50 years University of Mining and Geology "St. Ivan Rilski"
Annual, vol. 46, part I, Geology and Geophysics, Sofia, 2003, pp.315-320

INVESTIGATION ON THE REGIME OF PCHELINSKI BANI MINERAL WATER OCCURRENCE AND CURRENT ASSESSMENT OF ITS EXPLOITATION RESOURCES

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ABSTRACT
Pchelinski Bani mineral water occurrence is located in the north part of Dolna Banya thermal water basin. The terrain of the investigated area is built up by the granodiorites of the Gucal pluton. Thermal springs that have appeared in the zone of intersection of two faults were captured in general shaft. Two of the drilled wells are reserved – one as a duplicate exploitation water source and second – as a seismohydrogeological observation point. Up-to now the only operating water source is the thermal spring intake Pchelin. Thermal water is sulfate sodium by composition, with mineralization of 9.94 g/l, silicic, fluoric, radonic,hyperthermal (73 ^{o}C).
This mineral water occurrence is seismohydrogeological phenomenon – there is a manifested change in spring discharge after strong earthquakes occurring both in Bulgaria and its neighboring states.
The regime of thermal spring is investigated by the authors. The data obtained from regime observations on the discharge of the Pchelin captation for a period 1937-2003 is used. Up to 1990 the average spring discharge is 11.71 l/s and after (up to date) falls to 8.83 l/s. The prognostication assessment of the exploitation resources of mineral water and geothermal energy is made up to 2013, by processing the regression analysis of data for 1990-2003 period. According to this assessment the resources, at the end of prognostic period, will amount respectively to 8.76 l/s and 2092 kJ/s.

INTRODUCTION

Pchelinski Bani mineral water occurrence is located in the central west part of Bulgaria, 8 km to the north-east from the Kostenets town. Its mineral water is characterized with high temperature (73^{o}) and valuable balneotherapeutic properties - it is good for treatment of the locomotory system, the peripheral nervous system as well as of gynecological, skin and other diseases.

The first information of most general character concerning the geology of this region is given by A. Boue. Later on, the region has been survived by G. Zlatarski, G. Bonchev and others. The results from the geological mapping of the region are summarized by Iliev and Katskov (1990, 1993) in Geologic map of Bulgaria in M 1: 100 000 – map sheet Ihtiman. N. Dobrev (1905) carried out the first investigations on mineral waters composition, followed by those of Azmanov (1929, 1940).

The Catchment of the springs has been made under the guidance of minimg engeneer G. Vasilev in 1937. During the 1965-1967 period the Enterprise for Geological Explorations in Sofia conducted well-and-hydrogeological survey in the region of the mineral water occurrence. The occurrence is studied by K. Shterev (1964) and P. St. Petrov et al. (1970). Full hydrogeological characteristic of the mineral water occurrences in the hydrothermal basin of Dolna Banya, including also that of Pchelinski Bani, has been made in the paper of P. Penhev et al. (2003).

The purpose of the present work is to investigate the mineral water regime and to develop a prognostication model for assessment of its exploitation resources of mineral water and geothermal energy. Pointed are also the main prerequisites for its treatment as a seismohydrogeologic phenomenon, which is of scientific interest to the studies on the seismic activity in this country and in the other Balkan states.

DESCRIPTION OF THE MINERAL WATER OCCURRENCE

Pchelinski Bani mineral water occurence is located in the northern part of Dolna Banya thermal water basin. It is revealed in the southern slope of Cherni Rid, which belongs to the Ihtiman Sredna Gora mountain. The relief proceeds from low to medium-high mountainous and is characterized by well-expressed unevenness.

In a regional plan, the mineral water occurence falls into the catchment area of Maritsa river, the region immediately around it being drained by the small river Zhezhkata voda.

The climate is temperate continental of submountain character. The summer is hot and the winter is moderately cold. The average annual temperature is 8.8 ^{o}C. Precipitations as a basic factor in the formation of underground waters, is about 685 mm.

On the territory of the investigated region Paleozoic, Mezozoic and Neozoic formations are found. The geological structure of the region is shown in Fig. 1. Basic collector of thermal water are the granodiorites of the Gucal pluton ($gu\gamma\delta K_2$), which reveals itself within the region of Gucal and Pchelin villages, to the west from the village Momin prohod. Pluton is built of large-grain granodiorite, leuco – to mesocratic with massive texture whose mineral composition includes plagioclase, pottassium feldspath, quartz, amphibole, biotite, apatite, titanite, sericite, epidot. By their chemistry the rocks belong to the normal granodiorites from the potassium-sodium series. The pluton age is determined to 72.5 million years (Katskov, 1993).

