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## Environmental impacts of groundwater abstraction in Neresnica brook catchment (Slovak Republic)

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**Abstract** The main goal of the research was a detailed study of the consequences, caused by groundwater abstraction in the Neresnica brook catchment (Slovak Republic) since the water supply source Podzamcok was put in operation in 1973. This goal was supplemented by research of groundwater origin, groundwater chemical composition and its changes. Field measurements, analyses of water samples and statistical evaluation of hydro-meteorological data were used to gain and process the data. It was showed that overexploitation of groundwater in the catchment resulted in distinct diminishing of stream flow discharges in low flow

periods, groundwater level dropping and disturbance of hydraulic connection between surface and groundwater. Groundwater quality was quite stable during the whole period of observation. Groundwater modeling was proposed to be used for the re-estimation of utilizable groundwater amounts in the catchment.

**Keywords** Groundwater · Abstractions · Low flows · Surface and groundwater relationship · Groundwater origin · Slovak Republic · Central Slovakia · Podzamcok · Neresnica brook catchment

### Introduction

Groundwater abstraction is one of the most important human activities, which could influence ecological conditions in the catchment through their influence on natural regime of surface and groundwater.

The degree of impact is conditioned by several factors. First of all, geological and hydrogeological conditions of the area are of great importance. Properties like rock type, degree of rock disintegration, thickness of weathering zone, type of permeability, hydraulic conductivity, transmissivity, and storativity can influence importantly the flow velocity, groundwater reserves formation, and recovering time of depleted groundwater reservoirs. Climatic factors, mainly water balance equation elements—precipitation, evapotranspiration, and runoff, conditioned by geographical location influ-

ence groundwater recharge and discharge. The third group of factors, connected to man-made interference with the environment, put a lighter or heavier load on groundwater level depth and regime. It could influence the amount of water flowing in the rock environment and in surface streams, existence of hydraulic connection between surface and groundwater, and consequently, ecological conditions in the stream itself and in the adjacent areas could be changed importantly. Groundwater abstraction, spring yield tapping for water supply systems, stream regulations, and water reservoir construction are the prevailing types of interference.

The main goal of the research was a detailed study of the consequences, which were raised by groundwater abstraction in the Neresnica brook catchment since the water supply source Podzamcok was put on the operation in 1973.

Hydrogeological conditions of the area were studied since 1963 when the first phase of the groundwater resources investigation started. The aim of the research was to find and capture groundwater for water supply of the area, because the area was deficit on drinking water sources. The research was performed mainly by (Litva 1963, unpublished research report), (Skvarka 1967, unpublished research report), (Skvarka and Valusiak 1968, unpublished research report), (Valusiak 1970, unpublished research report). The second phase was aimed at increasing the pumping amounts, and was performed by (Fecek and Hlavaty 1980, unpublished research report). As it was estimated by Fecek and Hlavaty, groundwater amount of up to 210 l/s was proposed for abstraction from the hydrogeological structure.

The first evaluation of groundwater regime with the emphasis on long-term groundwater abstraction was done by Fecek in 1996. Since 1991, a detailed study of surface and groundwater inter-relationships in connection to groundwater abstraction has been performed by researchers of the Department of Hydrogeology, Comenius University in Bratislava—mainly by Skvarka et al. (1991, unpublished research report), Silar and Skvarka (1991), (Nemethy et al. 1992, unpublished research report) Nemethy and Vlckova (2000), (Kupcova 2002, unpublished research report) and Makisova and Zenisova (2003) covering surface water research with emphasis on the low flows development, groundwater research by studying of its origin, and the level changes in connection to water abstraction, as well as the surface and groundwater quality and their changes during the period of observation.

## Materials and methods

The input data consisted of climatic and hydrological data (provided by the Slovak Hydrometeorological Institute in Bratislava), groundwater abstraction data (provided by the Middle Slovakian Waterworks in Banska Bystrica), results of field measurements and sampling (current meter measurements, surface and groundwater chemical, and isotopic analyses) done by department members or by cooperating organizations (Water Research Institute in Bratislava, Geological Survey of the Slovak Republic in Bratislava), as well as some older data and research results from the archives and literature sources.

### Natural conditions in the research area

The area is located in the central part of Slovakia to the south of the city of Zvolen. It belongs to Plietovska kotlina depression. The catchment border

follows Hron and Slatina rivers in the North, Stiavnické vrchy Mountains (Mts) in the West, Javorie Mts. in the East and ridges of the Krupinska planina Mts and Krupinica river valley in the South. The altitude varies between 286 m above sea level (a.s.l.) in the northern part of the valley up to 908 m (a.s.l.) on the mountain ridge of Javorie Mts. The general location is shown in Fig. 1.

### Climatic conditions

According to Köppen's climate classification (Köppen, 1918), Slovakia belongs to the temperate climates (C-climates) to Cf climate regions. According to the Slovak climatic classification, the area belongs to middle latitude warm regions, moderately humid, with cold winter (Lapin et al. in Landscape atlas of the Slovak Republic, 2002).

Climatic conditions can be characterized by values of air temperature, precipitation and evapotranspiration. Unfortunately, there is no meteorological station in the catchment measuring all three characteristics. Therefore, values measured in the meteorological station in Viglas-Pstrusa, which is located in the same climatic region in a distance of approximately 50 km to the northwest are given for comparison.

