SURFACE AND GROUNDWATER RELATION IN STUDENÝ POTOK BROOK CATCHMENT

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Abstract: Interrelationships between surface and groundwater are very important for evaluation of natural groundwater sources. Final monitoring objects, constructed as a part of hydrogeological research tasks solution in the places, where regular monitoring network points are missing, often serve as a source of basic data for such analysis. These objects are very often monitored only for a very limited time period. Methods and results of data processing gained from the final automatic gauging stations built in the Studený potok brook catchment in High Tatra region are presented. They documented, despite of the length of time series, basic features of obtained data and their relations - close relationships between surface and groundwater and their physical properties (as water temperatures and electric conductivity). Final results will be utilised for making conclusions in the field of drinking water supply in the region.

Key words: surface and groundwater monitoring, relationships between surface and groundwater levels, data processing, statistical analysis

Introduction

Solution of specific research problems demands very often building of special final monitoring objects despite of the fact that relatively dense surface and groundwater monitoring network covers the territory of the country. Such objects are specific by their purpose, location, and length of the observation period, gained data and methods of data processing. Final monitoring objects are very often constructed as a part of hydrogeological research projects solution which goal is to secure new sources for drinking water supply. Finding and building of such sources must be based on very good knowledge of meteorological, hydrological and hydrogeological conditions in the area, surface and groundwater regime affecting factors, their interrelationships and groundwater reserves formation processes. Some parts of the Slovak territory are influenced by climate changes (Majerčáková, 1994, Szolgay et al., 1997, Kullman and Kullman, 1999), therefore researchers have to take into account also possible future trends of climatic and hydrological characteristics development (Némethy, 1996; Rapantová and Grmela, 2000). Hydrogeologists very often solve problems of looking for new drinking water supply sources in regions with very different hydrogeological conditions, such as mountainous areas, in which network of regular hydrological monitoring objects is not too dense. The only way, how to gain missing data, is to build final monitoring objects.

For the purpose of the research project „Crystalline of the part of High Tatra Mts. and Quaternary of its foreland – hydrogeological region QG-139“ (Fendek et al., 1997) 16 final monitoring objects were constructed. Thirteen of them were placed at surface streams to monitor surface water levels and temperatures; three were installed into lately bored wells to monitor changes of groundwater level and temperatures. Three of these automatic monitoring devices monitor also electric conductivity of water. Time interval of thirty minutes was selected for data recording. Monitoring started in the beginning of the hydrological year 2000 and finished in the end of the hydrological year 2001. Thus, results presented in the paper are based on data analysis assessment of one-year observation.

Characteristic of the studied area

Studený potok brook catchment is located in the eastern part of High Tatra Mts. It springs close to the montain rim of High Tatra Mts. between Gerlachovský štít and Lomnický štít peaks in the altitude of app. 2300 m above the sea level. Studený potok brook as a stream with typically mountainous torrential character.

The air temperature in the area is very variable according to the altitude. On the southern foothills in the altitude of 600 - 700 m, the mean yearly temperature reaches up to 6.0 °C. On the mountain rim it dos not rises higher than 0 °C, it varies mostly between -4.0 to -2.0 °C.

Tab. 1 *Mean monthly and yearly air temperatures [°C] for the period 1951-1980 (Kolektív autorov, 1991)*

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Poprad	-5.0	-3.4	0.1	5.6	10.6	14.2	15.5	14.8	11.2	6.4	1.5	-2.8	5.7
Štrbské Pleso	-5.3	-4.6	-2.1	2.4	7.3	110	12.4	12.1	8.8	4.8	-0.1	-3.5	3.6

Amount of precipitation rises with the altitude. The amount is limiting factor for recharging groundwater in the area. Mean monthly and yearly amounts of precipitation are given in tab. 2.

Tab. 2 *Mean monthly and yearly amounts of precipitation [mm] for the period 1951-1980 (Kolektív autorov, 1991)*

Station	I	II	III	II	IV	VI	VII	VIII	IX	X	XI	XII	Year
Poprad	24	27	28	42	66	94	81	73	43	41	43	30	593
Štrbské Pleso	63	60	60	67	91	122	129	95	71	61	71	73	962

Maximum monthly values are characteristic for May, June and August on the foothills and for March - July in higher altitudes. Summer period in High Tatra Mts. is typical by occurrence of summer storms. The whole area has app. 30 - 35 days per year with a storm. Mean yearly amount of evapotranspiration calculated by Budyko-Zubenok method (Tomlain, 1997) was estimated on 417 - 429 mm for High Tatra Mts. region, mean yearly potential evapotranspiration on 426 - 551 mm. Maximum values are typical for June - July, minimum for December.

