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Using recession curves to assess recharge in crystalline massif

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Abstract: There is large variability in type of spring recession in crystalline massifs. Calculations of recession coefficient based only on a single observation period could be misleading. Mangin's model appears more reliable than other recession models. It was shown by stream and spring discharge recession analysis. Stream discharge is sensitive to precipitation and springs should be preferred in reservoir volume estimation.

INTRODUCTION

Variation of spring and river discharge during low or no rainfall time period could be presented by recession curves. The groundwater recharge and hydraulic parameters of an aquifer can be estimated from recession models. For a homogenous medium a recession coefficient has a constant value for different drainage periods. However, for hard rocks this assumption is not valid. Due to heterogeneity the recession coefficient is not only a function of a water stage in the aquifer, but depends also on aquifer size, and effective porosity and permeability distributions. A small experimental watershed, located in Sudetes Mts. (SW Poland), was chosen to conduct field studies. Sudetes Mts. forms the north-eastern margin of the Bohemian Massif. Study area consists primarily of gneiss's, schist's, and locally of erlan rocks. A watershed is located at altitudes from 750 to 1100 m a.s.l.

SPRING'S RECESSION CURVES

Spring's discharge measurements were used to analyse a drainage process of crystalline massif aquifer. Three different time periods of low or no rainfall were chosen:

I 18.07-16.10.1992
II 01.05-10.07-1993
III 23.04-30.07.1994

During these time periods no infiltration into lysimeters located at depth of 0,9 m was observed. Discharges of six natural springs and one artificial outflow (an old mine shaft) were measured. Tab.1 shows physical characteristics of measurement points. Field recession curves were compared to theoretical models (Maillet, Tisson, Cotagne, Forkasiewicz and Paloc) and the best fitting model was chosen for each point and for each observation period (Stasko and Tarka 1994). Using determined recession model the values of recession coefficient for all observed outflows were calculated (tab.2). Large variability in recession type and different values of recession coefficient for a single spring is observed. There is no prevailing recession model valid for study area. Using determined models, the calculations of volumes of spring's reservoirs were made, however, there is a large uncertainty about correctness of calculated values. When field discharges are plotted in a logarithmic scale, the recession curves generally can be approximated by straight lines. There is a distinct split of recession lines into two or more parts with different slope (fig.1).

Observed recession type is consistent with Kowalski's theory (1992) for groundwater flow within clay regoliths of crystalline rocks. At the beginning spring is fed by saturated medium (filtration) and later it drainage's unsaturated medium (this is represented by different slopes of the recession line). Clay regoliths of the Sudetes Mts. can contain water in amount from several to 100 % of the void space. Laboratory experiments shown that constant saturated flow occurs for 70 % or higher saturation factor (Kowalski 1987). However clay regoliths usually contains less water then 70 % of the void space, and springs drainage unsaturated medium. For these conditions recession curves are of no use to estimate the total storage capacity of aquifers. For springs being fed by crystalline baserock the two-type recession is explained that at the beginning the outflow is from regolith surface cover and later only from fractured baserock. According to Scholler (1965) outflow from baserock could be described by Maillet's model. However field observations of this study point to Mangin's model as more accurate.

Table 1. Basic characterisation of springs

Spring	Lithology	Altitude [m a.s.l.]	Q_{max} [L/s]	Q_{min} [L/s]
K 1	gneiss	980	1,412	0,245
K 2	gneiss	980	1,395	0,347
K 15	erlan rocks	750	3,845	0,320
K 23	gneiss	880	7,925	0,434
K 25	gneiss	800	1,635	0,272
L 1	gneiss	895	3,381	0,598
L 2	gneiss	1000	10,4	0,260
L 5	schist	1010	4,864	0,015
L 6	schist	870	1,632	0,106
S 1	gneiss	860	42,7	16,5

Table 2. Characterisation of springs regression

	Period					
	I		II		III	
Spring	Equation	Coefficient	Equation	Coefficient	Equation	Coefficient
K 1	Maillet	0.00977	Forkasiewicz	0.0576	Forkasiewicz	0.02121
K 2	Tisson	0.00357	Forkasiewicz	0.0495	Forkasiewicz	0.02109
K 15	Maillet	0.01347	Maillet	0.01357	Maillet	0.01448
K 23	Cotange	0.00844	Cotange	0.0892	Forkasiewicz	0.02684
K 25	Forkasiewicz	0.06920	Forkasiewicz	0.0558	Forkasiewicz	0.03718
L 1	Maillet	0.00532	Maillet	0.01224	Cotange	0.01613
L 2	Tisson	0.00923	Cotange	0.2380	Cotange	0.08979
L 5	*		Tisson	0.07100	Tisson	0.06096
L 6	Maillet	0.04853	Forkasiewicz	0.0707	Forkasiewicz	0.05402
S 1	*		Forkasiewicz	0.00002	Cotange	0.01185