The average yearly air temperature with the value of 7.6°C was measured in Sasa station—located 8 km to the southeast of the Podzamcok water source (Fig. 1), which is the only station in the adjacent area measuring air temperatures. Values in the Table 1 represent average values for the period 1951–1980.

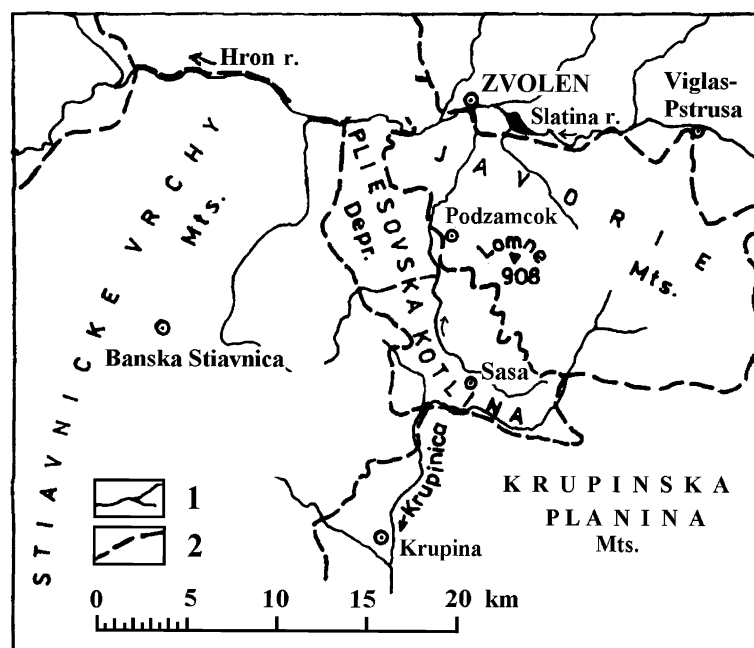
The average monthly and yearly precipitation values in millimeters for the same gauging station calculated for the period 1963–1998 are given in Table 2.

Values of the evapotranspiration (ETP) were calculated for Viglas-Pstrusa meteorological station, which has nearly the same climatic conditions as Neresnica brook valley. The difference in altitude is negligible—Viglas-Pstrusa station (Fig.1) is located in the altitude of 368 m a.s.l. and Sasa in 383 m a.s.l., so the difference is less than 20 m. The evapotranspiration gradient for Slovakia was estimated on 10–12 mm/100 m (Tomlain, 1980). Therefore, evapotranspiration values of Viglas-Pstrusa gauging station can be applied for Sasa as well. Average monthly and yearly values of potential and actual evapotranspiration in Viglas-Pstrusa gauging station for the period 1951–1980 are given in Table 3.

### Hydrological settings

The main stream of the catchment is Neresnica brook which flows in the south-northern direction. It has some minor left- and right-side tributaries. Regular monitor-

**Fig. 1** Geomorphological units  
1-rivers, 2-unit borders



ing of the river discharges started in 1963 in the gauging profile No. 7228 located in Zvolen at the altitude of 286.59 m a.s.l., close to the mouth of the Neresnica brook into Slatina River. Slatina River is the left-side tributary of the Hron River, flowing to Danube River, belonging to the Black Sea. The length of the Neresnica brook valley ( $L$ ) is 25.6 km and the catchment area ( $P$ ) covers 139.33 km<sup>2</sup>. The catchment has an elongated shape with the shape coefficient  $\alpha$  equal to 0.21 ( $\alpha = P/L^2$ ). The area covered by forests is only 40%. The absolute minimum discharge measured in the period 1963–2002 dropped to 0.009 m<sup>3</sup>/s (August 1990), the absolute maximum discharge in the same period reached 64.55 m<sup>3</sup>/s (January and September 1984). Long-term average yearly discharge was estimated on 1.159 m<sup>3</sup>/s. Neresnica brook is a perennial stream, but could dry in the upper most part of the catchment for several days in the summer period in some dry years. It should be mentioned that the hydrological year which was used as a basic evaluation period starts in Slovakia on 1st November and ends on 31st October of the next year.

#### *Geological and hydrogeological settings*

From a geological point of view, the wider area is built by Neogene volcanic rocks of the Stiavnické vrchy Mts

and Javorie Mts, typical of their stratovolcanic structure. They belong to Central Slovakian Volcanic field (Biely et al. 1996) of the Badenian through Pannonian age (16.5–8.5 Ma). Andesites build up stratovolcanoes formed by alternating lava flows, hyaloclastite breccias, pyroclastic breccias, tuffs and epiclastic breccias, grading outward into complexes of epiclastic conglomerates and sandstones. Intermediate pyroxene, hornblende-pyroxene, pyroxene-hornblende, and pyroxene-hornblende andesites and siliceous rhyodacites and rhyolites are dominant rocks building lava flows. Alkaline olivine basalts are also present. Volcanics evolved in a terrestrial and/or shallow marine environment. Geological structure of the area is showed in Fig. 2a, explanations in Fig. 2b.

Quaternary sediments are developed in river valleys—alluvial sediments and on valley slopes—delluvial sediments. Alluvial sediments consist of loams, sands, gravels, and loamy gravels with boulders. Their average thickness reaches 3–10 m. Delluvial sediments consist of loams and clayey loams, often containing sandy particles. Thickness of the delluvial sediments reaches up to 10 m, and with increasing altitude, their thickness decrease to 3–5 m.

