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Assessment of the Flow Regime Alterations in the Veleka River, Bulgaria

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Abstract: ***The aim of the present study was to characterise the natural flow regime of the Veleka River to determine the extent of its alteration and to design environmental flow regimes to protect aquatic habitats and species. A method for hydrologic alteration estimation has been examined and applied to characterize and evaluate the hydrologic alteration of the Veleka River flow regime using streamflow series. The region in concern belongs to the South Eastern climate and is mainly transitional Mediterranean climate. In the study area there are not hydrological perturbations. The used method, referred to as the "Indicators of Hydrologic Alteration" is based upon an analysis of hydrologic data available from existing measurement points. The hydrological status of the Veleka River was assessed by comparing the two periods. The most significant results suggest changes in low-flows. The current flow regime shows a significant reduction of stream flows. From this study we conclude that the indicators of hydrologic alteration proved to be a useful approach, capable of focusing, comparing and establishing levels of hydrologic disturbances.***

Keywords: River Flow Regime, Indicators of Hydrologic Alteration, Reference Conditions, Veleka River.

1. Introduction

In recent decades, the importance of natural hydrological regimes in maintaining the integrity of rivers has been widely recognized [1, 2, 3]. The natural regime defines the hydrological variability pattern and reflects the interaction between the climatic regime (precipitation and temperature) and the basin characteristics that regulate runoff (geomorphology, geology and vegetation). The structure and function of river ecosystems are strongly affected by natural flow regimes because the biota is adapted to its components. These components are defined as: magnitude, frequency, duration, rate of change and predictability of flow events [4]. The relevance of the hydrological regime is recognized by the Water Framework Directive (WFD) (EC, 2000) [5], which explicitly defines the hydro-morphological aspects as quality elements that must be used for the assessment of ecological status/potential. However, as a determinant of ecological status, the hydro-morphological quality elements are fixed only at *High Quality Status*, while, for other status classes, the hydromorphological elements are required to have "conditions consistent with the achievement of the values specified for the biological quality elements" (CIS, 2003) [6]. The hydrological regime of a water body is part of the hydro-morphological quality elements (Annex V, WFD). The revised text of the Bulgarian Water Law, which implements WFD, explicitly states that Basin Management Plans must include the environmental flow regime for each body of water, with priority given to protected zones. The environmental flow regimes will be necessary "to maintain or re-establish the proper state of conservation of habitats or species, meeting their ecological requirements and maintaining the long-term ecological functions they depend on". Additionally, the ecological flow regime must include the time distribution of maximum and minimum flows, flood and drought flows and the rates of flow change. The aim of the present study was to characterise the natural flow regimes of the Veleka River to determine the extent of its alteration and to design environmental flow regimes to protect aquatic habitats and species.

2. Materials and Methods

The watershed of Veleka River is situated in the Strandzha Mountain in South Eastern part of Bulgaria and covers an area of 1054.6 km^2 of which 266.6 km^2 are located in the territory of Turkey. It includes the natural park "Strandzha" which is one of the bigger protected territories in Bulgaria. The Veleka River flows into Black sea, near the village of Sinemorets and crosses Strandzha Mountain. The topography is characterized as a moderately mountainous area (Fig. 1). The region in concern is a very rural area. The forest types are broadleaf (92%) and coniferous (8%).

According to the climatic classification, the watershed of Veleka River belongs to the Black sea climate sub-type of the continental Mediterranean climate type. The climate is generated from west and north continental influence, Black Sea influence from east and Mediterranean influence from south. The Strandzha climate is mainly transitional Mediterranean climate. Local climatic differences are due, above all, to the proximity of the Black sea, which warms up the coastal zone in winter and cools it especially in spring. The precipitation features depend on atmospheric circulation and orography. The average annual precipitation is above 600 mm for the coastal region and in the inner part above 900 mm. The winter precipitation (with seasonal precipitation about 150-271 mm) is the highest precipitation in the South-Eastern part of Bulgaria. During the winter the predominant precipitation is in the form of rain, but about one third of cases the precipitation is snow. The snow cover is of short duration (15-16 days per year). During the spring the mean seasonal amounts of precipitation are 120-180 mm. In summer is sunny, dry and very warm, the amounts of precipitation are 100-120 mm and from June to the middle of September is dry. The drought period is very noticeable in the end of summer when the precipitation for August is 30 mm. Hydrological perturbations associated with water abstractions, point discharges and the presence of a dam there are not in the study area.

