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SURFACE AND GROUNDWATER INTERACTION OF THE BELA STREAM AND VIPAVA SPRINGS IN SOUTHWESTERN SLOVENIA

MEDSEBOJNI VPLIV POVRŠINSKE IN PODZEMNE VODE POTOKA BELE IN IZVIROV VIPAVE V JUGOZAHODNI SLOVENIJI

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Gerry Baker & Metka Petrič & Geoff Parkin & Janja Kogovšek: Medsebojni vpliv površinske in podzemne vode potoka Bele in izvirov Vipave v jugozahodni Sloveniji

Že starejše raziskave nakazujejo hidrogeološko zvezo med izviri Vipave in sosednjim potokom Belo. Izviri Vipave drenirajo kraški vodonosnik Nanosa. Potok Bela zbira vodo na zelo slabo prepustnem flišu na severozahodnem obrobju Nanosa, nato pa po prehodu na apnenec vzdolž toka postopno ponika. Sledilo uranin je bilo injicirano v Belo nad vasjo Vrhpolje in dokazana je bila hidravlična povezava z vsemi izviri Vipave. Sledilna krivulja za izvir z najvišjo izmerjeno koncentracijo uranina je bila analizirana z disperzijskim modelom. Z merjenjem pretoka na 8 različnih profilih in primerjavo razlik v pretokih posameznih odsekov smo proučevali hidrološke značilnosti Bele. Pokazalo se je, da se hidrološki odziv spreminja glede na delež napajanja iz kraškega ali flišnega zaledja. Z ločevanjem komponent toka na osnovi hidrokemičnih meritev je bilo ugotovljeno, da so tudi hidrološke značilnosti izvirov Vipave odvisne od območja napajanja. Dokazana povezava lahko vpliva tudi na kvaliteto vode v izvirih Vipave, ki so glavni vir vodooskrbe širšega območja, saj se v Belo stekajo neprečiščene komunalne odplake.
Ključne besede: kraška hidrologija, ponikalnica, pretoki, sledilni poizkus, Bela, Vipava, Slovenija.

Abstract UDC: 556.33(497.4)

Gerry Baker & Metka Petrič & Geoff Parkin & Janja Kogovšek: Surface and Groundwater Interaction of the Bela Stream and Vipava Springs in Southwestern Slovenia

Previous studies suggest a hydrogeologic link between the Vipava springs and the neighbouring Bela surface stream. The Vipava springs drain the Nanos karst plateau. The Bela stream drains the very low permeable flysch to the north west of the Nanos plateau before flowing onto limestone where it gradually sinks along its course. A tracer, uranine, was injected into the Bela upstream of the village Vrhpolje and hydraulic connection with all the Vipava springs was proved. A dispersion model was used to characterise the tracer breakthrough curve of one of the springs where the highest concentrations were found. The hydrology of the Bela was analysed by measuring the discharge of the stream at 8 different sections and analysing the difference in flow between each section. The conclusion drawn from the analysis was that the Bela stream has a different hydrological response related to whether the majority of recharge comes from the karstic or flysch area of the catchment. A flow separation analysis based on hydrochemical measurements indicated that the hydrological response of the Vipava springs also depends on the recharge source area. Proved connection leads to environmental concern for the water quality of the Vipava springs, which are the main water supply of the area, because untreated wastewater is discharged into the Bela stream.
Key words: karst hydrology, sinking stream, discharges, tracing test, Bela, Vipava, Slovenia.

INTRODUCTION

The permanent and intermittent Vipava springs are distributed along the western foot of the Nanos Karst plateau in the zone of High Karst of NW Dinarids at the contact of very low permeable Eocene flysch of the Vipava valley (Fig. 1). The Bela surface stream initially gathers water as it flows over the flysch on the northwestern border of the Nanos plateau. It then flows over the geological contact, on to the limestone, at Sanabor village. The stream flows along the foot of the Nanos close to the geological contact until it reaches the town Vipava where it flows back onto the flysch and joins the Vipava River downstream of the town Vipava. The low to medium waters

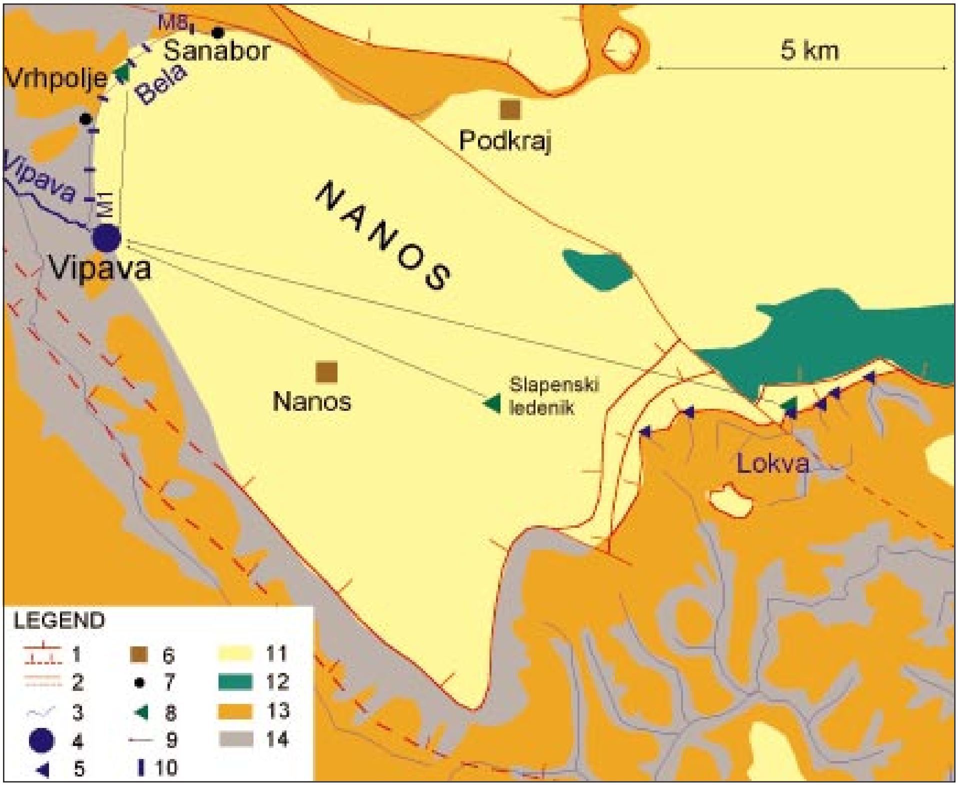

Fig. 1: Hydrogeological map of the area (1. Visible or covered thrust line, 2. Visible or covered fault, 3. Surface stream, 4. Spring, 5. Ponor, 6. Precipitation station, 7. Village, 8. Tracer injection point, 9. Proved underground connection, 10. Point of discharge measurement, 11. Karst aquifer, 12. Fissured aquifer, 13. Very low permeable beds, 14. Porous aquifer).
Sl. 1: Hidrogeološka karta območja (1. vidna in pokrita narivnica, 2. viden ali pokrit prelom, 3. površinski vodotok, 4. izvir, 5. ponor, 6. padavinska postaja, 7. naselje, 8. točka injiciranja sledila, 9. dokazana podzemna vodna zveza, 10. točka merjenja pretoka, 11. kraški vodonosnik, 12. razpoklinski vodonosnik, 13. zelo slabo prepustne plasti, 14. medzrnski vodonosnik).

of the Bela sink gradually along the course of the river downstream of Sanabor, only high water waves running on the surface to Vipava.

The sinking waters of the Bela are thought to discharge at the Vipava springs. This could have serious environmental implications because untreated sewage is discharged into the Bela in the towns of Sanabor and Vrhpolje and one of the springs in Vipava is captured for the water supply of the surrounding area.

The primary aim of this research was to prove the connection between the Bela stream and Vipava springs. A secondary aim was to describe the hydrology of the Bela itself.

PREVIOUS STUDIES

Nanos and the springs of the Vipava River have been the objects of geological, geographic, geomorphologic, speleologic and hydrologic investigation for over one hundred years. Hydrogeologic investigations of Nanos started more than forty years ago. Later, Habič (1982) investigated the Vipava springs. He describes precisely the situation of the springs, their hydrologic regime, physical, chemical, and bacteriological properties of the water, the water catchment area, and the threat to karst groundwater and necessary protection measures.