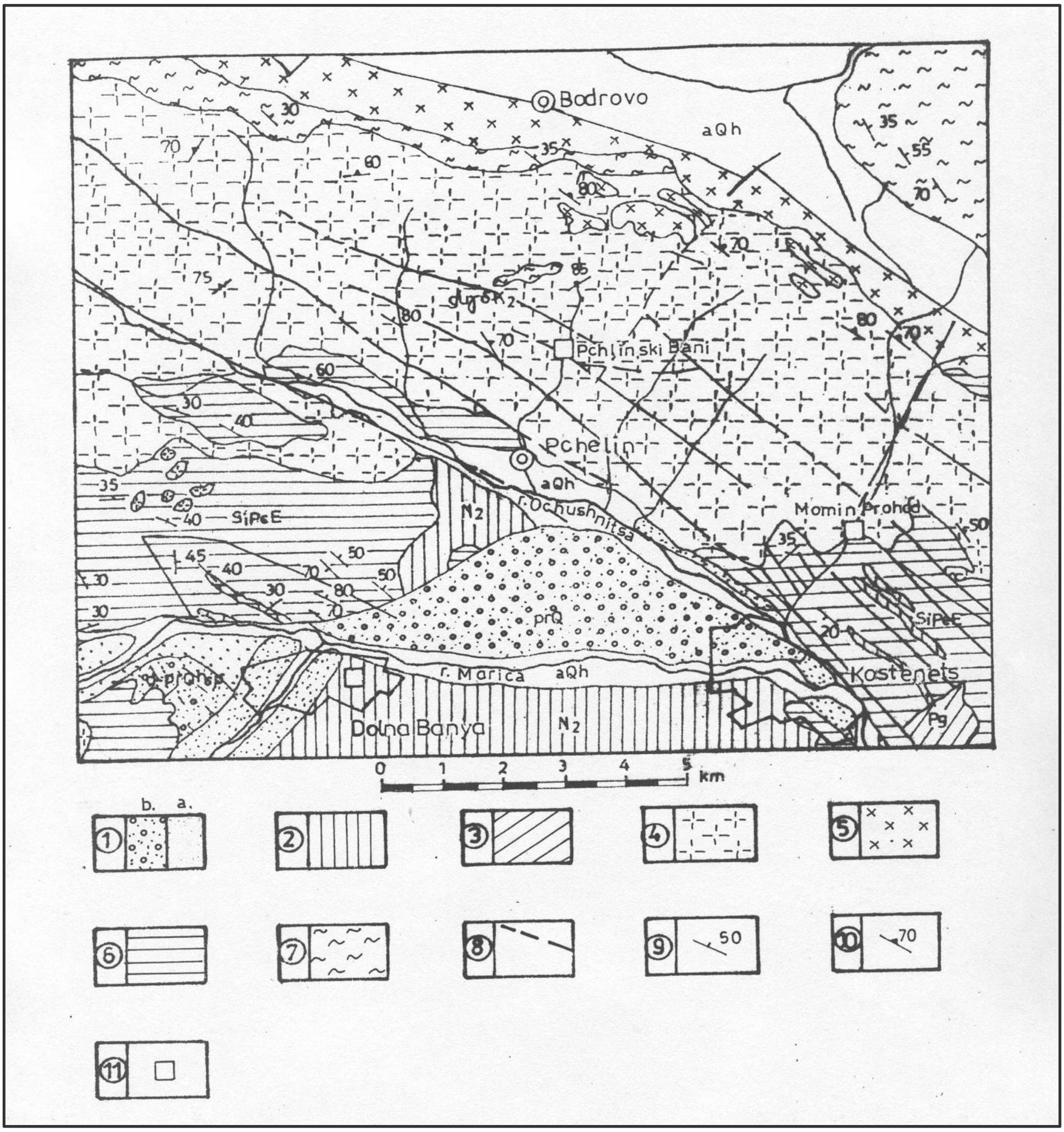

Figure 1. Geological map of the region and the vicinities of Pchelinski Bani mineral water occurrence (by Iliev, Katskov, 1990; Dimitrova, Katskov, 1990).
1- a) Alluvium and prolluvium (Holocene), b) Alluvium, delluvium and prolluvium (Pleistocene); 2 – Brecca-conglomerate-sandstone formation (Upper Pleistocene – Eopleistocene); 3 - Conglomerate-sandstone formation (Lower Oligocene); 4 - Gucal pluton – granodiorites (Upper Cretaceous); 5 – Varshilo pluton – granites (Paleozoic); 6 – Sitovo formation – gneiss-shales, shales, leptinites, gneissis (Lower Proterozoic); 7 – Prarodopska formation – migmatized gneisses, gneisses and gneiss-shales (Archean – Lower Proterozoic); 8 – fault; 9 – bedding; 10 – plane structures in magmatic rocks; 9 – the mineral water occurrence

Pchelinski Bani mineral water occurence reveals itself in the eastern part of the Gucal pluton. Before the catchment the mineral water has been drained by several small springs at an elevation of 632.6 m coming out from a 3 to 10 m wide fault of east-west direction and steep incline to the south. The springs have appeared at the place where the fault is intersected by transverse tectonic fissures of northeast orientation. The open part of the fault is filled with cavernous tectonic breccia from granodiorite fragments (pieces) that are intensively changed, covered and fused by ferrous hydroxides, zeolites and other materials, deposited by thermal waters.

The springs were intaked in a general captation shaft in 1937. Their total discharge before captation ammounted to 11.17 l/s and then to 11.7 l/s at temperature of the water 73 ^{o}C. Three hydrogeological boreholes - Wells №№ 1, 2 and 3 were drilled in the region of the reservoir during the 1965-1967 period by