AN ANALYSIS OF HIGH FLOWS FROM STREAM HYDROGRAPHS OF IALOMITA RIVER AT TARGOVISTE GAUGE STATION

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Abstract
The paper presents the analysis of 6 consecutive high flows using data from stream hydrographs of Ialomita River recorded at Targoviste gauge station between 2007 and 2009. The main purpose of hydrographs separation and trend analysis was to extract informative coefficients, to support the calibration and sensitivity analysis of simulation routines performed with SWAT model. Each episode had two time series i.e., H (cm) and Q (m^3 s^{-1}), which were statistically analyzed for central tendency, dispersion, and distribution. The baseflow was separated using data processing and filtering procedures. The recession constants (k) were derived from the slope of the recession curves and the lag time interval t. Another digital filter, based on frequency analysis, was applied to smooth hydrographic data. There were differences between spring and autumn high flows' episodes concerning the corresponding rainfall quantities and duration. Spring high flows had longer durations and the associated rainfall quantities were lower than autumn ones. The analyzed time series had a duration that ranged from 96 to 264 hours with a mean between 23.8 and 88.5 m^3 s^{-1}. The maximum values varied from 84 to 274 m^3 s^{-1}, while the minimum value ranged from 4.5 to 9.1 m^3 s^{-1}. The non-parametric trend estimator was applied for each time series and the results were integrated into a single flow-probability curve, which was fitted by a log-normal function ($p<0.05$).

Keywords: high flow, stream hydrograph, baseflow, trend analysis, recession curve

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1. INTRODUCTION

In the context of global climate changes, atypical and dangerous weather episodes with high intensities have been recorded in Romania in the recent past years. Although in the last four decades important floods did not occur in the majority of river basins, in 2005, high flows were the most significant as time, flow, and level in the last 100 years. The floods affected wider areas as compared to the precedent important floods from 1970, respectively 1975. In 2005, six extreme floods with a probability of occurrence between 1% and 0.5% (*ANAR, 2013*) occurred in Timis and Bega basins (April); Arges and Olt basins (June); Trotus and Inferior Siret basins (July); Superior Siret basin (August); Ialomita and Dambovita basins (September); and the hydrographic basins from the Banat area (December).

In the last few years, the negative effects of the dangerous hydro-meteorological processes were amplified by the massive deforestations, which have conducted to quick accumulations of the streamflow on the slopes determining excessive soil erosions, landslides, and significant alluvial materials transport in streams or arable lands. Streamflow is the main mechanism by which water moves from the land to the seas and oceans. Streamflow, or channel runoff, is the flow of water in streams, rivers, and other channels, and is a major element of the water cycle. It is one component of the water runoff from the land to water bodies, the other component being the surface runoff (*Fetter, 1994*). Water flowing in channels comes from surface runoff from adjacent hill slopes, from groundwater flowing out of the ground, and from water discharged from sewages and other discharging points. Flooding occurs when the volume of water exceeds the channel capacity. As natural processes with accentuated anthropogenetic influence, flood may occur periodically, in the phase of annual overflows and randomly, in any hydrological intervals, because of the strong and quick risings of the flows and levels (flash flows). The most dangerous floods have resulted from exceptional (catastrophic) high flows that occur once in 100-1000 years.

The flood risk is characterized by the nature and the probability of occurrence, the degree of receptors exposure (the number of inhabitants, goods and assets value), the susceptibility to floods of the receptors, resulting that for reducing the risk it is important to act on the abovementioned characteristics. The information on the timing and magnitude of floods is required in many practical applications of water resources engineering (*Cunderlik and Ouarda, 2009*) for local, seasonal and regional flood frequency analyses required in engineering design, in reservoir management, and operation of water infrastructure (*Ouarda et al., 2006*).

Many studies have been focusing worldwide on establishing trends of the intensity of annual extreme floods in basins ranging from medium to large scale (*Gratiot et al., 2010; Petrow and Merz, 2009; Whitfield et al., 2003; Douglas et al., 2000*). The impact of climate change and human induced environmental changes on water runoff in the watershed were quantified using long-term hydro-meteorological time series. Trend detection was often established using non-parametric methods such as the rank-based Mann-Kendall test (*Mann, 1945; Kendall, 1975*) for gradual trends, and the trend estimator (*Sen, 1968*) for magnitude of trends.