Placer (1981) explains the location of the Vipava springs with respect to the geology of the area. A recumbent fold of the Cretaceous limestone is thrusted over the Eocene flysch layers, and in the lowest gap

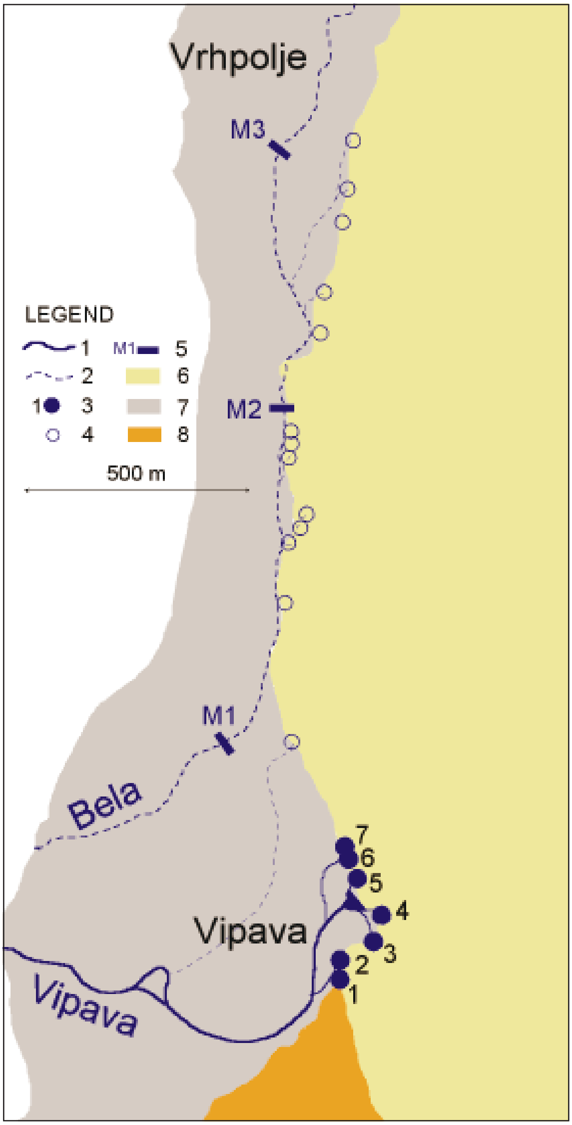

Fig. 2: Location of the Vipava springs (1. The Vipava river, 2. Temporary surface stream, 3. Permanent Vipava springs 1-7, 4. Intermittent spring, 5. Point of discharge measurement, 6. Karst aquifer, 7. Alluvial deposits, 8. Flysch).

Sl. 2: Položaj izvirov Vipave (1. reka Vipava, 2. občasni površinski vodotok, 3. stalni izviri Vipave 1-7, 4. občasni izvir, 5. točka merjenja pretoka, 6. kraški vodonosnik, 7. aluvij, 8. fliš).

with eroded flysch the Vipava springs are situated. Cretaceous limestones are eroded between the towns of Vipava and Vrhpolje and are partly covered by Quaternary clayey rubble sediments. In this region the flood overflow (intermittent) springs are distributed (Fig. 2). The permanent springs are situated at an altitude of 98 m, while the intermittent ones are at 100 to 125 m, showing the karst retention of high waters.

During dry periods the permanent springs have a combined discharge of only 700 l/s, but after heavy rain they reach discharges of more than 70 m^3/s. Low, medium and high discharges are in the ratio of 1:10:100, which is characteristic for simple outflow high karst.

The catchment area of the Bela is approximately 2 km^2. The Vipava gauging station is located about 500 m downstream of all the permanent springs of the Vipava, and probably also the medium and low waters of the Bela. Only the high waters of the Bela and the discharges of intermittent springs between Vipava (town) and Vrhpolje (which are only active at high waters and join the Vipava river downstream from the town) are not included in the gauging profile.

In 1992-1996 the Association of Tracer Hydrology conducted a major research project in the area (Kranjc1997). Evidence from this research suggested a link between the Bela stream and the Vipava springs, in particular the most northern permanent spring, Pod Farovžem (otherwise known as Spring 7 or Vipava 7). This evidence is outlined below.

During the analysis of electrical conductivity of the springs it was noted that Spring 7 “differs fundamentally” from the other springs, especially during the flood events. The dilution at Spring 7 showed a shorter retardation indicating the quicker outflow of low mineralised event water at the spring (Harum *et al.* 1997).

Also, two of the tracing experiments showed different results for Spring 7 than the others. In the second tracing experiment in Spring 1994, uranine was injected at the sinking stream Lokva (Fig. 1). When presenting the result of this experiment for each of the Vipava springs “the time concentration graph for station Vipava 7 had to be drawn with a concentration scale different from all the other stations, because of rather low values” (Behrens *et al.* 1997). In the fourth tracing experiment in autumn 1995 uranine was injected also in the pothole Slapenski Ledenik on the Nanos plateau (Fig. 1). The author notes “Uranine appeared in all the Vipava springs that were chosen for the observation. The concentration curves of the Vipava 2 and 5 are very similar, while the curve of the Vipava 7 is periodically different” (Zupan 1997a).

Measurements of temperature, specific electric conductivity, pH and total hardness, carbonate, calcium, chloride, nitrate and sulphate were also made on the Vipava springs. When comparing the results for the different springs the following was noted: “The measured parameters of the spring Vipava 7 differ considerably from the others where the differences are smaller. It reached the highest values of specific electrical conductivity, the highest total hardness, and also the highest levels of carbonate and calcium as well nitrate and sulphate” (Kogovšek 1997). Isotopic investigations with $\delta^{18}O$ also show a difference between the springs (Strichler *et al.* 1997).

METHODOLOGY

The first phase of our fieldwork was the injection of tracer in the Bela stream. A mass of 170 g of uranine, a fluorescent dye, was diluted with 15 litres of water and injected into the stream between the house Pri Tekcu and Vrhpolje on the 29th of May 2001 at noon. This location was chosen because there was a noticeable reduction in flow over a 20 m stretch of the stream. The injection point is 2.8 km from the Vipava springs. At the injection point the small channel flowed into a pool behind a dam 2.5 m high, the stream appearing again at the base of the dam through a small opening at the bottom. The outflow from the dam was smaller than the inflow where the tracer was injected. The tracer was exposed to the sunlight while it dispersed slowly through the pool. There was a gradual reduction of the discharge along this section of the Bela stream; therefore it was not possible to choose a point where the sinking of the dyed water would be practically instantaneous.

On the day of injection the weather was dry and sunny. The discharge of the Vipava springs was 3.8 m^3/s. Two days later there was a short intense thunderstorm in the Vipava area and the following day, 1st June, the discharge in the Vipava springs was 22 m^3/s.

An automatic sampler ISCO 6700 with a Sonde probe YSI 600 was located at Spring 7. Water samples were taken hourly, and specific electrical conductivity and temperature were measured every 5 minutes. The other permanent springs in Vipava were sampled by hand, and also specific electrical conductivity and temperature were measured at these springs by WTW conductometer LF196. Hand samples were taken in dark brown glass bottles to prevent any exposure to sunlight or reaction with the bottle. The fluorescence of the filtered water samples was analysed in the Karst Research Institute by a luminescent spectrometer LS 30 (E_{ex} = 492 nm, E_{em} = 515 nm) during June and July 2001.

Ten discharge measurements were made from the bridge at the confluence of Springs 6 and 7. Discharge of Spring 6 and Spring 7 were also measured separately on two occasions. All discharge measurements were made using an OTT C20 Current Meter and calculated using the midsection method (Shaw 1994).

Eight points were chosen along the Bela for discharge measurements (Figs. 1 and 2). The points were located at regular intervals along the stream except for the last point, which was located downstream of Sanabor on the contact between flysch and limestone. Measurements were made sequentially; the time between each measurement was as short as possible. Specific electrical conductivity and temperature were also measured at these points by the WTW conductometer LF196.

