Military training area in Kras (Slovenia)

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Abstract Slovenia's main military training area at Poček is located in the mountainous Javorniki Watershed. This is a karstic district without surface drainage or river valleys. The typical landscapes are conical hills and plateaus with many dolines. The lithology, tectonic structure and speleological data indicate a typical karst aquifer with underground water moving rapidly through fissures and conduits. Little attenuation occurs in such conditions and as a result there is a high risk of pollution. Tracer tests have shown that a significant proportion of the water recharging the Malni and Vipava springs comes from the vicinity of the military training area. As a result any polluting activities taking place within the military training area are likely to affect the two springs. This is a very serious matter as the springs have been developed to provide the water supply for the population of south-western Slovenia.

Key words Karst · Military training area · Karst hydrology · Tracing test · Kras · Slovenia

Introduction

The extensive district of Poček, south-east of Postojna, has been used as a central military training area in Slovenia for many years. Although various negative effects on the environment can be expected due to continuing military activities, far too little attention has been focused on this problem. An important step in the direction of environmental protection was taken in the middle of 1997, when the Ministry of Defence ordered the Karst Research Institute of the Scientific Research Center of the Slovene Academy of Sciences and Arts to conduct appropriate research on the impact of these activities on the environment. In the first phase, data were gathered on the geomorphological conditions, the geological and hydrogeological structure, and speleological phenomena of the area, while in the second phase, the danger of pollution was assessed. Because the military training area is in a karst region that is especially sensitive due to its particular characteristics, the problem of possible negative effects is very great.

Due to specific military activities and the fact that the karst waters from the Poček district represent some of the most important sources of drinking water in an extensive area of southwestern Slovenia, special attention was devoted to water protection. The risk of polluting the water source depends on the loading of the environment and the vulnerability of the aquifer. This loading comprises those features which represent existing or potential pollution threats to the water sources, while the parameters of vulnerability are defined by the characteristics of the aquifers. During the research in the Poček military training area, special attention was directed towards determining the level of vulnerability based on the assessment of the hydrogeological conditions in the aquifer.

The basic data on the structure and characteristics of the aquifer were augmented by tracing tests that enabled a more accurate assessment of the direction and characteristics of the flow of the underground waters.

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Geomorphological conditions

The study area includes the south-western part of the Javorniki range (Fig. 1), an 11-km wide and 30-km long chain of mountains running northwest-southeast. The highest parts are in the central ridge where they reach heights of up to 1287 m; most of the range, however, is somewhat lower. On the western side it borders the Pivka Basin (with heights of 500–600 m), and on the north-eastern side, Cerkniško polje (500 m) and Planinsko polje (450 m, Fig. 2). Planinsko polje is the lowest part of this area, and most of the water therefore flows underground towards it.

The surface topography is of two main types. The first type occurs on the peaks on the Javorniki range and its slopes, and the second type on the flatter plateaus on the margins of the Javorniki range, that is, the margin of the

