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KARST WATER RESEARCH IN SLOVENIA

RAZISKOVANJE KRAŠKIH VODA V SLOVENIJI

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Andrej Kranjc: Raziskovanje kraških voda v Sloveniji

Kras predstavlja 43 % površja Slovenije in preko 50 % prebivalstva se oskrbuje z vodo s krasa. Kras v Sloveniji delimo na alpski, dinarski in prehodni. Vsak izmed teh tipov ima svoje vodne značilnosti. Podzemeljske vodne zveze omenja že antična literatura. Sledenja podzemeljske vode na Krasu sodi med najstarejše take raziskave. Raziskovanje kraških voda lahko po tematiki razdelimo na več obdobij: ugotavljanje podzemeljskih vodnih zvez med posameznimi ponori in izviri (prva polovica 20. stol.), opravljanje kombiniranih sledenj (od 1970 dalje), ugotavljanje razvodnic na krasu, preučevanje prenikanja skozi epikraško in vadozno cono (od 1980). Posebno pomembna so tudi preučevanja kvalitete kraških voda in zakonitosti v hidrologiji krasa. Prispevek sklene vprašanje, katera preučevanja so najbolj perspektivna: sledenje še neznanih podzemeljskih zvez manjših potokov ali ponavljanje sledenj ob različnih hidroloških situacijah, podrobno določanje razvodnic in raztekanja kraških voda s pomočjo injiciranja sledil neposredno v podzemlje, razvijanje sledilnih tehnik in metod, terensko preučevanje prenikajoče vode, modeliranje, teoretične študije z namenom odkrivati zakonitosti. Posebno pozornost pa je treba posvetiti izobraževanju.
Ključne besede: hidrologija krasa, hidrogeološke raziskave, zgodovina raziskav, Slovenija.

Abstract UDC: 556.3(497.4)

Andrej Kranjc: Karst Water Research in Slovenia

About 43% of the territory of Slovenia is karst and more than 50% of its inhabitants are supplied with water from karst. Karst in Slovenia is divided into Dinaric, Alpine and transitional karst. Each of these types bears its own hydrological properties. Already in the antique literature underground water connections are mentioned. Water tracing in the Slovene Karst is among the first modern tracing research. Karst water research may be divided into several periods: (1) aimed at determining underground water connections between swallow-holes and springs (the first half of the 20th century), (2) to achieve combined water tracing tests (since 1970), (3) to define karst watersheds, (4) to study water percolation through the epikarst and the vadose zone (since 1980). In particular, the researches of karst water quality must be emphasised, as well as the study of karst hydrology as a phenomenon in itself. At the end a logical question appears: what are the future perspectives of karst water studies in Slovenia? Water tracing of not yet fully ascertained connections or repeating the water tracing tests under different hydrological conditions; a detailed determination of watersheds and water flow with the help of tracers directly injected underground; to develop water tracing techniques and methods; to study in the field percolation water behaviour; modelling; to theoretically determine physical laws. Special attention must also be paid to education.
Key words: karst hydrology, hydrogeological investigation, history of research, Slovenia.

INTRODUCTION

About 43% (8.800 km^2) of the territory of Slovenia is karst; this is why karst water is so important for the republic, as more than 50% of inhabitants are supplied by drinking water from karst. Not only the scarcely populated areas of the Dinaric Karst (for example Suha Krajina with 10 - 50 people/km^2) but also, for example, a part of Ljubljana (the total population of the town is 270.000), Nova Gorica (60.000) and its vicinity as a whole, and the whole Slovene Littoral (Koper, Izola, Piran) are supplied with water from karst.

Karst in Slovenia is divided into Dinaric, Alpine and transitional (isolated, intermediate, prealpine) karst. Each of these types bears its own hydrological properties. Alpine karst (22% of the karst in Slovenia) belongs to the diffuse-flow category, and Dinaric karst (57%) to the through-flow type of karst (Habič 1982). The rest (21%) of the karst in Slovenia belongs to the transitional type of karst. The most significant phenomena for a through-flow karst are sinking rivers and big karst springs.

