INVESTIGATION OF MOUNTAIN KARST SYSTEMS BEHAVIOUR BY TRACER TECHNIQUES
(ON THE EXAMPLE OF THE* NASTAN - TRIGRAD KARST SYSTEM *- BULGARIA)

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Abstract: A second tracer test carried out in the river Tenesdere during June 2000 allow us to confirm the connection between the river and the main springs of Beden and Nastan. The transient time is very short in this period which is interpreted us an evidence of high karstification of the system, which induce a high vulnerability especially from wastes dumped into the river.
Keywords: tracer test, transient time, karstic aquifer, vulnerability

Introduction

Tracer tests are a very good and usual tool in the study of karstic aquifers (Burger and Dubertret, 1975; Thrailkill et al. 1983; Gaspar, 1987; Lepiller and Mondain, 1988; Hoztl and Werner, 1992; Maloszewski, 1994; Kranj, 1997; Kass, 1998). It is also well known that an unique experiment is often not sufficient to characterize the flow and parameters of hydrogeological interest (Jamier, 1976; Drogue, 1980; Mangin, 1984; Leibundgut, 1995; Pulido-Bosch, 2001) due to the importance of the initial conditions of the system. We describe the new experience trying to verify this hypothesis and corrected some initial impressions.

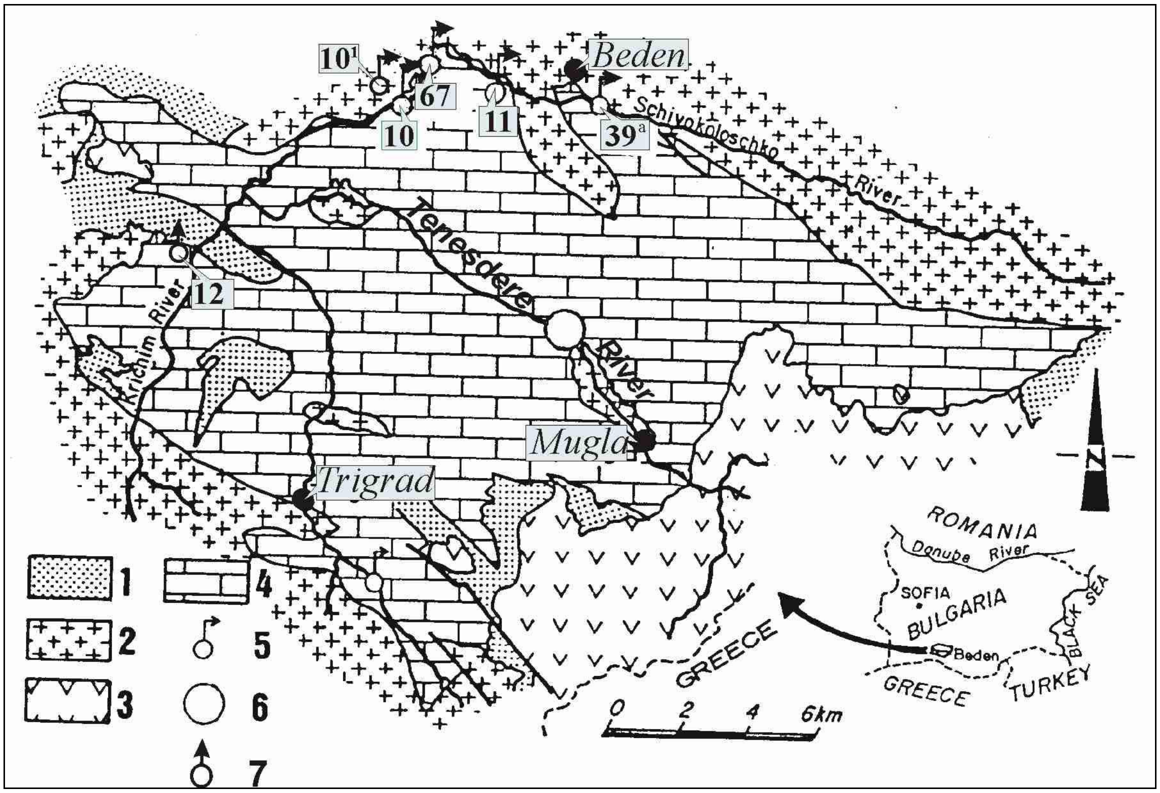
The Nastan -Trigrad system has been studied from different point of view in several occasions (Yaranov et al., 1959; Antonov and Danchev, 1980; Pulido-Bosch et al., 1995; Gabeva et al, 1995; Benderev et al, 1997; Machkova et al., 2000). The Nastan -Trigrad karst system has an average altitude of 1500 m a.s.l. It is constituted of Precambrian massive marbles (Dobrostan formation) which have a thickness of up to 1600 m (Kojuharov and Dimitrova, 1992). The marbles have an outcropping area of 143 km^2 (Figure 1) and are faulted and folded. They are in contact with metamorphic rocks (gneiss, schist, and less amphibolite) and with volcanic rocks, mainly rhyolite (Smolian volcanic massif), and with granite rocks (Barutin-Buinovski pluton). The granite dikes of Upper Cretaceous age are intercalated among the marbles.

