THE VERTICAL RUN-OFF OF RAINFALL THROUGH DOLINES
The examples of dolines above Planinska Jama and Pivka Jama

VERTIKALNI ODTOK PADAVIN SKOZI VRTAČE
Primer vrtač nad Planinsko in Pivko jamo

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Janja Kogovšek: Vertikalni odtok padavin skozi vrtače. Primer vrtač nad Planinsko in Pivko jamo

Za izdatnejše curke se predvideva, da se napajajo iz območij vrtač. To so ugotavljali s sledilnimi poskusi na območju Planinske in Pivke jame. Vrtača nad Planinsko jamo, ki jo ločijo od jame 100 m debeli apnenci, odvaja hitro in večje količine padavinske vode po glavnem, prepustnejšem prevodniku. Po spletu slabše prepustnih prevodnikov, ki so povezani z glavnim prevodnikom, pa se pretakajo počasneje manjše količine. Iz vrtače nad Pivko jamo vodita skozi 40 m debele kamnine dva prepustnejša prevodnika, ki odvajata večje količine vode. Spremlja ju večje število manjših prevodnikov. Zaledja curkov so med seboj prepletena, vendar so njihove medsebojne povezave zelo različno prepustne.

Ključne besede: krasoslovje, kraška hidrologija, prenikajoča voda, sledilni poskusi, vertikalna prepustnost, Planinska jama, Pivka jama, Slovenija

Abstract UDC 556.12:551.442(497.4)

Janja Kogovšek: The vertical run-off of rainfall through dolines. The examples of dolines above Planinska Jama and Pivka Jama

It was presumed that the abundant trickles are fed from the areas covered by dolines. Later we confirmed this by water tracing tests above Planinska Jama and Pivka Jama. The dolines above Planinska Jama, separated from the cave by a 100 m thick layer of limestones, drain the rainfall water fast through the main, more permeable conduit. By a system of less permeable conduits which are associated with the main one, smaller quantities drain much more slowly. From a doline above Pivka jama two highly permeable conduits lead through 40 m thick rocks draining a significant amount of water. Around them several smaller conduits exist. The recharge area of the trickles is connected but their mutual links are of various permeabilities.

Key words: karstology, karst hydrology, percolation water, water tracing test, vertical permeability, Planinska Jama, Pivka Jama, Slovenia

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INTRODUCTION

The difference between particular caves or their parts is evident by an attentive view of the underground spaces at equal or similar rainfall and hydrological conditions. In some places abundant trickles prevail, elsewhere only moderate drops, in some parts no infiltrated water may be seen. These facts aroused the question what is the reason that the rainwater from the surface gathers into abundant trickles in the cave. One of the reasons are dolines. Ford and Williams (1989) discuss the water discharge from the dolines where solution creates more and more significant vertical water permeability.

THE WATER RUN-OFF FROM THE DOLINE ABOVE PLANINSKA JAMA

For several years the solvent capacity of the abundant trickle 1 was monitored in Planinska Jama. Its discharge seasonally varied from 30 ml min^{-1} to 200 l min^{-1}, the annual quantity of infiltrated water amounted to 2000 m^3 and the quantity of carbonates, dissolved by the water in the cave roof and transported into the cave, exceeded 400 kg. We presumed that the trickle is fed by the area of doline on the surface. We tried to prove it by water tracing from the doline (Kogovšek & Habič 1981).

According to the known geological structure (Gospodarič 1976) we chose the most probable doline for draining the water into the observed trickle. It is about 15 m in diameter; in the bottom 3,5 m of soil was measured suggesting the possibility of accumulation and retention of the rainfall, and the prolongation of its discharge. Into a bore-hole, directly in the rock 100 m above the cave, we poured a solution of Uranin and within 90 minutes we flushed it by two cisterns of water (14 m^3). Three weeks before and after the injection there was no rainfall worth mentioning. Thus only the added water with tracer drained into the underground.