It is not a coincidence that already in the antique literature the first phenomena described from our karst are just karst water phenomena. Springs of the Timavus river (to the north-west of the town of Trieste, on the coast of the Adriatic sea) were an important source of water supply for ships sailing along the eastern coast of the Adriatic, and were first mentioned in the Pseudoskilax' Periplos (nautical guidebook) from the middle of the 4th century BC. Poseidonius of Apameia (135-50 BC), who studied the Timavus springs in connection with sea tide and who is quoted by Strabo, said that "a river, the Timavus, runs out of the mountains, falls down into a chasm, and then, after running underground about a hundred and thirty stadia, makes its exit near the sea" (Shaw 1992, 67). Without a doubt, by the term "chasm" the Škocjan Caves are meant. This is also the first known mention of an underground water connection between sink and rise in the karst of present-day Slovenia. The Timavus springs were mentioned by numerous later writers such as Livius and Plinius, including the poet Vergilius.

Beside other things, the Kras region is important for the history of tracing techniques (Käss 1992). The first known person who tried to prove the underground water connection between the Reka river (the "Upper Timavus") and the springs of the Timavus was Father F. Imperato (1599) by the means of "floaters". The water tracing of the underground Reka flow in the middle of the 19th century belongs among the first modern tracing researches: P. Kandler traced the Reka river in 1864 by using "blue dye - indigo". In 1891 the Reka river sinking at the Škocjan Caves was successfully traced by F. Müller using uranine.

Modern karst water research in Slovenia may be divided into several periods, during which an interest for a certain topic prevailed: (1) to determine the underground water connections between swallow-holes and springs (the first half of the 20th century), (2) to achieve combined water tracing tests (from 1970 to now), (3) to define karst watersheds, and (4) to study water percolation through the epikarst and the vadose zone (since 1980). In particular, the research of karst water quality must be emphasised, as well as the study of karst hydrology as a phenomenon in itself. In these last mentioned studies only a few researchers in Slovenia were temporarily involved in spite of the great amount of data obtained through various field studies and after many years of observations.

The advent of water tracing was already mentioned. In Slovenia, to prove or to detect under-

ground water connections, a large number of tracers have been used. Besides the fluorescent dyes (uranine, fluoresceine, fuxine), salts (sodium chlorode, lithium and strontium chloride and cesium salts), marked eels, Saccharomyces cerevisae, and accidental "tracers" (spills, saw dust, turbid waters, etc.) were used. By the beginning of the 2nd World War about 30 successful (some uncertain) traces were made (Šerko 1946). Still, some water basins (for example of the Kolpa river) were without any tracing, although numerous sinking streams and springs are there. By 1965 the number of traces exceeded 70 (Gams 1965). The last overview from 1990 listed nearly 100 of them, in spite of the fact that some were overlooked (Habič 1990).

After simple water tracing (to find out or to prove water connections between ponors and springs), primary attention was paid to so-called combined tracing tests, which took place mostly after 1970. The main reason for the combined tests was rational (economic) management, to get as much information as possible for as little money as possible (in any case, tracing tests cannot be achieved with "little money"). The first real extensive combined tracing test took place in Slovenia between the years 1972 - 1975, as the preparation field work for the Third symposium on underground water tracing which was held at Bled, in the framework of the Association of Tracer Hydrology.