The paper presents the analysis of 6 consecutive high flows using data from stream hydrographs of Ialomita River recorded at Targoviste gauge station between 2007 and 2009. The main purpose of hydrographs separation and trend analysis was to extract informative coefficients, to support the calibration and sensitivity analysis of simulation routines performed with SWAT model (*Dunea et al., 2013*), which are expected to improve the high flows approach in the model for this part of the watershed.

2. MATERIAL AND METHODS

2.1 Study area – Superior Ialomita hydrographical basin

In Romania, water bodies have been surveyed, classified, and encoded in the work “Water cadastre”. The process started from early 1958, considering the rivers that had in the mountain area a catchment of 10 km^2 and 50 km^2 in the plain area. Water Cadastral Atlases of Romanian waterways were edited in 1964 and 1993, with several volumes of texts, tables and maps (*Ministry of the Environment, Aquaproiect S.A, 1992*).

Consequently, over 4864 watercourses were registered with a total length of 78.905 km and were drawn on 1:200.000 maps. In some catchment basins, there were considered even 4 and 5 order affluents. Each watercourse detains a cadastral code that allows its identification. A number of 13 major catchment basins were delineated based on their discharging flow in the Danube River. One of these catchments is Ialomița River watershed with a reception area of 10,350 km^2 (4.34% of Romania’s total area). The length is 417 km with a sinuosity coefficient of 1.88.

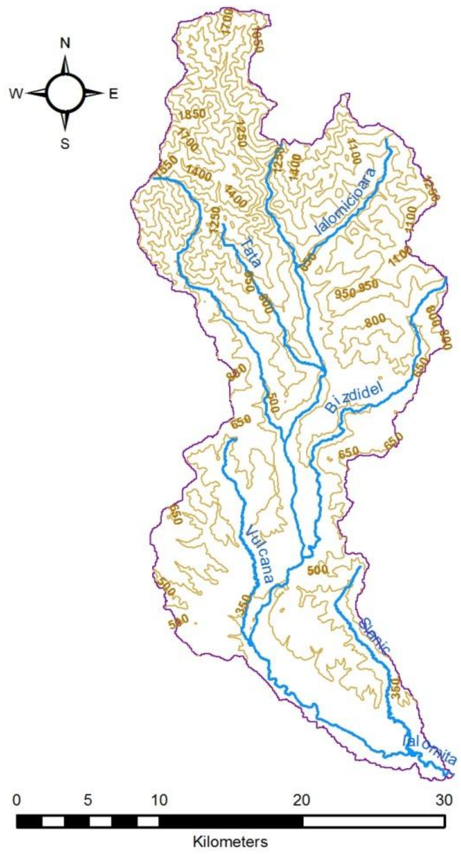

Fig. 1 The area of draining considering Targoviste gauge station as outlet situated in the Superior Ialomita River hydrographical subbasin (km 83 of the river); slope contours with 150 m equidistance.

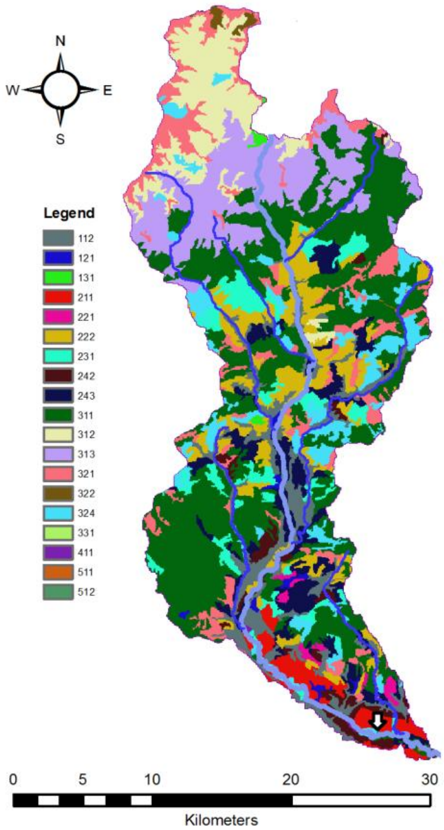

Fig. 2 The area of draining of the Superior Ialomita River hydrographical basin; Legend – numbers represents Corine Land Cover categories; Arrow points out the position of Targoviste Gauge Station.