Positive result was obtained at trickle 3 (increase of discharge and appearance of tracer) some meters only distant from the trickle 1, where less distinctive appearance of tracer without discharge reaction was noticed. There were no other significant trickles near; the tracer did not occur in the drops. However the major quantity of tracer and added water drained through the spring X that lies about 60 m west from the bottom of a doline in the Unica riverbed which was previously unknown to us; obviously it appeared seasonally after heavy rain and was active only during the time when the water level of the Unica increased and was hence it submerged by the flood water (Fig. 1).

Monitoring of the discharge showed the most intensive drainage of almost half of added water during the first ten hours; later the discharge decreased sharply and fluctuated about the value 2 l min^{-1} showing the connection of a main, very permeable conduit with a system of less permeable conduits. Spring X drained in the first ten hours after the injection more than 6000 l, and in following 20 hours additional 2000 l, altogether more than 60% of all the water and more than 20% of Uranin that were added. Relatively slow discharge of the remained tracer through spring X and secondary impulses of tracer and appearance of tracer in the trickles show that the recharge from the doline is done by numerous, interrelated conduits; however, the most permeable conduit is the one towards the spring X.

The knowledge was completed by the tracing result during naturally wet conditions when a six-times smaller amount of tracer was used. Tracer was dissolved in 30 l of water and poured into a borehole without additional water. At spring X the tracer appeared after 9 hours, although the first heavy rainfall occured after 2 days only. In that time the tracer appeared in trickle 3 as well, but it was not recorded in trickle 1. It shows that the recharge under the natural conditions is much slower than under intensive artificial watering. In trickle 1 we did not detect the tracer due to the small quantity that was injected, and due to big dilution.

Thus we concluded that trickles 1 and 3 are fed substantially out of the doline area, maybe from the nearby doline. From the doline where the tracing test was done the water flows through a system of conduits which are connected with the main X highly permeable conduit that recharges a significant amount of rainwater into the underground.

However, only parallel double tracing under exactly the same conditions from a doline and from a nearby area out of doline would record the differences in rainfall drainage from the karst surface. Till now only one tracing was achieved and at that time tracer was not injected into doline. This was tracing through 100 m thick cave roof above Kristalni Rov when tracer was injected into a cess-pit of waste waters, it means, directly in the rocky base of a roof (Kogovšek 1995). During 16 days the most abundant trickle drained only 3% of total 5 m^3 of water that was added to tracer. Compared to this statement the drainage from the doline above Planinska Jama into spring X is extremely fast. The flushing of Uranin out of a cave roof was intensified after each abundant rainfall and lasted for one year and a half. Unfortunately we did not possess appropriate equipment for continuous monitoring of discharge which would enable us to calculate the returned amount of tracer and would give us many concrete answers useful for future researches.

WATER RUN-OFF FROM THE DOLINE ABOVE PIVKA JAMA

A similar case of water run-off from the doline underground was observed in the area of Pivka Jama where we identified, on a basis of pollution, the trickles that receive the water within a doline area (Fig. 2).

The lavatories were built in the doline on the surface at Pivka Jama Camp and the waste water drained by a cess-pit without bottom directly to a rocky bottom through the 40 m thick cave roof into the trickles. The trickle area covers about 10 m in radius. In order to prove that conection and to get detailed picture about the permeability of particular trickles we carried out a tracing test with added water. From the water taps 4,7 m^3 of water were injected. The most intensive reaction was at the trickle on the pathway (8); other smaller trickles and droppings showed various smaller reactions (Kogovšek 1987). Obviously this was the reason that the cave managers built the roof at this place to protect the cave visitors.

During the summer season, when up to 400 people overnighted in the campsite above, we observed the recharge oscillations and the composition of the infiltrated water. There was no rainfall. The peaks in discharge appeared in the morning and in the evening, this is the time when the most of water is used in the campsite. For comparison we observed the droppings away from the polluted area where no discharge occurred.

We observed also how the trickle from this area reacts to rainfall, the so-called water pulse. The discharge of the less permeable trickle 3 reacted after 1 hour, but reached its maximum 4 hours after the rain began. The near droppings reacted immediately. The abundant trickle on the pathway (8) did not react before the other trickles reached the maximum and it decreased faster. Obviously the water from the doline is drained by differently permeable conduits.

