BRACKISH KARST SPRING PANTAN (CROATIA)

ZASLANJENI KRAŠKI IZVIR PANTAN (HRVAŠKA)

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Ognjen Bonacci: Zaslanjeni kraški izvir Pantan (Hrvaška)

V prispevku je predstavljena hidrološka analiza zaslanjenega kraškega izvira Pantan (Hrvaška). Avtor je imel na voljo hidrološke podatke devetmesečnih meritev v l. 1979. V skladu z meritvami je bila napravljena pretočna krivulja za sladko vodo v izviru in okvirno določena velikost zaledja. Preučil je tudi odnos med višino talne vode v zaledju in slanostjo izvira.

Ključne besede: hidrologija krasa, kraški zaslanjeni izvir, hidrološka analiza, odnos talne vode in zaslanjenosti, Hrvaška, Dalmacija, izvir Pantan.

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Ognjen Bonacci: Brackish karst spring Pantan (Croatia)

The paper presents the hydrological analysis of a brackish karst spring Pantan (Croatia). The available hydrological measurement data cover the period of nine months in 1979. The discharge curve for the spring fresh water and the approximate catchment area has been defined according to these measurements. The relationship between the groundwater levels in the catchment and the salinity of the spring water have also been studied.

Key words: karst hydrology, brackish karst spring, hydrologic analysis, relationship between ground water and salinity, Croatia, Dalmatia, Pantan spring

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INTRODUCTION

The brackish karst spring Pantan is located in the vicinity of the city of Split. It is a permanent and abundant coastal spring of the ascending type, with the opening at 2.6 m a.s.l. In its close vicinity there is a temporary spring Slanac and two vruljes Arbanija and Slatina. They represent part of the groundwater from a unique hydrogeological collector, through which a large area covered by rough, bare Dalmatian karst is drained. The catchment area is formed of highly permeable limestone rocks. The karstification process has been developed down to the depth of 40-50 m below the sea level. The opening of the spring is located in the contact zone between the limestone and flysch layers, about 200 m distant from the sea shore. The hydrological measurements at the spring have not been numerous. The discharge varies from 0.5 to 10 m^3 s^{-1}, and the water temperature ranges from 11.5 to 16.0 °C. The salinity varies from 90 to 10,000 mg l^{-1}, with an unfavourable distribution during the year. During the wet winter period, when the water quantities in the region are abundant, the salinity is exceedingly low. In the dry period the situation is the reverse.

ANALYSIS AND INTERPRETATION OF DATA MEASURED IN 1979

Figure 1 presents 5-day averages data for the following hydrological, hydrogeological, climatological and chemical parameters:

1 Precipitation **P** in the catchment expressed in mm,

2 Water level **H** in piezometer expressed in m a.s.l.,

3 Total discharge of all the water from the Pantan spring **Q** expressed in m^3s^{-1},

4 Concentration of chlorides **c** 1in the brackish water of the Pantan spring expressed in mg 1 .

Other available data are:

5 Discharge of sea water Q_s sucked from the sea and appearing at the Pantan spring expressed in m^3 s^{-1},

6 Discharge of fresh water of the Pantan spring Q_p expressed in m^3 s^{-1},

7 Air temperature **T** expressed in °C.

However, these data cannot be used to analyse the possible influence of tide on the capacity and salinity of the Pantan spring.

The discharge of the salty and fresh water was defined according to the following expression:

$$\mathbf{Q_s} = \frac{(\mathbf{Q_s} + \mathbf{Q_p})}{\mathbf{K}}\ \mathbf{c} \qquad (1)$$

where $\mathbf{Q_s}$ is discharge of the sea water intake in $m^3\ s^{-1}$, **K** is concentration of the chlorides in the sea water (taken to be 20,000 mg l^{-1}), $\mathbf{Q_p}$ is fresh water discharge from the Pantan spring $m^3\ s^{-1}$, **c** is measured concentration of chlorides in the water of the Pantan spring in mg l^{-1} . According to this relatively simple relation it was possible to define the discharge quantities of the fresh and sea water in the total discharge of the brackish water of the Pantan spring. This is an approximation, particularly due to the fact that the analysis is performed always with the same concentration of chlorides in the sea water.