The valley of the Neresnica brook follows deep tectonic zone of the meridional direction called Neresnica

**Table 1** The average monthly and yearly air temperatures

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Sasa	-4.2	-1.8	2.4	8.1	13.0	16.6	17.8	17.0	12.9	7.6	3.1	-1.8	7.6
Viglas-Pstrusa	-4.2	-1.6	2.7	8.2	12.8	16.3	17.7	17.0	13.1	8.0	3.4	-1.4	7.7

**Table 2** The average monthly and yearly precipitation values for Sasa (1963–1998) and for Viglas-Pstrusa (1951–1980)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Sasa	36	34	36	48	70	83	67	64	57	48	59	48	650
Viglas-Pstrusa	31	35	34	43	56	80	74	60	48	44	53	47	609

volcanotectonic zone (Konecny et al. 1998). The fault zone is crossed by longitudinal faults of the NW–SE and SW–NE direction. This tectonic structure acts as a drainage system conducting and storing water from adjacent mountains.

Hydrogeological conditions depend on geological ones. Fissure permeability prevails in effusive rocks (andesites), intergranular-porous in pyro- and epiclastic sequences. Two types of springs are present—fissure and talus springs and both of them have quite low yields. The exception was the spring area close to the Neresnica brook in Podzamcok with the yield of 25–30 l/s, close to which exploration wells were drilled in the 1960s and 1970s. The spring area represented the original outflow area of groundwater accumulated in the Neresnica volcanotectonic zone. Hidden inflows to Neresnica brook from the adjacent area were estimated at 140 l/s by current meter measurements. Transmissibility coefficient of water bearing rocks estimated by hydrodynamic testing of investigation wells varied from  $2.9 \times 10^{-4}$  to  $6.97 \times 10^{-2}$  m<sup>2</sup>/s, storativity coefficient from  $4.0 \times 10^{-5}$  to  $3.79 \times 10^{-2}$ .

The main hydrogeochemical process which forms the chemical composition of the groundwater is hydrolytic solution of silicates. High contents of H<sub>4</sub>SiO<sub>4</sub> reaching up to 95 mg/l are typical for this type of rock environment. Groundwater is of Ca–Mg–HCO<sub>3</sub> type with the value of TDS from 88 mg/l for non-polluted shallow groundwater to about 250 mg/l for water abstracted from the depth of 50–100 m up to 880 mg/l for shallow groundwater polluted by agricultural activities.

#### Abstractions in the catchment

Two water sources are under operation in the catchment; Podzamcok and Dobra Niva (Fig. 3).

The bigger one, Podzamcok, is located close to the village of the same name. Abstractions from the water source Podzamcok started in October 1973. In the first period, groundwater was taken by horizontal pumps.

The drawdown on wells reached 8 m below surface by the total amount pumped, of about 150 l/s in average. In August 1978 submersible pumps were installed in wells and a series of pumping tests including the long-term one was performed in the period from August 1978 to September 1979. The highest pumped amounts were reached in 1981–1989. The groundwater level sunk up to 20–22 m below the surface and in some wells up to 34 m. Since 1993, the pumped amounts gradually diminished to 83 l/s on average in 1999.

Five wells HGN-2 to HGN-6 (drilled in 1983–1984) are under operation at present. In the past, a lot of wells were drilled in the wider area, as HS-1 (drilled in 1967), RH-5 and 6 (1968), RH-7 and 10 (1980) and some others. The second water source Dobra Niva is located 6 km to the south of the Podzamcok water source. The withdrawals in the period 1980–1990 were around 35 l/s with the minimum value of 7.37 l/s, in 1990–1996 they were increased to about 60 l/s with the maximum value of 96.1 l/s. The average value for the period 1997–1999 was about 23 l/s.

Duty to announce the data on withdrawals to Slovak Hydrometeorological Institute started in Slovakia in 1980. Therefore, withdrawal data since January 1, 1980 are the only officially available.

Time series of withdrawals from Podzamcok and totals from Podzamcok and Dobra Niva water sources are shown in Fig. 4. The official data since 1980 are supplemented by data for 1973–1978 period available from the research report of Fecak and Hlavaty (1980). Unfortunately, groundwater level monitoring with regular observations started only in 1992. Observation wells are monitored by employees of Middle Slovakian Waterworks in Banska Bystrica.