In 1985 the campsite was renewed and the doline was deepened, the upper layer of rock was removed, and later modern lavatories and toilets were built. Due to construction work, blasting included, the waste water used the previous conduits out of the doline; when the works were done we assessed increased pollution of the infiltrated water but we explained it by intensive flushing of accumulated pollution from the cave roof because of building work.

The waste waters from the new lavatories were directed into treatment plant. But our analyses in the cave showed that the sewage system was not tight enough and in the cave polluted water still occured. The manager was not persuaded and by his order several tracing tests were carried out.

TRACER EXPERIMENTS IN PIVKA JAMA

In the years from 1992 to 1994 several tracing tests were carried out in the doline area. In all the cases when we injected the tracer directly into the sewage system some percents of water and tracer appeared in the cave. Hence it is obvious that the sewage system is not completely tight, however the majority of waste water drains into water treatment plant.

On June 19, 1992 we injected 31 g of Uranin into an external channel close to the wall and watered the tracer by 9 m^3. After one hour the tracer and increased discharge were noticed at the trickles 2, 4, 5 and 15*, being the most at the last. The trickle 15* lies about 10 m northwards from the bottom of a doline. The trickles 7 and 9 were slightly late with considerably poorer response of tracer and its concentration.

In May 1994, during low level of the cave infiltrated water, a combined tracing test from three different points into the sewage system was carried out (Kogovšek 1994). We used Uranin, Rhodamin and NaCl (into sinks of showers, toilets and washbasins). The tracers were diluted by 4,7 m^3 of water.

Only about one percent of the injected water appeared in the cave. A small recharge pulse was recorded at the most permeable trickle 15* while the trickles 4 (Tik levo) and 7 (Na stalagmit) did not react. At the points 2 (A ciklus), 5 (Na poševno skalo) and 9 (Na kopo) the discharge increased after 2 days only due to rainfall. Thus the injected water almost entirely flowed into the water treatment plant, one part remained in the very dry catchment area and only a smaller part appeared at the trickles. Uranin and Rhodamin appeared the most distinctly at trickles 4 and 15* immediately after the increased discharge and less distinctly with some delay at point 9 and after some days at points 2 and 5. At point 7, low concentrations of Rhodamin were recorded. Figure 3 shows the different permeability of trickles 4 and 15* and Figure 4 the occurrence of Uranin in both trickles.

In one case of tracing we injected the tracer solution in the soil at the bottom of doline. Thus the tracer had to overcome the layers of soil and later continued its way through the conduits within the carbonate massif. The thickness of soil is presumably less than 1 m as it was artifically deposited. This is why it is difficult to compare with dolines where several m thick layers of soil are found at the bottom. The tracer was recorded in all the observed trickles, even in trickle 2. As expected the highest concentration was recorded in trickle 15*, substantially lower at other trickles; only trickle 7, which is slow permanent dripping, reacted with long delay. Long lasting washing of the tracer followed but it was intensified after each heavy rain. After one year trickles 2 and 9 did not contain any tracer while the other trickles continued to flush small quantities of tracer after each rain. It shows an important retention capacity within the soil, with the slowed down washing and the retention respectively.

Later another tracing test was carried out from the outer channel. The most distinct appearance was at point 15* and less distinctive at points 4, 7 and 9, and none at all at 2.

The tracing when we injected 10 m^3 of water only (outer channel) considerably increased the discharge at the trickle on the pathway (8) and the trickle 15*, while trickle 2 did not react at all.

All the studies show that two very permeable conduits lead from the doline through 40 m thick limestones, draining significant amounts of water. The most permeable appears at the trickle on the pathway (8) where the water appears after heavy rain when the recharge area is filled. The discharge increases fast and then it decreases the first. Trickle 15* reacts faster but is less distinctive. Both trickles dry up during periods without rainfall, due to the high permeability. At several other smaller trickles or droppings retention occurs. The catchment area of the trickles is interconnected, but their connections are very different.