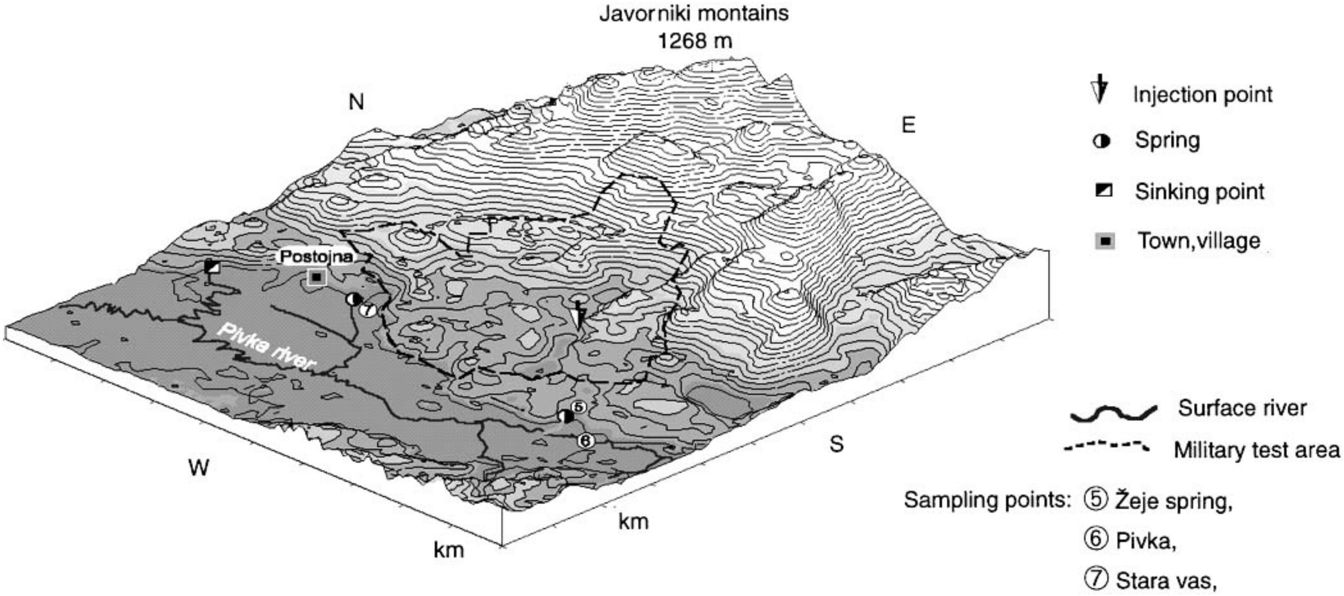


Fig. 1
View of southwestern margin of the Javorniki mountain range with the area of the military training reserve drawn in

karst section of the Pivka Basin. The Javorniki range has higher relief with heights of 650–700 m as well as peaks over 1000-m high, mostly in its eastern section. Large conical hills which have merged together into ridges are typical features. Due to the karst character of the region, all rainwater percolates underground. The surface is therefore not dissected by ravines, or river valleys but is rather smooth. The slopes rarely exceed 30°. In some places small conical hills rise from the slopes. Closed karst depressions of various sizes occur between these hills while on less inclined surfaces there are groups of smaller dolines.

Lower relief characterises the margins of the Javorniki range which merges gradually into the more or less undulating lower karst plateau. This surface has heights varying between 550 and 650–700 m. It is mostly flat and gently slopes from east to west. Individual conical hills rise to 100 m above the surrounding doline landscape with largely undissected slopes. There are no flowing surface streams to shape the relief into valleys and ridges. Dolines are the most common topographic feature, but there are big differences in their density and distribution. Dolines up to 50-m wide and 15-m deep are the most numerous. They occur in rows in the lowest parts between the conical hills or are scattered randomly on the flat surface. There are about 50 dolines per square kilometer. In the area of the firing range there is a thin layer of brown redzina soil with an average thickness of less than 20 cm. The layer of soil is frequently unconsolidated so the surface is very rocky. The rockiness of the surface depends on the local qualities of the limestone, mostly on its physical resistance to weathering. More resistant, more thickly bedded or unbedded limestones produce a more rocky surface. In the most rocky areas the forest remains while elsewhere the forest was cleared for meadows and pastures; however, the latter are now becoming very overgrown.

Thicker layers of colluvial soil sometimes formed at the bottoms of depressions and dolines. Some of this accumulated in past centuries during the clearing of the forests for pastures and meadows, but the amount of such soil is small.

The reason for the small degree of erosion is that there was not a great deal of soil on the surface. Soil develops only slowly on limestone because all the rock material dissolves and flows in solution in the water feeding the karst springs. Only a small percentage of insoluble material in the limestone remains to provide the basic mineral aggregate for the formation of soil.

Geological conditions

The majority of the Lower Cretaceous beds in the northwestern Outer Dinarids are lithologically similar to the Cenomanian, and fossil remains are rare. Therefore, from a lithological point of view, the limestones of the Lower Cretaceous and of the lower part of the Upper Cretaceous are indistinguishable. They are composed mostly of grey and dark grey platy limestone with patches of grained bituminous dolomite several centimeters thick. In fresh faults, the limestone also smells strongly of bitumen. Grained dolomite in some places shows sandstone characteristics while under the microscope it can be clearly seen that the grains are practically idiomorphic crystals of dolomite.

