minimum in June (0.81 %).

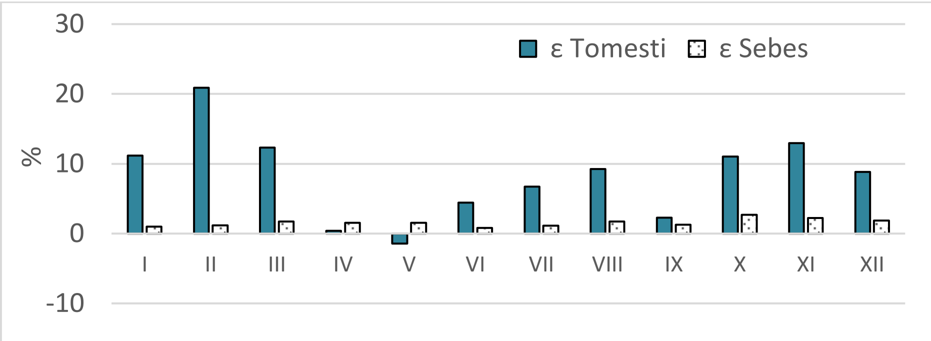

Fig. 5. The deviations relative to the Tomești and Sebeș Olt stations

The degree of influence on the natural runoff was also analysed based on multiannual average annual flows. Fig. 6 shows the evolution of multiannual average flow along the river. At all hydrometric stations, the drained flows are lower than the reconstituted ones, which indicates a predominance of water-consuming uses. There is a smaller increase in water flow at Sâncrăieni, after the river exits from the Ciuc Depression, and another strong increase at the Feldioara station, where the Oltul collects the rivers from the Brașov Depression.

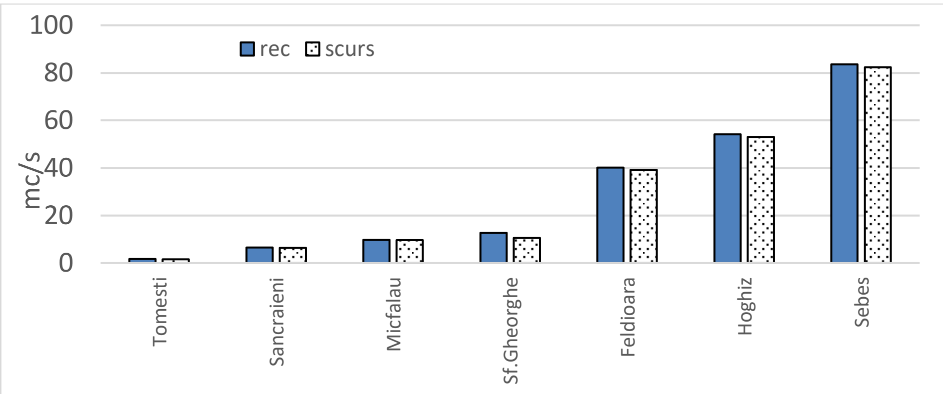

Fig. 6. The evolution of multiannual average flows along the Olt River

At the level of multi-year averages, the absolute deviations are clearly differentiated between the first three stations and the last four. Until entering the Brașov Depression, the deviations are very small, below 0.2 m^3/s. At the first important city encountered by the river - Sfântu Gheorghe - the influence of the uses is clearly felt. The deviation becomes over 2.0 m^3/s. Towards the downstream, although not so significantly, the high values of the deviations are maintained, around 1.0 m^3/s.

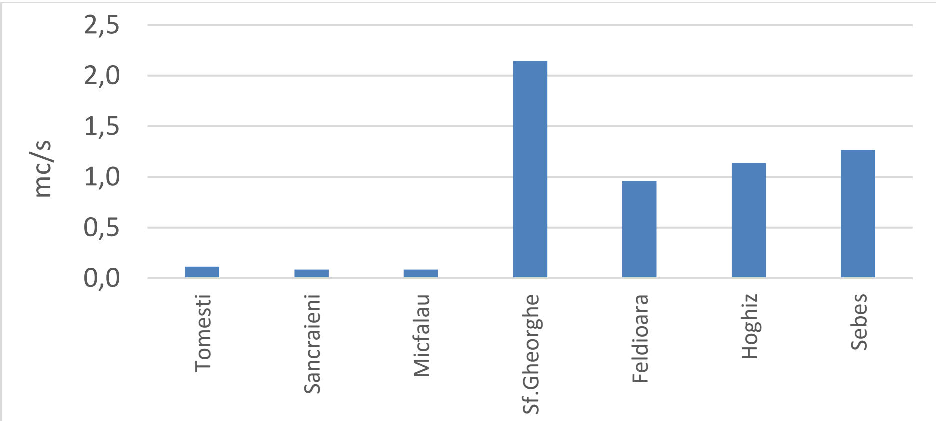

Fig. 7. The absolute deviations of the multiannual average flows

The relative deviations of the multi-year averages have a different evolution. In general, the degree of influence is small, below 0.2%. In Tomești there is a relatively high value (0.065 %), due to the small flow from the upper course of the Olt River. The minimum deviation is at the Micfalău station, 0.009%. At the Sfântu Gheorghe station, the highest value is recorded, 0.169%, due to the high water consumption in relation to the discharged flow. Downstream the deviations decrease again significantly, around the value of 0.02 %.