Table I presents the matrix of the coefficients of the linear correlation, *calculated for the seven climatological, hydrological, hydrogeological and chemical*

TABLE I

Matrix of the coefficients of the linear correlation calculated for seven parameters

r_{ij}	P [mm]	H [m a.s.l.]	Q [m^3s^{-1}]	Q_s [m^3s^{-1}]	Q_p [m^3s^{-1}]	c [mg l^{-1}]	T [°C]
P	1	.117	.140	-.059	.131	-.050	-.148
H		1	.912	-.771	.925	-.818	-.842
Q			1	-.727	.991	-.851	-.778
Q_s				1	-.811	.917	.807
Q_p					1	-.901	-.817
c						1	.717
T							1

parameters of the average five days values measured during the period from 1 January to 30 September 1979. The review of the results presented in Table I makes it possible to draw several conclusions. The first conclusion is related to the relationship between the rainfall and other parameters. The time increments of five days are not very suitable for the study of this relationship. The groundwater level in the piezometer is evidently the most important parameter for the explanation of the outflow process from the Pantan spring.

Very high values of the coefficient of the linear correlation with all the already studied parameters except rainfall, evidently show the predominant influence of the groundwater levels in the hinterland of the spring upon the outflow processes and the capacity of the spring. The most of the analysed relations between the parameters are not linear, but slightly nonlinear. Consequently, the analysed relations are even stronger than shown by the mentioned linear correlation coefficients. Most of these relations can be clearly explained from the physical standpoint. The relation between the total discharge and the groundwater levels is quite strong, as well as the interdependence (with negative sign) between the groundwater levels and the sea discharge as well as the concentration of chlorides in the brackish water of the Pantan spring. The appropriatness of separating the fresh water from the sea water can be proved, to a certain extent, by the high coefficient of the linear correlation between the discharge of the fresh water and the total spring discharge. It is particularly important to note the relatively high values of the coefficient of the linear correlation between the air temperature and all the other analysed parameters except precipitation. High values of the coefficients (both positive and negative) can be explained by the fact that temperature represents a climatic characteristic with the clearly marked seasonal features. In the summer warm period of the year the concentration of chlorides and the sea water discharge are high at the spring and thus there is a strong positive correlation between them, whereas the relation with the groundwater levels, total discharge and the fresh water discharge, is negative. The presented facts also show the main problem of the spring Pantan water exploitation for drinking and possibly for other technological demands. In the cold period, when the capacity of the spring is high, the water is practically fresh and it could be directly used. At that time the other springs supply the region with sufficient quantities of water so there is no special interest to use the water from the Pantan spring. In the warm summer period the situation is just the reverse, and the water demand increases greatly due to tourism. At that time the Pantan water is so salty that it cannot be used as drinking water. During the last few years there have been frequent droughts in the winter period of the year. Since there were no actual measurements for the situation, it can be supposed with certainty that the salinity of the water depends upon the groundwater levels in the hinterland and hence upon the discharge of the Pantan spring. Consequently, the salt content in the water of the Pantan spring will increase even in the cold period of the year. Table II presents the coefficients of the linear correlation between various parameters. As opposed to Table I this table deals with the strength of the links between time lags series. The index **(t-1)** represents the series moved five days back compared with the index **(t)**. In this case the analysis does not refer to all possible combinations, but only to those which have some physical sense. The review of the results presented in Table II entirely confirms the conclusions drawn after discussing the results from Table I, and proves the strong interior chronological link of the parameters.