CONCLUSIONS

The described researches indicate that the rainwater thus drains differently through the dolines through very permeable or less permeable conduits which are interconnected. The main conduit drains significant amount of rainwater into the karst underground. The discharge of the most permeable trickle increases just after the catchment area is filled and later decreases very fast. Due to such run-off these conduits or trickles in the caves are seasonally active only. The parallel system of less permeable conduits drains smaller amount of water with big retention. The catchment area of the trickles is interconnected, but their connections are very different.

However these statements open a question about a drainage from the surface away from the doline area; the question may be answered only by simultaneous checking of both cases under equal conditions.

Water tracing tests proved to be very useful at studying the run-off water from the dolines into the underground. If they are done by adding water the conduits and their permeability from the surface to the interior are shown. This provides bases for understanding the drainage of eventual harmful substances spilt into karst; this happens frequently at the road accidents where the transportation of liquids is involved (Knez et al., 1994; Kogovšek 1995a). Water tracing tests under naturally wet conditions show the drainage dynamics which is essential for the corrosion processes.

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VERTIKALNI ODTOK PADAVIN SKOZI VRTAČE
Primer vrtač nad Planinsko in Pivko jamo

Povzetek

Različno izdatni curki prenikle vode, ki jih srečujemo v podzemeljskih jamah, in ki so stalni ali pa se pojavljajo le občasno po izdatnejših padavinah, so dali slutiti, da imajo zelo različna zbirna območja. Predvidevali smo, da se preko vrtač odvajajo v podzemlje večje količine padavin.

Večletna podrobna opazovanja pretakanja skozi curke v Planinski in Pivki jami so podala letne količine pretekle vode, dinamiko pretakanja glede na padavine ter obseg in dinamiko korozijskega raztapljanja pri vertikalnem prenikanju, kar je pokazalo na hitrost večanja prepustnosti curkov. Za ugotavljanje povezav curkov s površjem smo uporabili sledilne poskuse, najprej z vlitjem sledil nad Planinsko jamo ter kasneje nad Pivko jamo.

Sledilni poskusi z dodatno vodo in fluorescentnimi sledili so se izkazali kot zelo uporabni pri ugotavljanju povezav vrtač na površju s podzemljem kot tudi pri študiju odtoka vode iz vrtač. V primerih, ko se vlito sledilo zalijemo z večjo količino vode, dobimo informacijo o prepustnosti prevodnikov. To pa je tudi osnova za sklepanje kako odtečejo morebitne razlite nevarne snovi v kras, če pride do takega izlitja. V zadnjem času se kar pogosto dogaja, da pride ob prometnih nesrečah, kjer so udeleženi prevozniki raznih tekočin (mineralna olja, nafta...) do izlitja in ogrožanja kraške vode. Sledenja, ki jih izvedemo ob naravnih pogojih, kjer sledilo spirajo le padavine, pa nam dajo informacijo o dinamiki prenikanja, ki je pomembna za korozijsko raztapljanje karbonatnih kamnin oz. večanje prepustnosti prevodnikov.

Vse omenjene raziskave so pokazale, da odvajajo vodo iz vrtač različno prepustni prevodniki. Osrednji prevodnik odvaja v kraško podzemlje znatne količine padavin. Pretok takih curkov po padavinah ali vlitjih vode močno naraste, nato pa hitro upade in kasneje presahne prav zaradi velike prepustnosti svojega prevodnika. Vzporedno pretakanje po spletu manj prepustnih prevodnikov je dušeno. Pretok teh curkov manj izrazito narašča in kasneje le počasi upada, kar pa jim zagotavlja njihovo stalnost. Ob ugotavljanju pretakanja skozi vrtače pa se postavlja vprašanje, kakšno pa je pretakanje izven njih, kar pa bi pokazala le testiranja obeh primerov ob enakih pogojih.

