MAIN HYDROLOGICAL STATISTICAL CHARACTERISTICS OF LOW WATER AND HIGH WATER ON THE TUR/TÚR STREAM (I)

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ABSTRACT. – Main hydrological statistical characteristics of low water and high water on the Tur/Túr stream. The Tur/Túr river network (1261 km^2) is the secondary left bank tributary of Tisa. The catchment is shared by Romania (96%) and Hungary (4%). Daily streamflow data for the description of low flow conditions are available since 1961, namely 49 years long series for Negreşti-Oaş, Turulung (RO) and Garbolc (HU) consequently. Lower reaches of the river were considerable modified during the 19th and 20th century river training and flood protection works including the topology and geometry of channel network, while the hydrological regime of the upper hilly and undulating regions remained nearly natural until 1972. Discharge series until 1973 are or only slightly influenced, while the impact of reservoir Călineşti-Oaş the temporal distribution of runoff is felt after that period.

Key words: minimum and maximum discharge, low flow periods, high flow periods, hydrological statistical analysis, water uses, discharge values probabilities.

1. The hydrographicalal attributes and the impact of hydraulic engineering measures on hydrological regime of the investigated river reach

The Hungarian-Romanian border is crossed by 8 rivers, which spring from the Carpathians and flows directly or indirectly into the Tisa/Tisza River from its left bank. Among these, the Tur/Túr River, with its catchment area of 1261 km^2, is a small river. Besides the natural factors, its water level fluctuation, especially the low water and flood discharges, are significantly influenced by technical interventions.

The Tur River springs in the Carpathian Mountains, in Romania, above the town of Negreşti-Oaş, at the altitude of 989 m. On its catchment area, especially in

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highlands, compared to the mean height above sea level, the many year mean rainfall is high, and its quantity increases from west towards east. On the highest areas of the catchment area the annual precipitation is 1000-1300 mm, while on the drier parts of Hungary it is 550-700 mm. The spatial distribution of the many year mean flow is similar to the precipitation.

The water level fluctuation is significantly influenced by the natural-geographical and the hydrological factors, therefore on the highland section the streamflow is abundant, on the lowlands it is much lower. The many year average value of the annual mean flows on Tur River at Negreşti-Oaş is 0,990 m^3s^{-1}, at Turulung it is 9,73 m^3s^{-1}, at Garbolc it is 10,2 m^3s^{-1}. On the lower section the rate between the highest and the lowest annual mean flow is 1:6.

It cannot be detected any regularity in the alternation of wet/high water, or dry/low water years, year groups. In the last half century the following were wet and high water years: 1966, 1970, 1974, 1980, 1985, 1995, 2005, 2006. In the years: 1954, 1961, 1972, 1973, 1990, 2003, 2007, low rainfall and low waters were typical. Before the regulation, the Tur lower section was very tortuous and it reached the Tisza River near Olcsvaapáti. Due to the water regulation works, the Túr section in Hungary became significantly shorter, and on a distance of 62 km from Sonkád to the earlier mouth, the river bed operates as a main channel of inland water drainage. On the Hungarian river section, a 75,6 km long flood control dike and a 1600 km long drainage channel system have been constructed. There had been constructed dikes along the Tur River, between Călineşti-Oaş and the Romanian-Hungarian border, on 77,2 km, as well as in Turţ, Talna Mare, Racta and Egher Valley. These dikes protect against flooding an area of 28.102 ha. Above Negreşti-Oaş, the river is provided with dikes only on a short section.