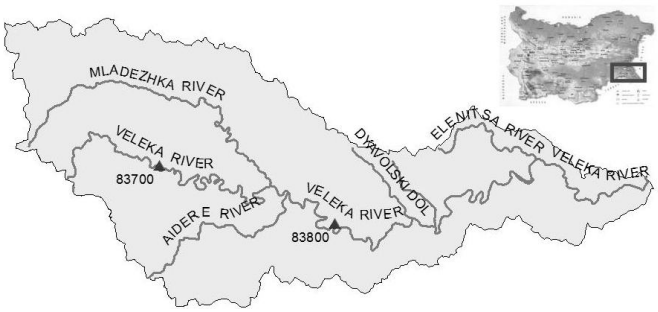

Figure 1: The Veleka River basin with gauging stations

To characterize the hydrological regime is necessary to have recorded data for both natural and altered (modified) regime for at least fifteen full years of daily water discharges or monthly streamflow; although in the latter case, the parameters used for the characterization of the hydrological regime will obviously be less. The hydrological characterization of the Veleka River was based on the series of monthly mean flow rates gathered from the National Institute of Meteorology and Hydrology (NIMH) for the period 1961-2007 at the gauging station Zvezdets. The hydrological conditions of Veleka River is assessed by comparing the two periods, representing the regime of the reference period (1961-1990) recommended by the World Meteorological Organization and the period of the last current year (1991-2007). During these periods in the studied river has not been established hydrological alterations that are associated with anthropogenic pressures, such as dams, point source discharges, surface water abstractions, and hydropower.

In this study are applied the Indicators of Hydrologic Alteration in Rivers, which are based on Richter's ideas [3, 7]. These indicators summarize the main characteristics of the hydrologic regime, allowing the comparison between natural and modified conditions [8]. Five components are generally used to describe the flow regime: magnitude of discharge (amount of water moving past a fixed location per time unit), frequency (refers to how often a flow above a given magnitude recurs over some specified time intervals), duration (period of time associated with a specific flow condition), timing (regularity with which flows of defined magnitude occur) and rate of change (refers to how quickly flow changes from one magnitude to another) [2]. Modification in these flow components has effects on the ecological integrity of rivers.

Several metrics (also called hydrological descriptors or indicators) have been developed for characterizing the patterns of river flow, and specific hydrological components, which have a direct or indirect influence on biological communities [9]. A general approach for hydrological alteration assessment is based on the analysis of these metrics, which are compared before and after a river has been altered by human activities [3]. This methodology, as well as other methods generally used to analyse the status variations within a system over time, or to compare an altered system to a reference system, are based on streamflow data, which are referred to as un-impacted and impacted conditions. Both as the reference period regime (period 1961-1990) and the regime of last current years (period 1991-2007) were analyzed through the computer application IAHRIS [8], by means of which are calculated as the parameters characterizing both regimes, and hydrological indicators that assess the extent of alteration.

3. Results and Discussions

To describe the natural flow regime and evaluate the degree of alteration, the Indicators of Hydrological Alteration in Rivers were used via the IAHRIS software. This software calculates 24 hydrologic metrics (7 for habitual flows, 9 for high flows and 8 for low flows) that adequately describe the hydrologic regime of Mediterranean streams. The degree of alteration in each indicator (0: maximum alteration, 1: minimum alteration) is established by dividing its value in regulated conditions by the indicator value in natural conditions. Considering that only have a monthly values of river flow, rather than daily data, will be characterized the flow regime by assessing the parameters for magnitude, variability and seasonality. Before proceeding to the study of habitual values of the flow regime is required to characterize the annual variability. This characterization is aimed at determining the annual volume thresholds of river flow in order to segregate each year into one of three types of years: wet, dry or normal. To determine the thresholds for "wet", "normal" and "dry" years of runoff volumes as limits are used respectively 25% and 75% percentiles (Fig. 2). Multi-annual variability in river flow volumes of the Veleka River are presented in Figure 2 below.