The region of Nastan-Trigrad is located in the Rhodope mountain (SW of Bulgaria, figure 1) nearby to the Greek border. It is characterized by the presence of abrupt karst relief, which configure different basins with patent hydraulic breakout. The underground feeding toward these basins is carried out by means of karst springs that can overcome more than 2 m^3/s of discharge (Table 1 and figure 1). Some of these springs (№67 and №39[a]) have a control of quality and quantity by the NIMH (National Institute of Meteorology and Hydrology) in Sofia.

Table 1. Main characteristics of the sampling points

Characteri-stics	Spring 10	Borehole 10[1]	Spring 67	Spring 11	Spring 39[a]	Borehole 12	River Tenesdere upstream
Discharge [L/s]	~20	-	582	97.0	720	1.0	721
Altitude a.s.l. [m]	760	770	709.9	780	785	820	1260
Distance	8.75	8.80	9.25	7.25	7.0	10.75	0

from the injection place [km]							
Altitude difference [m]	500	490	550	480	475	440	0



Legend: *1 Breccia-conglomerate, conglomerate, sandstones, siltstones; 2 Granites, gneisses, schists; 3 Rhyolites; 4 Marbles; 5 Spring; 6 Injection place; 7 Borehole*

Figure 1 Hydrochemical scheme of the Nastan – Trigradska karst system

The objective of the present paper is to interpret the results obtained during a new tracer experiment carried out in this region. The initial objective of the previous one was to check the possible hydraulic relationship among the losses of the river Tenesdere and the spring of Beden (№ 39[a]), one of the most important springs in this karst system. This new experiment could contribute to the scarce knowledge on the complex structure of this karst aquifer, as well as the presumably inertial or non-inertial behavior of that system. Tracing test are basic tools to define karstic aquifer conceptual models (EU, 1995), establishing convenient criteria to obtain vulnerability hydrogeological maps for karstic aquifers, and for establishing criteria in order of define protective zones of sources.

Two previous tracing experiments were carried out in this place; the first was in August – September 1954 for the purposes of the hydrotechnical construction in the region, using NaCl as tracer (Yaranov et al., 1959), and the second one in July 1999. In the first experiment they injected 9 tons salt (sodium chloride) closely at the same input point of our experiment. The outlet of the trace took place through the “Thermal” and “Nastan” springs after 41 and 63 hours respectively (Numbers 10 and 67 in Table 2).

Table 2. *Hydraulic parameters of the system obtained by mean of the mathematical model.*

Spring	Mean transit time (hours)	Mean flow velocity (m/h)	Dispersion parameter	Percentage of tracer recovery
67 – Nastan	56	167	0.005	29 %
11 – Beden	56.5	128	0.022	10 %

The data obtained in the second experiment did not agree with those of the Yaranov's tracer test, neither in form nor in time. Some of the confronted consequences of these dual studies have been related with the own structure of the karstic massif and seasonal or even recent historical changes in the piezometric level of the aquifer (Machkova et al, 2000), it is considering that Yaranov's tracer test experiment was carried out more than 40 years ago.