Ialomita River has 142 encoded tributaries and a hydrographical density of 0.30 km km^{-2}.

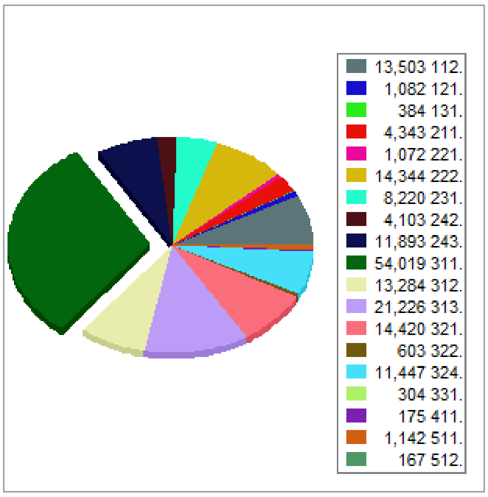

Fig. 3 Land cover distribution in the study area classified using Corine Land Cover categories; legend presents areas (ha) and corresponding Corine codes.

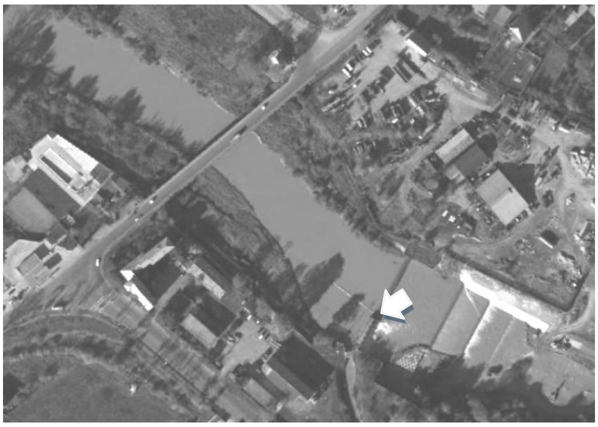

Fig. 4 Location of the Târgoviște gauge station (Stereo 1970 coordinates X – 381393.22 and Y – 537766.09 m) – *geoportal.ancpi.ro*

The average altitude varies from 327 m to 42 m at the confluence with an average slope of 15 ‰ (*Dunea et al., 2013*). The area of study envisaged the superior part of the watershed (fig.1) starting from Northern mountains to the location of the Targoviste gauge (km 83 of the river), which was considered as outlet.

Table 1 Main physiographical and hydrological characteristics of the Ialomita River Basin at various gauge stations in Dambovita County

Gauge Station		Moroeni	**Targoviste**	Baleni
River length	(km)	43	**83**	106
Area	(km^2)	264	**686**	901
Altitude	(mdM)	1359	**909**	761
Multi-annual Average Flow	(m^3 s^{-1})	5.16	**7.81**	9.17
Monthly Flow (m^3 s^{-1}) with insurance:	80%	1.51	**2.93**	3.6
	90%	0.99	**1.96**	2.35
	95%	0.47	**0.995**	1.1

The multiannual average flow of Ialomita River increases from 1 m^3 s^{-1} in the mountainous area (Bolboci) to 7.81 m^3 s^{-1} at Targoviste gauge station (table 1).

Figure 2 shows the land cover in the area of study classified using Corine Land Cover categories. The thematic map is useful to observe the human influence resulted from specific activities (e.g. agricultural practices, forestry operations, etc.).

Several water facilities (dams and water treatment plants) have influence on the water discharge parameters and on the water quality.

In the study area, land cover was classified using Corine Land Cover categories resulting the first four most important land utilizations (fig.3) such as forestry (42.82%), grasslands (8.21%), orchards (8.16%) and urban with low density population (7.68%).

The most important urban area is Targoviste City with a population of approx. 74,000 inhabitants, having a centralized water supply and sanitation system, which discharge treated effluents in Ialomita River downstream of gauge station. The gauge station is located in the Northeast part of the town (fig.4).

2.2 Data and methods

Six consecutive high flows were considered for the trend analysis using data from stream hydrographs of Ialomita River recorded at Targoviste gauge station between 2007 and 2009.

The high flows occurred in the following intervals: March 22-28 and October 22-26 in 2007, April 14-20 and September 15-20 in 2008, and March 5-16 and October 19-23 in 2009.