Tectonic processes cut the Lower Turonian light grey limestone and breccia with frequent vertical fissures and faults that enabled gravel to form along the hollows during the mechanical weathering of the surface. The Turonian limestone merges into the Senonian limestone that occurs in the western and south-western part of the Pos-

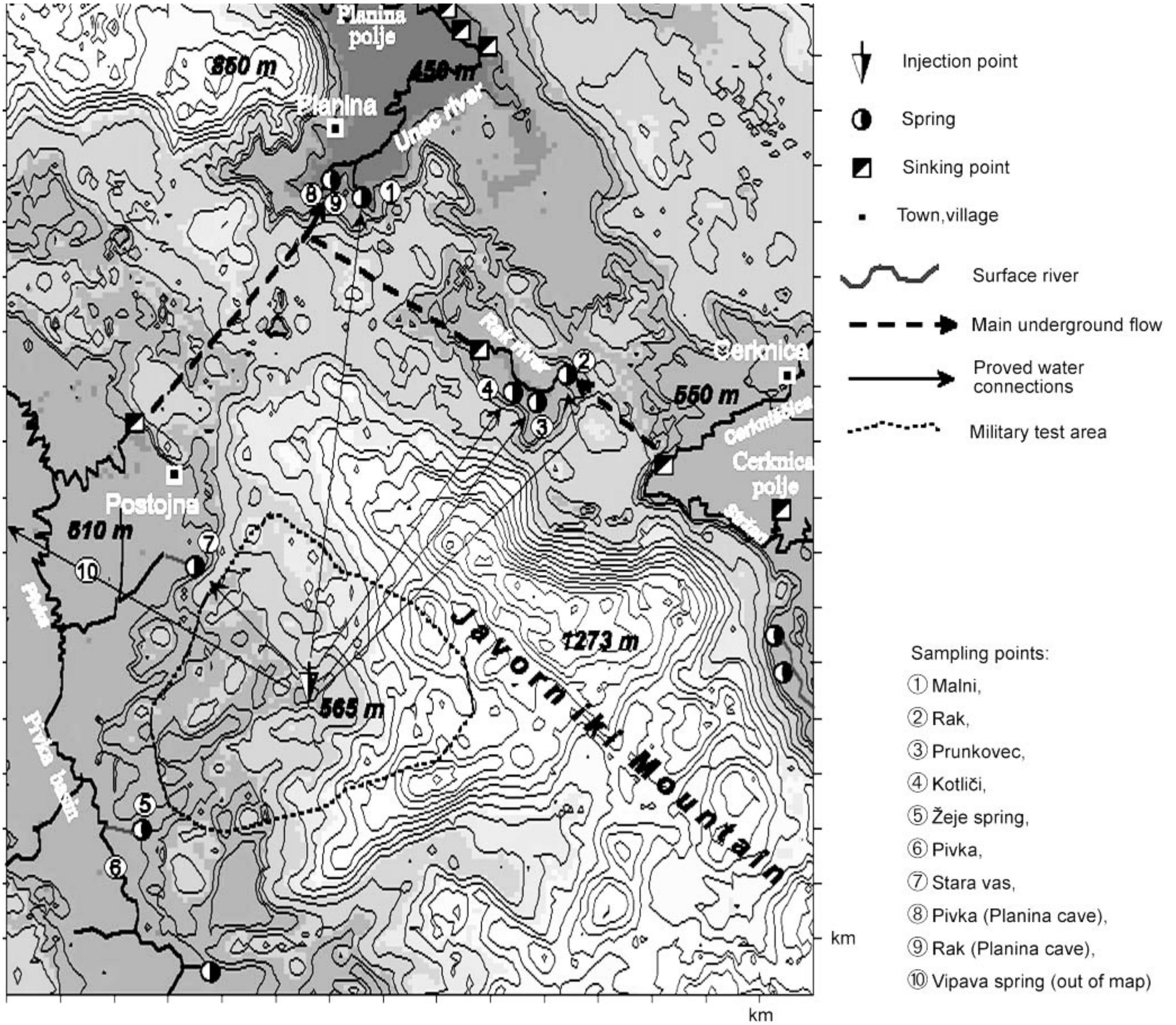


Fig. 2
Water connections determined by injecting tracer in the area of the Poček military training reserve