the Enterprise for Geological Exploration – Sofia. Their depths are respectively – 497 m, 348.9 m and 350.3 m, passing entirely into granodiorites. In the course of the hydrogeologic studies, experimental tests of the wells have been made, no artesian flow being obtained as a result. Water from Well № 1has been pumped for a short time and by intervals. A discharge also of 0.161 l/s has been obtained and also drawdown of 9.20 m in the well at statical water leve (SWL) 6.68 m under the terrain. Wells №№ 2 and 3 have been pumped one in a time or as a group at three stages with total duration 25 days without reaching stabilization. From wells №№ 2 and 3, when singly pumped, maximum discharge have been achieved, respectively 30.0 and 27.7 l/s, at drawdown of 1.26 and 3.25 m. The temperature of pumped water was 73 °C.

The data obtained from the group pumping of Wells №№ 2 and 3 are summarized in Table 1. The course of water level recoveries in the wells after the end of the pumping is shown on Fig. 2.

Table 1. Results from the group pumping of wells №№ 2 and3, during the 20-25.08.1968.

Stage	Duration, h	Total discharge at the end of stage Q, l/s	Drawdown at the end of stage, m	
			Well №2	Well №3
I	30	54.8	2.00	4.10
II	37	49.7	1.90	2.18
III	32	34.4	1.82	1.48

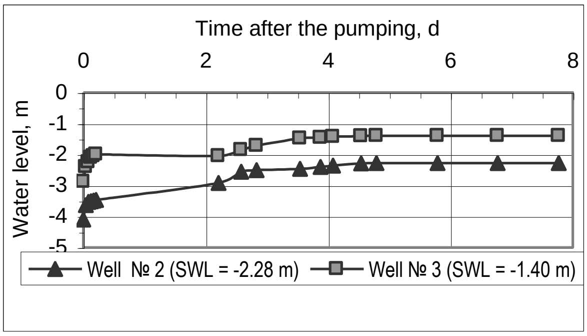

Figure 2. Diagram of the water level recovery in Well №№ 2 and 3 after their group pumping during 20-25.08.1968.

During the experimental water pumping the discharge in the spring intake has declined and at their end the spring has completely dried up. Appearance of artesian flow from the captation occurred 84 h (3.5 d) after the completion of the pumping while the discharge reached its initial values following a period of a month and a half. This process is shown on Fig 3.