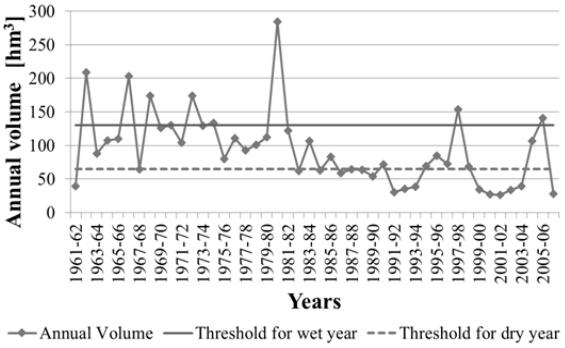

Figure 2: Multi-annual variability in river flow volumes (hm^3) of the Veleka River at Zvezdets

In Figure 2 can be seen, the magnitude and inter-annual variability of annual flow volumes. As regards the amount of annual flow volumes, one can see the great amplitude (range) of variability from about 26 to 285 hm^3, with alternating periods with years of significant flow volumes against very dry periods. The annual variability of the water volume for each annual type is shown in Figure 3.

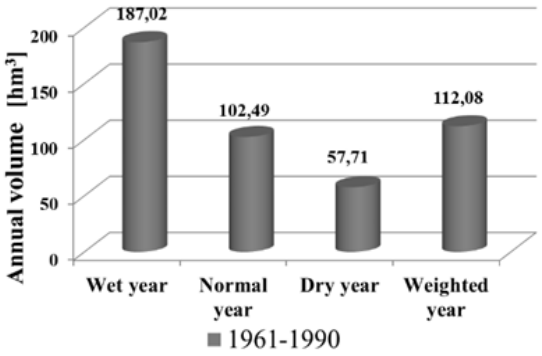

Figure 3: Magnitude of annual volumes for every type of year

The intra-annual variability of the water volumes during the reference period for every type of year is shown in Fig. 4. We can see that during the reference period, the largest flow volumes occur on January-April with maximum in March for wet and normal years, while for dry years the maximum occurs on February. The course of intra-annual variability over the past 16 years is the same.

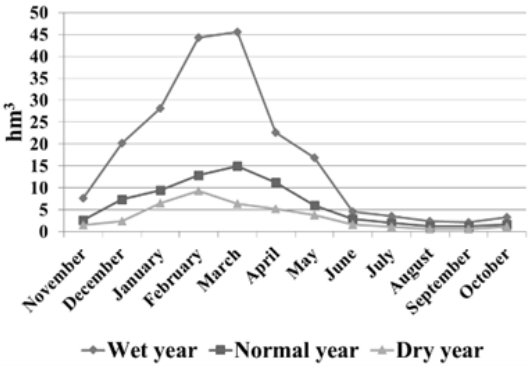

Figure 4: The intra-annual variability of the water volumes during the reference period (1961-1990)

The hydrological aspects of the flow regime with high environmentally significance (magnitude. variability and seasonality) for reference period are presented on Table 1. It can be seen average annual volumes but also the difference between maximum and minimum monthly volumes along the year and the month with the maximum and minimum water volume for each type of year (wet, normal, dry and weighted year). The weighted year represents the weighting percentage of each type of year in the series (25% for wet and dry years and 50% for normal years). Table 1 includes the results of the characterization of the natural flow regime of the river with respect to each of the obtained parameters and for each of the specified types years.