tojna karst region without a lithologically distinct border. The greater part of the Turonian and Senonian rudist limestone has not yet been mapped in detail. Turonian-Senonian limestone is light to dark grey and usually bedded. In some places it is very rich in macrofossils. Where the macrofossils are few or absent the limestone is usually darker, thin bedded and in some places contains quartz. One block of Senonian limestone is at least 500-m thick, but its original thickness cannot be established because the rock was partly eroded before being covered by Eocene flysch.

The military training area is situated within the tectonic unit called the Snežnik Thrust. This forms the margin of the allochthon which has been emplaced on the parautochthon. More widely the area belongs to the Outer Dinarids which is typically folded and thrusted toward the south and south-west.

Owing to the inversion of the bed at the front of the Snežnik Thrust Unit, a thrust plane was formed in the centre of the syncline or in the inverted limb. The movement of the thrust unit onto the parautochthon is estimated at about 7 km (Placer 1981).

Nappe units were thrust onto the Eocene flysch either during its sedimentation or on its eroded surface. The Snežnik Thrust Unit is a reversed fault nappe which has been driven substantially over the footwall (up to a maximum of 10 km). The thrust plane of the thrust unit does not end in the flysch layers of the Pivka Basin but continues farther towards the north-west (Placer 1981).

In the Poček military training area neotectonic structures such as the Dinaric oriented (NW-SE) Predjama Fault (Placer 1996) also occur along with the older thrusting. The beginning of the older thrusting is post Cretaceous, with the main thrusting mostly occurring during or after the deposition of the Eocene flysch. Along with the deformation from thrusting, the surface was also subject to folding after the deposit of the Eocene flysch. The fissures and faults that were formed in this area were reactivated by later tectonic events since the tension was released along all possible structural planes. Thus many tectonic phases caused the strong tectonic fracturing of the carbonate rocks that form the geology of the Poček military training area.

Speleological characteristics in the vicinity of the military training area

There are 39 caves in the district with an average of two caves per square kilometer. Data on the caves have been collected in the Cave Register of the Karst Research Institute ZRC SAZU.
Potholes (19) formed by the percolation of water from the permeable karst surface to the underground water dominate. They are most frequently found along pronounced fissures. The deepest pothole, which extends to the water table is 72 m deep; another is deeper than 50 m, and seven are deeper than 30 m. There are 12 horizontal or inclined caves. Younger potholes frequently lead to them, and the gently sloping caves can also be accessed through entrances under low cliffs. The longest cave is 100 m and three others are over 50 m. The diameters of old passages range from 1 to 5 m. The horizontal and slanting passages are the remains of old caverns through which streams formerly flowed. This is proven by the interlacing of passages, their circular transverse sections, and the cave passage morphology. Three of the caverns are cliff caves.
The 72-m deep *Brezno v Kobiljih Grižah* pothole is a water cave. It is situated in a crack in the limestone that formed along a fault zone and is up to 3-m wide. The water level which represents the height of the underground water in this part of the aquifer oscillates by 16 m.
The caves testify to the development of the mostly unsaturated aquifer of the high karst due to the gradual drop of the underground water level. However, the western and south-western edges of the aquifer have the characteristics of saturated aquifers since the waters between the karst poljes surrounding the aquifer flow through them. There are many siphon springs. Except for the Planinska jama cave which collects waters from the Pivka Basin, Javorniki mountain, and Cerknica Lake, spring caves are mostly smaller; among them is also a distinctive estavelle on the edge of the periodic Palško jezero lake. Dry caves showing traces of water currents were formed when the underground water level was more than 10 m higher. The aquifer was surrounded by impermeable rock at higher altitudes. Later, the aquifer was also deformed tectonically. Traces of previous slow flowing water currents in the higher old caves, that were formed when this part of the aquifer was still under water, provide proof of the rapid drop of the underground water level. Today, rainwater disperses and percolates through the permeable surface to the underground waters and continues to transform the old caves as well.