RESULTS AND ANALYSIS

Three aspects of the measured data were analysed, relating to the tracer experiment, the stream flow measurements, and a flow separation of the Vipava springs based on SEC data. These analyses required daily discharges for the individual Vipava springs. Measured data at the confluence of Springs 6 and 7 were correlated against the total Vipava river discharge for which daily measurements were available (Fig. 3). A linear correlation gave an R^2 value of 0.97. This linear correlation equation was then used to estimate the daily combined discharge of Springs 6 and 7. On the two occasions that discharge measurements were made separately at Springs 6 and 7, the discharge of Spring 7 was 50% of the total flow at the confluence and Spring 6 was lower than 5%. This of course means that there are additional inflows before the confluence. In later calculations these proportions were used to divide the correlated discharge values when it was necessary to make calculations for the individual springs.

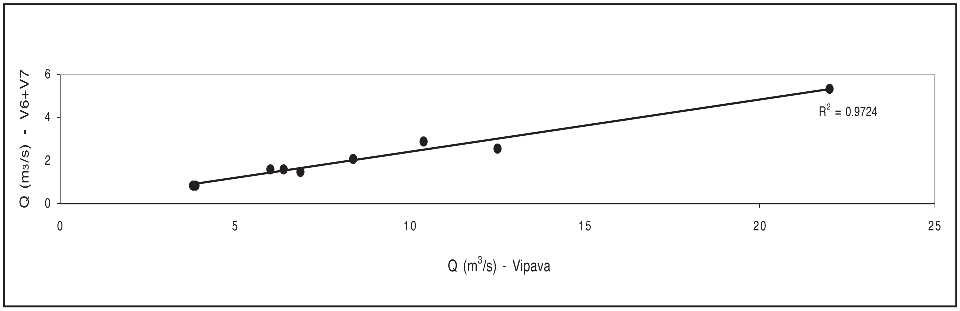

Fig. 3: Correlation between the total Vipava river discharge and discharges at the confluence of Springs 6 and 7.
Sl. 3: Korelacija med skupnim pretokom Vipave in pretoki na sotočju izvirov Vipava 6 in 7.

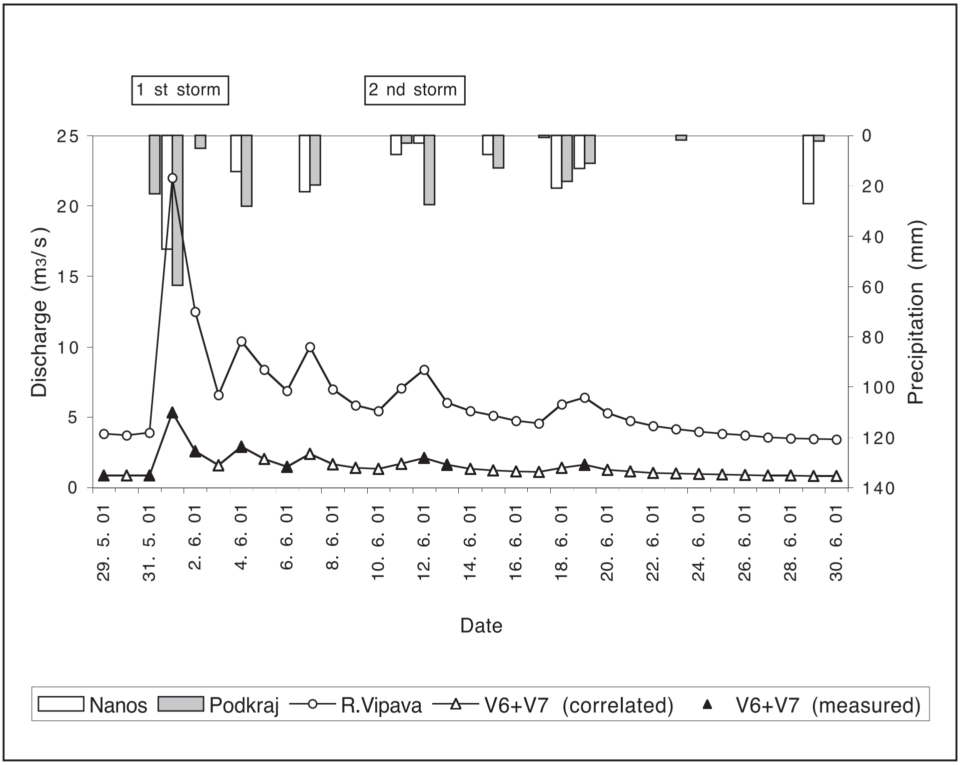

Fig. 4: Precipitation at Nanos and Podkraj, discharges of the River Vipava, and measured and correlated discharges at the confluence of the Springs 6 and 7.
Sl. 4: Padavine na Nanosu in v Podkraju, pretoki Vipave ter merjeni in korelirani pretoki na sotočju izvirov Vipave 6 in 7.

Fig. 4 shows the precipitation at the stations Nanos and Podkraj (measured daily at 7 a.m.), discharge of the River Vipava (expressed as daily average) gathered by the Hydrometerological Institute of Slovenia, and measured and correlated discharges at the confluence of the Springs 6 and 7. The peak discharge of 22 m^3/s for the River Vipava on the 1/6/01 runoff was caused by the previously mentioned thunderstorm.

Fig. 5 shows the tracer breakthrough curve for the Vipava springs. When compared with the discharge for the spring it is clear that the tracer does not begin to arrive until the discharge from the thunderstorm has receded. The peak of the graph occurs on the 4/6/01 at 4 a.m., which is 136 hrs after injection. This gives a dominant velocity of around 20 m/h. The peak concentration is 0.16 mg/m^3. There are some trailing peaks, which coincide with smaller discharge peaks at the spring. Springs 5 and 6 have a higher concentration of tracer than the other springs until the 11/6/01. After this the tracer concentration in Springs 2 and 3 increases to equal that of Springs 5, 6 and even 7.

To calculate the mass of tracer recovered at this spring the tracer concentration values were averaged to give daily values. These were then multiplied by the daily discharge value for Spring 7, and Simpson's rule was used to calculate the integral of these points to give the mass of tracer recovered (Bronštejn & Semendjajev 1980). This procedure was repeated for Spring 6. Table 1 shows the recovered mass and proportions. It was found that 59% of the tracer mass was recovered in Springs 6 and 7 combined, with 55% of the tracer mass recovered in Spring 7 and 4% in

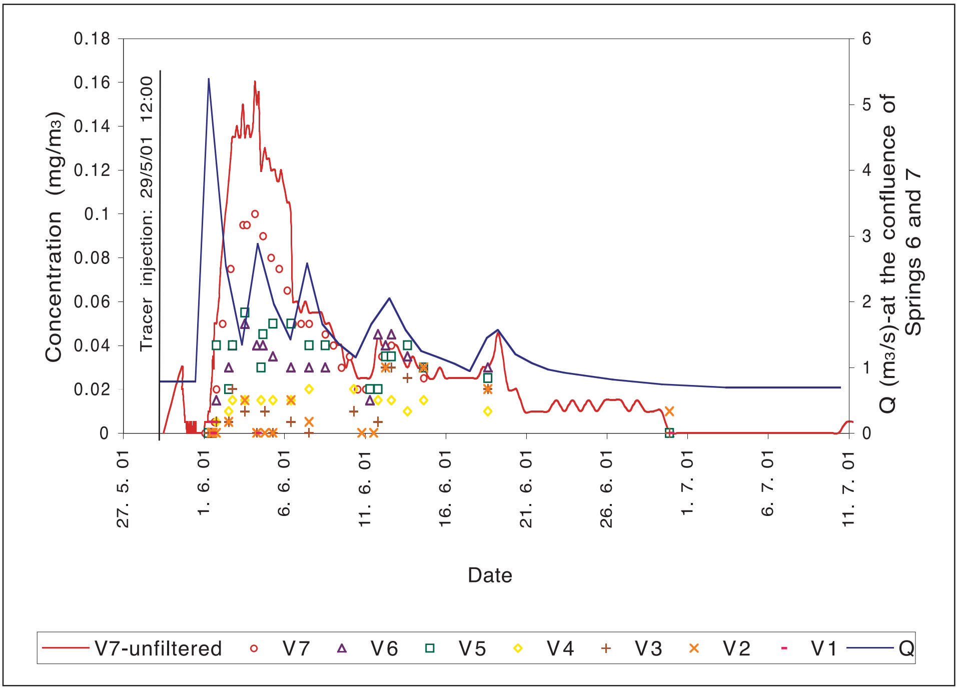

Fig. 5: Tracer Breakthrough Curves for the Vipava springs.
Sl. 5: Sledilne krivulje za izvire Vipave.