Methodology and experiment implementation

The experiment started on 9 June 2000 when five kilos beforehand diluted fluorescein, were injected at 12 o'clock noon. Historically, it was known that the river Tenesdere has significant stream flow losses in its high course. The selected injection place was located at Tenesdere riverbed 200-300 meter upstream the dry course of the river, 3.5 km far to the north of the village of Mugla at an altitude of 1260 meters (Figure 1). The river discharge at the time of injection was 721 l/s (Table 1).

The control of the tracer exit was carried out in continuous in the spring №11 and №67, located in the fish farms of Beden and Nastan, respectively, by means of an automatic sampler Edmund Bühler model Calipso 4.20.2-04. Collection of samples was planned for intervals of an hour. Likewise, the possible tracer exit was controlled in the points № 10, 12 and 39[a] (Table 1), where they were taken samples each 12 hours, and charcoal packs during the experience were placed.

One-liter "zero" water samples to estimate the back-ground were taken from all control springs immediately after the injection. Water samples were analyzed by spectro-fluorometry at the laboratory of the Institute of General and Inorganic Chemistry from Bulgarian Academy of Sciences (Sofia, Bulgaria). The fluorescein concentrations of water samples were determined by quantitative luminescent analysis using the dependence of the fluorescence intensity on the substance concentration in water. The determination is made by single-beam spectral photometer (SPEKOL 10, Carl Zeiss Jena) having analogue indicator light. It works by the deviation method. The monochromatic dispersion system is a diffraction frame with 651 lines per mm as well the spectral diapason ranging from 340 to 850 nm. The source of radiation is Hg (mercury) lamp. An amplifier is used to increase the sensitivity. The maximal intensity is measured within the range 490 to 510 nm. The determination limit in these conditions is 5 ppb. The fluorescein from charcoal pack samples was eluted using 100 ml 15% KOH during 15 minutes.

Subsequently the description and main characteristic of the points of the water samples are presented (Table 1):

- The spring № 67 is located in the non-private fish farm at the road Nastan-Devin. Its discharge was 582 l/s, considered constant during the experiment. The sampler was started on 10 June at 10 o'clock a.m. It was taking samples at hourly intervals, thus 92 water samples were taken from 10 to 14 June. Eleven (two times per day) water samples were taken in the period 14-19 June. Three charcoal packs were consecutively placed at this point, as the last one was taken on 1st July, 23 days after the injection.
- Spring № 11 located at the road Nastan-Pamporovo in the private fish farm was equipped with a similar automatic water sampler (Table 1). It was started on 10 June at 11 o'clock a.m. The spring discharge was 97 l/s during the experiment. Seventy-five water samples were taken at this spring from 10-14 June, less than the mentioned above, because of some irregularity of the sampler. Eleven (two times per day) water samples were taken within the

period 14-19 June. Similarly three charcoal packs were placed at this point, as the last one taken on 1st July 2000.

- In the major spring "Beden" № 39[a], outflowing at the left bank of Shirokolaschka River, were taken 19 (two times per day) water samples from 10 to 19 June. Three charcoal samples were also taken, as previously. The average discharge of the spring during the experiment was 720 l/s.
- In the so called "Thermal" spring (№ 10) were taken 19 water samples from 10-19 June, nine of them from the spring outflowing at the right bank of Vacha river. The rest ten water samples were taken from the borehole (№10[1] "Thermal") drilled for the "non-private" fish farm needs. It is located opposite to the spring at the left Vacha riverbank. Four charcoal samples were taken at this place, one from the spring and the rest three from the borehole.
- Six water samples were taken from the borehole in Teschel sawmill (№12) from 11 to 14 June as well as one charcoal sample. The sampling in this point was cut off on 14 June at noon because of the place outlying.