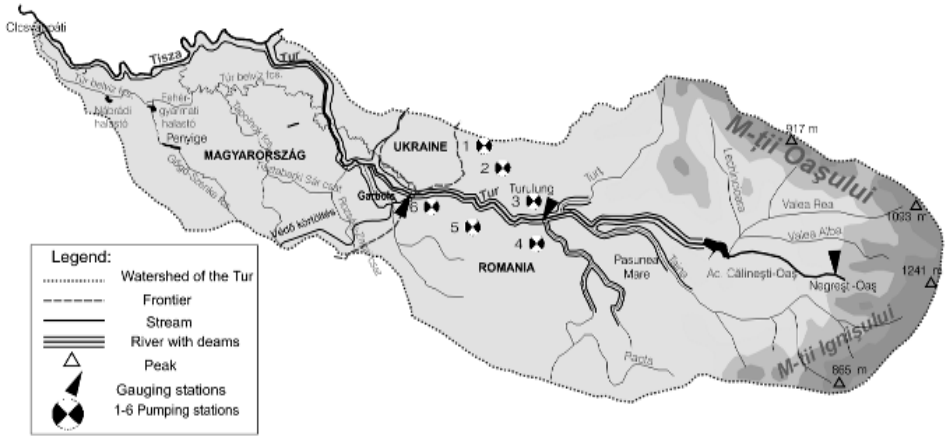

Figure 1. The topography, water network, main water structures and hydrometric stations with long time streamflow on the catchment area of Túr/Tur River.
Pumping stations: 1. Cidreag; 2. Porumbeşti; 3. Mesteacăn; 4. Drăguşeni; 5. Micula; 6. Cer.

Between 1972 and 1974, on the upper section of Tur, there was constructed the dam and reservoir from Călineşti-Oaş. A part from the volume of the reservoir, which is 23 millions m^3, is reserved for flood decrease. A flow of approximately 200 m^3s^{-1} can be simultaneously outlet.

The total lifting capacity of the six pumping stations placed on the river section between Turulung and Garbolc is 28 m^3s^{-1} (Figure 1). When these ones operate, the streamflow on the lower section can increase with 10-20%. The pumping stations do not operate on low water periods, so they do not affect the low water flows.

Before the installation of the reservoir in Călineşti-Oaş, floodings occurred very often. According to the data of the National Institute of Hydrology and Water Management (INHGA) in Bucureşti, since 1973 the low water flows are significantly more influenced by the water use. The difference between the average water flows of the natural close and the influenced periods varies in time. Between November-June (excepting February) after the installation of the reservoir, due to the storage the low water flows decreased, but in July-October they increased, due to the outlet of the excess water from the reservoir.

We communicate the main morphological and mean water flow data of one hydrometric station operating on the Hungarian section and two hydrometric stations operating on the Romanian river section (Table 1). The lengths of the uninterrupted available streamflow data series are: 49 years (1961-2009) at the Romanian station in Negreşti-Oaş, 56 years (1954-2009) at the Romanian station in Turulung, 53 years (1957-2009) at the Hungarian station in Garbolc. At the other stations shorter time series are available. The streamflow time series for a common period of 49 year are long enough for hydrological statistical analysis. In the period before 1973 the low flows can be considered natural close, because they were only slightly influenced by human interventions. In the period between 1973-2009 the streamflow was rearranged in time, the influence became more significant.

Table 1. The morphological and hydrological data typical to the middle and lower section of the Tur/Túr River

Gauging section	Distance from the mouth [chkm]	Catchment area [km^2]	Gauge "0" [mBf]	Qm aa [m^3s^{-1}]
Tur Negreşti-Oaş	80,0	45	230,00	0,925
Tur Turulung	49,5	708	124,49	10,3
Túr Garbolc	27,7	944	116,50	10,6

2. Hydrological characteristics of low water

The low water periods are preceded by rainfall deficient periods, when the quantity of falling rain is below the many year mean quantity typical for that period. The development of the rainfall deficient periods is basically caused by the long stable presence of dry air masses, the anticyclones (Stanciu 2007).

During the low water periods significant decreasing of flow occurs and low water flow can be observed in the stream beds. The low water period is such a time function, that does not exceed a preset flow value (Kovács-Domokos 1996). This low water flow consists of the basic water flow from the under surface and the streamflow from the near surface, and it is called streamflow threshold (Q_0).