Table 1: Tracer recovery.

Spring	Mass (g)	Proportion
V7	93.04	0.55
V6	7.14	0.04
V6+7	100.18	**0.59**
Injected	170.00	1.00

Spring 6. It is important to bear in mind that the discharges used in these calculations are the correlated discharges and not actual measured results.

A Multi-Dispersion-Model (MDM) was used to analyse the tracer breakthrough curve at Spring 7. This model was developed by Maloszewski *et al.* (1992), and is an extension of the classical convection-dispersion model after Lenda and Zuber (1970). The shape of the measured breakthrough curves suggested that the tracer is transported in several parallel flow paths (subsystems). It is assumed that the tracer transport can be considered separately for each flow path and that there are no interactions between the flow paths. Possible diffusion of tracer from the mobile water into the stagnant water in the microporous matrix and/or in the temporarily non-active parts of the karst system is neglected. Fitting of the model to the breakthrough curve of a tracer experiment allows the parameters describing convection (mean transit time) and dispersion (dispersivity) processes to be determined. The mathematical background of the model was illustrated in detail in Maloszewski *et al.* (1992). The following equation is valid for every flow path:

$$C_i(t) = \frac{M_i}{Q} \frac{1}{t_{oi}\sqrt{4\pi P_{Di}\left(\frac{t}{t_{oi}}\right)^3}} \exp\left[-\frac{\left(1-\frac{t}{t_{oi}}\right)^2}{4P_{Di}\left(\frac{t}{t_{oi}}\right)}\right]$$

where C_i = tracer concentration
M_i = tracer mass
Q = discharge
t_{oi} = mean transit time

and

$$P_D = \frac{D}{vx} = \frac{\alpha}{x}$$

where P_D = dispersion parameter
D = dispersion coefficient
v = mean flow velocity
x = distance
α = dispersivity
i = index of the flow path.

The total concentration is the superposition of the individual flow paths:

$$C(t) = \sum_{i=1}^{N} C_i(t)$$

The model was calibrated using 4 separate flow paths. The resulting parameters are given in Table 2. The graph of the fitted curves is shown in Fig. 6. This fit gives a correlation coefficient of 0.97.

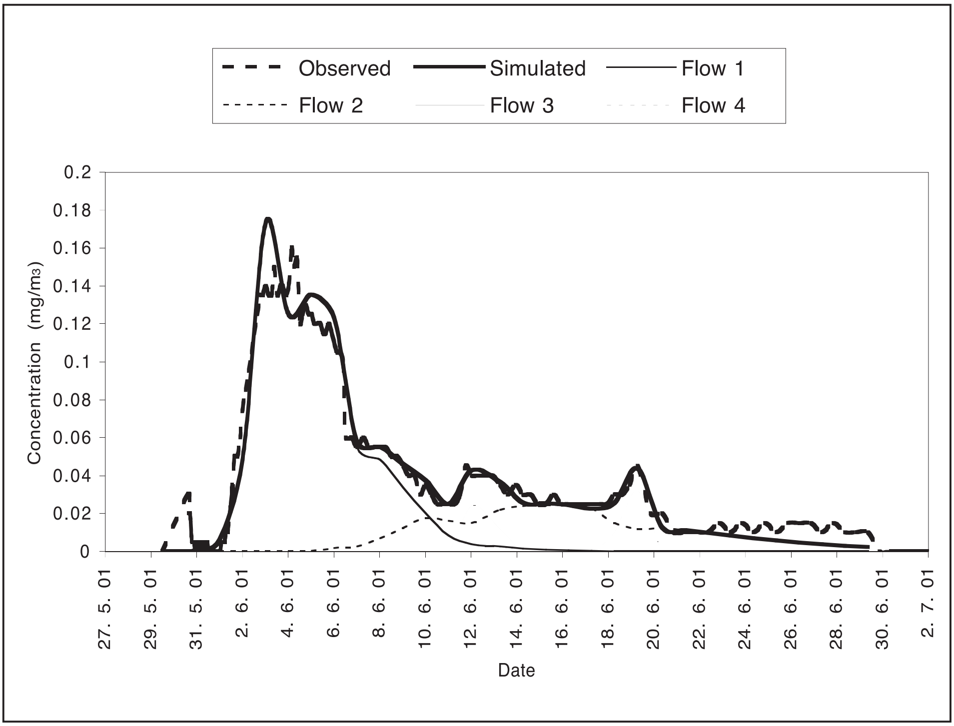

Fig. 6: Results of the Multi-Dispersion-Model for spring Vipava 7 (Pod Farovžem).
Sl. 6: Rezultati multidisperzijskega modela za izvir Vipava 7 (Pod Farovžem).

Table 2: MDM Parameter results.

Parameters	M_i (g)	P_D	t_{oi} (hrs)	x(m)	t(s)	v(m/s)	D(m^2/s)	α(m)
Flow 1	70.0	0.0530	168	2800	604800	0.0046	**0.687**	**148.4**
Flow 2	17.0	0.0450	423	2800	1522800	0.0018	**0.232**	**126.0**
Flow 3	3.0	0.0005	346	2800	1245600	0.0022	**0.003**	**1.4**
Flow 4	3.0	0.0002	500	2800	1800000	0.0016	**0.0009**	**0.6**

Discharges measured on the Bela stream are shown in Table 3. There were eight measurement points labelled M1-M8 with M1 at Vipava town and M8 at Sanabor (Figs. 1 and 2). The distance of each of these from the measurement point M8 in Sanabor is given in Table 3. Discharge measurements were made on 10 occasions.

Table 3: Discharge measurements (m^3/s) on Bela.

	M1	M2	M3	M4	M5	M6	M7	M8
29-May	0	0	0	0	0	0.022	0.02	0.026
31-May	0	0	0	0.029	0.098	0.102	0.055	0.088
01-Jun	2.543	0.446	0.484	0.478	0.650	0.325	0.494	0.512
04-Jun	0.053	0.095	0.189	0.158	0.291	0.174	0.264	0.195
06-Jun	0	0	0.067	0.063	0.093	0.044	0.070	0.118
08-Jun	0	0	0.028	0.051	0.056	0.065	0.090	0.116
11-Jun	0.436	0.505	0.277	0.584	0.741	0.561	1.210	0.980
12-Jun	0.033	0.147	0.154	0.214	0.181	0.211	0.260	0.337
13-Jun	0	0	0.034	0.067	0.069	0.078	0.098	0.147
14-Jun	0	0	0.013	0.051	0.108	0.066	0.084	0.085
Distance (m)	4080	3490	2790	2180	1730	1330	1010	0

A method described by Bonacci (1987) was used to analyse these results. For each date, the discharges of the upstream station of the section are plotted on the ordinate, and the difference in discharge between the downstream and upstream section for that date is plotted on the abscissa. Negative values for the difference in discharges indicate a losing river, and positive indicate a gaining river. The intersection point where a curve crosses the axis is called a “limit discharge” - this is an important hydrological parameter. The area defined by the curve and the ordinate axis in the negative domain is a qualitative indication of the quantity of loss. When the limit discharge is exceeded it can mean that the groundwater level has risen to the river (Bonacci 1987).