Once represented the analytic values obtained in the springs along the time (breakthrough curves), they were interpreted with the aid of the software Traci for Windows 95 version 4.0.4B (Werner, 1998). This beta version program, developed in the University of Karlsruhe, allows fitting observed breakthrought curves to several 1D models of tracer transit. The parameters obtained in the different models give some information about the hydrodynamics of the aquifer (flow velocity, dispersion) in the longitudinal direction.

Likewise, the percentages of tracer recuperation were obtained for this same method and by means of electronic tables designed to such effect.

Results

The breakthrough curves of the fluorescein for the springs №11 and №67 are represented in the figure 2; in both is appreciated how has been obtained a complete reconstruction of the tracer transit. The selection of these two main points of control responds to the prior knowledge of the system obtained in the former tracer test carried out the previous year (Machkova et al., 2000). The fluorescein was detected in a visual way to the 13:45 hours of 11/06/2000 in the spring №11 (Beden). In the spring №67 (Nastan) the tracer was detected analytically by first time to the 9:30 of 11/06/2000.

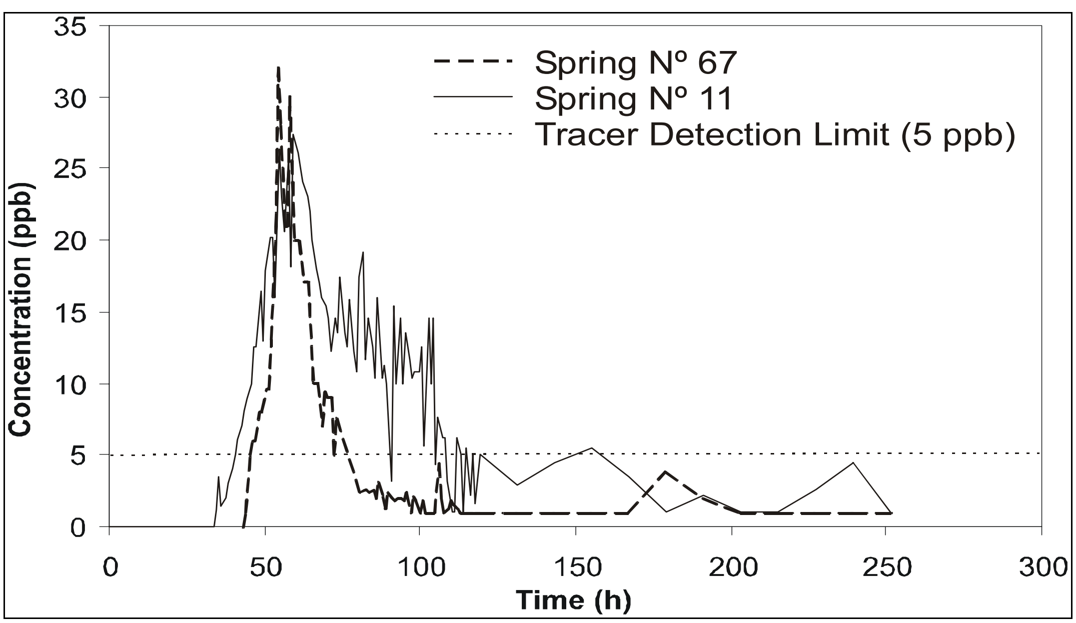


Figure 2. Breakthrough curves of the fluorescein in the two sampled springs.

In the spring №67, the maximum value, 32 ppb, was reached at 18:30 in 11/06/2000 or 54:30 hours after the injection. The apparent longitudinal flow velocity in this case was 170 m/h.

The higher value of tracer concentration in the spring №11 was detected approximately upon the 21:30 hours of the 11/06/2000, which correspond to an average velocity of the subterranean flow in the shorter injection-spring way of some 126 m/h. Just as it is appreciated in the figure 2, the average velocity of the flow in the direction to spring №11 is something more less than toward the spring №67, in spite of that in that was detected before the tracer arrival, given that more near the point of injection is found.