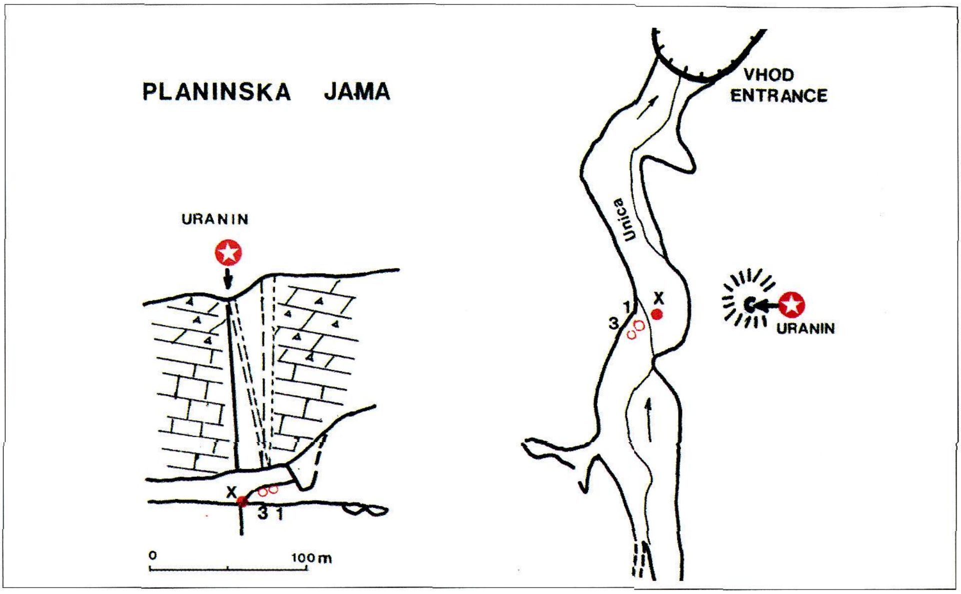

Fig. 1: Situation of the observed trickles in Planina cave
Sl. 1: Položaj opazovanih curkov v Planinski jami

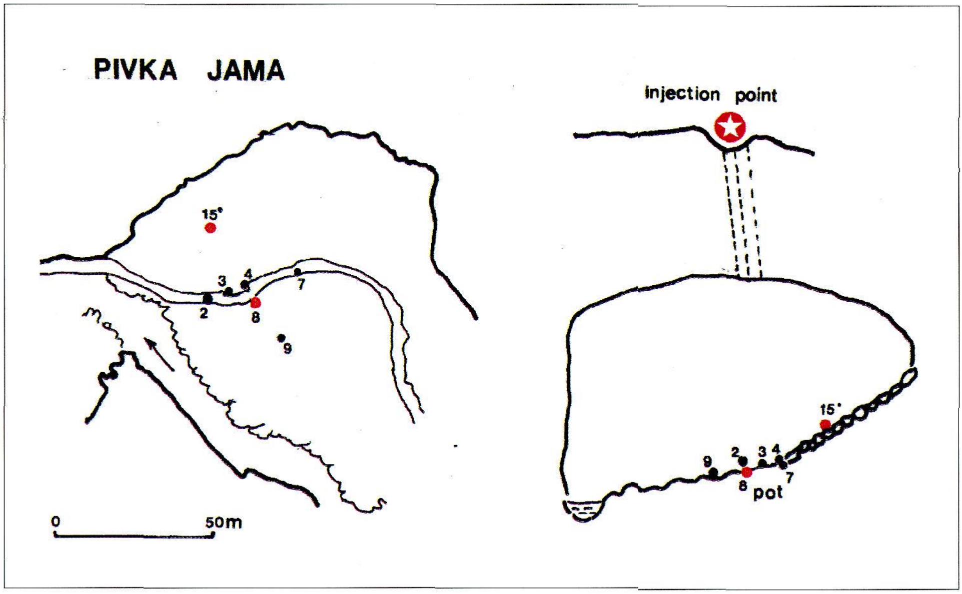

Fig. 2: Situation of the observed trickles in Pivka cave
Sl. 2: Položaj opazovanih curkov v Pivki jami