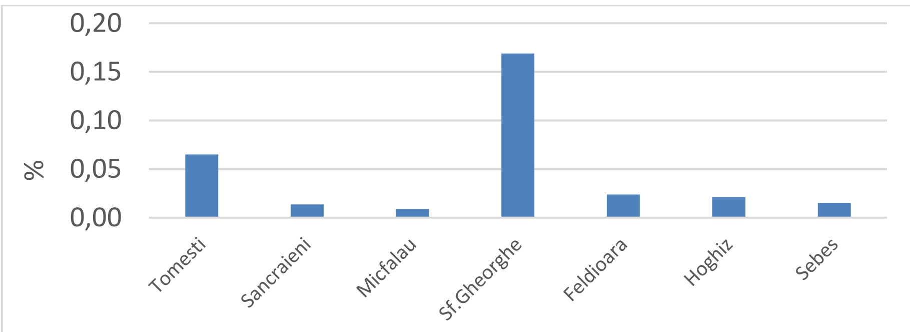

Fig. 8. The relative deviations of the multiannual average flows

Influenced flow regime

From the analysis of the annual average monthly runoff graphs and their comparison with the types of uses, it appears that four types of influenced flow regimes can be differentiated (Pandi, 2011). Their characteristics are as follows.

In case of the surplus type, the influenced flows are higher than the corresponding natural ones, in every month of the year (Qinf > Qnat). It is carried out on rivers that receive an additional supply of water, thanks to derivations. The deficient type has lower monthly outflows than the corresponding natural ones (Qinfl < Qnat). It is characteristic downstream of intakes, through which a certain amount of water is directed into the neighbouring hydrographic basin or water is consumed by utilities. The sinusoidal type characterizes the rivers downstream of most reservoirs, with a predominant role of water redistribution over time, the regularization being annual. In this type, in the months of water retention, the influenced flows are lower than the natural ones, and in the months of discharge, the ratio is reversed. In the irregular type, there is a random alternation of the ratio between the influenced and natural monthly flows. It is characteristic downstream of the reservoirs with the function of mitigating flood waves, where after a period of accumulation follows a period of de-accumulation.

At the hydrometric stations of the Olt River hydrographic basin, the influenced runoff is *deficient*. At all stations Qinfl < Qnat. That is, in the Transylvanian Depression, along the entire river, the drained flows are lower than the reconstituted ones.

Of course, the size of the reports varies from station to station and throughout the year. This fact is due to the different degree of water use, which is variable depending on the nature and size of the uses. At the same time, it follows that the influence of flow redistributor reservoirs is insignificant. In the upper basin, the water supply function of the reservoirs predominates, and in the Făgăraș Depression, the energetic function of the lakes primarily requires the transit of flows.

The Qinf/Qnat ratios are the lowest at the Tomești hydrometric station, with a minimum of 0.791 in February. The highest ratios are observed at the Micfalău station, where the value highest from unity is 0.984, in March. Values very close to unit can be found at the stations on the Upper Olt in different months: Tomești 0.996 in April, Sâncrăieni 0.998 in January, Micfalău the same value in February.