Aiming to separate the low water periods, the method of Kille (1970) uses a threshold, that is the many year average value of the „basic water flow" originating from under surface. This threshold was determined by the water flow occurring with 50% probability from the monthly lowest flow series of the natural close running water in the period before 1973 (Table 2). The low water flow thresholds determined this way for the three hydrometric station on Tur are the following: Negreşti-Oaş 0,211 m^3s^{-1}, Turulung 1,40 m^3s^{-1}, Garbolc 1,78 m^3s^{-1}.

The low water periods have different intensity and length, in time they are contiguous or interrupted (Zelenhasič et al. 1987, Kovács-Domokos 1996, Tallaksen 2007). In case between two low water events a threshold exceeding lower discharge increasing, flood wave is formed, but its duration is short, one day in case of Tur Negreşti-Oaş station with its total catchment area of 45 km^2, three days in case of Turulung and Garbolc stations with several times bigger catchment area – is considered to be a low water period. In case a low water event extends from one year to the other, then it was calculated only to one of the subject period, to that one when its start has been.

Table 2. Setting the discharge threshold (Q_0) based on monthly minima

Hydro metric station	$Q_{month\ min}$ – month/year MM/YY	$Q_{month\ min\ mean}$	C_v	Low flow values of different probability [m^3s^{-1}]				
				50%	80%	90%	95%	97%
Negreşti-Oaş	0,011 / 12,63	0,286	0,92	**0,211**	0,101	0,069	0,055	0,028
Turulung	0,100 / 07,64	1,86	0,83	**1,40**	0,630	0,394	0,233	0,110
Garbolc	0,150 / 07,72	2,26	0,75	**1,78**	0,950	0,657	0,529	0,300

Time series have been investigated for the following annual characteristics: minimal discharge ($Q_{min\ a}$), minimal daily mean discharge ($Q_{m\ min\ d}$), number of low water periods (case), number of low water days (day), total length of low water periods (day), the longest contiguous low water period (day), amount of water deficit (W_{def}), the water deficit of the longest uninterrupted low water period (W_{def}), amount of the biggest daily water deficit ($W_{def\ d}$).

To evaluate the characteristics of the river fluctuations, to determinate the utilisable water resources, to assess and manage the potential hazard situations, it is necessary a detailed examination of the temporal and spatial changes of extreme water fluctuations. If we considerate many year development of the annual average discharges, it can be observed that at the Negreşti-Oaş hydrographical station on the upper river section besides the different fluctuations, between 1961-2009 the

streamflow did not change significantly (Figure 2). This partly can be the result of natural processes, but probably the effect of water outlets above the section. There is a different situation on the middle and lower section of the river, as well as at Turulung and Garbolc hydrographicalal stations situated below the reservoir from Călineşti-Oaş, as here it can be observed an increase of annual mean discharges.

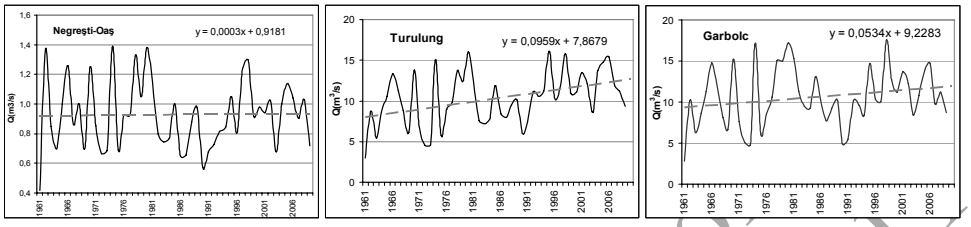

Figure 2. The development of annual mean flows on Tur between 1961-2009.