TABLE II
Coefficient of the linear correlation for the time lag series parameters

r_{ij}	$Q_{(t)}$	$Q_{s(t)}$	$Q_{p(t)}$	$C_{(t)}$	$H_{(t)}$
$H_{(t-1)}$	.846	-.797	.873	-.822	---
$Q_{(t-1)}$	.934	-.732	.934	-.842	.899
$Q_{s(t-1)}$	-.722	---	---	---	---
$Q_{p(t-1)}$	.936	---	---	---	.908
$C_{(t-1)}$	-.836	---	---	---	-.792
$T_{(t-1)}$	-.787	---	---	---	-.847

DISCHARGE CURVE FOR THE FRESH WATER OF THE PANTAN SPRING

The essential problem of all hydrological analyses is to define reliable discharge curves. The data obtained by measurements in 1979 made it possible to define this curve for the Pantan spring. Evidently, the only way to define the discharge curve for the Pantan spring is to determine the dependence between the spring outflow discharges and the groundwater levels measured in the spring hinterland. The groundwater measurements obtained by piezometer, which is located in the hinterland about 500 m distant from the spring, are the best, since they actually represent the general and dominant state of the aquifer which essentially affects the spring capacity.,

Figure 2 presents the definition of two analytical expressions which can be used as discharge curves of the fresh water from the Pantan spring. The first expression:

$$Q_p = 1.266 \ (H-2.75)^{0.613} \qquad (2)$$

was defined exclusively according to the principles of the least squares theory, whereas the second expression:

$$Q_p = 1.496 \ (H - 2.60)^{0.5} \qquad (3)$$

was also defined according to the least squares theory, but considering the flow in a fully rough zone, which is reflected by the value of the exponent of 0.5 and by taking the level of the spring opening to be at 2.60 m a.s.l. If these two expressions are compared analytically and graphically, it can be stated that the difference between them is insignificant. According to the previously stated facts, a hypothetical statement can be reached. The outflow from the Pantan spring occurs through a karst pipe (conditionally speaking), which is under pressure. According to the expression 3, the following general equation for the discharge curve of the Pantan spring can be written:

$$Q = a \ (2g \ (H - Z))^{0.5} \qquad (4)$$

$$a = A * \alpha \qquad (5)$$

where **A** is the hydraulic measurement cross section area of the hypothetical karst pipe, α is discharge coefficient, **g** is the acceleration of gravity, and **Z** is the level of the outflow opening. If we take the value of the flow coefficient α to be 0.6, it follows that the dimensions of the diameter of the hypothetical pipe is 0.75 m. Since it is evident that coefficient α can be both higher and lower, and it is difficult to assume it is actually a pipe, the dimensions of the analysed conduit are probably different and more irregular along the conduit. The mentioned dimensions of 0.75 m is only the order of magnitude, which has strong supportive arguments. According to the past measurements it is not possible to put forward any hypotheses on the position of the conduit pipe system in space. This is probably an ascending siphon flow caused by geological factors and primarily by the lower sea level in the Pleistocene.