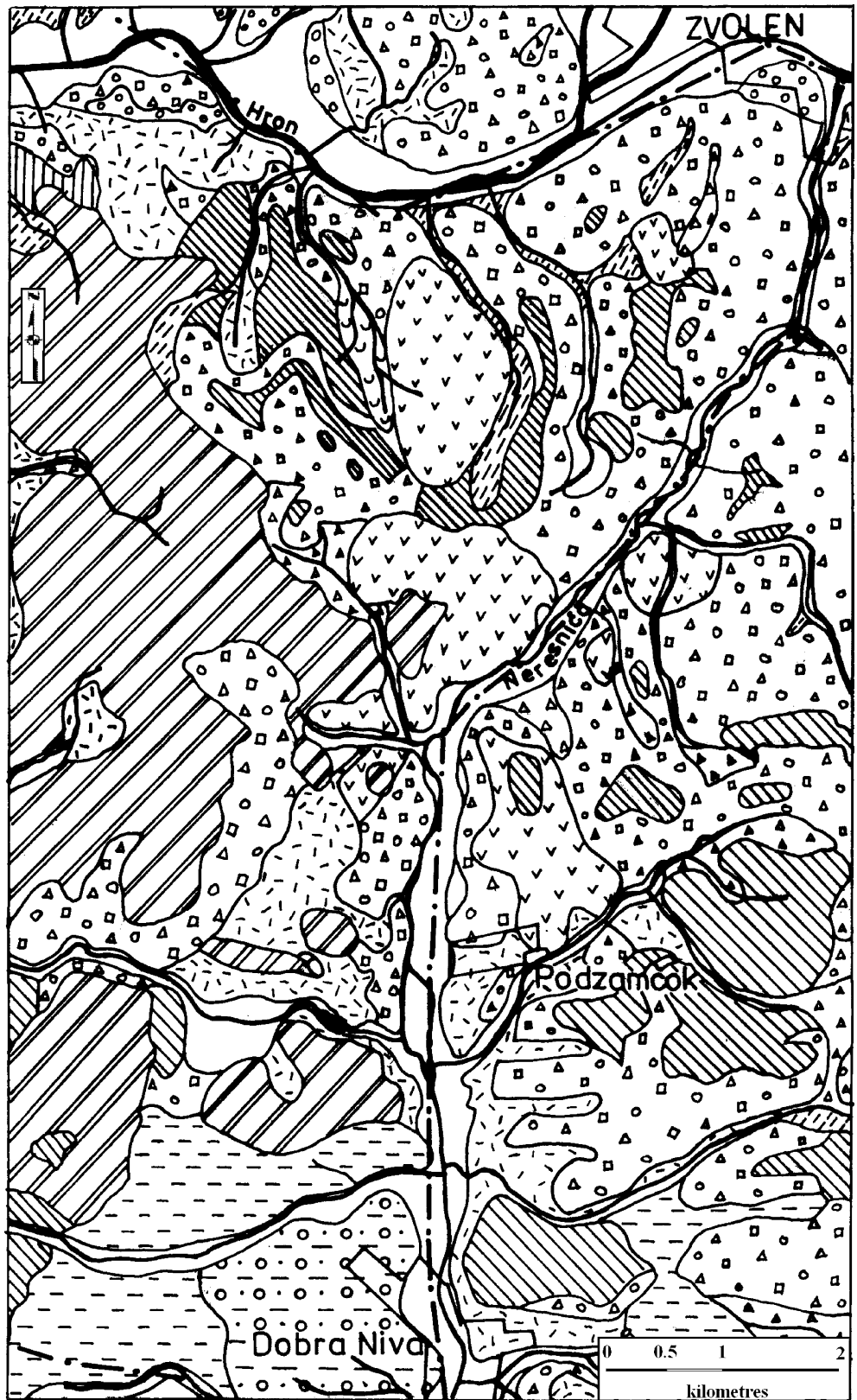
#### Methods utilized

Several groups of methods were utilized for data processing. First of all, a double mass curve (DMC) method was used for the identification of periods with different

**Table 3** The average monthly and yearly potential and actual evapotranspiration values

ETP	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Potential	0	5	31	61	89	108	113	96	58	30	10	1	602
Actual	0	5	23	49	73	86	79	61	37	21	7	1	442

**Fig. 2 a** Geological map of the area. **b** Explanation to geological map: 1-fluvial sediments, 2-fluvial gravels, 3-delluvial-fluvial loams, 4-limnic clayey loams with fine gravels, 5-delluvia (unspecified), 6-elluvial-delluvial loams, 7-polygenic slope loams, 8-Quaternary landslide sediments, 9-alkaline olivine basalts-lava flows, 10-unspecified andesite-lava flows, 11-unspecified andesite-lava breccias, 12-amphibolite-pyroxene andesite, 13-unspecified epiclastics, 14-tectonic lines, 15-surface streams



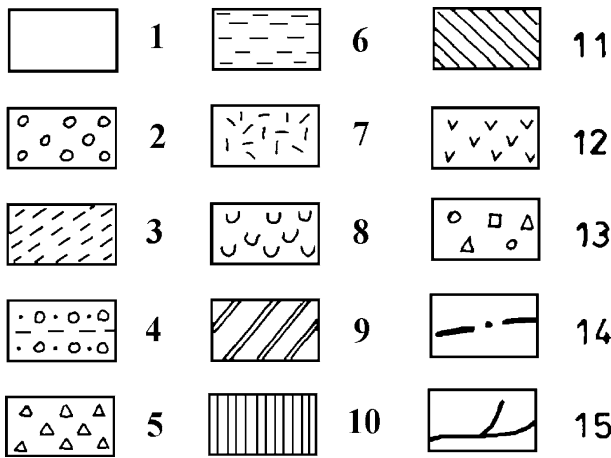


Fig. 2 (Contd.)

conditions of groundwater abstraction. Then simple and advanced statistical methods were applied on hydrological and climatic data, which included basic statistical evaluation and time series analysis. Monthly and yearly precipitation amounts, minimum monthly discharges, average monthly abstraction and average minimum monthly discharges in a year were used as the input data.

Water samples taken from surface and groundwater were analyzed and evaluated using comparative studies and trend analyses.

**Results**

**Double mass curve interpretation**

Yearly amounts of precipitation and average minimum yearly discharge in respective years of (calculated from 12 minimum monthly discharges in the respective year) 1964 to 1998 were used as the input data for DMC construction. The value of the correlation coefficient calculated for the relation of precipitation and minimum discharges for the non-affected period was 0.823 which is statistically significant value on the significance level  $\alpha$  equal to 0.05 (Sachs 1984). The results are shown in Fig. 5.