Hydrologically, the whole area belongs to the river Poprad catchment. Studený potok brook is the right-side tributary of the river Poprad. The lowest discharges are typical for February, the highest mainly for May, on the foothills they can start in April; reaching maximum values in June. Discharge regime is of snowy-rainy type. From the geological and hydrogeological point of view, crystalline granitic rocks - mainly diorites of Variscan age, build the catchment. Crystalline rocks are covered by weathered rock debris and in the lower part of the catchment by glacial sediments of Pleistocene age. Glacial sediments (boulder to sandy sediments) have very high permeability and create very good conditions for infiltration of precipitation. Infiltrated water flows very quickly through the rock environment and flows up to the surface in the form of springs or hidden inflows into the surface streams. Water in surface streams and groundwater levels are often in hydraulic connection. Minimum specific groundwater runoff from the areas built by granitic rocks was estimated on 2.9 - 31.3 l/s.km^2, from the glacial sediments on 4.79 l/s.km^2 (Hanzel et al., 1984).

Input data and processing methods

Automatic monitoring station was built 50 m above the mouth of the Studený potok brook into the river Poprad. Observation started on December 7, 2000. Another one was installed in the well FVT-3, situated in the distance about 2000 m to the north of the surface water monitoring object.

Following input data were used for assessment of surface and groundwater relationships:

- groundwater levels [m] in the time period 14.11.2000 - 15.11.2001 with one hour step (variable marked as GW_L),
- groundwater temperatures [°C] for the same time period and time step (variable marked as GW_T),
- groundwater electric conductivity [μS/cm] for the same time period and time step (variable marked as GW_C),
- Studený potok brook discharges [l/s] for the period 7.12.2000 - 15.11.2001 with one hour time step (variable marked as SW_D),
- surface water temperatures [°C] for the same time period and time step (variable marked as SW_T),
- surface water electric conductivity [μS/cm] for the same time period and time step (variable marked as SW_C).

Methods utilised for data processing reflect their quality, number and time intervals. They consist of basic statistical evaluation, assessment of their interrelationships and very simple analysis of time series. Time series elements like seasonality and long-term periodicity could not be assessed, trend assessment would not be representative (Pekárová, 2000).

Data homogeneity and normality assessment would not be representative because of the time series data character and length.

Results of the basic statistical assessment are shown in Tab. 3. Table contains statistical measures like count - n, arithmetic mean - x_a, median - x_{me}, extreme values like minimum - x_{min} and maximum x_{max}, measures of variability like standard deviation s_x and coefficient of variation C_v, as well as skewness coefficient C_s.

Tab. 3 *Results of basic statistical data assessment*

	n	x_a	x_{me}	x_{min}	x_{max}	s_x	C_v	C_s
GW_L	8779	1.92	1.95	1.14	2.59	0.19	0.09	-0.79
GW_T	8779	3.9	4.1	-0.2	8.1	2.58	0.66	-0.12
GW_C	8779	50.0	51.0	32.0	74.0	10.40	0.21	-0.05
SW_D	6614	937.1	599.9	134.2	8065.2	933.58	0.99	2.73
SW_T	6614	5.3	5.0	-0.5	17.3	4.76	0.89	0.38
SW_C	6614	162.3	168	92.0	231.0	31.76	0.19	-0.65

Obtained results document very low variability of groundwater level fluctuation in the well FVT-3 (between 1.14 and 2.59 m below benchmark), as well as very stable values of surface and groundwater electric conductivity. Other variables have quite high variability expressed by coefficient of variation with values from 66 to 99 %. The highest variability was documented in the case of surface stream discharges - values varied between 134.2 l/s and 8065.2 l/s.