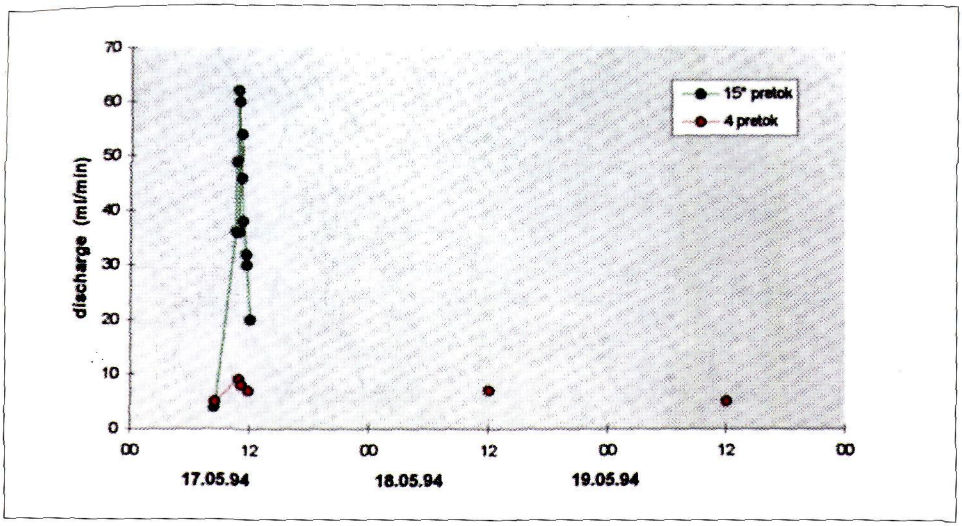

Fig. 3: Combined water tracing test in May 17,1994: After the water was added a smaller water pulse was recorded at trickle 15 while trickle 4 did not react*
Sl. 3: Kombiniran sledilni poskus 17. maja 1994: po vliti vodi smo zaznali manjši vodni val pri curku 15, medtem ko pretok curka 4 ni reagiral*

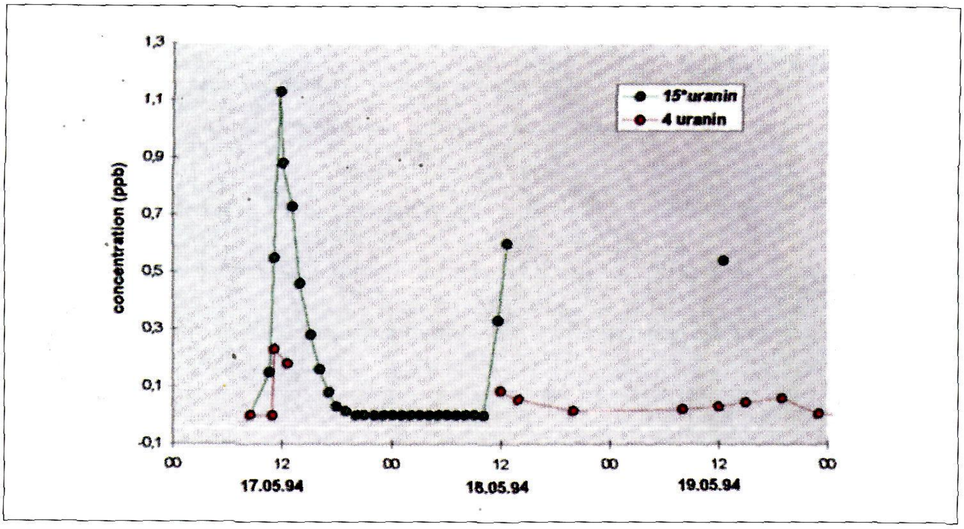

Fig. 4: Combined water tracing test in May 17, 1994: a distinctive occurrence of Uranin in permeable trickle 15 compared to poorly permeable trickle 4, is seen*
Sl. 4: Kombiniran sledilni poskus 17. maja 1994: viden je izrazit pojav uranina v dobro prepustnem curku 15 v primerjavi s slabo prepustnim curkom 4*