Table 1: Hydrological aspects of the flow regime for the period 1961-1990

Components of the natural regime		Aspect	Parameter		
			Description	Value (hm³)	
Habitual data	Monthly or annual volumes	Magnitude	Average of the annual volumes	Wet year	187.02
				Normal year	102.49
				Dry year	57.71
				Weighted year	112.08
		Variability	Difference between the maximum and the minimum monthly volume along the year	Wet year	72.31
				Normal year	29.59
				Dry year	14.90
				Weighted year	36.35
		Seasonality	Month with the maximum and minimum water volume along the year	Wet year	MAR; SEP
				Normal year	MAR; SEP
				Dry year	FEB; SEP

On Table 2 are given statistical parameters of the Veleka River at Zvezdets to characterize aspects of the flow regime for the period 1961-1990. These parameters are derived based on annual and monthly volumes river flow. The estimated parameters for the intra-annual distribution for the period 1961-1990 are presented in Table 3.

Table 2: Statistical parameters characterizing the flow regime of the Veleka River at Zvezdets

Components of the natural regime		Aspect	Parameter	
			Description	Value (hm³)
Habitual data	Annual Volumes	Magnitude	Average of annual volumes	112.08
			Median of annual volumes	106.67
			Coefficient of variation of annual volumes	0.49
	Monthly Volumes	Magnitude	Average of monthly volumes	See table 3
			Median of monthly volumes	See table 3
			Coefficient of variation of monthly volumes	See table 3
			Extreme variability	36.41
		Seasonality	Relative frequency of maximum for each month	See table 3
			Relative frequency of minimum for each month	See table 3

Table 3: Parameters to characterize the intra-annual distribution of natural flow regime

	Average (hm³)	Median (hm³)	Coef, of variation	Relative frequency of maximum	Relative frequency of minimum
Nov	16.33	10.15	0.77	0.17	0.00
Dec	25.96	15.81	1.14	0.31	0.00
Jan	20.76	14.92	0.69	0.31	0.00
Feb	13.03	11.19	0.56	0.03	0.00
Mar	8.20	5.97	0.63	0.03	0.00
Apr	3.26	2.90	0.44	0.00	0.00
May	2.20	1.97	0.66	0.00	0.03
Jun	3.15	1.23	2.69	0.03	0.34
Jul	1.52	1.24	0.77	0.00	0.45
Aug	2.65	1.58	1.55	0.00	0.07
Sep	4.21	2.59	1.04	0.00	0.10
Oct	10.81	7.34	1.31	0.10	0.00

Below will be discussed hydrological regime of the Veleka river at Zvezdets for the period 1991- 2007 and will be difined the parameters with highlighted environmentally

significance that characterize this regime (parameters for magnitude, variability and seasonality). Thus will be characterized and will be compared with reference period (1961-1990). Based on these periods the degree of alteration has been assessed by calculating the indicators that connect the values of the same parameter for both regimes. On Table 4 are given statistical parameters to characterize aspects of the flow regime for the period 1991-2007 based on annual and monthly flow volumes. The estimated parameters of the intra-annual distribution of river flow for period 1991-2007 are presented in Table 5.

Table 4: Environmentally significant indicators characterizing the flow regime of the Veleka River at Zvezdets for the period 1991-2007

Components of the altered regime		Aspect	Parameter	
			Description	Value(hm³)
Habitual Data	Annual Volumes	Magnitude	Average of annual volumes	61.76
			Median of annual volumes	38.77
			Coefficient of variation of annual volumes	0.66
	Monthly Volumes	Magnitude	Average of monthly volumes	See table 5
			Median of monthly volumes	See table 5
			Coefficient of variation of monthly volumes	See table 5
			Extreme variability	17.31
		Seasonality	Relative frequency of maximum for each month	See table 5
			Relative frequency of minimum for each month	See table 5

When comparing the characteristics of the period in natural regime (reference period 1961-1990) with the period for last current regime (1991-2007) a significant change in the flow regime (Table 2 and Table 4) can be seen, that the mean annual volumes significantly have been reduced (around of 44%).