Figs. 7a and 7b show the results plotted in this format. No clear pattern is apparent. This method of analysis assumes that upstream discharge is the only variable that determines the losses or gains of the river. It seemed likely that some other variable must have an influence on the results. It is important to note that during the measurement period there were two storms of significant interest. The first was the thunderstorm already described, which occurred on the 1/6/01. The second was a less intense storm on the 11/6/01. Fig. 4 shows the precipitation data from two rain gauges in the area. The Nanos rain gauge is located on the karst plateau, and the Podkraj station is located near the source of the Bela stream (Fig. 1). From Fig. 4 it is clear that the second storm has a much higher rainfall on the Podkraj station than on the Nanos station, but there was much higher proportion of rainfall on the Nanos station on the first storm. Taking into account that the catchment area for the Vipava springs is probably much greater than for the Bela stream, the total rainfall volume in the first storm was likely to be greater over the Nanos plateau than over the Bela catchment, and vice-versa for the second storm. The discharges in the Vipava springs, which are mainly recharged from the Nanos area, confirm this. On the 1/6/01 there is a

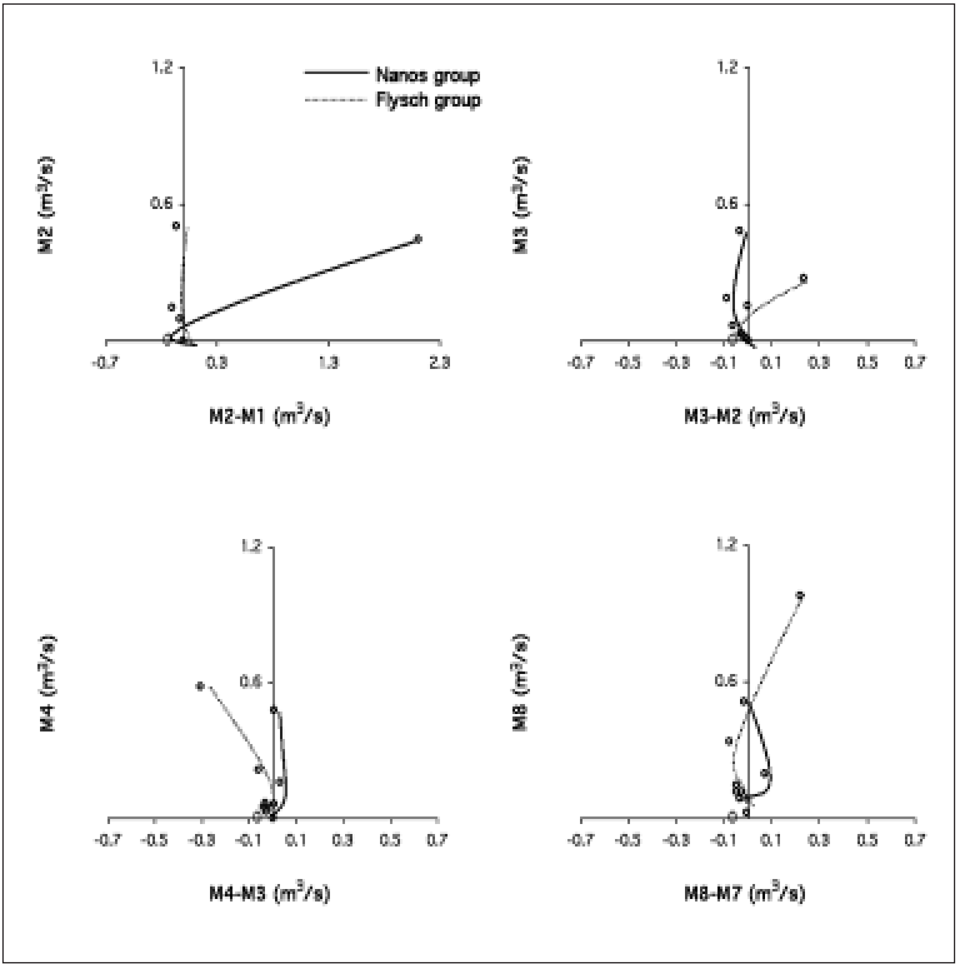

Fig. 7a: Analysis of Differences diagrams for the Bela stream.
Sl. 7a: Diagrami analize razlik pretokov za potok Belo.

very high discharge peak of 22 m^3/s (Fig. 4). The peak from the rainfall of the second event is much lower (8.4 m^3/s).

Fig. 8 shows the downstream change in the discharge of the Bela stream for each day it was measured. M8, the point closest to Sanabor is on the left of the graph and M1, at Vipava, is on the right. The discharge of the Bela stream at Sanabor (M8) is higher on the 11/06/01 (0.98 m^3/s) than on the 1/6/01 (0.521 m^3/s), but the discharge of the Bela stream in Vipava is much higher on the 1/6/01 than on the 11/6/01. There is a sudden increase in discharge between M2 and M1 on the 1/6/01. This is caused by the activation of the intermittent springs along this section (Fig. 2). These springs did not become active on the 11/06/01 despite a higher discharge at M8.

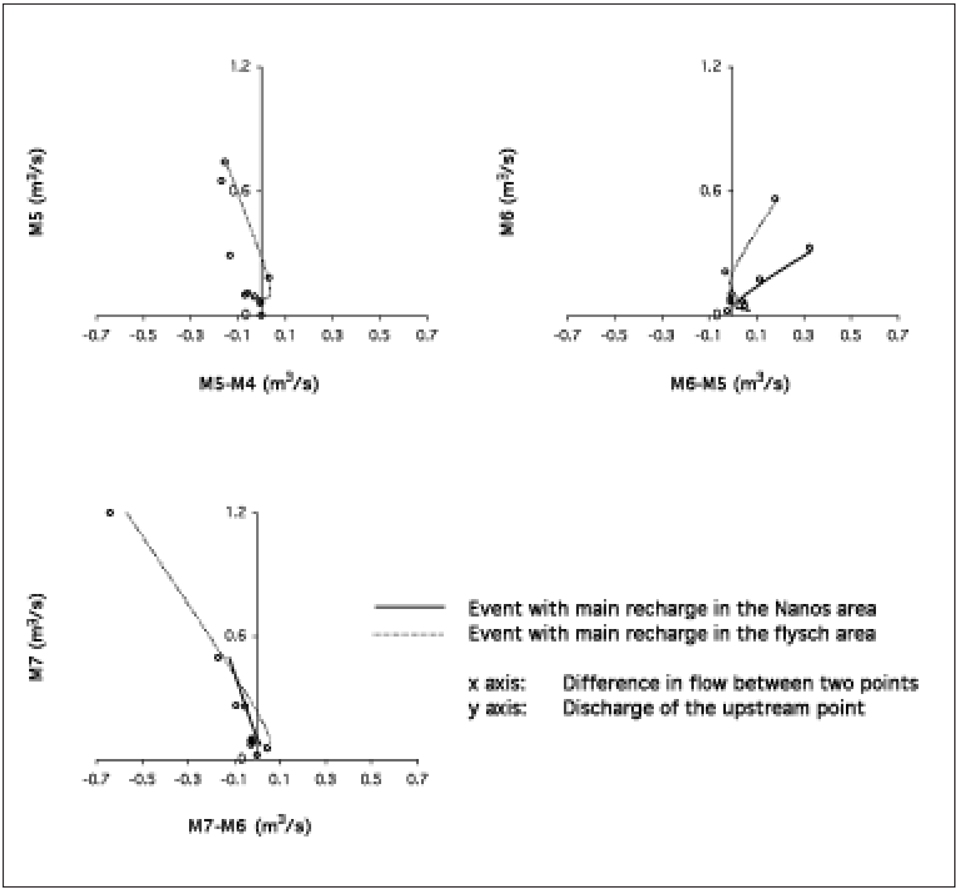

Fig. 7b: Analysis of Differences diagrams for the Bela stream.
Sl. 7b: Diagrami analize razlik pretokov za potok Belo.

This evidence leads to the conclusion that the Bela stream will function differently depending on which area of the catchment the recharge comes from. The precipitation station Podkraj is located in the flysch part of the catchment and the Nanos station on the limestone. The storm on the 11/6/01 was predominantly on the flysch side of the catchment, while on the 1/6/01 the rainfall on the Nanos was much higher. Therefore it seems plausible to separate the discharge measurements of the Bela in two groups: a Nanos group, which were taken during the recession period of the event on the 1/6/01, and a Flysch group, which were taken during the recession period of the event on the 11/6/01. Figs. 7a and 7b show the results once the discharge measurements have been separated into these groups. It is clear from these graphs that the river can increase or decrease in discharge between two sections depending on the location of the recharge area. Also, for the same upstream discharge the magnitude of losses or gains can increase or decrease for different recharge scenarios.