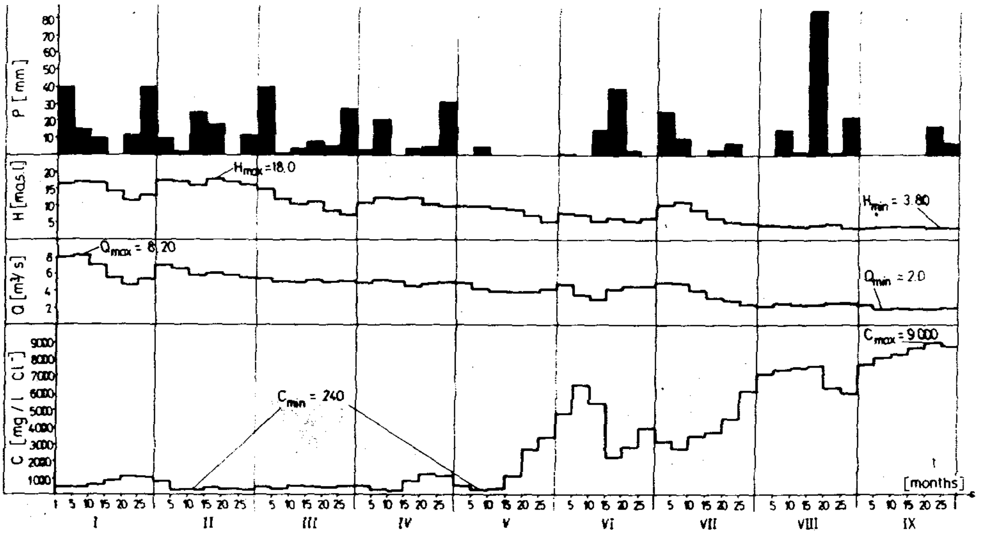

Figure 1

TIME SERIES OF THE GROUNDWATER LEVEL (H), DISCHARGE (Q) AND SALINITY (C) OF THE PANTAN SPRING AND 5 DAYS PRECIPITATION (P) ON ITS CATCHMENT AREA (H, Q, C - 5 DAYS AVERAGE DATA)

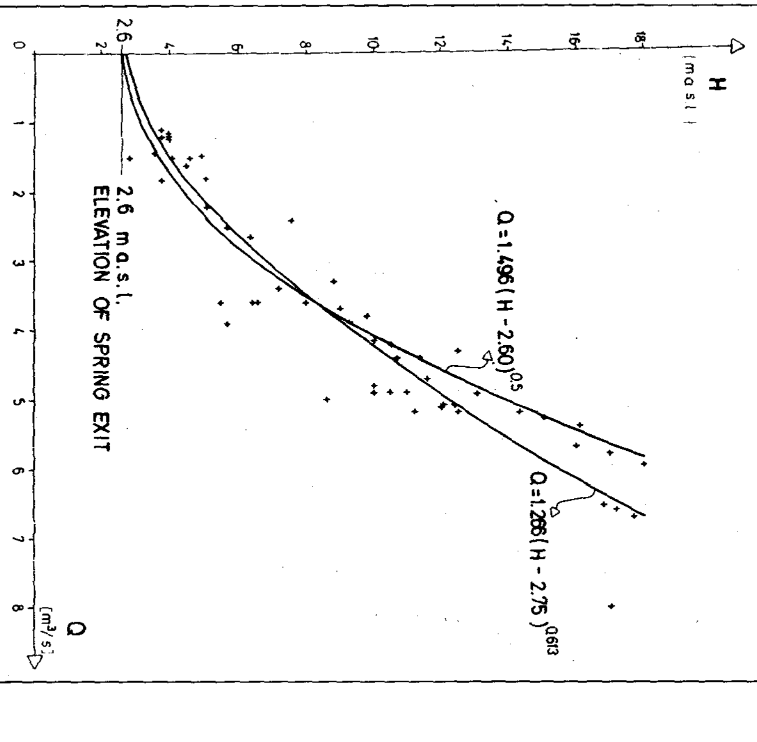

Figure 2

DISCHARGE CURVES OF THE PANTAN SPRING

DETERMINATION OF THE CATCHMENT AREA OF THE PANTAN SPRING

The catchment area of the Pantan spring cannot be reliably determined, due to the insufficient data. It is possible only to define approximately the hypothetical catchment area. The method of the outflow coefficient was used in order to achieve this. The outflow coefficient for the Dinaric Karst, for one year as a time unit, ranges in values from 0.5 to 0.7. The basic period for the definition of the outflow coefficient was the period covering nine months measurements of the discharges of the fresh water from the Pantan spring. Since the catchment area was not known, the calculations of the precipitation volume were performed with a number of alternatives for different catchment areas. Realistic results for the outflow coefficient were obtained only for the assumed areas covering 200 to 260 km², which can be seen from the results shown in Table III. Obviously, this simplified approach cannot guarantee