There are two high flow periods in the annual course of the Tur runoff. The first peak value of the monthly run-off appears in the period between February and April, the second one in June. An interesting contradiction is that on the lower river sections 47% of the highest monthly average flows occurs in February and March, when the fewest precipitations of the year falls. That indicates the significance of the runoff from the melting of the snow collected in the winter months. In the wettest months of the year: in June and July, the highest average flow occurs only in 5% of cases.

Below the fluctuation extremes of the three hydrometric stations on the Romanian and Hungarian section of the Tur/Túr river is well reflected by he significant differences between the development of the daily discharges of a high water (1970) and a low water (1961) (Figure 3). 1970 is a characteristically high water year, both regarding the annual medium, minimum and maximum discharge values and the short term distribution of discharges. Flood waves followed each other in the winter, spring and summer periods, the most significant of which occurred in May. However, in 1961 the annual characteristic mean, maximum and minimum discharges were much lower, it hardly occurred a significant flood wave.

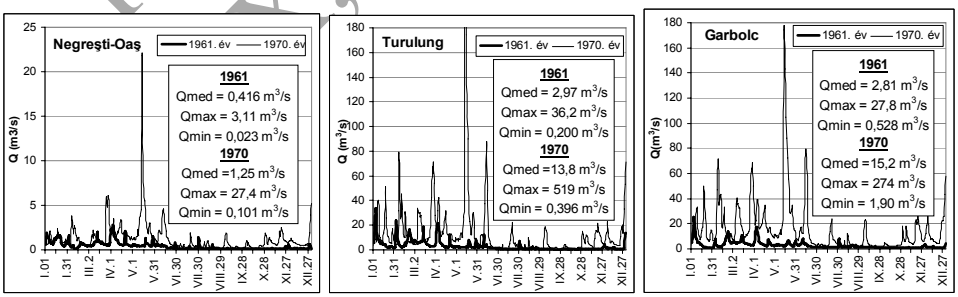

Figure 3 Hydrographs of daily discharges and characteristic annual values for the high water year - 1970, and low water year – 1961 at stations Negreşti-Oaş, Turulung and Garbolc.

The timely and every section development of minimum discharge values in a low water period are influenced by the hydrological processes developing the low water fluctuation together with spatial distribution of runoff, groundwater inflow, seepage, evaporation and water uses. To this it may also contribute the measurement and calculation inaccuracies, mistakes, which are accepted up to 10%. On the Tur, from Negreşti towards the mouth, the discharges change proportionally with the increase of the catchment area, but sometimes they can be influenced by the technical interventions and the local hydraulic or the geological-hydrological situations.

Based on data of the instantaneous minima of discharges and the annual minima of daily mean discharge, it can be observed that at the three examined sections on Tur, in the period between 1961-2009, the low streamflows do not show any significant trend type changes (Figure 4).

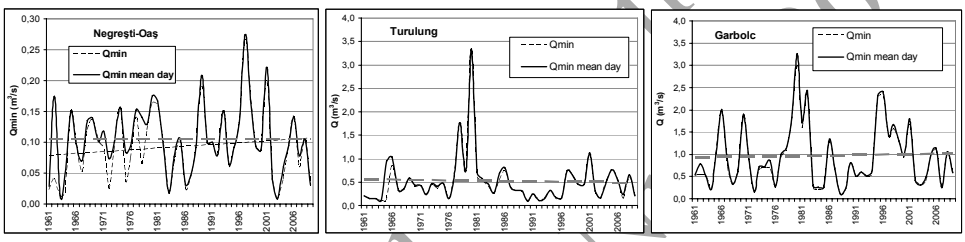

Figure 4. Annual minima of daily mean discharges (continuous lines) and instantaneous minima (dashed lines) with linear trends at stations Negreşti-Oaş, Turulung, Garbolc (1961-2009)