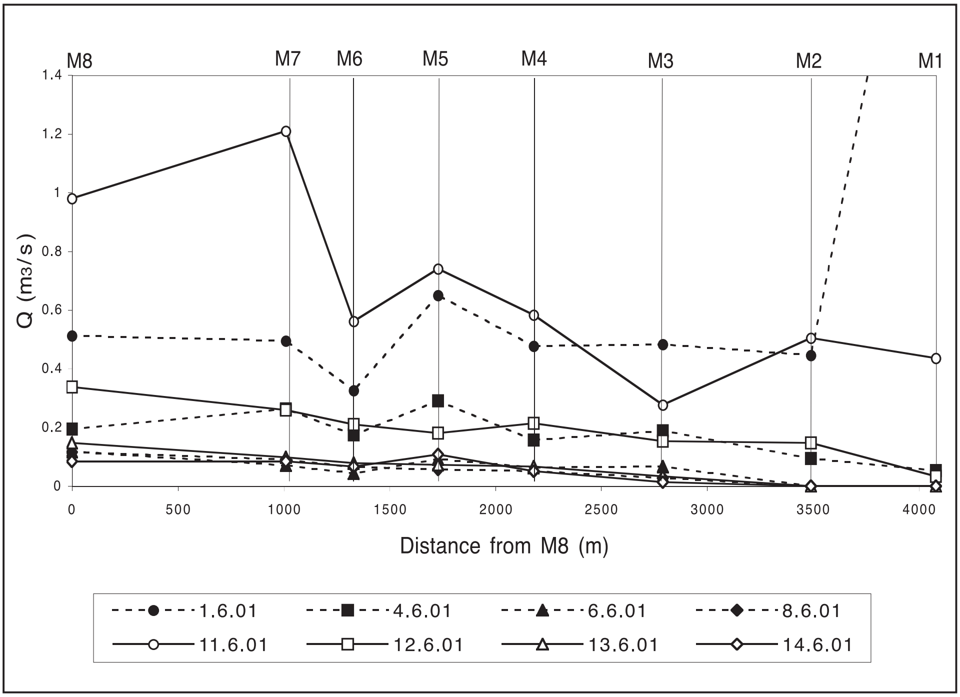

Fig. 8: Flow accretion profiles for the Bela stream.
Sl. 8: Spreminjanje pretoka v profilih potoka Bele.

The data in Fig. 8 can also be separated into Nanos and Flysch recharge events, since only the section M7-M6 shows consistent losses, and all the other sections can be either losing or gaining on different days. The 1st, 4th, and 6th of June show a similar trend for the three days: sections tended to be either losing or gaining, except for M1-M2 which is affected by the intermittent springs.

Conductivity and temperature measurements were also made on most of these occasions. Fig. 9 shows the change in the conductivity of the Bela with distance downstream. There was a general trend of a slight reduction in specific electrical conductivity downstream on most dates, with the exception of 11/6/01 when there was a much lower conductivity than on the other days and an increase between M7 and M2. Fig. 10 shows the change in temperature of the Bela with distance downstream. The trend for temperature shows a general increase with distance downstream. The stream becomes more exposed as it moves downstream, initially flowing through deep gorges in forests and later emerging into the open around Vrhpolje. There is a sharp increase in temperatures between M4 and M3 at the town of Vrhpolje which may be due to exposure to sunlight or to the inflow of sewage.

Linear mixing model equations or mass balance equations are a simple and versatile tool used to separate flow into component parts. If a certain discharge is thought to have two components

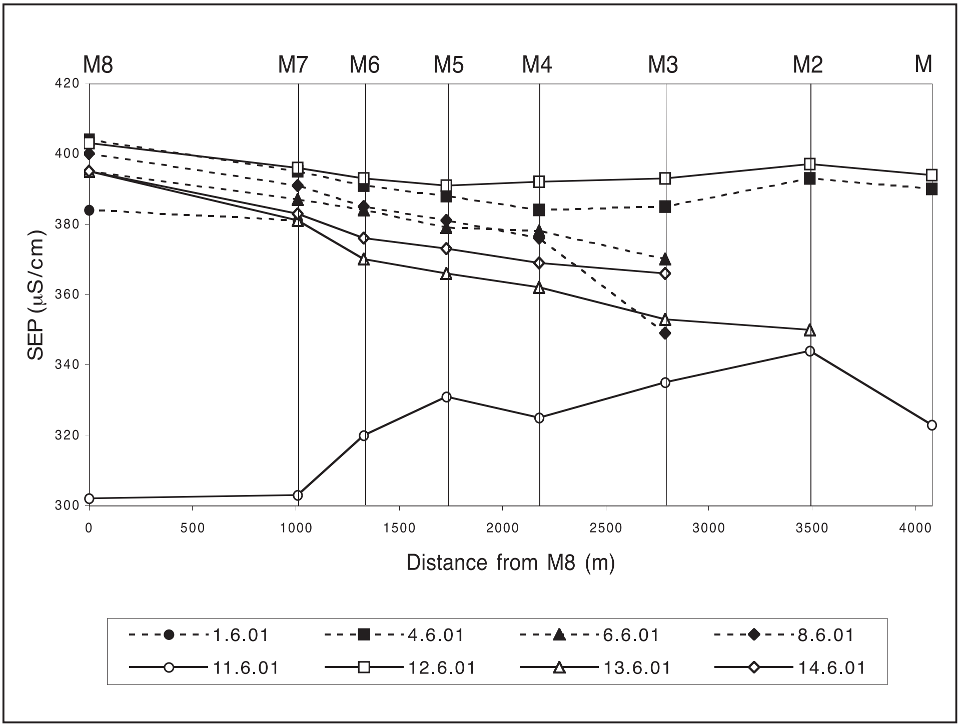

Fig. 9: Specific electrical conductivity versus distance along the Bela stream.
Sl. 9: Spreminjanje specifične električne prevodnosti vzdolž potoka Bele.

then the following is true:

$$Q_{V7} = Q_N + Q_B$$

$$Q_{V7}C_{V7} = Q_N C_N + Q_B C_B$$

where Q is discharge and C is the concentration of some chemical parameter. In this case the total discharge of Vipava 7 (Q_{V7}) is comprised of water from the Bela (Q_B) and water from the Nanos plateau (Q_N), and the chemical parameter is specific electrical conductivity.

For the calculation, Q_{V7} is the daily flow at Vipava 7 which has been estimated as discussed above, and C_{V7} is measured by the automatic sampler. Q_B is flow from the Bela which is not known, and C_B is the conductivity of water from the Bela. Conductivity measurements were made on the Bela by hand; these measurements were averaged for each day. It is now known from the tracer experiment that there is a six-day transit time from the Bela to Vipava. Therefore the value for C_B used to calculate the separation on a certain day will be the value measured on the Bela six days before that. Measurement on the Bela began on the 29/5/01 so until the 4/6/01 the total average Bela conductivity for the period of measurement was used. Q_N is the flow from the