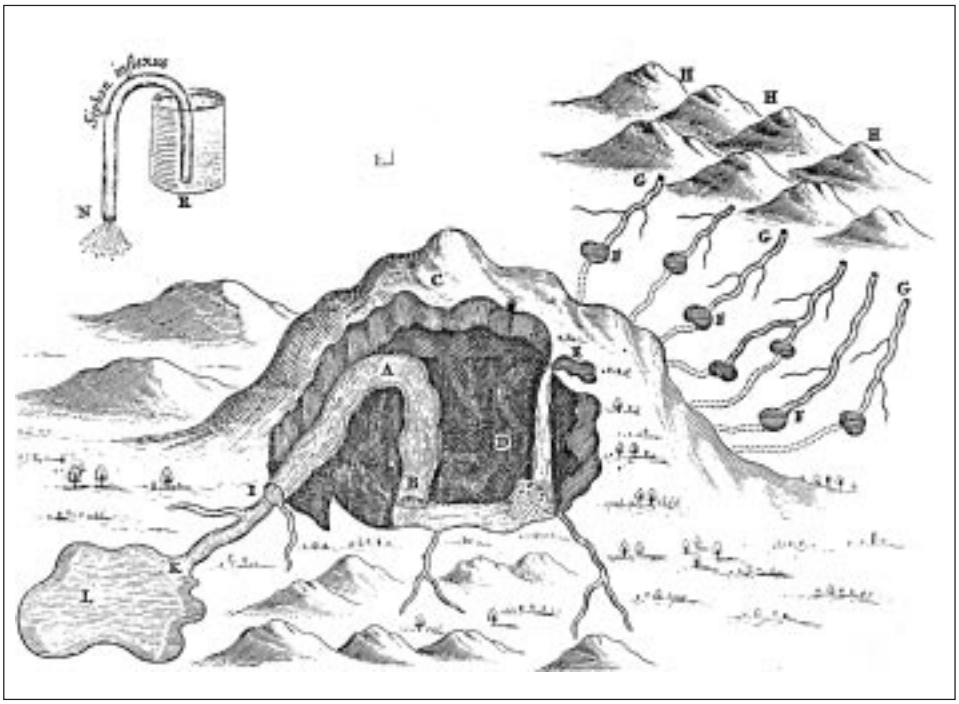

Fig. 1: One of the first illustrations which helps to explain the seasonal functioning of Cerkniško Jezero periodical lake (Kircher 1678, 306).
Sl. 1: Ena prvih ilustracij, ki ponazarja razlago presihanja Cerkniškega jezera (Kircher 1678, 306).