As it can be seen in Fig. 5, the whole period could be divided into some sub-periods for which regression relations were estimated and correlation coefficients were calculated. Points were added/deleted to/from the regression line according to the highest correlation coefficient reached for the period.

The first sub-period identified on DMC curve is the period 1964–1971. The value of the correlation coefficient  $R_{xy}$  for regression line was 0.998. It is one year shorter than the non-affected period without any withdrawals in the area as estimated by Fecek (1996).

The second sub-period includes years 1972–1977 ( $R_{xy} = 0.995$ ). The water source was put under operation

in October 1972; horizontal pumps were utilized for groundwater withdrawals during the period. Points representing years 1978, 1979 and 1980 did fit neither to the second nor to the third sub-period. Detailed study of the report of Fecek and Hlavaty (1980) showed that since August 1978 till September 1979 series of short- and long-term pumping tests were performed in the water source with the pumped amounts up to 277 l/s. The outstanding position of the year 1980 is not clear yet; it could be reasoned by gradual re-starting of the water source operation.

The third sub-period identified on the DMC is the period 1981–1992 ( $R_{xy} = 0.978$ ), in which the highest amounts of groundwater were withdrawn using submersible pumps. Drawing one regression line through

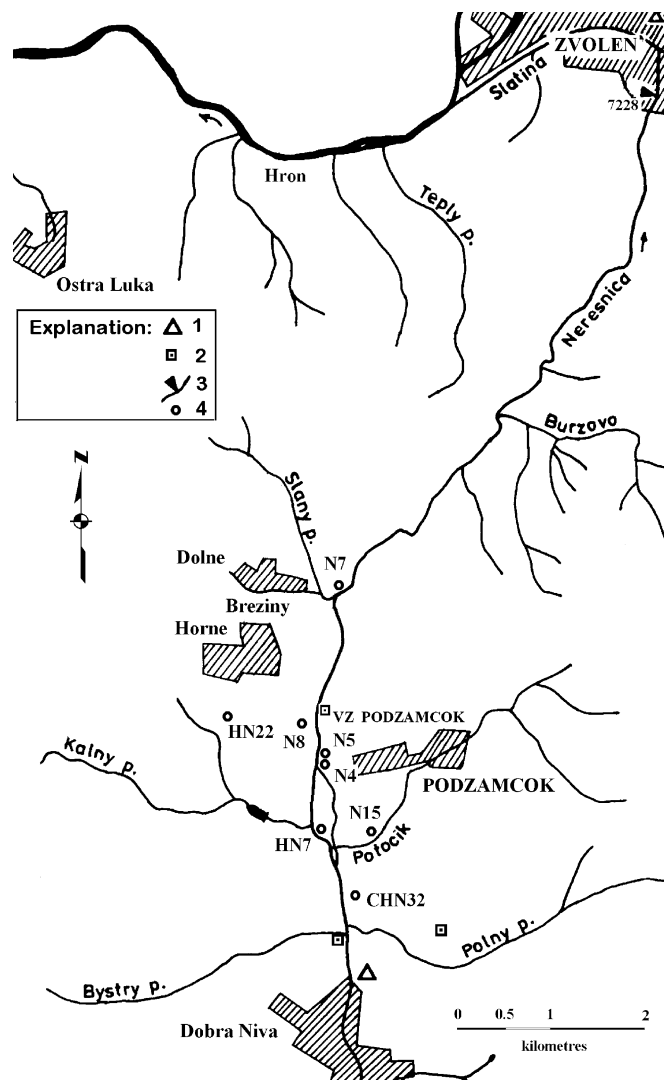
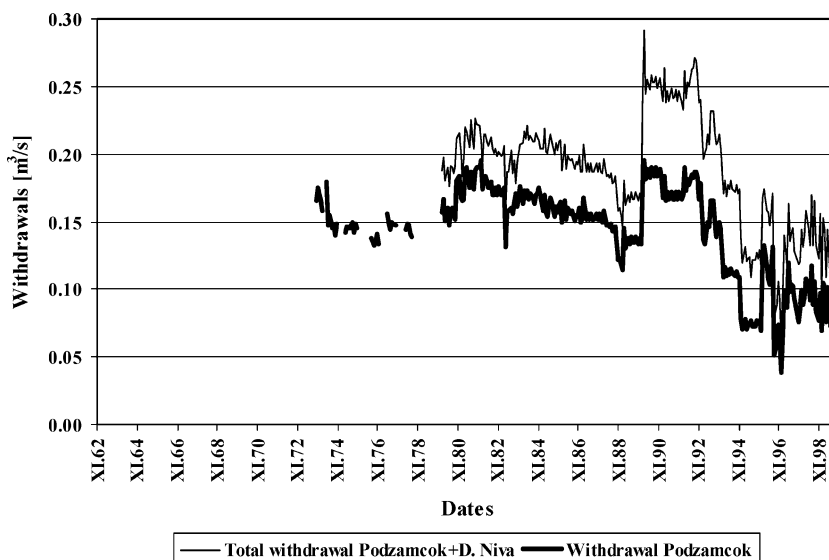


Fig. 3 General situation: 1-precipitation gauging station, 2-water source, 3-discharge gauging station, 4-observation well