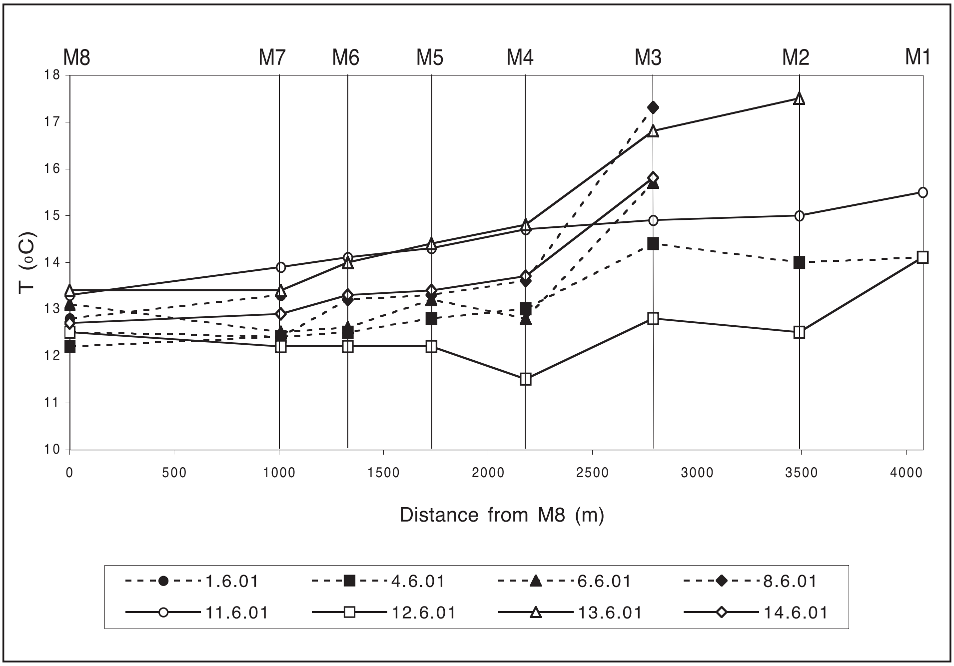

Fig. 10: Temperature versus distance along the Bela stream.
Sl. 10: Spreminjanje temperature vode vzdolž potoka Bele.

Nanos, which is not known, and C_N is the conductivity of water from the Nanos plateau. For this conductivity, C_N, measurements made at Vipava 2 were used because the tracer concentration in this spring was the lowest and therefore this conductivity is the best approximation of the conductivity of water derived from the Nanos. Fig. 11 shows the data used in the separation and the result, which demonstrates the same dual hydrological response in this spring. The proportion of water from the Bela decreases on the 1/6/01 and increases on the 11/6/01.

DISCUSSION

Figs. 7a and 7b illustrate the hydrological behaviour of the sections along the Bela stream for a given upstream discharge. From this analysis we can conclude that the various sections of the Bela stream function differently depending on what part of the catchment the rain is coming from. For example, section M7-M8 can be either losing or gaining for the same upstream discharge. For an upstream discharge of 0.25 m^3/s the section is gaining during the Nanos event but losing during the Flysch event. If the difference in flow between two sections is positive i.e. the section is gaining, this does not necessarily mean that there is no water lost, rather the net difference in the flow is positive.

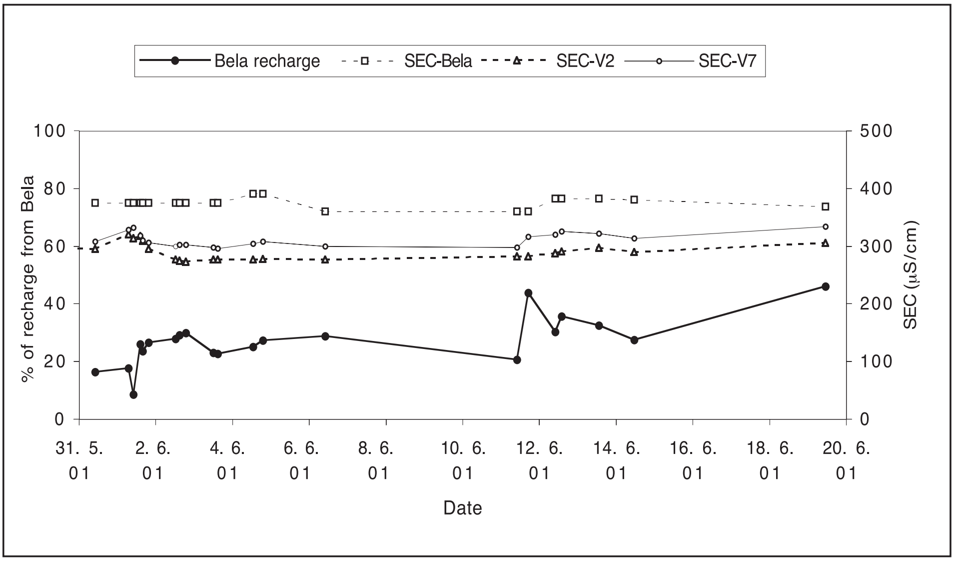

Fig. 11: Flow separation of spring Vipava 7.
Sl. 11: Ločevanje komponent toka v izviru Vipava 7.

In some stretches of the stream where there are no bed sediments and the river flows over bare limestone, small hairline cracks are visible on the surface of the limestone. Water losses in a section probably occur through these small proto-conduits. In other areas where there are alluvial sediments, it is most likely that this is underlain by the same massive limestone. Although there are no groundwater data for the area, according to the recorded spring and stream discharges groundwater levels were low in June 2001. The water table was below the river level resulting in the stream losing water through the proto-conduits. When the stream is gaining it does not necessarily mean that the water table has risen to the river bed level. The stream is gaining because the overland flow and through flow into the channel is greater than the losses. This is why losses will increase with upstream discharge to a certain point (where the infiltration capacity of the bed is reached) after which the losses will remain constant but the stream will continue to gain water. The net losses will therefore decrease until the limit discharge is reached and the section has a net gain. This is why the stream is only gaining for the short period during the flood events and afterward returns to a losing section. This can be seen by the fact that all the lower discharge values are on the losing side of the x-axis (Fig. 7a).

It is more difficult to give a reasonable explanation for the opposite case. For example in section M7-M8 the Nanos flow event is originally losing then it is gaining and at the highest discharge losing again. A possible explanation for this may be that the graph is incomplete (the highest discharge measured at Sanabor was 1.21 m^3/s, whereas discharges up to 4.5 m^3/s have been measured previously (Trišič 1997)), and a different pattern may be evident over a greater range of flows. It is clear, however, that there is a different response to the recharge events, but to explain this fully would require a deeper understanding of the area e.g. infiltration capacity of the bed sediments, soil permeability, and location of fractures in the karst. Inflows from the karst are more likely to be from a point source e.g. a fracture along the riverbank, whereas inflows from the flysch are likely to be more diffuse.

The results of the tracing test (Fig. 5) clearly prove the connection between the Bela and the Vipava springs. Tracer has been found in all springs. The tracer concentration was the highest in Spring 7, medium amounts in Springs 6 and 5 and lower amounts in the rest of the springs. Low values of concentration can often be attributed to measurement error or contamination. The tracer was absent from Spring 7 during the peak discharge in the spring. When the tracer was injected it was dry and sunny weather and the flow in the Bela was quite low. Then three days later there was an intense thunderstorm over the Nanos plateau. The small peak in the tracer breakthrough curve on the 30/5/01 may have been where the tracer began to break through (Fig. 5). This peak reduces as the rising limb of the hydrograph increases.

From the 29/5/01 to the 31/5/01 the discharges from the Bela to the Vipava Spring 7 would have been low because discharges on the Bela were low. Once the very high discharges of the Nanos began it would hold back the flow from the Bela and probably cause it to accumulate in the aquifer. Then as the flow from the Nanos reduced, the water from the Bela would begin to flow again carrying with it the tracer breakthrough curve. This implies that when the flow from the Bela does begin to discharge, then it is under a higher head than would have occurred if there was no storm on the Nanos. Also when the water was backing up this would have caused an accumulation of the tracer. On the first peak of the tracer breakthrough curve on the 29/5/01 the concentration is nil, then the next day the average value is 0.03mg/m^3. On the second peak the tracer concentration on the 1/6/01 is nil, then the next day the average concentration is 0.075mg/m^3. This simply means that the second peak rose quicker than the first. The discharge on the 2/6/01 was higher than the 30/5/01 therefore there was more water from the Nanos to dilute the tracer or in other words the rate of increase of the mass of tracer would show an even sharper increase. This seems to agree with the idea of the tracer accumulating as the water from the Bela was backed up in the aquifer.

It is interesting that the concentration in Springs 3, 2 and 1 increased on the 11th June to a concentration equal to Spring 7. It seems likely that the increase in the proportion of flow from the Bela experienced in Spring 7 on the 11th June may also have occurred in the other springs. This increase would carry with it more tracer. Up until this point the flow in Springs 3, 2 and 1 were probably dominantly Nanos flow so there was little tracer found.