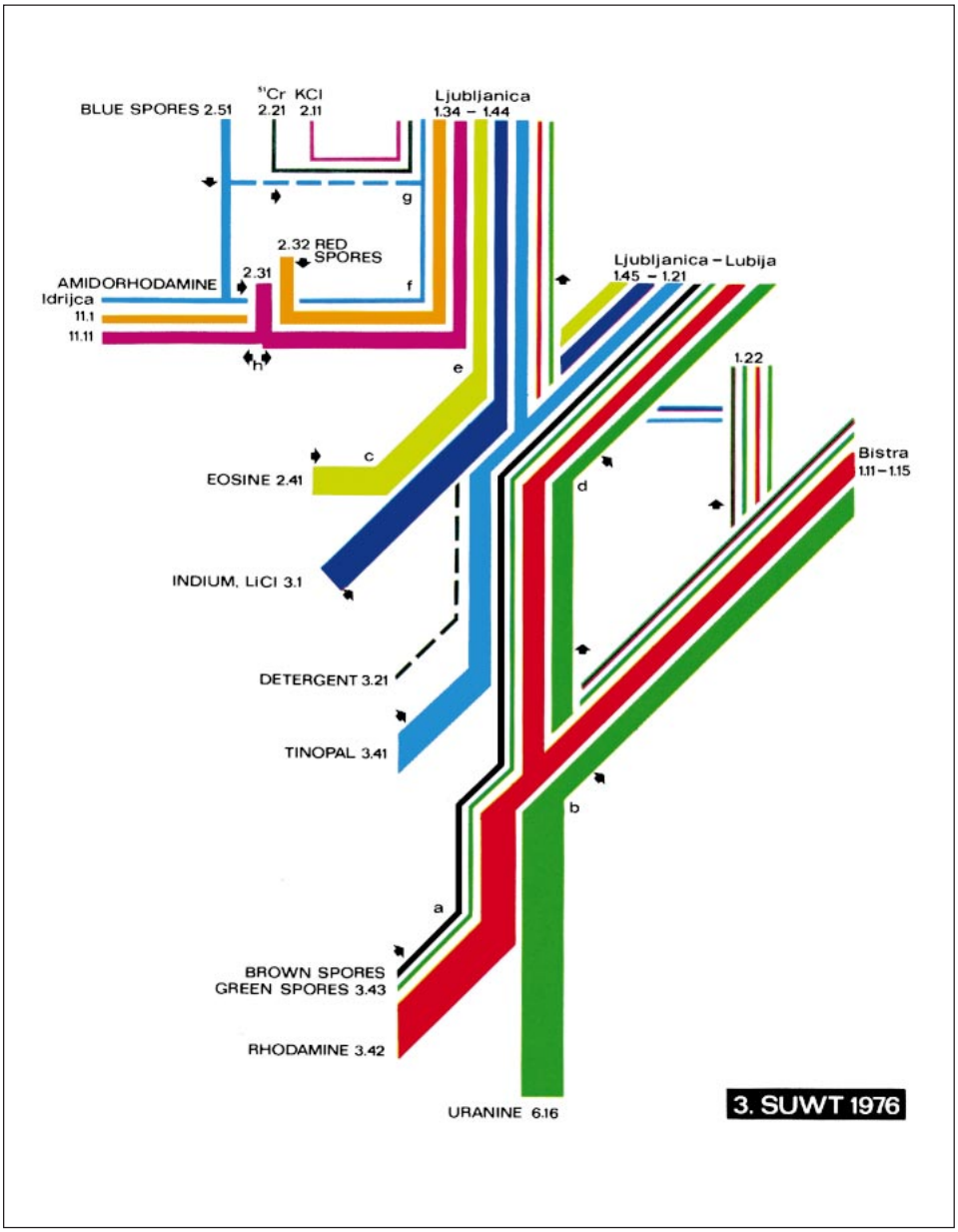

Fig. 2: The underground water connection scheme related to results of water tracing experiments in 1975 (Gospodarič & Habič 1976, fig. 79).
Sl. 2: Shema podzemeljskih vodnih zvez po rezultatih sledilnega poskusa 1975 (Gospodarič & Habič 1976, fig. 79).

The test was conducted in the water catchment area of the Ljubljanica river springs, between Cerkniško, Planinsko and Logaško karst poljes and the Ljubljansko Barje (Ljubljana basin). A large variety of tracers were used: uranine, rhodamine, eosine, tinopal, amidorhodamine, dyed lycopodium spores, lithium chloride, potassium chloride, isotope ^{51}Cr, and hard detergents (Marlon A 375). Detailed results were published in a special book (Gospodarič & Habič 1976).

Next, similar combined extensive water tracing tests were organised for the Seventh Symposium on Water Tracing from 1993-1996. The test site was the high Dinaric karst plateau Trnovsko-Banjška Planota. During this test, less tracers were used (uranine, pyranine, bacteriophages, lithium chloride, strontium chloride), due to the fact that the emphasis was not on the applicability of the different tracers nor to prove as many underground water connections as possible, but to study the water connections in different water situations and to get from the tracing as much information as possible about the aquifer. The results were published in a special volume of Acta carsologica "Karst Hydrogeological Investigations in South-Western Slovenia" (Kranjc 1997). Of course, combined tracing tests are not used regularly for karst water investigations as they are complicated to organise and quite expensive. For "everyday" use one tracer test is usually employed, for example to find out the underground drainage from the military training area in the Javorniki Mts. (Kogovšek 1999). But combined tests were used, too. The most extensive one was carried out in south-eastern Slovenia in the catchment area of the karst spring Krupa. Krupa was heavily polluted and can no longer be used for water supply, therefore other karst springs had to be involved. For that reason there was extensive research in Bela Krajina and its neighbourhood, including combined tracing tests, using bacteriophages, uranine, eosine, and rhodamine (Habič & Kogovšek 1992).

Investigations in the Krupa catchment area are also a good example of karst water investigations aimed to define the watershed. This is of the highest importance in order to delineate protection zones of karst springs (Habič et al. 1990).

When the importance of the epikarstic zone for karst water research and especially for karst water protection was recognised, the study of water behaviour in the epikarst began. In Slovenia, the researchers focused on this question quite early (Kogovšek & Habič 1981). This research has been looked upon as a part of hydrological research in karst. In Slovenia, epikarst was mainly studied from the hydrological point of view. The most important were studies of quantity, quality, and movement of water percolating through this zone. Tracing techniques proved to be very useful for this research too, as can be seen from the many examples from the karst in Slovenia (Kogovšek 1996). Also, the investigation of karst water in the vadose zone needs attention (Kogovšek 1997). High priority has to be given to the investigation of karst water quality and measures for its protection (Knez et al. 1995).

It is maybe surprising that despite such rich and numerous data and the deep knowledge of our karst, the studies on karst hydrology in general are rare. It seems that karst hydrology is more important as an applied study on the one hand, and a field study on the other. When we are still in the stage of data gathering, that is an analytic stage and not yet a stage of syntheses. Often the title of a published work implies a general study, but in fact it is case study. Maybe the best examples of hydrological studies are those of Breznik (1998), Krivic (1982), and Petrič (1995).