The next stage after the characterization of the two regimes is the comparison of the two periods 1961-1990 and 1991-2007 through indicators of hydrological alteration (IHA). Attending to CIS-WDF recommendations [6, 8] five levels or hydrological status have been established. The alteration in the habitual values will be assessed separately for each type of year. The obtained results are very similar to each year. The values of the indicators of hydrological alteration that correspond to the weighted year are shown on Table 6. The values that show a greater alteration in the magnitude of the monthly volumes (M2=0.36) are an indicator of poor hydrological status. The magnitude of the annual volumes (M1=0.55), the monthly variability (V2=0.57) and the extreme variability in the flow volume (V4=0.48) have moderate status.

Table 5: Parameters to characterize the intra-annual distribution for flow regime (period 1991-2007)

	Average (hm³)	Median (hm³)	Coef. of variation	Relative frequency of maximum	Relative frequency of minimum
Nov	6.84	5.2	0.73	0.13	0.00
Dec	10.83	6.88	1	0.38	0.00
Jan	12.78	6.22	1.15	0.31	0.00
Feb	8.09	5	0.86	0.13	0.00
Mar	4.97	4.17	0.62	0.00	0.00
Apr	2.68	2.81	0.43	0.00	0.00
May	4	1.58	2.15	0.00	0.06
Jun	1.06	0.95	0.72	0.00	0.25
Jul	0.75	0.79	0.38	0.00	0.31
Aug	1.29	0.94	1.04	0.00	0.25
Sep	2.62	1.64	0.93	0.00	0.13
Oct	5.85	3.51	1.12	0.06	0.00

Performing a detailed study month by month reveals that the magnitude of the flow volume prevails poor status, the indicator M3 (Table 7) varies between 0.2 and 0.4 in nine months (January, February, March, April, May, September and October) and bad status is observed in August (M3=0.19). In June, the status is moderate (M3=0.45) and in July is high or correspond to the reference period (M3=1). The indicator values show that during 1991-2007 there was a strong reduction in river flow of the Veleka River at Zvezdets. From the table 7 can be seen that the indicator V3, which evaluates the variability of monthly volumes fluctuate between 0.4 and 0.6, indicating that the hydrological status is moderate. In August the indicator V3 is equal to 0.97, which shows that hydrological status is high. In September (V3=0.60) and October (V3=0.65) the status is good. In order to make easier the global analysis for the main elements of the regime an indicator of global alteration is calculated for each component. This indicator sums up the values of the indicators selected to assess all aspects considered for this component of the regime [8]. The value of the global alteration indicator for habitual values (IAG_H=0.41) shows that hydrological status is good for the Veleka River at Zvezdets (Table 8).

Table 6: Indicators of hydrological alteration (IHA) for the habitual values

Aspect		Indicators of Hydrologic Alteration (IAH)			Level I	Level II	Level III	Level IV	Level V
		Value	Code	Description	0.8<I ≤1	0.6<I ≤0.8	0.4<I ≤0.6	0.2<I ≤0.4	0< I ≤0.2
Habitual Values	Magnitude	0.55	M1	Magnitude of the annual volumes			**Yes**		
		0.36	M2	Magnitude of the monthly volumes				**Yes**	
	Variability	0.75	V1	Variability of the annual volumes		**Yes**			
		0.57	V2	Variabilityof the monthly volumes			**Yes**		
		0.48	V4	Extreme variability			**Yes**		
	Seasonality	1.00	E1	Seasonality of maximum values	**Yes**				
		0.83	E2	Seasonality of minimum values	**Yes**				

To perform an environmental assessment of river sections in the study area was analyzed both the current situation in which the river is encountered, as well as was compared with the situation which the river would have had if there had not

been a change by humans, i.e. in their natural status. Consequently is determine the degree of conservation or deterioration. This assessment is complemented by determining the possible effects on the watershed that can determine its current status, as well as circumstances that may determine or limit recovery of the condition. The obtained mean values for environmental flow regime in wet, normal and dry years are below the average natural regime (Fig. 5) and have low variability but they follow the patterns of intra-annual variability of the natural regime. The annual volume of natural regime is around 201.2 hm^3 for wet years, 73.3 hm^3 for normal years and 40.3 hm^3 for dry years (Fig. 6).