Hydrogeological conditions

Poček is the part of the karst aquifer of the Javorniki range which in the hydrogeological sense is bordered by the Pivka River valley with its tributaries in the west and by the streams between Cerkniško polje, Rakov Škocjan, and Planinsko polje. The Malni spring has been dammed for the purpose of supplying water to Postojna and the surrounding district and is a potential source for ensuring additional amounts of drinking water for an extensive area of south-western Slovenia.
The assessment of the flow characteristics of underground water in the Javorniki karst aquifer is based on measurements of the water level oscillation in wells and water caves. However, as the hydrodynamic regime inside the karst system also depends on hydrological conditions on its margins, the flow of surface streams and karst springs was taken into account as well. Habič (1985) made a map of the underground water levels on which the equipotential lines indicate the various directions of underground flow. We can therefore assume flows in different directions with bifurcation, a characteristic karst phenomenon that has been frequently proven by tracing tests in karst aquifers. The groundwater gradient, indicates flows from the Poček area north to the Malni spring and the underground course of the Pivka River, north-east to the Kotliči and Prunkovec springs and the underground course of the Rak river, and west and south-east to the springs beside or in the riverbed of the Pivka. Of course, forming conclusions about the direction and characteristics of the flow of underground waters only on the basis of water table measurements at individual sites is very risky due to the complex hydrodynamic conditions in karst aquifers. They can be reliably confirmed only by carrying out tracing tests under various hydrological conditions.

Hydrological conditions and underground water connections

Rainfall in karst areas sinks directly through the cracked carbonate rock of the unsaturated zone deeper into the karst where the underground karst waters flow. In the study area after heavy precipitation, rainwater percolates through 100 m of limestone in just a few hours, while during dry summer periods with only light showers, it takes 2–3 months (Knez and others 1990, 1995; Kogovšek 1995a, 1997a; Kogovšek and others 1997). Apart from geological and morphological conditions, the depth of the underground water and how it flows through the unsaturated zone of the karst region depends primarily on hydrological conditions that are dictated by the rainfall and its quantity and distribution. In the study area the annual precipitation is 1500–1600 mm.

The various waste waters follow the same entry paths to the deep karst as the precipitation (Kogovšek 1997b). Accidental spills (on the surface) of various water immiscible fluids such as oil derivatives, also follow these recharge paths (Knez and others 1994; Kogovšek 1995b). Rainfall occurring after the spills causes them to spread farther. In the same way, rainfall leaches through any wastes that are on the surface.

Habič (1985) compared water levels beneath the Javorniki range, and discovered karst water gradient increases in the direction of the Planinsko polje, so that the greatest flow velocity can be expected in the vicinity of the military training area and north of it. In low-water periods, the waters from the Javorniki range are presumed to flow toward the Malni spring (Habič 1989; Habič and Kogovšek 1990) and during high-water periods to Planinska jama. Tracing tests, during a low-water period in August 1988 when uranine was injected into a swallowhole of the Pivka River, near the town of Pivka, proved that there is a connection between this swallowhole and the Pivka river in Planinska jama and the Malni and Vipava springs. New tracing tests were done in June 1997 in this same area.

Rainfall and hydrological conditions

The closest rainfall station is at Postojna. However, during the tests from June through October, the station was not very useful for the tracing area since large variations in rainfall amounts occurred over small distances. Therefore its data were only used as a general guide.

Before the injection, only 166.5 mm of rain had fallen in February–May of 1997, considerably below the average (480 mm in the 1961–1990 period). The transpiration from vegetation must also be taken into account, as the vegetation starts to take up significant water in May and continues this process throughout the summer.

After the tracer was injected on 10 June 1997, heavy rain fell in the middle of June (20.5 and 37 mm) and again in the middle of July (53 mm, followed by 44 mm). This second rain had a substantial effect on the flow of water and tracer through the karst aquifer. The Postojna weather station recorded 87 mm of rain in August, 26 mm in September, and 143 mm in October. No such heavy rainfall occurred in the Javorniki area, particularly in October as is clearly seen in the tracing curve for the Malni spring. It was only in November that significant rainfall occurred here (368 mm) and continued through December (216 mm).