Figure 5 presents the time series of each high flow ($m^3\ s^{-1}$) using an hourly scale.

Table 2 Rainfalls (mm) cumulated at decadal intervals in the month with the corresponding high flows episode recorded at Targoviste meteorological station (WMO id 153750)

Month/ year	Decade			Total	No. of days	High flows episode
	I	II	III			
March-07	-	-	-	-	-	March 22-28
Oct-07	3.4	14.4	95	112.8	13	October 22-26
Apr-08	32.4	45.7	32.9	110	14	April 14-20
Sep-08	1.2	68.8	11.2	81.2	9	Sep. 15-20
Mar-09	44.5	9.8	7.1	61.4	9	March 5-16
Oct-09	20.4	61.4	14.4	96.2	13	October 19-23

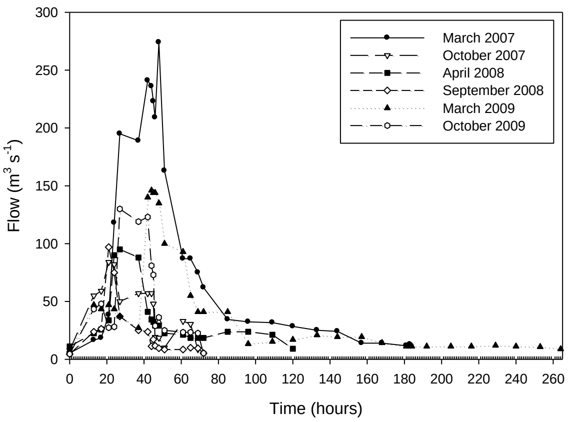

Fig. 5 The time series of 6 high flows recorded at Targoviste gauge station between 2007 and 2009

Table 2 shows the rainfall regime on month decades associated to the high flow episodes (excepting March 22-28, 2007) for a better understanding of the baseflow characteristics at Targoviste gauge station. The number of days with precipitations is also presented.

Each episode had two time series i.e., *H* (cm) and *Q* ($m^3\ s^{-1}$), which were statistically analyzed for central tendency, dispersion, and distribution. Because time series had different lengths, geometrical means were also computed to allow comparisons.

Furthermore, the signal to noise ratio, defined in decibels, provided complementary information about the time series specificity (equation 1).

$$S/N = 20\ log\left(\frac{\mu}{\sigma}\right) \quad (1)$$

Stream hydrographs are the time-series record of stream conditions (i.e., water level or flow) at a gauging site having two components – quickflow (mainly resulting from rainfall events) and baseflow (long-term discharge from natural storages) (*Brodie and Hostetler*, *2005*).

The baseflow as a component of the streamflow time series was separated using data processing and filtering procedures.

The algorithm of *Chapman and Maxwell* (1996) was used (equation 2).

The high-frequency quickflow signal removal and the deriving of the low-frequency baseflow signal are possible by using recursive digital filters, which are routine tools in signal analysis and processing (*Nathan and McMahon 1990*).

$$q_{b(i)} = \frac{k}{2-k} q_{b(i-1)} + \frac{1-k}{2-k} q_{(i)} \quad (2)$$

where,

$q_{(i)}$ - original streamflow for the i^{th} sampling instant;

$q_{b(i)}$ - filtered baseflow response for the i^{th} sampling instant;

$q_{b(i-1)}$ - filtered baseflow response for the previous sampling instant to i;

k - filter parameter given by the recession constant.

The recession constants (k) were derived from the slope of the recession curves and the lag time interval t (equation 3)

$$k = \left(\frac{Q}{Q_0}\right)^{1/t} \quad (3)$$

where,

Q - current flow;

Q_0 - initial stream flow at the start of the recession segment;

t - lag time interval.

Another digital filter, based on frequency analysis, was applied to smooth hydrographic data and to generate flow duration curves (equation 4).

Equation 4 provides the probability p that a given flow might be equaled or exceeded.

$$p = 100 \frac{m}{n+1} \quad (4)$$

where,

p - probability (%);

m - ranking number to each flow, starting with 1 for the maximum flow to n for the minimum flow;

n - the number of flow measurements.

A log-normal plot typically presents the flow-probability relationship (*Fetter, 1994*).