**Fig. 4** Time course of withdrawals



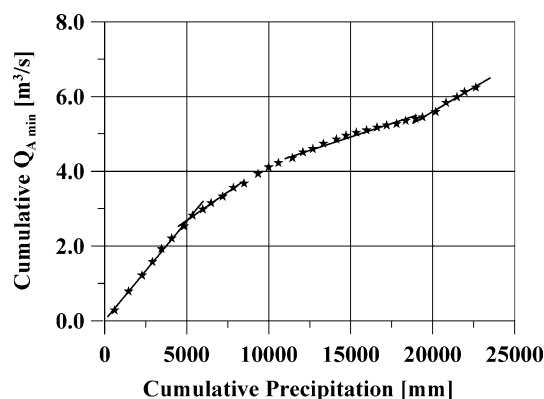
the entire period 1978–1992, correlation coefficient value of 0.975 was reached.

The last sub-period started in 1993 (the fourth part of the curve,  $R_{xy} = 0.989$ ). Withdrawal amounts have been diminished substantially during this period.

According to the results, division of the whole period of years 1963–1999 into three sub-periods was proposed for further evaluation. The first one represents non-affected period in 1963–1971, the second one period of years 1972–1992 with the highest withdrawals and the third one the period with diminished withdrawals in 1993–1999.

#### Relation of precipitation and low flows

Minimum monthly discharges, representing groundwater runoff from the catchment, were used as the input data for stream flow analysis. After the division of whole



**Fig. 5** Double mass curve

time series into three sub-series, all three parts were evaluated separately. Stream flow data were assessed using time series analysis method, namely seasonal decomposition. The same procedure was applied on precipitation data.

Afterwards, regression analysis was applied to assess the relation of precipitation (P) and minimum monthly discharges (Q). As a result, weak relation was found;  $R$ -squared correlation coefficients were statistically not significant. Graphical relation of precipitation and minimum monthly discharges for non-affected period 1963–1971 is shown in Fig. 6.

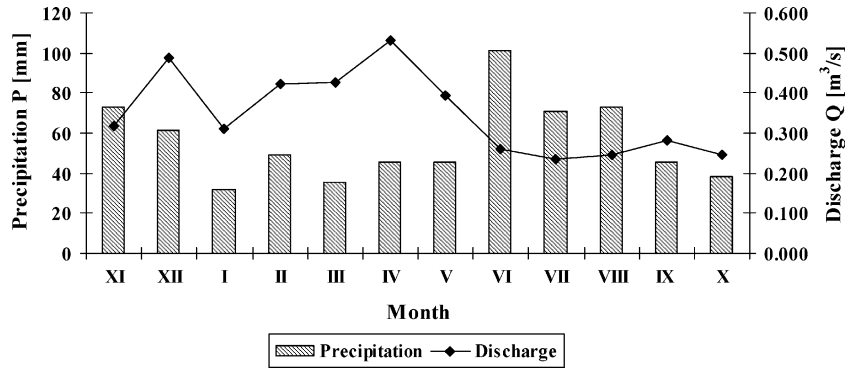
It is clear that seasonal components of precipitation and minimum monthly discharges are different. Highest precipitation occurs in the summer months (June–August) and is lowest in winter and spring months. On the other hand, minimum discharges—low flows—are on the lowest level in the summer months and reach the highest value in April.

Results of seasonal decomposition of minimum monthly discharges for three assessed periods are shown in Fig. 7. It can be seen that not only values, but also the course of the seasonal component has changed. The course of the seasonal component in affected periods is more smoothed; the highest minimum monthly discharges are shifted from April to March in comparison with non-affected period. Minimum monthly discharges have increased in the period 1993–1999, but they still have not reached the values of the period 1963–1971.

#### Effect of abstractions on stream flows

Human interference with the stream flow is very often reflected by values of low flows. Existence of inter-relationships between low flows (minimum discharges) and

**Fig. 6** Seasonal components of precipitation and discharge



withdrawals was examined using regression analysis. To exclude the disturbing influence of seasonal component in time series, minimum yearly discharges and mean yearly withdrawal amounts were calculated and utilized in performed analysis.

Results of the logarithmic regression and polynomial regression of the fourth order are shown in Fig. 8. In the figure, correlation coefficients  $R_{xy}$  and  $R$ -squared values, as well as regression equations are mentioned. Calculated values of correlation coefficients were checked on their statistical significance using Fisher's test (Sachs 1984). Both were statistically significant at the significance level of  $\alpha$  equal to 0.01.

Irregular groundwater level observations showed that the groundwater level dropped in 1980s and early 1990s up to 24 m below the surface and the hydraulic connection between surface stream and groundwater was broken. The spring area dried. After diminishing of abstractions since 1993 the groundwater levels started to rise again, as it can be seen from Fig. 9. Unfortunately, only observations covering the period since February 1992 are at the disposal. Well No. N7 (Fig. 3) is located in the area not connected hydraulically with the water source; therefore no influence of withdrawals is visible

on the groundwater level course. Well No. N8 (Fig. 3) was influenced by withdrawals, as well as well No. CHN32 (Fig. 3). The groundwater level rising is clearly visible.