The lowest discharges observed on the river section occurred after 1973, in different years, but only in summer months (Negreşti-Oaş 0,008 m^3s^{-1} / 08/2003, Turulung, 0,069 m^3s^{-1} / 07/1990, Garbolc 0,099 m^3s^{-1}/ 08/1988). The annual minima of he daily mean discharges at Tur Negreşti-Oaş gauge is 0,008 m^3s^{-1} (28,29/08/2003), at Turulung it is 0,096 m^3s^{-1} (07/08/1990), at Garbolc it is 0,111 m^3s^{-1} (21/08/1988) (Table 5). The latter values are slightly different from the instantaneous annual minimal discharges. The many year average value of the minimum daily mean discharge ($Q_{m\ min\ d\ aa}$) at Negreşti-Oaş gauge it is 0,093 m^3s^{-1}, at Turulung it is 0,479 m^3s^{-1}, at Garbolcnál it is 0,907 m^3s^{-1}.

At the three analysed sections on Tur, between 1961-2009, in April and May never occurred annual minimum flow, even at Negreşti-Oaş nor in March (Figure 5). At Negreşti-Oaş the highest monthly frequency of annual minimum flows occurred in August (26,5 %) and October (20,4 %), at Turulung in July and September (21,4 %), at Garbolc in July (20,8 %) and January (17,0 %). (The differences between the data of the Negresti-Oas station and the two lower stations occur due to the differences between the climatic characteristics of highlands and

lowlands. The differences between Turulung and Garbolc can be explained by the differences between the measurement and data processing methodology in the glacial periods. At Negreşti-Oaş and Garbolc the annual minimum occurred in the winter semester above 50 % (55,1 %, and 52,8 %) and in the summer semester below 50% (44,9 %, 47,2 %), while at Turulung it occurred more frequent in the summer semester, 64,2 %, in the winter semester only 35,8 %.

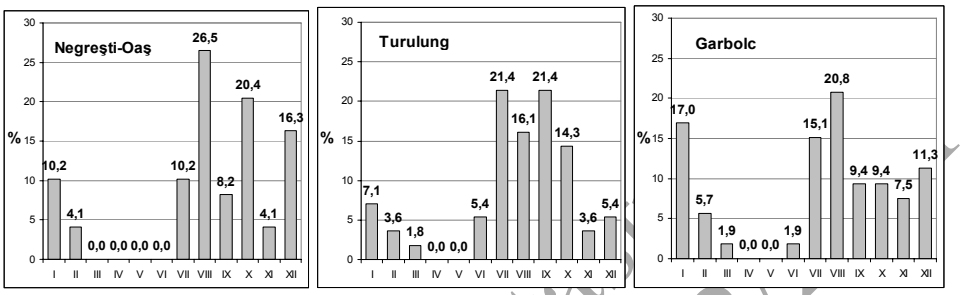

Figure 5 Seasonal frequencies of annual minima of daily mean flow

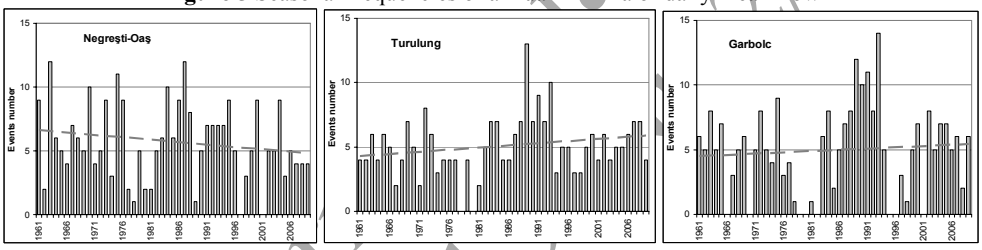

Figure 6. Annual number of low flow events below the threshold level.