Tracing was therefore carried out in a low-water period when slow velocities of underground water flow prevailed in the karst region. Apart from other factors (e.g. geological and morphological), rainfall is crucial for the flow of water through the unsaturated zone, in particular its quantity, and during the active vegetation period, its distribution as well.

Tracing from the Poček military training area

The tracer was injected almost directly on the rock bottom of a small active doline and thus avoided any significant absorption into the soil. A solution of 4 kg of uranine was injected together with 11 m^3 of water.

Regular samples were taken at the 9-km distant Malni spring and at the more than 24-km distant Vipava springs (Table 1). Both springs are dammed for the purpose of providing a regular supply of drinking water. In parallel, samples were taken at eight other sites: 2–4 at Rakov Škocjan, sites 5–7 from the Pivka River, and sites 8 and 9 at Planinska jama (Fig. 2).

Table 1
Tracing results. t-1 time when tracer first appeared; t-2 time when maximum concentration of tracer appeared; v-max maximum apparent velocity of flow; v-dom velocity according to the maximum concentration of tracer; M returned amount of tracer

Spring	Altitude	Altitude difference	Distance	t-1	t-2	v-max		v-dom		M
	m	m	m	h	h	m/h	cm/s	m/h	cm/s	g
Poček	565									
Malni										
1st pulse	446	119	9287	260	360	35.7	1.0	25.8	0.72	155
2nd pulse				842	956	11.0	0.31	9.7	0.27	727
3rd pulse				3597	3653	2.58	0.07	2.54	0.07	
Vipava	99	466	24 609	864	936	28.5	0.8	26.3	0.7	