Time series courses are shown in Fig. 1 and 2. Fig. 1 shows course of discharges and groundwater levels, surface and groundwater temperatures, in Fig 2 the synchronised pattern of surface and groundwater electric conductivities is visible. Basement building of the open-air swimming pool Rybka, built close to the FVT-3 well, must be technically dewatered in July 2001. The effect of dewatering is clearly visible in the course of groundwater level. The effect was strongest up to September 23, 2001 with the maximum decrease value of 2.59 m below the benchmark. In the end of monitored period, groundwater levels fluctuated again in their natural - non-disturbed ranges. Another visible feature is the more smoothed course of groundwater temperatures in comparison with temperatures in the surface stream. Also certain time shift between both of temperature time series can be seen.

Time shift between pairs of variables was evaluated using cross-correlation method. The largest lags were estimated in the case of two pairs of variables: surface water electric conductivity and discharges; surface water temperature and discharges. The lag of approximately 9 days (223 and 213 hours) was proved. Shorter time shift - app. 1,3 days (32 hours) was proved between groundwater levels and stream discharges. No time shift (0 hours) was typical for surface and groundwater electric conductivities. It was not possible to prove statistically the time shift of surface and groundwater temperatures.

Interrelationships of assessed variables were evaluated also using correlation matrix. Results are given in Tab. 4. Thick letters are used for statistically significant correlation coefficients at the probability level of $p < 0,05$.

Tab. 4 *Resulting correlation matrix of variable relationships*

Variable	SW_T	SW_C	SW_D	GW_L	GW_T	GW_C
SW_T	1.00	**-0.52**	**0.46**	**-0.79**	**-0.40**	**-0.63**
SW_C	**-0.52**	1.00	**-0.71**	**0.61**	**-0.23**	**0.85**
SW_D	**0.46**	**-0.71**	1.00	**-0.67**	**-0.06**	**-0.58**
GW_L	**-0.79**	**0.61**	**-0.67**	1.00	**0.45**	**0.60**
GW_T	**-0.40**	**-0.23**	**-0.06**	**0.45**	1.00	**-0.19**
GW_C	**-0.63**	**0.85**	**-0.58**	**0.60**	**-0.19**	1.00

Highest correlation coefficients were reached for relationship of surface and groundwater electric conductivities (R_{xy} = 0.85), discharges and surface water electric conductivity (R_{xy} = 0.71), groundwater level and discharges (R_{xy} = 0.67), as well as groundwater level and groundwater electric conductivity (R_{xy} = 0.60). The worst results (but even statistically significant because of large number of evaluated values) were obtained for interrelationships between discharges and groundwater temperature (R_{xy} = -0.06), as well as between groundwater temperature and electric conductivity (R_{xy} = -0.19).

Interrelationships of variables were evaluated using single and multiple regression models. First, single regression models were utilised for description of relationships of surface and groundwater temperature, surface and groundwater electric conductivity and discharges and groundwater levels. Obtained results can be expressed by following equations:

$GW_T = 2.405 - 0.40*SW_T$ with the value of $R^2_{xy} = 0.16$

$GW_C = 20.13 + 0.85*SW_C$ with the value of $R^2_{xy} = 0.72$

$GW_L = 2.06 - 0.669*SW_D$ with the value of $R^2_{xy} = 0.45$

Afterwards, equations for groundwater level, temperature and electric conductivity estimation were compiled using multiple regression models as follow:

$GW_T = 10.188 - 0.669*SW_T - 0.806*SW_C - 0.326*SW_D$ with the value of $R^2_{xy} = 0.472$

$GW_C = 24.343 + 0.776*SW_C - 0.274*SW_T + 0.097*SW_D$ with the value of $R^2_{xy} = 0.777$

$GW_L = 2.051 - 0.594*SW_T - 0.362*SW_D - 0.045*SW_C$ with the value of $R^2_{xy} = 0.737$

In all cases, statistically significant squared multiple correlation coefficients were obtained (the highest in the case of GW_C and GW_L). Equations are usable for estimation of single values of variables in the case of missing values.

Conclusion

Hydrological data gained by final monitoring objects can give assistance by characterisation of hydrological conditions in the places, were objects of regular monitoring network are missing.