In the analysed period at Negreşti-Oaş, with a small catchment area, there were 279 low water periods, on yearly average 5,7, maximum 12 (1963, 1987), at Turulung there were 247 low water periods, on yearly average 5,0, maximum 13 (1989), at Garbolc 247 low water periods occurred, on yearly average 5,0, maximum 14 (1989). At Csenger there were 199 low water periods, yearly, on average 3,4, maximum 11 (in 1991). On the section at Negreşti-Oaş there were 2 years with such rich flow, when did not occur any low water period below threshold (1997, 2001). At Turulung in 2 years (1978, 1980), at Garbolc in 8 years (1966, 1970, 1979, 1980, 1982, 1995, 1996, 2001). At Negreşti-Oaş the linear trend of annual number of cases is decreasing, while it is increasing at Turulung and Garbolc, due to the outlet waves in reservoir caused by interruptions (Figure 6).

At Negreşti-Oaş gauge **the annual numbers of days (in calendar years) with discharges below the threshold** totalled 3115 during 49 years. This value fluctuates between 0 and 177 days (1961), the many years average is 63,6 days/year. At Turulung the number of days totalled 4537, it fluctuated between 0

and 184 days (1961), the many year average is 88,2 days/year. At Garbolc the number of days with discharges below the threshold totalled 4146, it fluctuated between 0 and 196 days/year, the many years average is 82,4 days/year. Low water days exceeding 150 days/year occurred 6 times at Negreşti-Oaş, 7 times at Turulung, 7 times at Garbolc. Accordingly, at Negreşti-Oaş the annual number of flow events below threshold was maximum 48,4 % of days, and 17,4 % if we consider the total of days in the whole period, at Turulung 50,4 % and 25,4%, at Garbolc 53,7 % and 23,2 %. The time series composed by the annual number of days does not indicate any definite trend to any section (Figure 7).

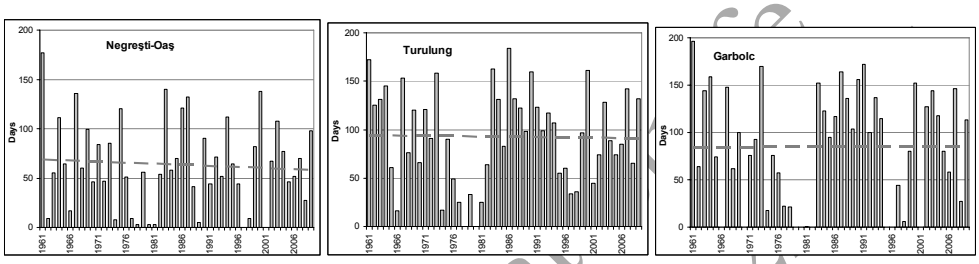

Figure 7. Day number of low water events, days below the threshold (Q_0).

When defining the **annual length of the low water periods with discharges below threshold**, so when summarizing the days, it was not taken into account the interruptions of maximum 1 day at Negreşti-Oaş and three days at Turulung and Garbolc occurred in the low water periods. In this case, at Negreşti-Oaş can be indicated low water periods with a length between 0 days/year and 181 days/year (1961), At Turulung between 0 days/year (1986) and 192 days/year, at Garbolc 199 days/year is the maximum value.

We also analysed the development of the length of the **annual longest uninterrupted low water periods.** Their length was maximum 102 days/ 17/08/1983-26/11/1983 (Negreşti-Oaş), 160 days/ 20/06/1961 (Turulung), and 141 days/ 17/08/1983-04/01/1984 (Garbolc).

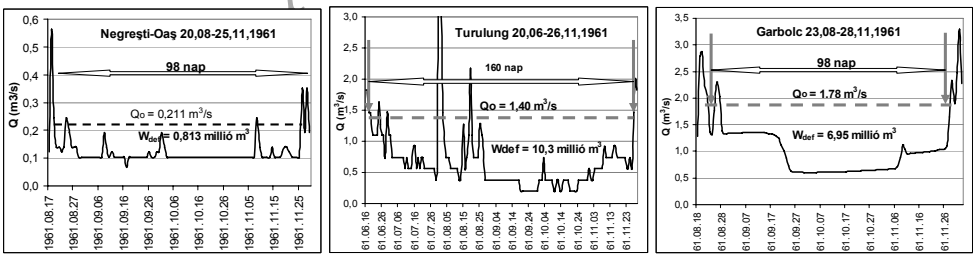

Figure 8. Low flow periods at Negreşti-Oaş, Turulung and Garbolc in 1961 and illustration of streamflow deficit (W) below the threshold flow rate.