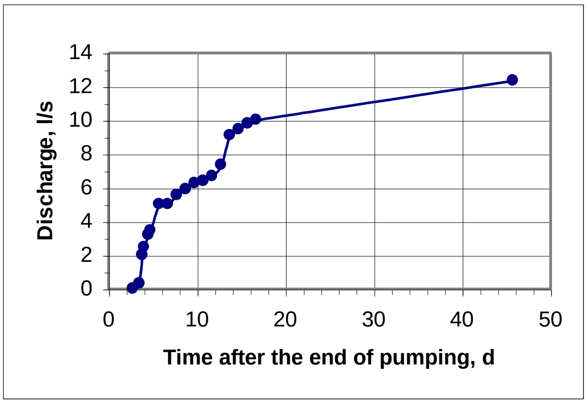

Figure 3. Diagram of the thermal spring discharge recovery after the end of the group pumping in Wells №№ 2 and 3.

The reaction of the spring shows that the yield of groundwater during the pumping has exceeded the natural resources of the reservoir as a result of which part of its elastic resources has been taken away.

Well №1 has been liquidated after the end of the surveying works. Well №2 has been equipped with a hydrograph as a seismohydrogeological observation point by the Main Board of Hydrology and Meteorology at the Bulgarian Academy of Sciences, but at present no daily observations are made. Data from previous observations will have to be found and interpreted. Well № 3 is adapted for pumping exploitation. For the time being it is not used since the discharge of intaked spring supplies the water amount required for satisfying the needs of consumers (Balneotherapeutic unit, greenhouses, etc.).

Now the only operating water source is the intaked spring known as Pchelin captation. Mineral water flows out at an elevation of 632.9 m, the spring discharge varying around 8.8 l/s.

The physical-and-chemical composition of Pchelinski bani mineral water has been repeatedly investigated, the values of the macrocomponents fluctuating within comparatively narrow limits, while the water temperature remains unchanged, being in the range of 72-73 °C. Present-day physical and-chemical , as well as radiologic analyses of the water from the reservoir were made in 2002. The data obtained are given in Table 1.

Table 1 Macrochemical composition of mineral water

Date	Tempe-rature, °C	pH	Chemical compounds, mg/l							Minerali-zation, g/l	Total β-activity Bq/l
			Na + K	Ca	HCO_3	SO_4	Cl	F	H_2SiO_3		
25.02.2002	73	7.20	259.2	27.6	82.4	483.1	22.1	9.0	103.4	0.987	0.347

On the basis of the comparative analysis of all investigations made up to now (1904-2002), the mineral water of the Pchelinski bani is determined as fresh - with mineralization 0.92 – 0.98 g/l, hyperthermal (72.8 °C), sulfate sodium by composition with slightly alkaline reaction (pH up to 8.0) The content of metasilic acid is 95 – 112 mg/l, which characterizes the water as silicic. By content of fluoride - 8÷10 mg/l the water is strongly fluoric. The content of radon in the water reaches 110 ÷ 120 Em (407 ÷ 444 Bq/l), which characterized it as slightly radonic. Nitrogen dominates among the gases diluted in the water - 96.7 volume %, followed by argon (1.7 vol.%) and helium (0.25 vol.%).

FACTUAL MATERIAL AND METHODS OF INVESTIGATION

The investigation on the mineral water regime have been carried out on the basis of an analysis of data obtained from regime observations on the discharge of the spring intake for a period of 66 years (1937 – 2003).

The first observation was made in 1930 before the catchment of the springs when a discharge of 11.17 l/s was measured. After captation the discharge of the spring reached 11.67 l/s and the water was 72.8 – 73 °C (Azmanov, 1940). There are preserved data from regime observations for the 1958-1969 period (Segmenski, 1968). Regular regime observations have been made by the Specialized Hospital for Rehabilitations in Momin prohod in the course of the 1977-2000 period. They have been carried out with changing frequency, no measurements at all being made during some periods and only sporadic ones in other periods.

Up-to-date measurements of the discharge of Pchelin thermal spring were made by the authors in August 2001 and March 2003. The results from the regime observations for the 1937-2003 period are visualized in Fig.4.

The assessment of the exploitation resources of mineral water is made empirically – by processing data from long-year regime observations. As a result of analyzing all available data, two periods have been differentiated that are characterized with different values of the discharge. The discharge values for each of the periods are processed by the method of the regression analysis - through selection of various functions (linear, logarithmic, exponential, etc.). A linear trend that ensures best approximation of the data obtained from regime observations is chosen.