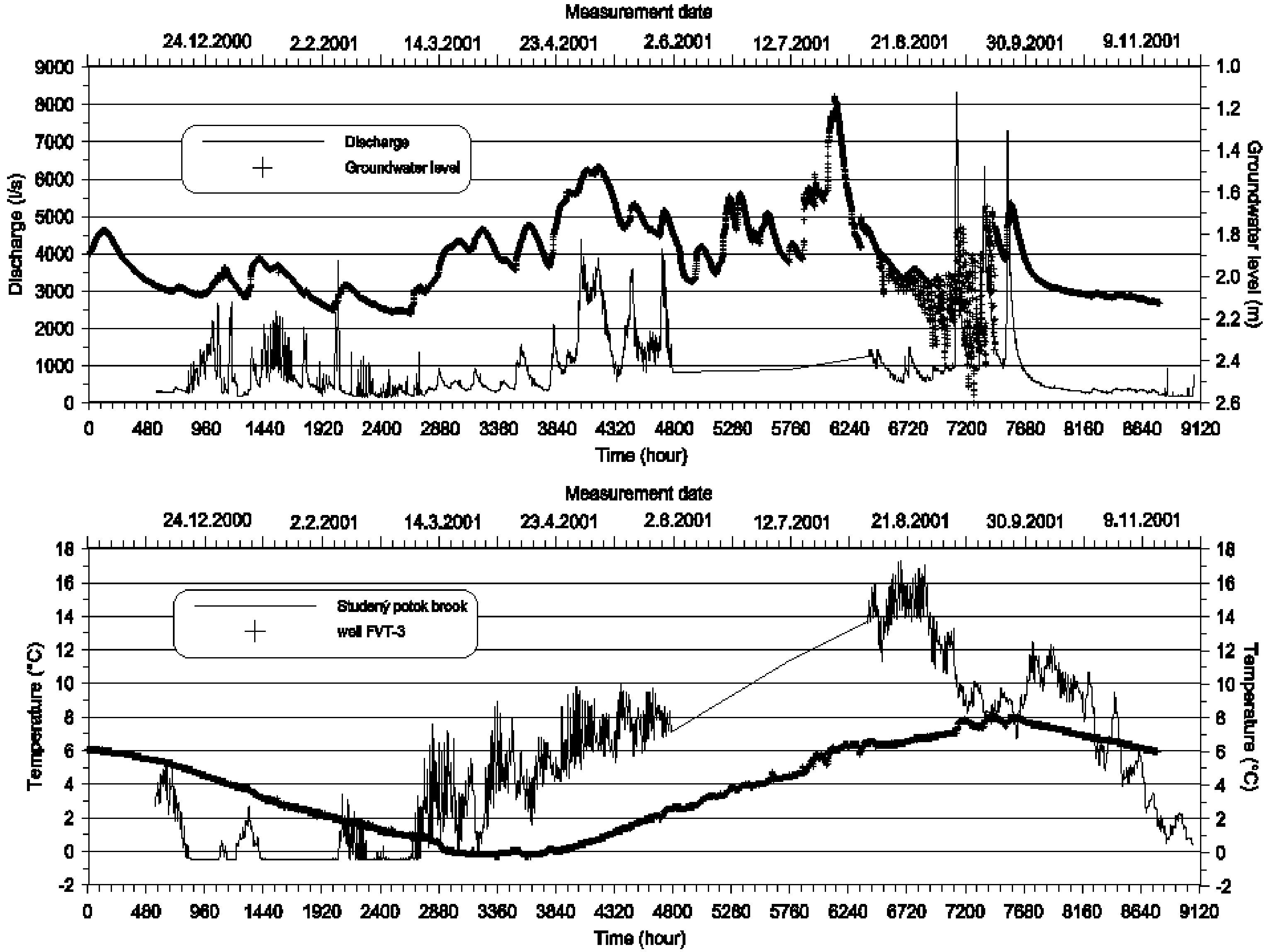

Fig. 1 *Course of groundwater levels and temperatures in the well FVT-3; discharges and surface water temperatures in Studený potok brook*