The trend of resulted flow distribution curves was estimated using the non-parametric trend estimator (*Sen*, *1968*) for magnitude of trends (equation 5).

$$\beta = median\left[\frac{x_j - x_i}{j-i}\right] \quad i < j \quad (5)$$

where,

β - median of all pair wise slopes in time series;

x_i - data points measured at times i;

x_j - data points measured at times j.

Table 3 Descriptive indicators of the high flows trends using data from stream hydrographs of Ialomita River recorded at Targoviste gauge station between 2007 and 2009

Episode	March 22-28, 2007		October 22-26, 2007		April 14-20, 2008		September 15-20, 2008		March 5-16, 2009		October 19-23, 2009	
Descriptor	H (cm)	Q (m^3/s)	H (cm)	Q (m^3/s)	H (cm)	Q (m^3/s)	H (cm)	Q (m^3/s)	H (cm)	Q (m^3/s)	H (cm)	Q (m^3/s)
Hours (Valid n)	155(28)	155(28)	96(16)	96(16)	156(21)	156(21)	120(17)	120(17)	264(35)	264(35)	110(17)	110(17)
Mean (μ)	314.8	88.5	271.8	42.3	261.2	33.8	244.8	23.8	273.1	44.6	291.4	49.5
Geometrical mean	304.2	49.1	270.0	33.4	259.8	27.8	242.9	16.2	269.1	28.3	287.1	34.5
Median	272	36.4	284	49	250	23.8	230.0	11.7	250	21	278.0	28.9
Maximum	476	274	319	84	330	95	332.0	97.0	380	146	365.0	130.0
Minimum	213	5.36	222	7.7	226	9.1	212.0	4.5	220	7.68	215.0	4.6
Std. Deviation (σ)	86.4	88.2	31.8	24.8	29.4	25.1	33.1	25.4	50.3	45.8	51.6	40.7
Coeff. of variation	27.5	99.7	11.7	58.6	11.3	74.3	13.5	106.7	18.4	102.6	17.7	82.2
Skewness	0.7	0.9	-0.3	0.1	1.5	1.8	1.6	2.2	1.2	1.4	0.2	1.1
Kurtosis	-1.1	-0.8	-1.1	-1.0	1.6	2.2	2.4	4.3	0.2	0.6	-1.3	-0.1
S/N ratio	11.2	0.0	18.6	4.6	19.0	2.6	17.4	-0.6	14.7	-0.2	15.0	1.7