Table 7: The indicators of hydrological alteration (IHA) of intra-annual distribution of river flow

Aspect	Month	Indicator M3 - Magnitude of the month volume	Indicator V3 - Variability of the month volume
Habitual values	Nov	0.34	0.57
	Dec	0.30	0.58
	Jan	0.23	0.55
	Feb	0.23	0.57
	Mar	0.34	0.47
	Apr	0.34	0.50
	May	0.33	0.55
	Jun	0.45	0.55
	Jul	1.00	0.34
	Aug	0.19	0.97
	Sep	0.27	0.60
	Oct	0.27	0.65

Table 8: The global alteration indicator for habitual values of volumes of river flow

Indicators of global alteration			Level I	Level II	Level III	Level IV	Level V
Aspect	Value	Code	0.64<I≤1	0.36<I≤0.64	0.16<I≤0.36	0.04<I≤0.16	0<I≤0.04
Habitual values (M1, M2, V1, V2, V4, E1, E2)	0.41	IAG_H		Yes			

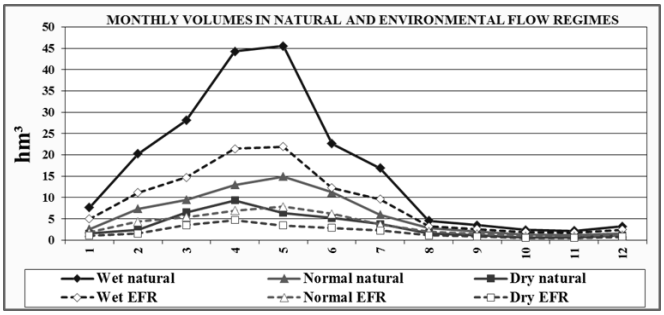

Figure 5: Natural and environmental flow regime of river runoff (hm^3)

Under scenario with a high level of protection for aquatic ecosystems (m=1.2) the final outcome of the flow volumes of the environmental flow regime was 107.9 hm^3 for wet years, 42.7 hm^3 for normal years and 23.0 hm^3 for dry years. This means that water which will be available for other purposes is 93.1 hm^3 in wet years, 30.6 hm^3 in normal years and 17.3 hm^3 in dry years. Otherwise, if it do not be complied with these water quantities, the components, functions and processes of the river ecosystem that are associated with the regime of the river flow will be affected by the use and management of water resources in the studied river.

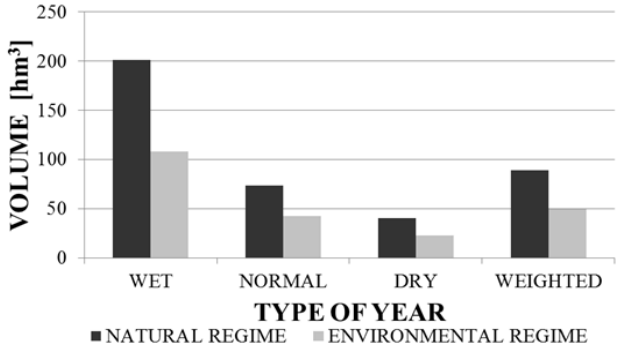

Figure 6: Average annual volumes of natural and environmental flow regime for different types of years

4. Conclusion

In conclusion can be drawn the following conclusions:

1) The employed methodology objectively allowed evaluating the hydrological flow regime of Veleka River.
2) The values of the indicators of hydrological alteration for the average year showed greater alteration in the monthly flow volumes corresponding to the presence of poor hydrological status. The magnitude of annual volumes and extreme variability of the river flow volume indicate moderate hydrological status in concerned stretch of the river.
3) The global alteration indicators for habitual values of flow volumes for the Veleka River show good hydrological status. Compared to monthly runoff volume prevails poor status. The indicator values show that during 1991-2007 there was a strong reduction in river flow of the Veleka River notably in August.
4) A significant change in the flow regime of Veleka River can be observed, the mean annual volumes have been reduced about of 44%.

It could be concluded that the results of this study showed that indicators of hydrologic alteration are useful to focus, compare and define levels of hydrological alterations.

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