In the springs №№39[a], 10 and 12 (Figure 1), the values observed are under the limit of detection (5 ppb) during the experiment, besides showing an irregular distribution of concentrations in the time (Figure 3), for which cannot be assured that the tracer was clearly recognized at these sprints. The spring № 39[a] is practically disconnected of the system, for which the water would flow from another area of recharge.

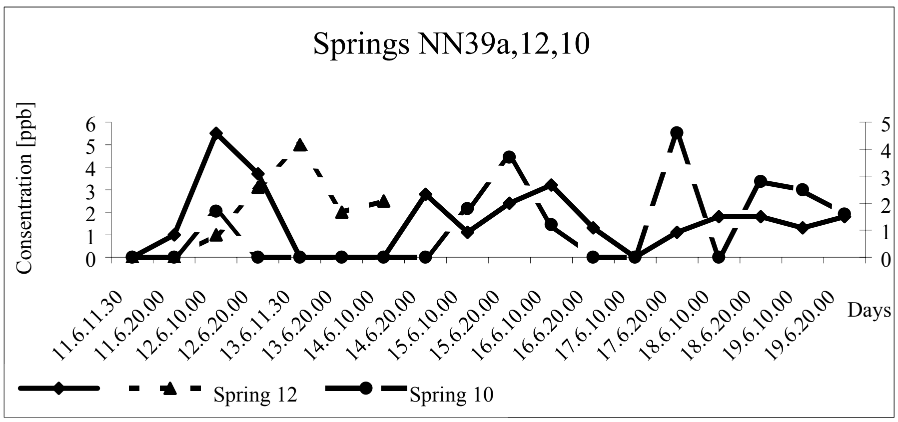


Figure 3. Possible breakthrough curves of the tracer for springs 39[a], 12 and 10 (on the abscissa are shown days and hours)

The analysis has been focused, therefore, in the springs №67 and №11 where the fluorescein was manifested clearly so much visual as analytic (Figure 2). The table 2 collects the values obtained after the application of some 1-D mathematical model of interpretation of the tracer transfer into the system, as the code Traci95. The modeling of the breakthrough curves (Figure 4) has permitted to obtain information upon some hydraulic characteristics of the system (Table 2). As expected, the average longitudinal velocity of subterranean flow toward the spring №67 Nastan is greater, which is observed in the sharpest form of the breakthrough curves and in its smaller value of dispersion. The tracer percentage recuperated on this point is the highest, almost 30%.

Both springs recuperate close to 40% of the tracer injected; this fact, together with the high velocities of longitudinal flow and the presence of an only arrival in both springs does to suppose that this aquifer must be highly karstified with preferential pathway flows.