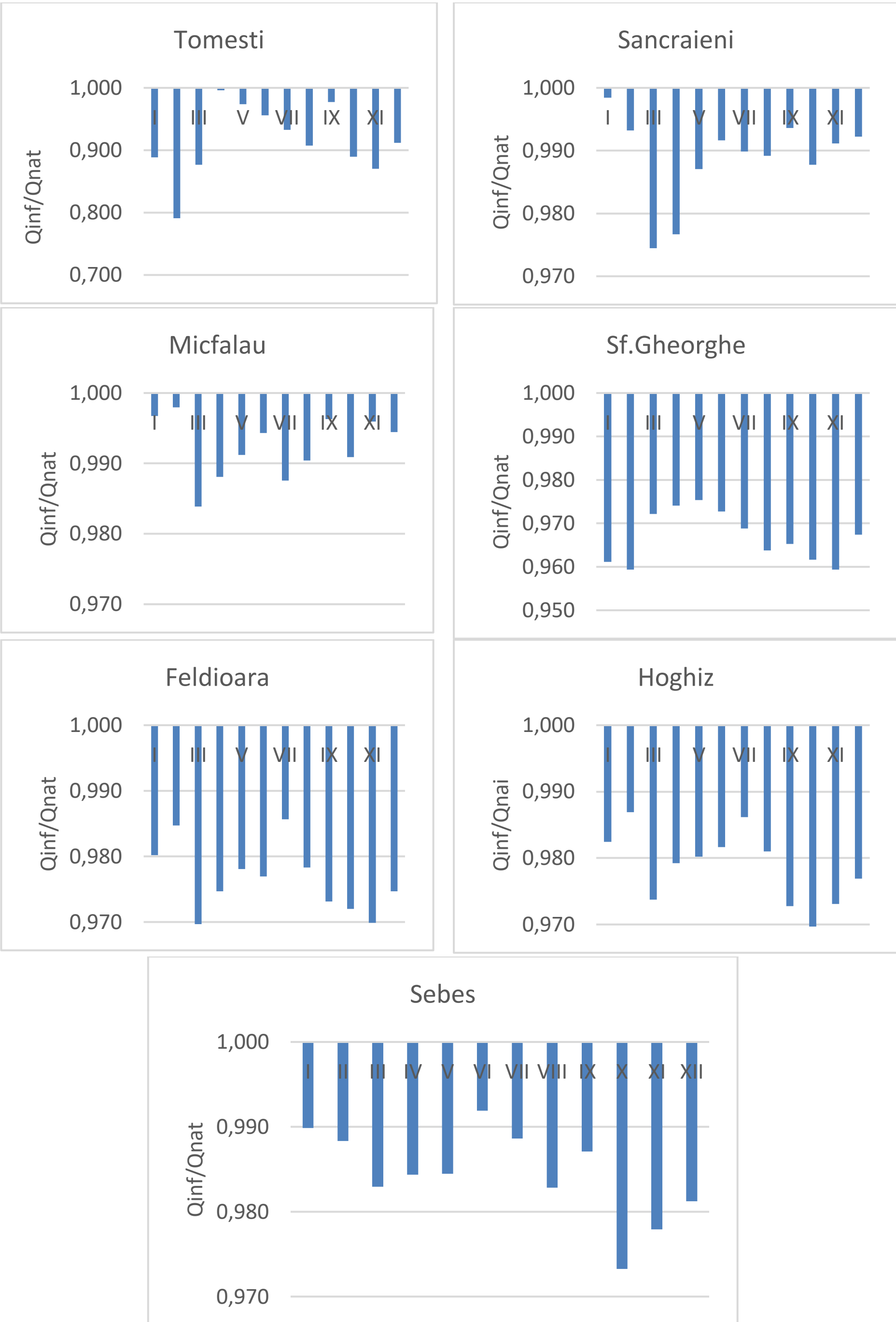

Fig. 9. The deficient type of flow influenced along the Olt

Downstream, starting with the Sfântu Gheorghe hydrometric station, the Qinf / Qnat ratios are lower. At St. George in February and November there is the same value of the ratio - 0.959. At the next three stations, the minimum ratios are around 0.970, being recorded in different months. The maximum ratio at Sf. Gheorghe only reaches the value of 0.975 in May, at the following stations it is much higher: Feldioara - 0.986 in July, Hoghiz - 0.987 in February, Sebeș Olt - 0.992 in June.

6. CONCLUSIONS

The natural flow of the Olt River is influenced by reservoirs on the main course and tributaries, to which is added an intensive use of water resources for feeding.

The degree of influence, taking into account the monthly average values from all stations, shows large oscillations. Expressed in absolute values, there is a strong increase in deviations along the river course. If the maximum value of this deviation is 0.249 m^3/s in Tomești, it increases in Sebeș Olt up to 2.379 m^3/s. Relative deviations evolve in the opposite way. They have high values at the first hydrometric station (maximum at Tomești 20.88 %) and decrease until the last (maximum at Sebeș Olt 2.68 %).

The natural multiannual mean flows are higher than the influenced ones at all hydrometric stations. There are large differences between the stations in both ways of expressing the degree of influence. In terms of absolute deviations, the maximum from Sfântu Gheorghe is 2.15 m^3/s, and the minimum from Sâncrăieni and Micfalău has a value of 0.09 m^3/s. The extreme relative deviations are also at the same hydrometric stations: Sfântu Gheorghe 0.169%, Micfalău 0.009%.

The influenced runoff regime shows the same type along the river. All hydrometric stations belong to the deficient type, due to the fact that reservoirs do not play an important role in redistributing runoff over time, and uses consume significant amounts of the water resources of the hydrographic basin.

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