The accumulation of **water mass deficit** in the low water periods indicates the difference between the flowed water in the days with discharges below threshold compared to the value of the water that would have flowed in case of adequate flow. In the figure presenting the example of the longest uninterrupted low water period in 1961 (Figure 8), besides the daily mean flow values, dashed lines indicate the streamflow threshold (Q0), it is selected the start and the end, the length (number of days) of period, as well as the calculated total water deficit (W_{def}) in million m^3.

On the Tur section at Negreşti-Oaş the many years average of run-off water is 29,2 millions m^3/year, the many years mean water deficit is 0,394 millions m^3. Here the highest total of water mass deficits were 1,68 millions m^3 in 1983, 1,38 millions m^3 in 1961, 1,07 millions m^3 in 1987 and 2003. The annual water deficit four times exceeded 1 million m^3, and in 11 cases the 0,5 million m^3. At Turulung the many years average run-off is 325 million m^3/year, the many years mean total of water deficit is 3,89 million m^3. The highest total of annual water deficit was 13,8 million m^3 in 1962, 11,1 million m^3 in 1961, 8,20 million m^3 in 1990. The annual water deficit exceeded 10 million m^3 in 2 cases and 5 million m^3 in 17 cases. At Garbolc the many years average of run-off water is 334 million m^3/year, the many years total of annual water deficit is 4,29 million m^3. The highest total of annual water deficit was 13,5 million m^3 in 1991, 13,1 million m^3 in 1988, 11,8 million m^3 in 1964. The annual water deficit exceeded 10 million m^3 in 4 cases, and 5 million m^3 in 5 cases.

Analyzing the **water deficit in cotinuous low flow periods with maximum duration**, we established that at Tur Negreşti-Oaş gauge water deficit periods exceeding ,5 million m^3 occurred in seven cases and within these, in one case it exceeded 1,0 million m^3. The three highest water deficits: 17/08/1983-26/11/1983 (102 days) – 1,28 millions m^3, 20/08/1961-28/11/1961 (98 days) – 0,813 million m^3; 07/07/2009 (67 days) – 0,796 million m^3. The highest daily water deficit was 17.539 m^3/in 28,29/08/2003. At the Turulung gauge on Tur, there were seven periods with water deficit exceeding 5 million m^3 and within these two periods with water deficit exceeding 10 million m^3. The three highest water deficits: 03/08/1962-19/11/1962 (109 days) – 11,5 million m^3, 20/06/1961-26/11/1961 (160 days) – 10,3 million m^3; 02/07/1967-05/12/1967 (156 days) – 8,11 million m^3. In these extremely low water periods the highest daily water deficit was 112.666 m^3/ in 07/08/1990. At Túr Garbolc gauge there were eight periods with water deficits exceeding 5 million m^3 but there did not occurred any value exceeding 10 million m^3. The three most prominent: 24/05/2003-04/10/2003 (134 days) – 7,29 million m^3, 23/08/1961-28/11/1961 (98 days) – 6,95 million m^3; 23/07/2009-20/10/2009 (90 days) – 6,30 million m^3. In these extremely low water periods the highest daily water deficit was 146.880 m^3 in 21/08/1988.