The second period of observation is used for appraisal of the mineral water exploitation resources excluding those values of the discharge, which have been affected by earthquakes. The regression model obtained, by its essence represents a model for prognostication, used in the assessment of the exploitation resources $Q_{exp.}$ This assessment concerns a period of 10 years – up to 2013, in the course of which, new regime observations will be made with the purpose of calibrating the model.

The appraisal of the exploitation resources of geothermal energy (GTE) which represent the admissible and possible average annual yield of heat from the thermal spring has been carried out according to the well-known formula (Gulabov et al. 1999):

$$G_e = Q_e \,.\, C_B . \Delta T$$

where: *Ge* is the heat power, kJ/s; Q_e is the prognosticated exploitation resources of mineral water; C_B is the volume heat capacity of water, C_B = 4,19MJ/m^3. K; $\Delta T = T_{av} - T_o$ is the temperature difference; T_{av} is the average temperature of the thermal water; T_o is temperature of the thermal water after its cooling.

RESULTS AND DISCUSSION

Investigation of the thermal spring regime and assessment of its mineral water and geothermal energy resources.

The diagram of regime observations presented in Fig. 4 shows that two periods may be differentiated in the flow of the Pchelinski Bani thermal spring. The first period includes the time from the catchment of the spring in 1937 to 1989 (on Fig. 4 it is marked as "□") and the second one is from 1990 to 2003 ("○").

During the first period the discharge of the spring varies around the average weigh value of 11.71 l/s. The beginning of the second period sets in 1990 when there occurs a sharp fall in the discharge of tehrmal spring with nearly 3 l/s. From that time on the discharge average weight value amounting to 8.83 l/s. Since the thermal spring is the only operating water source in the mineral water occurence and its exploitation is effected by artesian flow on a fixed elevation, the authors assume that the sharp fall of the discharge after 1990 is due to a technogenic influence which probably still persists.

From the graphical interpretation of regime observations made in Fig.4 it can be seen that the averaged lines show trends toward lowering of the discharges for both periods. Their comparison shows that the trend toward lowering the first period is more abrupt. The trend-line approximating the data from the second period is nearly parallel to the absciss axis, which is an indicator for relative stabilization of the artesian flow from the thermal spring

The prognostication assessment of the exploitation mineral water resources from Pchelinski banii mineral water occurence has been made by using data from the 1990-2003 period, since it shows the current state of the thermal spring regime. The established linear trend (Fig 3) for alteration in the spring discharge (Q) within time (t) has been used and a prognostication period – up to 2013 has been determined:

$$Q_{екс} = 8{,}78 - 4.10^{-7} . t \quad ,$$

where: Q_{exp} is the prognostic value of the exploitation resources, l/s; *t* is the time from 1900,d.

The straight line of the regression approximates only those data that are shown as circules in Fig. 3. The remaining data from the discussed period, which are not taken into account at the approximation, are visualized with the sign "x". The exploitation mineral resources in the reservoir toward the end of the prognosticated period (01.07.2013) are assessed to:

$$Q_{екс} = 8{,}76\, l/s \quad .$$

The exploitation resources of geothermal energy are determined by the amount of the thermal water obtained and the degree of its cooling when being used. In the specific case they are calculated at T_o = 15 °C:

$$G_e = 8{,}76\,.\,4{,}19\,.\,57 = 2092\ kJ/s\,.$$

Seismogenic effects on the mineral water regime

Pchelinski bani mineral water occurrence is characterized with an expressed postseismic response, which is manifested in the sharp fall in its discharge immediately after strong earthquakes occurring both in this country and in its neighboring states. In separate cases a full stop of the artesian flow from the spring captation occurs and the mineral water there appears only after one or several days. The first well-known example in this respect are the destructive earthquakes in Gorna Trakija within the period 14-19.04.1928 when the springs suddenly dried up and appeared again only several days later. Analogic is the response of the reservoir observed after the earthquake on 18. 03. 1953.

The diagrame of regime observations presented in Fig. 4 shows that there were several extremely low values of the spring discharge during the 1937-2003 period. On the basis of the study conducted in this respect it was established that those values were measured immediately after stronger earthquake shocks occurring in Bulgaria or in its neighboring countries. Such wererespectively the earthquakes in 1977 – Romania (Vrantcha); 1999 – West Turkey; 2001 – Romania; 2002 – Macedonia (Skopie) and Kosovo.