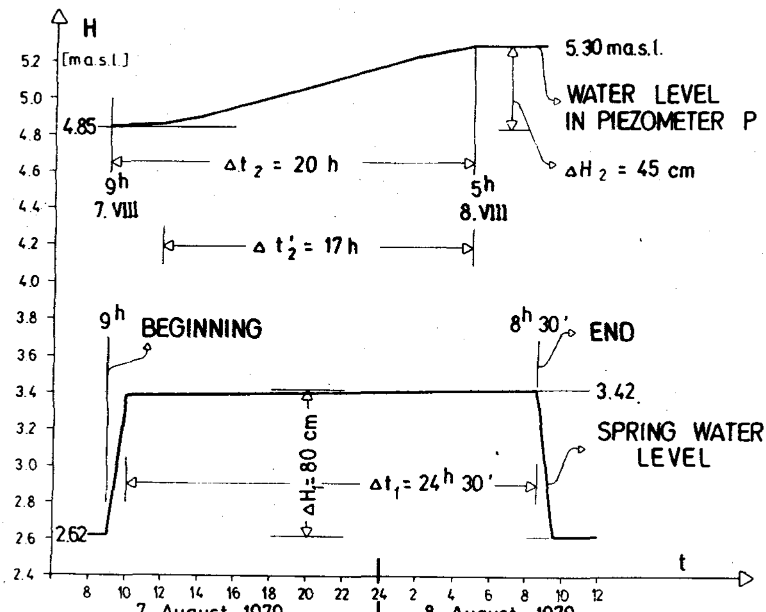

Figure 3
WATER LEVEL HYDROGRAPH AT PANTAN SPRING AND PIEZOMETAR P DURING RAISING

reliable results, but it is also certain that it makes it possible to define the order of magnitude catchment area of the Pantan spring.

TABLE III
Outflow coefficient of the Pantan spring for various assumed catchment areas calculated for the period Jan.-Sept. 1979

Catchment area [km^2]	180	200	220	240	260
Outflow coefficient	0.722	0.650	0.590	0.541	0.500

CONCLUSION

According to the analysis of the climatological, hydrological, hydrogeological and chemical parameters, measured in the catchment of the Pantan spring in the period from January to September 1979, several relevant conclusions were reached in this paper regarding the functioning of the spring. According to the reliability of the measured and processed data the obtained results can be evaluated as preliminary. Nevertheless, these results are logical and acceptable from the hydrology and hydrogeology standpoints. The connection of the groundwater with the spring Pantan water is direct and very clear. According to the additional interdisciplinary analyses and measurements it will be possible to obtain clearer and more direct relations. The catchment area of the Pantan spring ranges from about 200 to 260 km^2, which represents the first approximation of the real state.

ZASLANJENI KRAŠKI IZVIR PANTAN (HRVAŠKA)

Povzetek

Zaslanjeni kraški izvir Pantan je v bližini Splita. To je stalni in obilni kraški izvir 2,6 m nad morjem. V njegovi neposredni bližini so presihajoči izvir in dve vrulji. Zaledje grade dobro prepustni apnenci, zakraseli do globine 40 - 50 m pod morsko gladino. Izvir je na stiku s flišnimi plastmi, okoli 200 m od obale. Pretok se spreminja med 0,5 - 10 m^3 s^{-1}, temperatura med 11,5 - 16,0°C, slanost pa od 90 - 10000 mg l^{-1}. Pozimi, ko je povsod v regiji dovolj vode, je slanost izredno nizka, ob suši pa je obratno.

V prispevku je več zaključkov o delovanju tega izvira, glede na analize klimatoloških, hidroloških, hidrogeoloških in kemijskih parametrov (januar - september 1979). Zveza med talno vodo in izvirom je tesna in očitna. Zaledje izvira obsega 200 - 260 km^2, kar je prvi približek resničnemu stanju.