Tracing tests as a tool for the estimation of possible impacts of human activities on karst waters – examples from Slovenia

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Abstract: To protect effectively karst waters against negative impacts we should first have as much information as possible about the characteristics of karst aquifers. In our practice the tracing tests were proved as a very useful tool for the acquisition of such information.

Key words: karst waters, tracing tests, Slovenia.

Introduction

Karst aquifers as very important water resources are very vulnerable to human activities. To protect them properly their specific properties should be first defined by adequate research methods. Tracing tests as one of them were proved as a very useful tool for the acquisition of the information on extent of recharge zones, characteristics of groundwater flow and transport of pollutants. In our practice very good results were obtained by tracing with fluorescent dyes. Three examples are described as illustration of the applicability of tracing tests in the field of geological engineering on karst.

Results and discussion

The study of the possible impacts of the activities on the main Slovene military training reserve Poček near Postojna (Fig. 1) on karst waters was initiated by the Ministry of Defence. The reserve is located within the area of Cretaceous limestone and partly dolomite of the Javorniki mountain range. In the hydrological sense this karst aquifer is bordered by the Pivka basin in the west and by the sequence of karst poljes in the east and north. The aquifer supplies many karst springs, the most important being

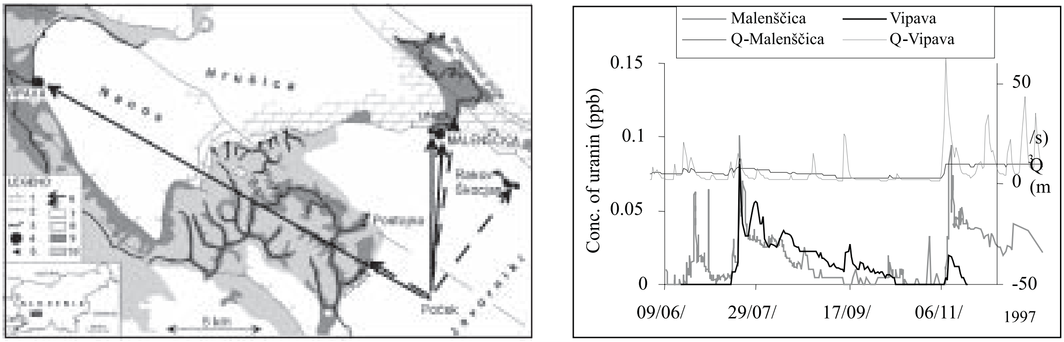

Figure 1. Hydrogeological map with results of tracing test in the Poček area (1. Visible and covered thrust plane, 2. Visible and covered fault, 3. Surface stream, 4. Spring, 5. Ponor, 6. Main and secondary direction of proved underground water connection, 7. Karst aquifer, 8. Fissured aquifer, 9. Porous aquifer, 10. Very low permeable rocks)

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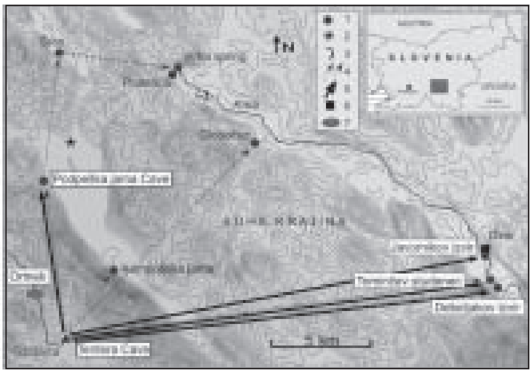
the Malenščica spring which has been captured for the water supply of the broader Postojna region. For more accurate definition of directions and characteristics of groundwater flow from the training reserve a tracing test with the injection of uranine on the rock bottom of a smaller doline was carried out at low waters in spring 1997[1]. Results showed that an important proportion of water flows towards 9.3 km distant Malenščica spring (Q_{mean}= 6.5 m^3/s) and 24.6 km distant Vipava spring (Q_{mean}= 6.8 m^3/s), which is also captured for the water supply (Fig. 1). In this way the main direction of groundwater flow from the Javorniki area towards the springs on the Planinsko polje was confirmed, but also with some previous tests indicated[2] groundwater flow below the flysch of the Pivka basin towards the Vipava springs was proved. In both directions the tracer was flowing with the dominant flow velocity v_{dom} = 0.7 cm/s (with regard to the time of maximal concentration). The tracer appeared distinctly also at smaller springs in Rakov Škocjan, and with the lowest velocity at only 3.4 km distant Stržen southern from Postojna. Traces of uranine in the Malenščica spring during rainfall almost 1 year after the injection demonstrate long-continued washing out of the soluble substances through the aquifer. Retardation would be even longer in the case of the additional flow through the soil. The assessed returned share of uranine amounts to almost 100 %, the greater part of it occurred in the Malenščica (55 %) and Vipava (26 %) springs[3]. By the tracing test it was confirmed that any pollution on the surface of the reserve seriously endanger the quality of water in several springs, especially in two most important sources of drinking water in the region.