After these falls the discharge usually restores its values up to the limits typical for it under normal conditions. This is also confirmed by the current measurementsmade by the authors in 2001. A series of earth tremors and activation of Etna volcano were registered at the end of July and at the beginning og August (20.07 – 03.08. 2001). On 03.08.2001 a discharge of 5.22 l/s was measured while the measurements made afterwards were already within the range - 7.59 /s (10.08.2001) and 9.42 l/s (23.08.2001).

The last postseismic responses of the spring were observed on 24 and 29.04.2002, when a series of earth tremors had been registered in Macedonia (Skopie) and Kosovo (Gnilyane) with a magnitude reaching between 5.3 and 4.5 accorging to the Richter scale. The discharge of the spring showed a sharp fall and stopping entirelly after the last stronger tremor. On 30.04.2002 the discharge restored its value up to about 6.5 l/s (measurements were made by workers in the Specialized Hospital for Rehabilitation in Momin prohod).

All stated above substantiates the dependance between anomaliesin the thermal water discharge and the earthquakes in Bulgaria and its neighbouring states. Imperfection in the study on these phenomenon is the lack of observation on the behavior of the spring immediately before the beginning of the seismic activity. In this connection it is necessary to renovate the regular observations over the changes in the water level in Well № 2 which is 44 m from the captataed spring in a south-easterly direction.

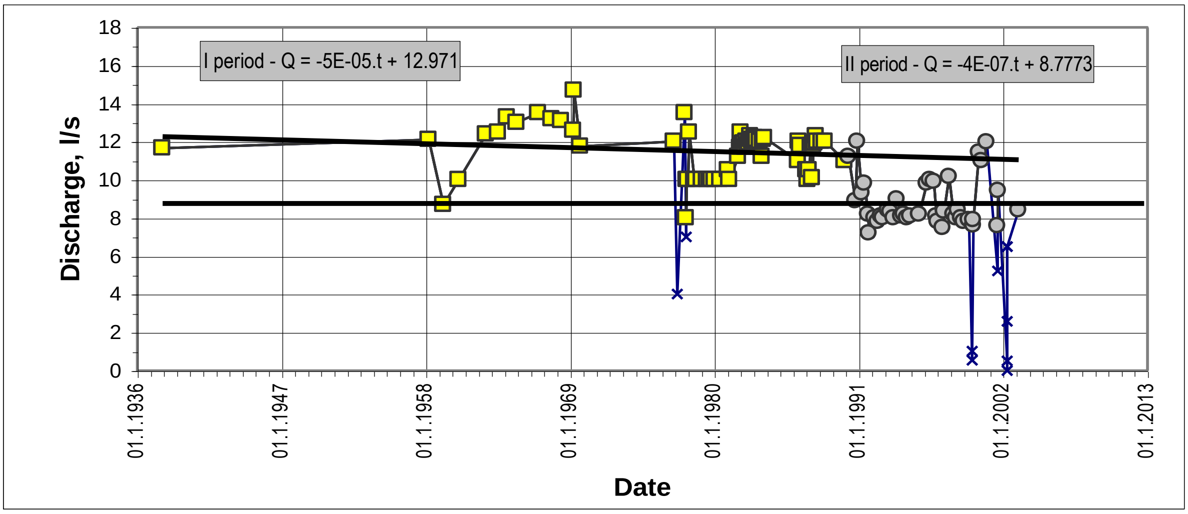

Figure4. Visualization of data, obtained from regime observations on the discharge of thermal spring for 1937-1989 and 1990 – 2003 periods.

CONCLUSION

As a hydrogeological object of a fissure-vein type, the occurrence of mineral water Pchelinski banii may be used as a model for investigation of similar structures with the purpose of elucidating the factors affecting the regime of mineral water – climatic, seismic and technogenic.

A prognostication assessment of the resources of mineral water is made for a period of 10 years according to which at the end of the prognosticated period (2013) the discharge would amount to 8.76 l/s. The resources of geothermal energy at cooling from 72 °C to 15 °C are evaluated to 2092 kJ/s. Under the regime of exploitation established that way – at artesian flow from the Pchelin captation and at permanent environmental conditions, no essential changes in the thermal spring resources are envisaged.

Acknowledgements are due to Assoc. Prof. P. Penchev and Eng. M. Markov from the University of Mining and Geology “Sv. Ivan Rilski” - Sofia, also to Y. Donova and V. Zahariev from the Specialized Hospital for Rehabilitation in Momin prohod, for their kind assistance.

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