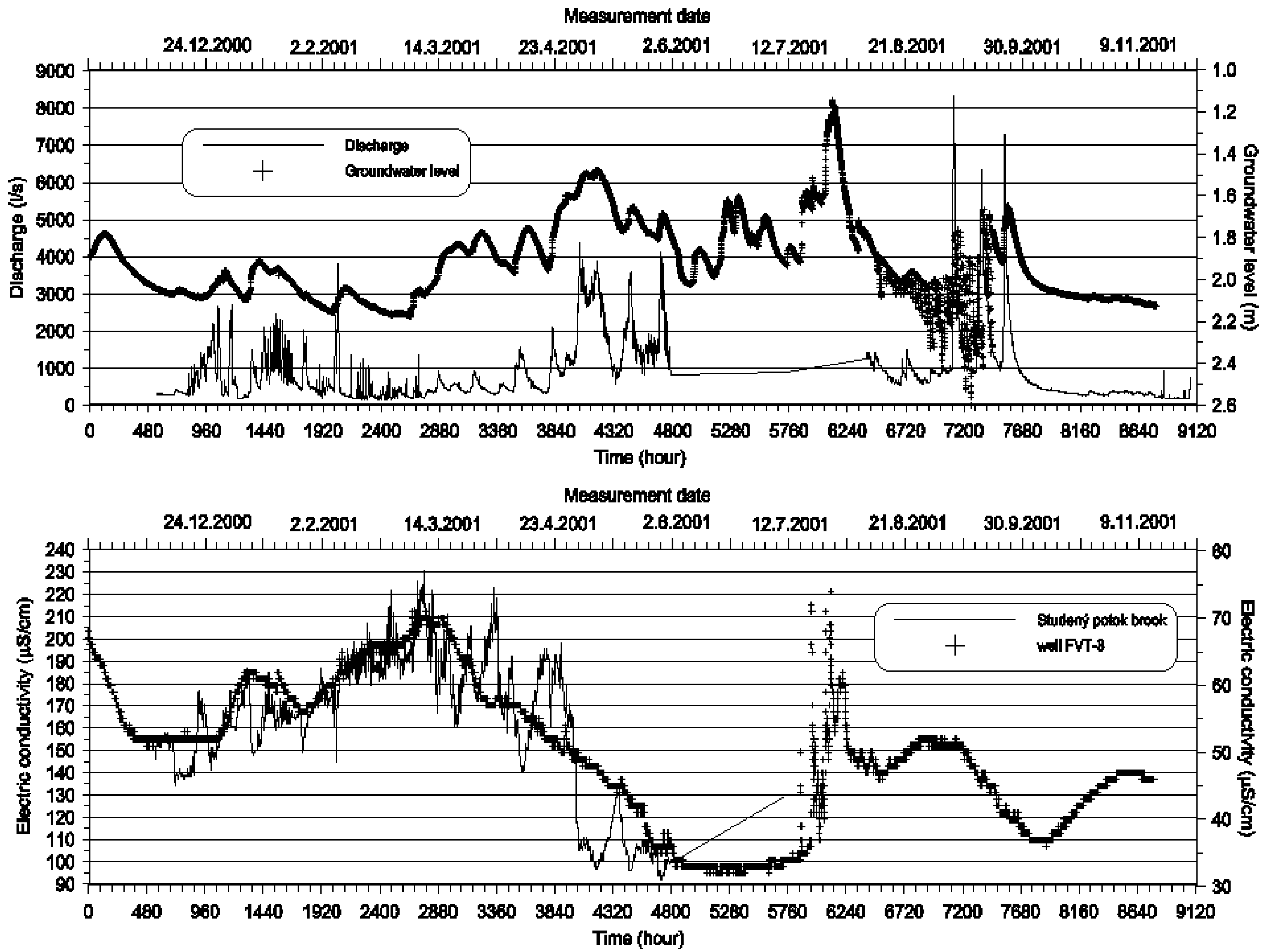

Fig. 2 *Course of groundwater levels and electric conductivity in the well FVT-3; discharges and surface water conductivity in Studený potok brook*

They are often built as a part of special research projects, and are monitored for a relatively short time period (mostly not longer than for 3 years, bur very often not longer than for two years) with different time steps of measurements. Despite of that, gained data have to be evaluated to contribute to the successful finalising of a research project. Because of their special character, only some of statistical methods can be used for data analysis. In the case study of the Studený potok brook, basic statistical evaluation, simple analysis of time series, cross correlation methods, simple and multiple regression models were successfully utilised for solution of the problem of surface-groundwater relationship assessment.

Acknowledgment

The contribution was compiled thank to the project of the Ministry of Evironment of Slovak Republic „Crystalline of the part of High Tatra Mts. and Quaternary of its foreland – hydrogeological region QG-139"solved by Geological Survey of Slovak Republic (M. Fendek) and to the VEGA Grant Project No. 1/7226/20 Changes of the natural environment- their influence of usability of surface and groundwater sources (M. Fendeková).

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