The second case demonstrates typical characteristics of the contact karst where surface streams sink through ponors into the underground. These are particularly vulnerable points because surface streams enter directly into well permeable karst conduits and in this way bring pollutants immediately into the karst system. Tracing tests can point out possible directions and time needed for the transport of pollutants at certain hydrological conditions. During an accident at the repository of oil derivatives near Ortnek (Fig. 2) in October 1998 an unknown quantity of gas oil was flowing away into the surface stream Tržiščica which sinks into karstified and well permeable Jurassic and Cretaceous carbonate rocks at the Tentera Cave. Possible influences on the water quality were observed by immediate analyses and one-year monitoring with fluorescent spectrophotometer in the karst spring Globočec which is an important source of drinking water. Gas oil was appearing in the spring after intensive rains up to May 1999, but rarely in concentrations above 0.01 mg/l. Occasionally the presence of derivatives and more frequently also distinctive odour were perceived. In spite of relatively small pollution the supply of drinking water from tank lorries was necessary for quite a while.



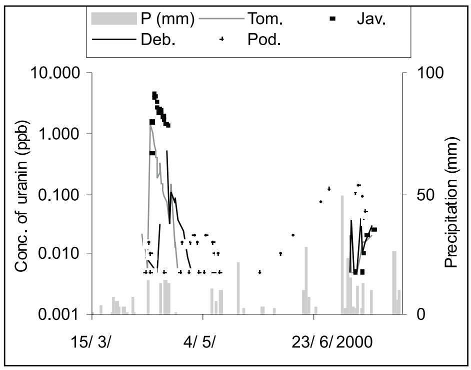


Figure 2. Topographic map with results of tracing test in the Ortnek area (1. Spring, 2. Precipitation station, 3. Gauging station, 4. Proved and uncertain underground water connections, 5. Proved underground water connection by tracing test in the year 2000, 6. Village, 7. Repository of oil derivatives)

In the frame of the planned enlargement of the repository the Commodity Reserve Institution had to prepare also the evaluation of possible impacts on waters. As one of the research methods the tracing test with uranine was carried out in 2000 at the hydrological conditions of recession from medium to low waters (at the Globočec spring a decrease of discharge from 750 l/s to 90 l/s). The fastest flow towards the Tominčev studenec spring (v_{dom} = 4.6 cm/s), and somewhat slower towards the Javornikov izvir and Debeljakov izvir springs near the village Dvor were proved by the results[4]. In two months approximately 2/3 of the total amount of injected tracer had been recovered at these springs. After heavy rain at the end of the 2 months long period of recession, the tracer in lower concentrations was detected also in other observed springs, except in the Globočec spring in which the sampling was the most frequent. So at described conditions expected connection with this spring was not confirmed. Obtained results indicate that hydrological conditions significantly influence the characteristics of groundwater flow in karst. The major part of the soluble tracer flows fast through the primary drainage paths. The rest is retained for longer time in the underground, and during low waters it is washed out after rain also in other available directions. According to our experiences with the substances which are not soluble in water and can be due to their specific characteristics hindered in the underground, we can conclude that they can first accumulate and then be washed away towards the springs in the long-continued process[5]. And we can also state that already small pollution with a dangerous substance can have very serious consequences.
The third example of the application of tracing tests is connected with the planned construction of the new railway track in south-western Slovenia. A very important karst spring Rižana (captured for the water supply of the whole Slovene Coast), as well as the Boljunec spring area (with springs Pri Pralnici, Na Placu and Jama) in Italy are situated in the broader area of influence of this line (Fig. 3). The contact karst with the alternation of Upper Cretaceous and Palaeocene limestones and Eocene flysch is characteristic for the whole area. The closest to the railway line are the ponors of the Beka-Ocizla Cave system. According to the results of previous researches sinking waters from this area are flowing underground towards the Boljunec springs[6].