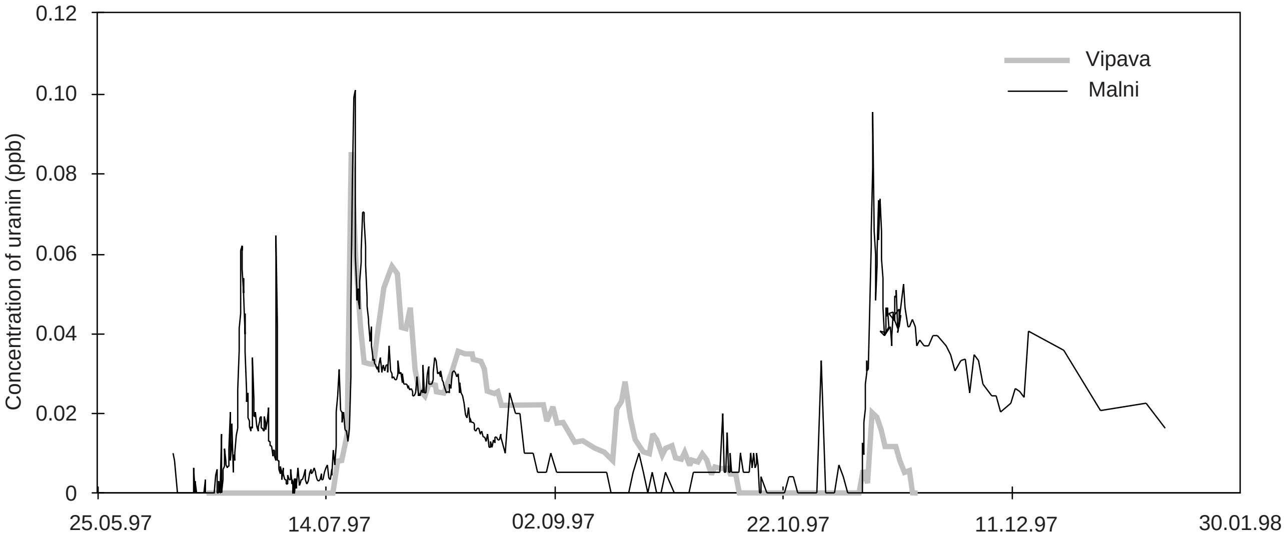


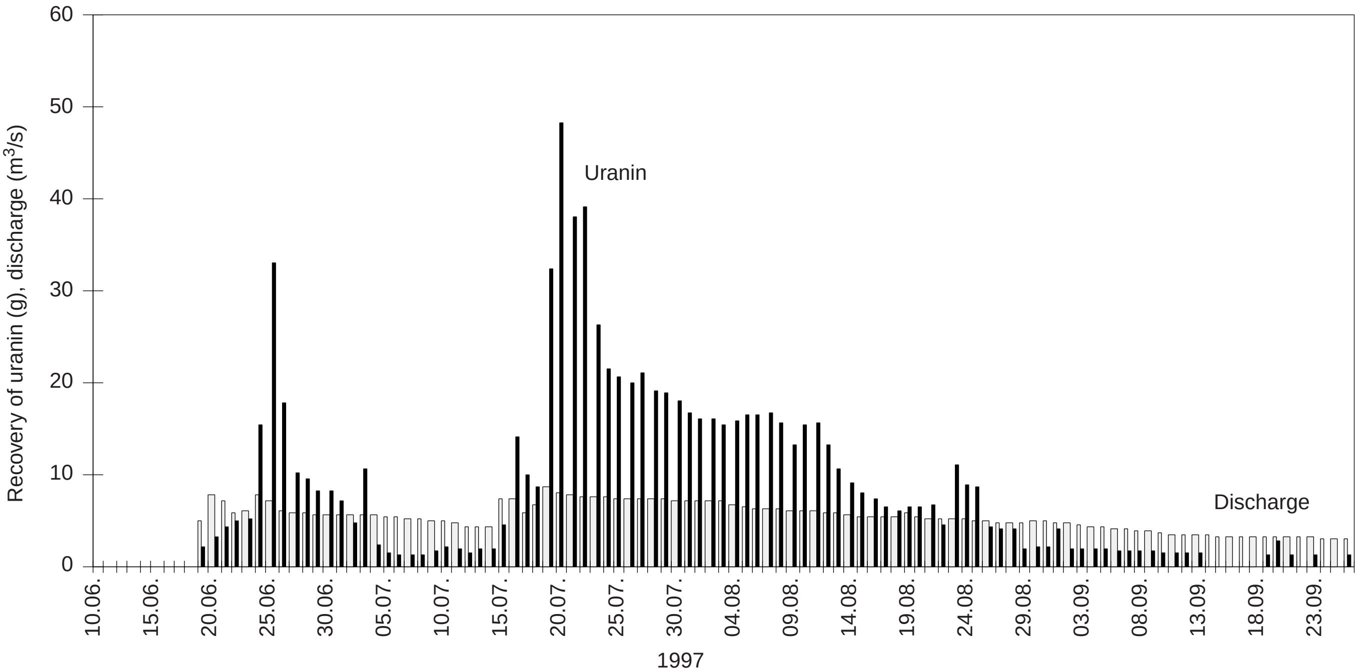
Fig. 3
Concentration of uranine (tracing curve) in the Malni and Vipava springs

Tracing results at Malni spring

The content of the uranine tracer in consecutive samples is shown in Fig. 3. The rain in the middle of June flushed the uranine to the Malni spring and created the first pulse of tracer. Lighter rainfall followed with no substantial influence on the flow of the tracer since the major part of the rainfall was taken up by the vegetation. The next heavier rainfall in the middle of July created the second large pulse of tracer. On this occasion, a larger quantity of tracer reached the Malni spring than during the first pulse of tracer as seen in Fig. 4. After a dry summer, heavy rainfall in November and December washed down the remaining uranine and created the third tracer pulse. By measuring the fluorescence and the known air distances between the Poček injection site and the Malni and Vipava springs, the apparent travelling velocity of the tracer was calculated as recorded in Table 1.