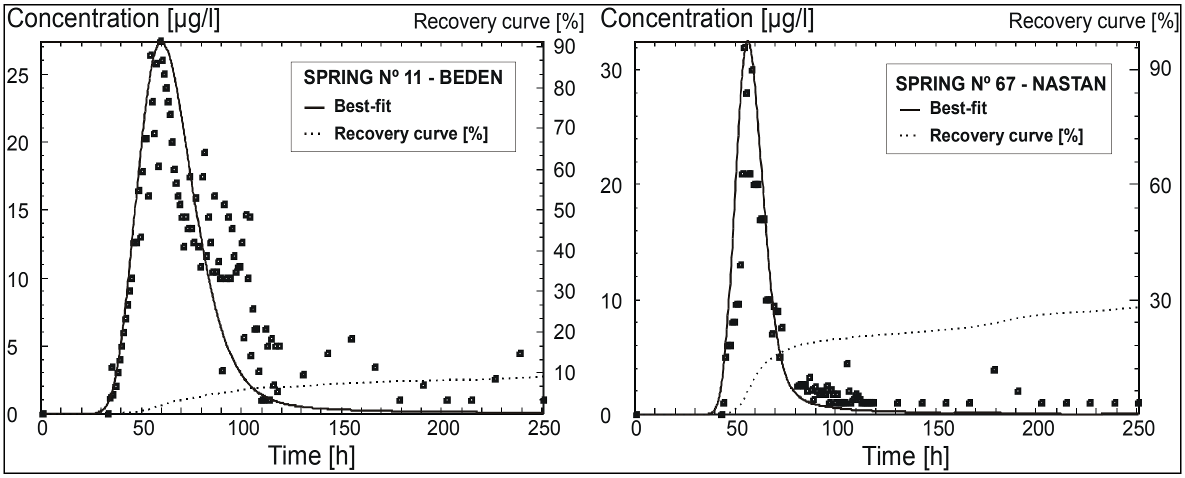


Figure 4. Modeling of the breakthrough curves of the tracer in the springs 67 and 11.

The concentration of fluorescein found in the charcoal packs corroborate the results obtained previously in the springs №67 and №11, though seems that there is a reduced tracer exit late in the point №10, nearby to the springs №11 and №67. This fact would show, in part, the existence of a preferential path flow, and relatively quick, since the point of injection in the Tenesdere riverbed to the Nastan and Beden springs. On the other hand, the sector of the karst related to the spring №39[a] would be disconnected hydraulically of the injection zone, because the tracer has not been detected neither visual neither analytic in the samples of water as in the charcoal packs.

Final considerations

The tracer test "2000" carried out at Nastan-Trigrad karst system one year after the first attempt (Machkova et al, 2000) have been prepared according to the previous experience, avoiding the past errors due to the absence of an adequate observation equipment, lack of knowledge on the outlet points as well scarce previous information. At this second time two automatic samplers were available, which improved the sampling effectiveness.

The obtained results show the system complexity and the way how with an unique injection point in a riverbed, the tracer can outlet from more than one point, with different pathway and transit times. It should be noted that part of the tracer volume flowed with surface waters before its final infiltration into the aquifer, because of its long transit time.

The information obtained from the breakthrough curves interpretation lead to the conclusion that the system is highly karstified. That is why contaminants dumped into the river reach the discharge point (spring) in a very short time, which constitutes a high potential risk for the water users. In terms of vulnerability, the "Tenesdere" riverbed should be considered as highly vulnerable, much more than other areas closer to the protected source. That is frequent in this type of terrains with high heterogeneity (Doerfliger and Zwahlen, 1996).

This seems in contradiction with the previous research based on the correlation and spectral procedures (Pulido Bosch et al., 1995) where it was conclude that "The degree of karstification of the system was low (absence of highly transmissive conduits)….there was a clearly dominant component of baseflow and an estimated memory of 64-83 days. The distribution of the discontinuities and conduits would be quite regular, without the large transmissive conduits becoming very developed". Of course these conclusions should be acceptable for the whole system, but not for the "local" part river-main springs, where the links can be direct and fast; this aspect is very important, because the general behaviour of a system can have local variations, sometimes very high. Also, correlation and spectral analysis must be used in complex systems with care, especially when more than one discharge points representing different flow components exist. According to this, studies of certain natural phenomenon need to be multi-approach to avoid the modelling simplification limitations of each one.

Other aspects to be taken into account concerning the rate of tracer recovery in complex aquifers are related to: first, the difficulty to determine with precision the whole points and places where the tracer can appear and second, according with the previously referenced studies on the response of the system to external signals (precipitation or inflow), the base flow is discharging in a long interval of time and a peak at the breakthrough curve not detected in the time of control might be expected. Possible trapping of certain quantity of the tracer in some parts of the aquifer could not be neglected.

From a practical point of view these results are very important, especially for springs protection perimeter design. Opposite to the normal procedure in a porous media, different protection zones should be established in karstic terrains, taking into account the fact that the potential pollutant transit time is lower in the transmissive elements as karstic channels and conduits. That is why in some times areas far from the spring must be included in the highest level of protection, while other areas closer to the source could be of low rate of protection, if karstification is low.

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