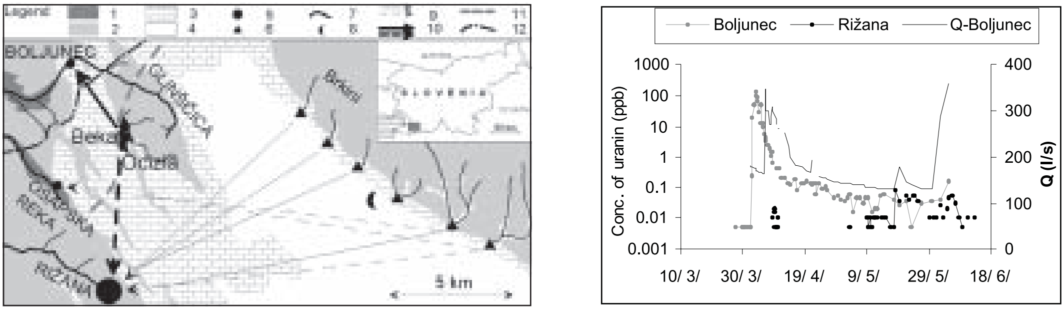


Figure 3. Hydrogeological map with results of the tracing test in the Beka-Ocizla system (1. Porous aquifer, 2. Very low permeable rocks, 3. Karst-fissured aquifer, 4. Karst aquifer, 5. Spring, 6. Ponor, 7. Surface stream, 8. Karst cave, 9. Main and secondary direction of underground water flow, proved by previous tracing tests, 10. Main and secondary direction of underground water flow, proved by tracing test in 2001, 11. Planned railway line, 12. State border)

For more reliable confirmation of these findings the tracing test was carried out in a preliminary research of possible impacts of the construction of new railway line, initiated by the Slovenian Railways. After injection of uranine in March 2001 the main underground water connection with the Boljunec springs was confirmed at conditions of medium waters. Already before precipitation, 84 hours after injection, the tracer was detected at the springs Pri Pralnici and Jama. Also for the peak of concentration (v_{dom}= 33 m/h) and the main outflow of tracer through the spring (in 4 days 84 % of the total amount of injected tracer had been recovered) the conditions of constantly decreasing discharge were characteristic. After washing away of the retained tracer in the beginning of July the amount of recovered tracer reached 91 %, but smaller amounts were flowing out also later. Uranine was not detected in the spring Na placu, which differs from the spring Pri pralnici also according to the physico-chemical parameters. Considerable lower were concentrations of tracer in the Rižana spring (Q_{mean}=4 m^3/s). First traces were perceived 10 days after the injection, but higher concentrations were measured not earlier than 50 days after injection at the conditions of low and even decreasing discharge. Until June around 2 % of injected tracer had been recovered through this spring, and the washing away was probably continuing also later. In other observed springs uranine was not detected. Although weak, the connection of the planned railway line with the regionally important water source of Rižana should be considered in the preparation of water protection measures.

CONCLUSIONS

Tracing tests are a very useful research method for the study of the characteristics of groundwater flow, and as such can be used also in the field of geological engineering on karst. In karst aquifers groundwater flows fast and often in different directions at different hydrological conditions. Only with long lasting tracing tests it was possible to define certain flow paths, which are activated only at extremely low waters. Also different characteristics of pollutants are important. The most dangerous substances are a serious threat to drinking water already in very low concentrations; therefore also such weak connections can be fatal. So in the case of pollution on karst we should consider not only the first, intensive runoff, but also the belated outflow especially towards the springs captured for water supply. Of course tracing tests are just one of the tools which can give us good results in the study of karst, but an adequate combination of different research methods is necessary in order to get a more complete picture of the functioning of karst aquifers.

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