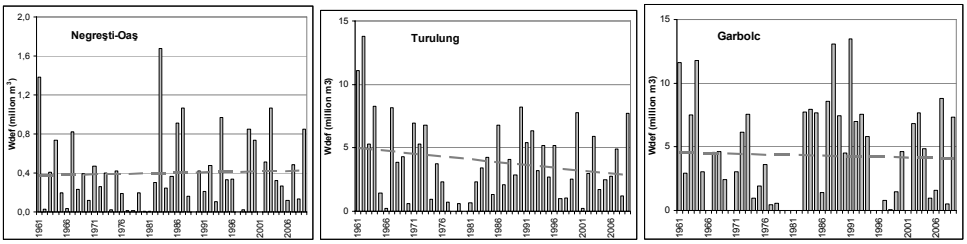

Figure 9. Annual streamflow deficit at Tur Negreşti-Oaş, Turulung and Garbolc.

On the basis of the figures presenting the time series (1961-2009) of the annual total water deficit calculated for the three gauging sections on the Tur (Figure 9) it can be established that these values indicate clear decrease at Turulung, smaller decrease at Garbolc, but they do not indicate significant tendencies at Negreşti-Oaş gauge. These differences indicate the impact of the Călineşti-Oaş reservoir on the low water flows.

The water deficit in low water periods is significantly influenced by the duration of periods. At the three hydrographical stations between the two parameters established in annual frequency, the graphical co relational connection indicates a close polynomial-type relation (Figure 10).

The main hydrological statistical characteristics of low streamflows of Tur in the period 1961-2009 are summarized in Table 3.

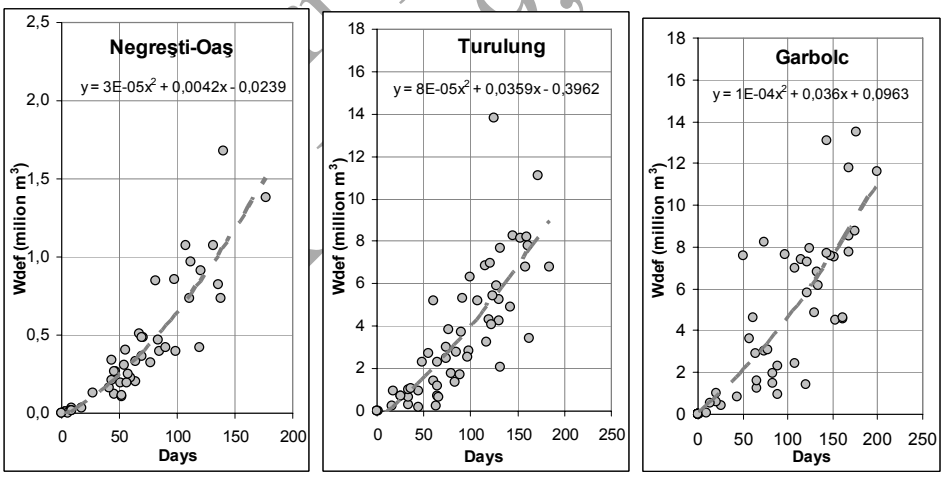

Figure 10. The relation between the annual water deficits in low water periods and the number of annual low water days.

Table 3. Characteristic discharges in extreme low water years at three Hydrometric station on Tur stream

Q_{min} [m^3s^{-1}]		$Q_{min\ day}$ [m^3s^{-1}]		Duration of low flow periods below Q_0 [day]		Number of low flow events, below Q_0 [-]		Annual streamflow deficit $W_{def\ a}$ [million m^3]	
Mean	**Minima**	**Mean**	**Minima**	**Mean**	**Maxima**	**Mean**	**Maxima**	**Mean**	**Maxima**
Negreşti-Oaş									
0,093	0,008/03	0,105	0,008/03	65,2	181/61	5,7	12/87	0,394	1,68/83
Turulung									
0,479	0,069/90	0,519	0,096/90	88,2/86	192/86	5,1	13/89	3,60	13,8/62
Garbolc									
0,907	0,099/88	0,963	0,111/88	84,8/61	199/61	5,0	14/93	4,19	13,5/91

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