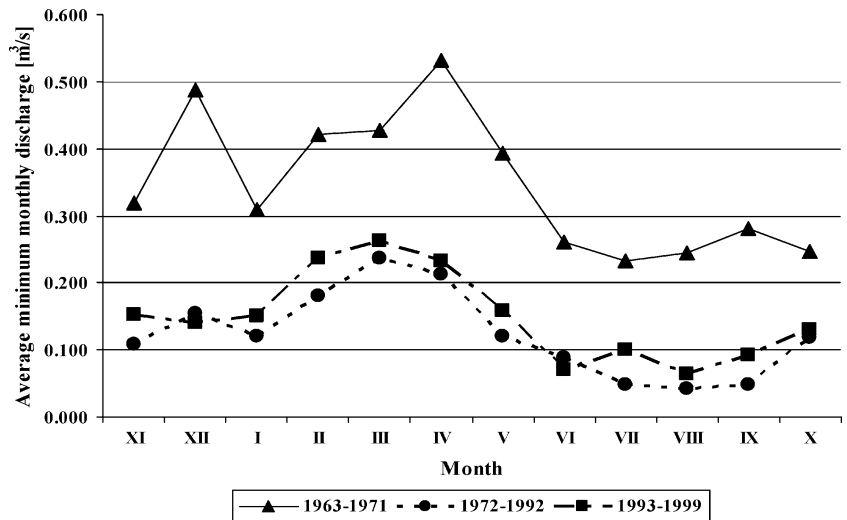
Because of lowered pumping rates, one of the wells in the water source area must be used now for partial lowering of groundwater level in order to prevent flooding of pumping wells by rising groundwater level.

Surface stream drainage function was restored and low flows have been increasing gradually, as it can be seen from Fig. 10.

**Groundwater origin**

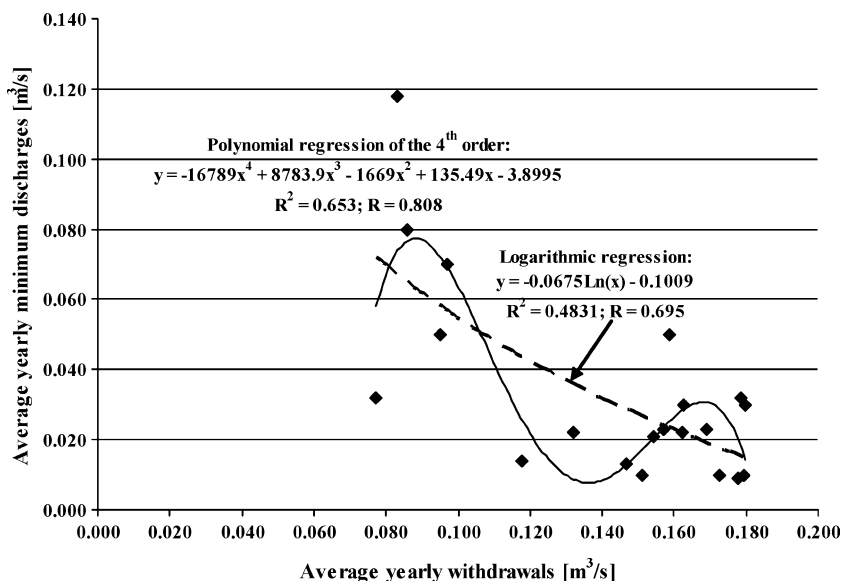
Origin of the groundwater was studied using isotope techniques. Samples for the estimation of oxygen, sulfate sulfur and tritium activity were taken in 2002 and analyzed in Water Research Institute in Bratislava. Obtained results were compared with some older data (see Table 4) of Kantor et al. (1987, unpublished research report), marked with "+" and Silar and Skvarka (1991), marked with "\*" concerning wells belonging to the same water source.

**Fig. 7** Seasonal component of discharge in subseries





**Fig. 8** Relation of withdrawals and discharges



The results are as follows:

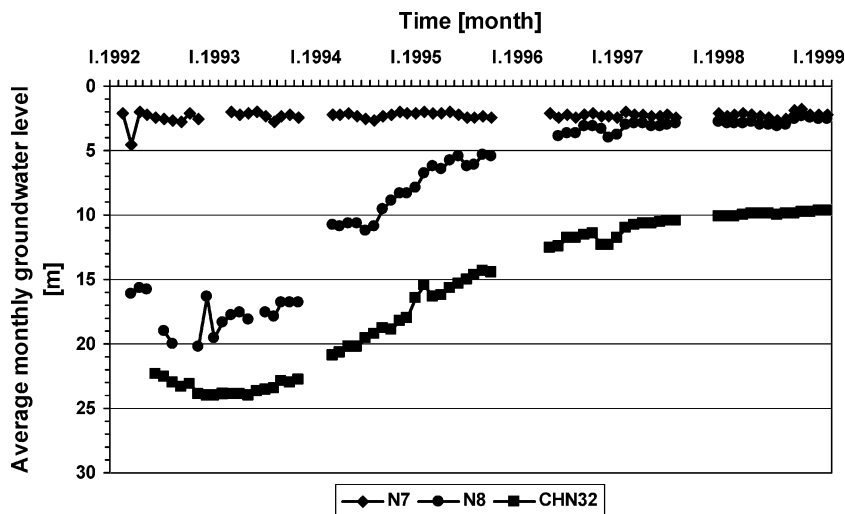
- Oxygen  $\delta^{18}\text{O}$  concentrations confirm meteoric origin of groundwater, they follow meteoric water line. Isotopic composition of oxygen has not changed significantly for 15 years. According to Silar and Skvarka (1991) 13 samples taken in late 1980s from different wells located in volcanic rock environment had very similar  $\delta^{18}\text{O}$  concentration varying in the interval from  $-9.8$  up to  $-11.5\text{‰}$ .
- Tritium concentration is very low and water can be supposed to be the one which infiltrated before 1952.
- Isotopic sulfur  $\delta^{34}\text{S}_{\text{SO}_4}$  concentration excludes any influence of evaporites of the sea origin in groundwater formation processes. Its value is close to the sulfur natural background concentrations in the area, slight influence of sulfidic sulfur is also possible.