* - undefined

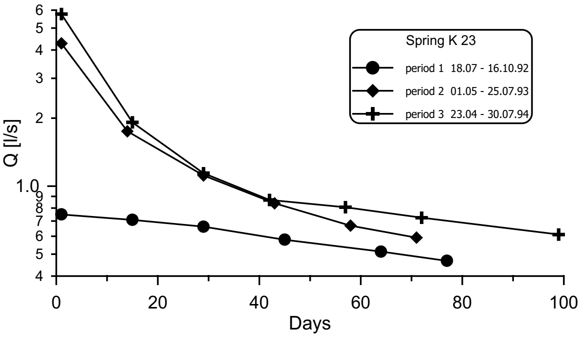

Figure 1. Changes of tempo regression in dependencies from time period

Most of permanent springs in Snieznik Massif have relatively constant water temperature (a maximum amplitude is 2°C). Constant water temperature and small fluctuations of spring discharges allows one to postulate that spring's outflow originates in fractured baserock. Based on this assumption Mangin's model was used to analyse recession process. Tab.3 presents results of the total storage volume of springs' reservoirs calculations by fitting method (that is, chosen the best model, see tab.2) and by Mangin's model. The sum of local and regional reservoirs volumes (V_l and V_r, respectively) is two, three times higher then value determined by fitting method. Naturally, a question which method is more adequate arises. Capacity indicator calculations could be an answer:

$$\Delta V = \frac{V}{A}$$

where: V - storage volume of spring's reservoir; A - reservoir area.

Table 3. Volume of water of reservoirs drained by each outflow

		Fitting method	Mangin's method	
Spring	Period	V_t [m^3]	V_l [m^3]	V_r [m^3]
K 23	II	4167	2495	10448
K 25	II	-	60	11196
L 2	II	3630	5548	9866
L 5	II	5531	2822	2184
L 6	II	-	557	9067
L 1	III	18110	3003	41498
S 1	III	304040	19024	545325

Table 4. Capacity indicator of reservoirs drained by each outflow

	Area	Fitting method	Mangin's method	
Spring	[m^2]	ΔV_t [m]	ΔV_r [m]	ΔV_l [m]
K 23	133270	0.031	0.078	0.019
K 25	49003	-	0.228	0.001
L 1	76666	0.236	0.541	0.039
L 2	166817	0.022	0.059	0.033
L 5	60071	0.092	0.036	0.047
L 6	46496	-	0.195	0.012
S 1	1282969	0.237	0.425	0.015

Values of reservoir area A for particular springs were estimated by multiplying the total volume of discharge from the spring in the whole observation period (1992-1994) and average infiltration from the same time period (Tarka 1997). Results of capacity indicator calculations are presented in tab.4. Mean wage capacity indicator for natural springs (K 23, L 1, L 2 and L 5) is - 0.072 m, and for all outflows (adding an old mine shaft S1) is - 0,195 m according to fitting method. For Mangin's model these values are 0,145 m and 0,354 m (using regional reservoir volume). Use of an average specific yield as 1 % allows calculating saturated thickness of baserock aquifer. Mangin's model gives the value of saturated thickness of 35 m, when according to fitting method the saturated thickness is only 20 m. Boreholes in study area indicate 40 m of weathering fractures zone. Thus Mangin's model seems to be more applicable for crystalline rock aquifers.

Based on recession analysis results a residence groundwater time was calculated. Average annual groundwater recharge for study area is 0,55 m (Tarka 1997). The renewing time for groundwater are from 3 (according to fitting method) to less then 1,5 times a year (Mangin's model). These are very large rates of flow. Isotopic composition of groundwater in the study area is not consistent with these renewing rates. There is no variability in isotopic composition during the year (Ciezkowski *et al.* 1990). The conclusion is that real reservoir's volumes are higher then ones estimated by Mangin's model. However Mangin's model still gives more reliable results then fitting method.

With the correction that some amount of aquifer is drainage by streams, the capacity indicator calculations on the basis only of spring discharge recession should be lower then recharge. Incorporating this additional stream drainage is a logical postulate.

SUMMARY

There is large variability in type of spring recession in crystalline massifs. Calculations of recession coefficient based only on a single observation period could be misleading. Mangin's model seems to be more reliable than other recession models. This was shown by stream and spring discharge recession analysis. Stream discharge is sensitive to precipitation and springs should be preferred in reservoir volume estimation.

The discrepancies were observed for recession coefficient for the same spring in different time periods and in single observation period for springs in the same area. As mentioned before, recession coefficient is not only a function of stage of water in the aquifer, but depends also on aquifer size and porosity, and permeability distributions. Heterogeneity of crystalline rock aquifers is the direction in which future study has to be concerned.

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