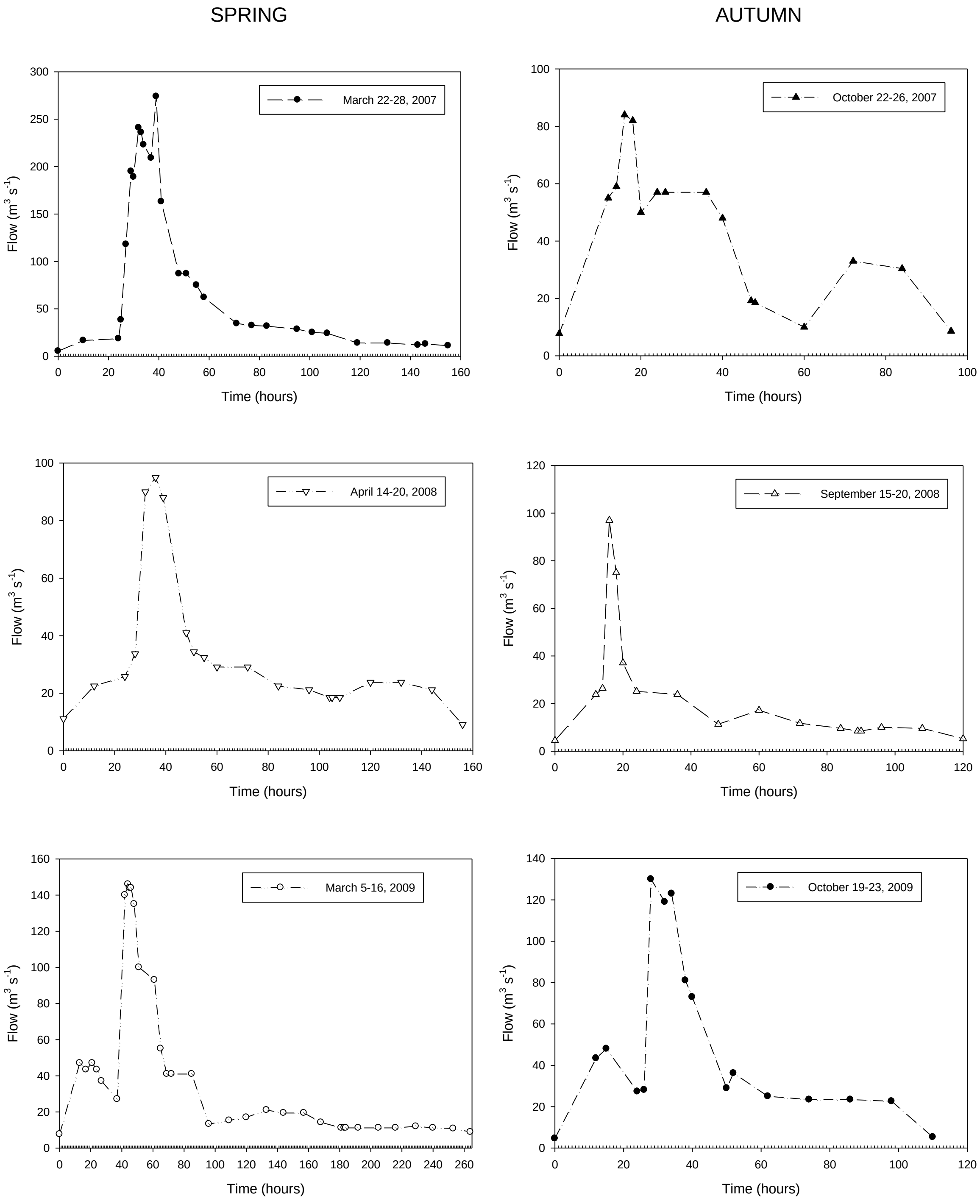

Fig. 6 Individual pattern of the time series showing the flood hydrograph

3. RESULTS AND DISCUSSIONS

We have observed an increase in streamflow with input of quickflow dominated by runoff and interflow due to contributing rainfall. There were differences between spring and autumn high flows' episodes concerning the corresponding rainfall quantities and duration. Spring high flows had longer durations and the associated rainfall quantities were lower than autumn ones. An explanation is the contribution of snowmelt from the mountains in spring. In Germany, the seasonal analysis revealed larger changes for winter compared to summer and the fact that flood behavior is climate-driven (*Petrow and Merz, 2009*).

Figure 6 presents the individual pattern of each high flow time series showing the flood hydrograph. The time series initiated the rising limb towards the crest of the flood hydrograph. The quickflow component eventually passed, expressed by the falling limb. The baseflow returned along the falling limb after quickflow ceased in the same way for almost all analyzed episodes. One exception was observed for October 2007 episode, which showed two recharge events due to rainfall contribution. This high flow had the shortest duration (96 hours).

The statistical analysis provided the descriptive characterization of each high flow event based on *H* (cm) and *Q* (m^3 s^{-1}). The main descriptive indicators are presented in table 3. Concerning the flow (*Q*), the analyzed time series had a duration that ranged from 96 to 264 hours with a mean between 23.8 (September 2008) and 88.5 m^3 s^{-1} (March 2007). The maximum values varied from 84 (October 2007) to 274 m^3 s^{-1} (March 2007), while the minimum value ranged from 4.5 (September 2008) to 9.1 m^3 s^{-1} (April 2008). Coefficient of variation varied from 58.6 (October 2007) to 106.7% (September 2008). Data from October 2007 were less dispersed because of the recharging events. Distributions of time series were normal and left skewed (positive asymmetric distribution) having skewness coefficients that ranged from 0.1 to 2.2. Most of time series presented a platikurtic distribution excepting September 2008 with a leptokurtic one.