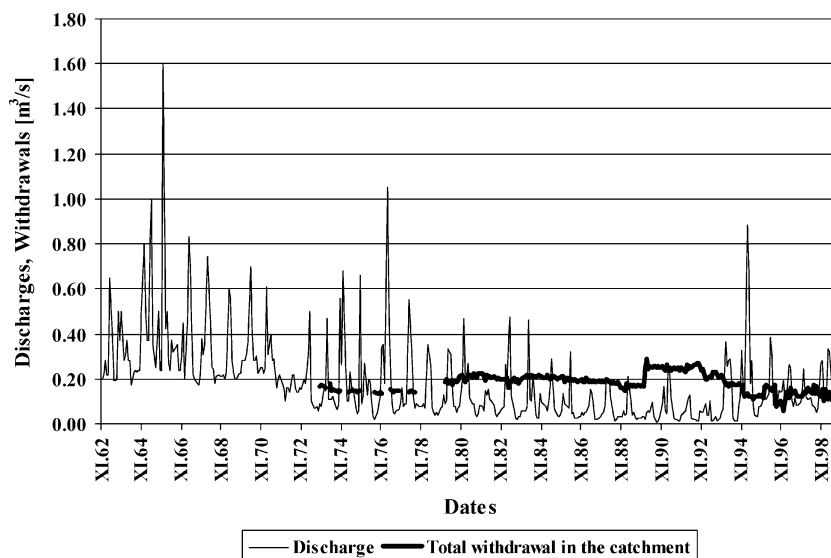
- Isotopic composition of the total inorganic carbon explained deep or metamorphic origin of  $\text{CO}_2$  (Silar and Skvarka 1991). Activity of the radioactive carbon  $^{14}\text{C}$  with the value of about 70 pmC could be interpreted by slightly increased age of groundwater of about 1,000 years, or as a result of rock–water interaction or mixing of different groundwater, respectively.

#### Chemical composition of groundwater

Comparison of groundwater chemical composition during the time of groundwater abstraction was performed as well. The results showed that there is no significant change in groundwater composition and physical properties of groundwater during the whole

**Fig. 9** Time series of groundwater levels in observation wells



**Fig. 10** Time series of discharges and withdrawals**Table 4** Isotopic composition of groundwater in Podzamcok

Well	Year	$\delta$ D SMOW [‰]	$\delta^{18}\text{O}$ SMOW [‰]	$\delta^{34}\text{S}_{\text{SO}_4\text{CDT}}$ [‰]	$\delta^{13}\text{C}_{\text{DICPDB}}$ [‰]	$\delta^{18}\text{O}_{\text{DICSMOW}}$ [‰]	$^{14}\text{C}$ [pmC]	$^3\text{H}$	
								[Bq/l]	[TU]
HGN-5	2002		-10.20	2.48	–	–	–	< 0.2	< 1.69
RH-6	1987 <sup>+</sup>	-67.60	-10.16	–	–	–	–	–	–
HS-1	1987 <sup>+</sup>	-67.96	-10.29	–	–	–	–	–	–
HS-1	1991*	–	–	–	-18.4	-9.80	70.79 ± 1.82	–	< 3

period of water source utilization. Value of total dissolved solids varies in the interval 241.9–281.6 mg/l, pH from 6.7 to 7.9. Average groundwater temperature of 15°C confirms deep circulation of groundwater. Typical components of groundwater chemical composition are  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$ , as well as  $\text{H}_4\text{SiO}_4$ . Ca-Mg- $\text{HCO}_3$  is the basic chemical type of groundwater. Concentrations of metals and organic compounds are minimal. Saturation indexes calculation confirmed that the most stable component of the silica-water system is kaolinite, water is under-saturated towards calcite, dolomite, and anhydrite (Makisova and Zenisova, 2003). Hydrolytic solution of silicates was confirmed to be the most important process generating groundwater composition. The only problematic parameter of groundwater is microbial pollution which must be treated before putting water into the water supply system.

## Discussion and conclusion

Results gained by the authors confirmed important factors affecting the minimum discharges representing

groundwater runoff by withdrawals in the Neresnica brook catchment. According to the results of DMC interpretation, non-influenced period lasted only till 1971 and not till 1973 as supposed by Fecek (1996). So the whole observation period of surface stream discharges could be divided into three parts: 1963–1971, 1972–1992 and 1993–up to present.

Abstraction amount of 210 l/s is too high. Such an abstraction resulted in groundwater level dropping to more than 20 m below the surface, disconnection of surface and groundwater runoff, and in distinct lowering of surface discharges, mainly in low flow periods. Natural drainage function of the surface stream was restored by diminishing of withdrawals.

High-pumping rates did not influence groundwater chemical composition. Compilation of the mathematical model is proposed to gain the tool for calculation of utilizable amounts of groundwater in the area taking into account response of low flows and groundwater levels.

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