The flow velocities ranged from 0.7 cm/s to 0.07 cm/s. The rainfall that created the first pulse of tracer at the Malni spring flushed only a small part of the tracer to the underground water. The heavy mid-July rainfall was more efficient at leaching the rest of the uranine that remained in the unsaturated zone, as if a new injection had

Fig. 4
Returned amounts of uranine in the Malni spring in the first and second tracing wave



taken place. The slow fall of the tracer and the oscillation of its concentration are primarily influenced by the characteristics of the unsaturated zone but also reflect the nature of the horizontal flow in the epikarst zone. Nevertheless, there was still some tracer left in the unsaturated zone that was washed out only by the later heavy autumn and winter rains.
Because the tests were carried out during very low water levels, the estimated velocities only apply for the stated conditions. Numerous water tracings in the karst region have shown that the flow is faster during high-water periods and that the water can also change its course of flow. The proportion of water in particular can vary due to bifurcation. Only additional tracing tests during high-water periods could provide a more complete picture of the flow and the maximum flow velocity in this area.
The assessed returned amount of tracer (based on the available calculation of flow that was taken once a day) flowing through the Malni spring up to the end of September (during the first and second pulses of tracer) amounts to 880 g of uranine from the 4 kg injected, that is, 22%. In November and December however, a further major influx of tracer to the spring was recorded in a third pulse during very high flows. The amount has not yet been calculated.

Other observed springs

At the Vipava spring, a distinct pulse of tracer (Figs. 2, 3) was recorded after the heavy rains in mid-July. The concentration dropped until the end of September. Extremely heavy rainfall in November, when part of the town of Vipava was flooded, produced a final small amount of the tracer. The flow velocity in the first pulse of tracer was roughly equal to that of the Malni spring.
The tracer appeared clearly at springs 2–4 in Rakov Škocjan and in spring 7 (Stara vas), while at sites 5 and 6 (spring near Žeje and the Pivka river above Žeje) a less definite occurrence of tracer (Fig. 2) appeared.

Pollution of the military training area and sediments in the Malni spring

Analyses showed that in the military training area, cadmium, nickel, bromine and iodine exceed permitted levels in the soil (report of the Maribor Institute for Sanitary Protection on soil research relating to the content of specific toxic substances). Furthermore, the possibilities exist of accidential spills during fueling operations and, if more people are based here, of pollution by communal waste waters.
Analyses of sediment in the Malni spring showed temporary increases in the amount of nickel, cadmium, copper and zinc in the 1991–1993 period, so that based on the amount of metals in the sediment, the water in the Malni spring would be classified in the first to second quality class of EU and WHO guidelines (Zupan 1997). Lead usually reached the level for the second quality class. Highways also run through the catchment of the Malni spring and therefore a certain level of pollution with metals, primarily lead and cadmium, is possible from this source (Kogovšek and others 1997). Furthermore, on the edge of this area is the Postojna municipal waste dump for which a more suitable location has long been sought.

Conclusion

Slovenia's main military training area at Poček is located within the recharge catchment of the Javorniki mountain range. The surface is karstic without flowing surface waters or fluvial relief forms. Typical for the relief are conical hills and plateaus studded with dolines.
The entire area of the military training area is composed of Lower and Upper Cretaceous karstified limestone and some localized dolomite. The rock are dominantly grey and dark grey platy limestones with patches of grained bituminous dolomite.
The carbonate rock has been tectonically fractured in several directions with crushed fractured zones mostly trending northwest-southeast and northeast-southwest. The north-south and northeast-southwest trending fissures are especially suitable for the vertical and horizontal flow of water. These are open fissures that were formed under destress conditions. The easiest path for the water is through these fissures as they have been enlarged by corrosion as much in the vertical as in the horizontal direction. The network geometry of smaller caves however reveals that the aquifer is highly cavernous.
The lithological and tectonic structure, and speleological data indicate a typical karst aquifer, with fast flowing underground waters through conduits and fissures. There is very limited attenuation capacity and consequently a high risk of pollution, as is typical for such areas.
Tracing tests (Figs. 2–4) showed that a high proportion of the water in the Malni and Vipava spring is recharged from the military training area.
The Malni spring has been dammed to supply water to Postojna and its surroundings and is a potential source of additional drinking water for an extensive area of south-western Slovenia.
In his final report on possible measures to protect this aquifer against pollution, Habič (1987) classified the military training area as a restricted zone: a narrow protection zone that has direct connections to the spring and must therefore be suitably protected. In planning the protection of the underground waters, it must also be remembered that some of the water from the military training area flows toward the Vipava spring intended to supply water for Vipava Town and its surroundings area.

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