CONCLUSION

At the end a logical question appears: which are the future perspectives of karst water studies in Slovenia? Regarding the previous researches and literature, the following tasks appear:

- Water tracing of not yet fully ascertained connections of smaller water flows (there is a lot of them, in particular in the through-flow karst, in the shallow karst of Dolenjska and Bela Krajina, in contact karst and in the fluviokarst regions), which was pointed out by numerous authors (Habič 1983; Savnik 1962).
- Repeating the water tracing tests under different hydrological contitions (the previous researches have shown that the underground directions can be very different if controlled by different hydrological conditions) (Habič 1997).
- Detailed delineation of watersheds and water flow by the help of tracers injected directly underground (which is especially important at threatened sites, in the recharge area of captured karst springs) (Knez et al. 1994).
- Development of water tracing techniques and methods.
- Field investigations of the percolation water behaviour (together with various pollutants) in the epikarst and the vadose zone (field stations) (Čenčur-Curk & Veselič 1999).
- Modelling.
- Theoretical studies to determine the general physical laws.

Not research, but nevertheless a very important task, is the education and instruction of all the inhabitants, from politicians and experts who (may) directly influence the threat and protection of karst water (deputies, mayors, planners, communal workers, constructors, economists), to pupils. For protection of karst water the most important task is to fill the gap between the karst specialists with their knowledge and "non-karst" specialists, also highly educated, with sometimes striking ignorance of karst and karst water.

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RAZISKOVANJE KRAŠKIH VODA V SLOVENIJI

Povzetek

Kras predstavlja 43% površja Slovenije in ker se preko 50% prebivalstva oskrbuje z vodo s krasa, je zato še pomembnejši. Ne le redkeje poseljeni deli dinarskega krasa, ampak tudi del Ljubljane, vsa Nova Gorica s širšo okolico in celotna Obala dobivajo vodo iz krasa. Kras v Sloveniji delimo na alpski, dinarski in prehodni (osameli ali izolirani). Vsak izmed teh tipov ima svoje vodne značilnosti. Alpski kras prištevamo k raztočnemu tipu krasa, dinarski pa k pretočnemu. Najznačilnejši vodni pojavi pretočnega krasa so reke ponikalnice in zato ni slučaj, da so med prvimi našimi kraškimi pojavi, omenjenimi v antični literaturi, prav podzemeljske vodne zveze (Pozidonij iz Apameje, 135-50 pr.n.št.). Sledenje teka podzemeljske Reke, opravljeno na začetku 20. stoletja, sodi med prva sodobna sledenja na svetu.

Raziskovanje kraških voda lahko po tem, kaj je ljudi najbolj zanimalo, razdelimo na več obdobij: ugotavljanje podzemeljskih vodnih zvez med posameznimi ponori in izviri (prva polovica 20. stol.), opravljanje kombiniranih sledenj podzemeljskih voda (od 1970 dalje), ugotavljanje razvodnic na krasu, preučevanje prenikanja skozi epikraško in vadozno cono (od 1980). Posebno pomembna so tudi preučevanja kvalitete kraških voda in zakonitosti v hidrologiji krasa. Kljub obširnemu zbranemu gradivu, kljub številnim terenskim raziskavam in dolgoletnim opazovanjem pa je le malo slovenskih avtorjev, ki so se lotili kraške hidrologije z bolj teoretične plati.

Prispevek sklene vprašanje, katera preučevanja bi bila v bodoče najbolj perspektivna: sledenje še neznanih podzemeljskih vodnih zvez manjših potokov (teh je veliko predvsem v pretočnem krasu, na plitvem dolenjskem in belokranjskem krasu ter na fluviokraških področjih) ali ponavljanje sledenj ob različnih hidroloških situacijah (predhodne raziskave so pokazale, da so smeri podzemeljskega odtoka lahko zelo različne glede na hidrološko situacijo); podrobno določanje razvodnic in raztekanja kraških voda s pomočjo injiciranja sledil neposredno v podzemlje (kar je posebno pomembno na ogroženih delih zbirnih območij zajetih kraških izvirov); razvijanje sledilnih tehnik in metod; terensko preučevanje prenikajoče vode (obenem s polutanti) v epikraški in vadozni coni (s pomočjo terenskih postaj); računalniško modeliranje; teoretične študije z namenom odkrivati zakonitosti. Posebno pozornost pa je treba posvetiti izobraževanju vsega prebivalstva, od strokovnjakov, ki (lahko) neposredno vplivajo na ogrožanje in varovanje kraške vode (načrtovalci, komunalni delavci, gradbeniki, ekonomisti), do šolske mladine.