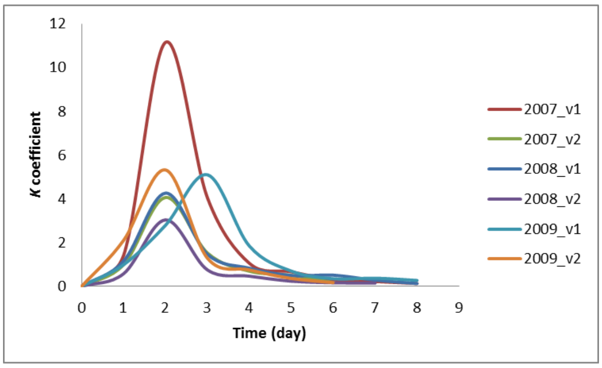

Fig. 7 Recession curves for each hydrograph (computation of the recession constants - *k*)

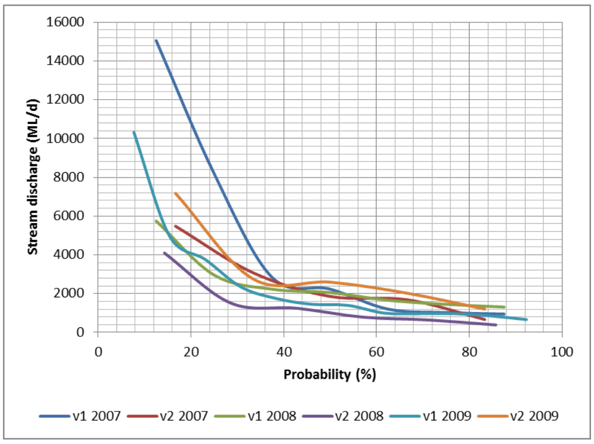

Fig. 8 Flow distribution curves of the stream discharge (ML/day) at Targoviste gauge station

S/N ratio showed several values greater than 0 dB indicating more signal than noise, but also a value of 0 and two negative ones (September 2008 and March 2009). These two series presented the most abrupt falling limb. Geometrical means adjusted the central tendency according to time series length, showing values between 16.2 (September 2008) and 49.1 m^3 s^{-1} (October 2007).

Recession curves, which are specific parts of the stream hydrograph after the crest due to the rainfall event, were built using equations 2 and 3. Figure 7 presents the recession curves for each episode of high flow. Application of the multiple comparison procedure (Fisher's LSD test) to determine which means of the recession curves are significantly different from which others showed no statistically significant differences ($p<0.05$). This suggests that the resulted curves belong to one homogenous group, despite some differences in amplitude (October 2007) and length (March 2009).

Recession behavior is time-dependent determining modifications of the curve shape. The main responsible factors are rainfall distribution, residual storage in connected surface water bodies, watershed wetness, saturated aquifer thickness, or depth of stream penetration into the aquifer (*Brodie and Hostetler, 2005*). Seasonal effects such as variations in rainfall and evapotranspiration also influence baseflows.

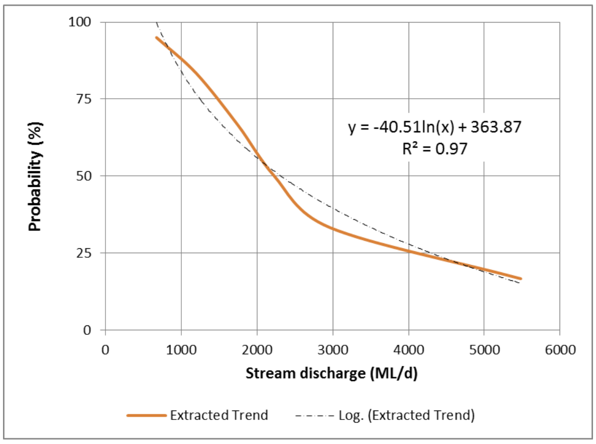

Fig. 9 Extracted flow-probability relationship using trend slope estimator (Sen, 1968)

Hydrographic data were smoothed to generate flow duration curves using equation 4. Figure 8 shows the resulted flow distribution curves of the stream discharge (ML/day) for each analyzed high flow at Targoviste gauge station. The non-parametric trend estimator (equation 5) was applied for each time series and the results were integrated into a single flow-probability curve (fig.9). A log-normal plot had fitted the resulted plot ($p<0.05$).

4. CONCLUSIONS

The results contribute to the studies regarding flood forecasting and flood risk assessments. Extracted indicators will be used to improve hydrological modeling and simulation performed with SWAT model in Ialomita watershed. It is expected that such system will support the emergent knowledge of the possible flood dangers, the efficient operational management, and the population education, which might lead to the reduction of the vulnerability in the envisaged perimeter and to diminish the negative effect of floods in the Ialomita River watershed.

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