Spring 2 is captured for the water supply of Vipava region. The water has a Grade 2 quality standard, which means that it only requires primary treatment (Zupan 1997b). The water quality of the Bela is poor because of the sewage influent from Vrhpolje and Sanabor. The possible connection found between Spring 2 and Bela must be taken into account when considering the vulnerability of spring. It was not possible to gain any indication of what proportion of Spring 2 came from the Bela because no discharge measurements were available or measured for the spring. Future industrial or urban development in the Bela catchment must take this connection with the Vipava springs into account. A more stringent approach to environmental protection and monitoring of the Bela is necessary. As the towns of Vrhpolje and Sanabor grow so will the volume of effluent entering the Bela, therefor a wastewater treatment facilities in these towns should be given immediate consideration.

The results of the MDM are shown in Fig. 6 and Table 3. The conditions of injection must be borne in mind when interpreting the results. The tracer movement was retarded in the surface pond at the injection point, exposing it to sunlight. The model gave the best fit when using four flow paths. The first two flow paths described the majority of the breakthrough curve, possibly representing flow through the larger fissures and joints in the aquifer, and through smaller openings. The third and fourth flow paths represent the flushing of tracer from storage during periods of higher discharges.

The dispersivity values of the two main flow paths are higher than those expected from a well-developed karst aquifer (Werner & Maloszewski 1997). The presence of a surface stream flowing over karst is evidence in itself that the area is not well karstified. The results of an uncertainty analysis are given in Table 4, which shows the values of the parameters that can be used which reduce the value of the correlation coefficient to 0.96 (from its optimal value of 0.97). This shows there is a high degree of uncertainty in the results, particularly in the dispersion parameters. The possible values for the dispersion parameter for Flow 4 ranges over 3 orders of magnitude: this is because this small peak has relatively little importance on the calculation of the objective function for the whole tracer breakthrough curve.

Table 4: MDM Sensitivity analysis.

Parameter	High	Low
PD Flow 1 (m)	0.07	0.035
toi Flow1 (hrs)	175	158
PD Flow 2 (m)	0.8	0.015
toi Flow 2 (hrs)	510	330
PD Flow 3 (m)	0.1	0.011
toi Flow 3 (hrs)	360	324
PD Flow 4 (m)	0.01	0.00002
toi Flow 4 (hrs)	530	487

CONCLUSIONS

Analyses of discharge measurements on the Bela have shown the river has different hydrological responses related to the location of the area of the catchment where rainfall occurs. The catchment is divided into Limestone and Flysch, each producing a different hydrological response. The intermittent springs between Vipava and Vrhpolje only became active when rainfall occurs on the Nanos plateau.

The hydrogeological connection between the Bela stream and the Vipava spring was proved by a tracing experiment. Tracer was found in all the Vipava springs. Pod Farovžem (Spring 7) shows the strongest connection with the Bela stream, and 59% of the tracer was recovered at this spring. Analysis of the tracer breakthrough curve using a dispersion model gave values of dispersivity of the aquifer of 148 m and 126 m, related to different flow systems. Mass balance analysis of Spring 7 shows this also exhibits a dual hydrological response.

The results have certain implications for the water quality of the Vipava springs. The possible connection with the Bela and Spring 2, which is used for public water supply, may be important. Consequently, consideration needs to be given to the installation of wastewater treatment facilities in Vrhpolje, and future development in the area should be closely monitored.

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MEDSEBOJNI VPLIV POVRŠINSKE IN PODZEMNE VODE POTOKA BELE IN IZVIROV VIPAVE V JUGOZAHODNI SLOVENIJI

Povzetek

Stalni in občasni izviri Vipave so razporejeni vzdolž zahodnega roba kraške planote Nanosa na stiku z neprepustnim flišem Vipavske doline (Sl. 1 in 2). Na severozahodnem robu je Nanos omejen z dolino reke Bele, ki zbira vodo na flišu, med Sanaborjem in Vipavo teče po apnencu in aluvialnih naplavinah, končno pa se po flišu Vipavske doline izlije v reko Vipavo. Ob nizkih in srednjih vodah na apnencu postopno ponika in samo ob visokem vodostaju teče površinsko do reke Vipave.

Že starejše raziskave so pokazale, da se ponikle vode verjetno stekajo proti izvirom Vipave, v članku pa smo te trditve preverili še s tremi metodami: sledilnim poizkusom z injiciranjem uranina v Belo nad Vrhpoljem, meritvami pretokov Bele na različnih odsekih vzdolž toka in ločevanjem komponent toka na osnovi meritev specifične električne prevodnosti.

Pri sledilnem poizkusu smo 29. maja 2001 ob nizkem vodostaju injicirali 170 g uranina v Belo na odseku med hišo Pri Tekcu in Vrhpoljem. Čez dva dni so se po močnejši nevihti pretoki značilno povečali. Z avtomatskim zajemalcem in ročno smo zajemali vzorce v vseh stalnih izvirih Vipave. Ob tem smo merili pretok izvirov 6 in 7, podatke o skupnem pretoku Vipave pa smo pridobili na Hidrometeorološkem zavodu Republike Slovenije (Sl. 4). Rezultati sledilnega poizkusa so jasno dokazali zvezo med Belo in izviri Vipave, saj se je sledilo pojavilo v vseh stalnih izvirih Vipave (Sl. 5). Največja koncentracija uranina je bila zabeležena v izviru Vipava 7, skozi katerega je izteklo 59 % sledila. Srednje vrednosti so bile izmerjene v izvirih 6 in 5, v ostalih izvirih pa je bil signal slabši in je lahko tudi odraz onesnaženja ali napake meritve. Za izvir 7 je bil postavljen še multidisperzijski model, ki je dal najboljše rezultate pri privzetju 4 tokovnih poti (Sl. 6). Prvi dve predstavljata pretežni del krivulje prihoda sledila in ju lahko razlagamo z načelom dvojne poroznosti oz. tokom skozi večje razpoke in kanale ter pretakanjem skozi manjše razpoke. Vrednosti disperzivnosti 148 in 126 m sta večji kot je značilno za dobro razvite kraške vodonosnike. Tretja in četrta tokovna pot pa odražata izpiranje uskladiščenega sledila v kasnejših obdobjih povečanega pretoka.

Pretoki Bele so bili merjeni v osmih profilih, ki so bili približno enakomerno razporejeni vzdolž toka (Sl. 8). Po metodi, ki jo je predstavil Bonacci (1987), je bila izdelana primerjava pretokov v sosednjih odsekih (Sl. 7). Negativne vrednosti kažejo na izgube toka, pozitivne pa na dodaten pritok. Analiza dobljenih rezultatov v prvi fazi ni dala značilnega vzorca hidrološkega režima. Šele primerjava z razporeditvijo padavin v kraškem in flišnem zaledju (Sl. 4) je pokazala, da se hidrološki odziv v posameznih odsekih spreminja glede na delež napajanja iz različnih delov zaledja. Za bolj natančno ovrednotenje pogojev spreminjanja pa bi bile potrebne dodatne analize ob različnih hidroloških razmerah.

Hkrati z merjenjem pretokov so potekale tudi meritve specifične električne prevodnosti in temperature vode v posameznih odsekih Bele in vseh stalnih izvirih Vipave. V splošnem SEP vzdolž toka upada (Sl. 9), temperatura pa narašča (Sl. 10). Z upoštevanjem izmerjenih vrednosti SEP Bele in izvirov Vipave v enačbi mešanja sta bili ločeni komponent toka iz flišnega in kraškega zaledja v izviru Vipava 7 (Sl. 11). Tudi ta metoda je potrdila dvojnost hidrološkega odziva izvira ob različnih scenarijih napajanja v zaledju.

Dobljene rezultate bi bilo treba upoštevati tudi pri ocenjevanju ranljivosti izvira Vipava 2, ki je zajet za vodooskrbo širšega območja Vipave. Dokazana možna povezava z Belo, v katero se stekajo neprečiščene komunalne odplake iz Sanaborja in Vrhpolja, zahteva ustrezne ukrepe.