Much more difficult is to explain the underground connection between Mrzli Log and Divje Jezero. The dye was injected in the sinkhole formed in the Uppertriassic dolomite of Trnovo nappe. As in the Čekovnik interjacent slice near Črni Vrh a hanging fissured aquifer is proved by a hydrogeological borehole it can be supposed that the dye gets lost through the shallow dolomite lid into the lower limestone of Koševnik interjacent slice, where a normal karstic flow towards Divje Jezero is possible. The horizontal distance between Mrzli Log and Divje Jezero is 7,2 km, while the altitude difference is 455 m.

This geological cross-section (Fig. 7.4) explains the hinterland of the Vipava spring. P. Habič (1989) proved that the sinking stream Stržen near Rakitnik in the Postojna basin flows away in two directions, towards the Timava springs as towards the Vipava. The cross-section shows that the Lokva can have a normal underground karst flow towards the Vipava spring without any hydrogeological barrier. It has to be pointed that Lokva at low water can flow of into the limestone of Snežnik thrust sheet and trough it towards Timava. Although this geological cross-section is only supposed, it gives an explanation for the phenomenon, that the dye injected at low water in the Lokva stream did not appear in the Vipava spring.

## 7.2. UNDERGROUND WATER CONNECTIONS DEPENDENT ON HYDROMETEOROLOGICAL CONDITIONS (P. HABIČ)

### 7.2.1. The aim of water tracing by artificial tracers

From 1993 to 1995 combined water tracing tests in the area of Trnovski Gozd and Nanos were achieved mostly at the same points but during various meteorological and hydrological conditions. Using mostly the same tracers provided that tracing results may be well compared one to another. Except in two cases, the tracers were poured into epikarst vadose zone, this is why their travel up to springs highly depended on rainfall, in particular on consecutive showers that washed the tracer from the injection area. The analyses of water and tracer pulses in such cases are specially interesting.

The results of three consecutive water tracing tests in Belo Brezno below Golaki are important to understand water drainage in the area of Trnovski Gozd. Major part of tracer from the injection point at 1200 m a.s.l was flushed by rainwater into Mrzlek near the Soča (77 m a.s.l.), distant 19 km and partly into Lijak (water level between 77 and 116 m); smaller part flowed into near, 6,9 km distant Hubelj spring near Ajdovščina (water level between 220 to 270 m; See Chapter 6 about water tracing). Water tracing in immediate recharge

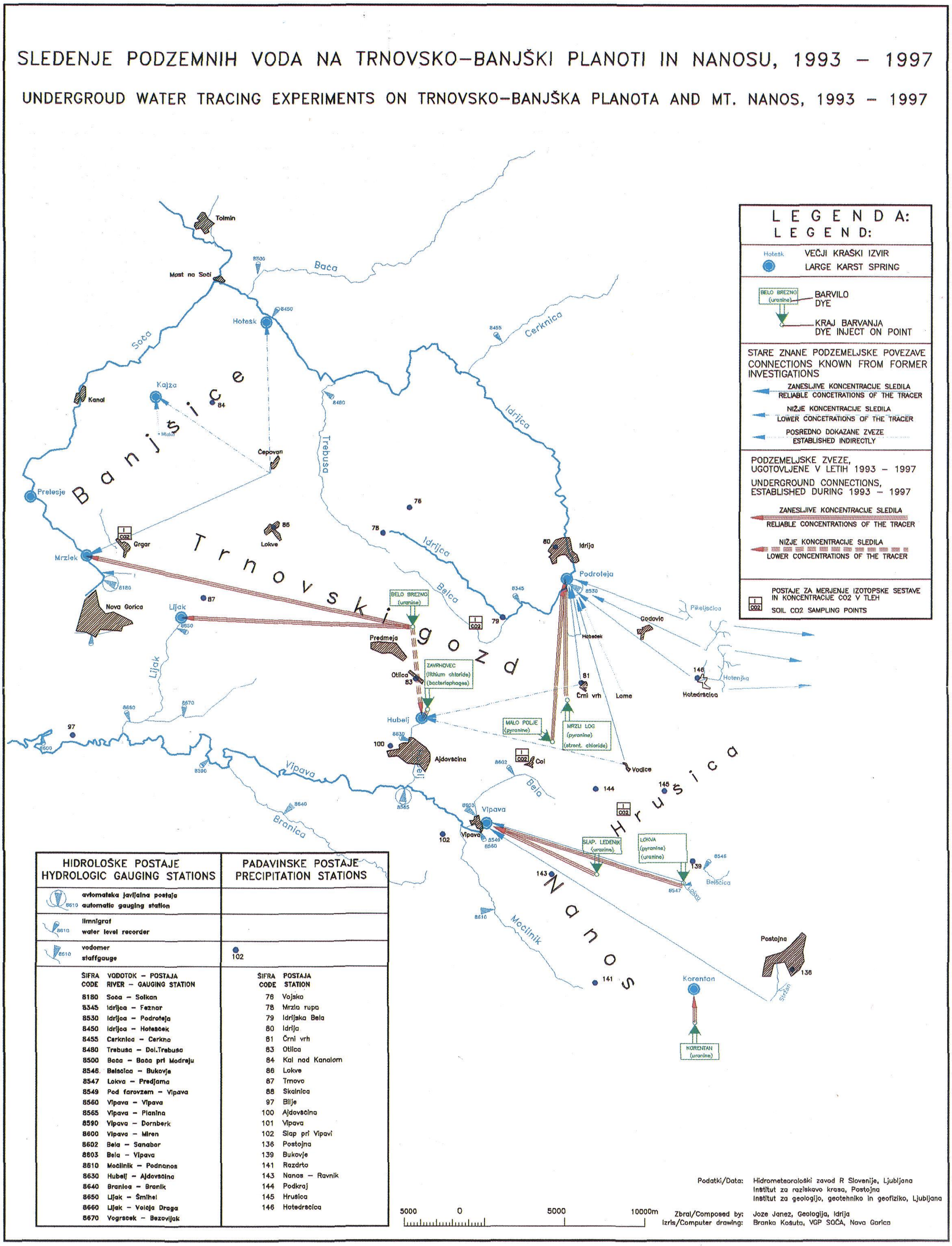


*Fig. 7.5: Underground water tracing experiments on Trnovsko-Banjška Planota and Mt. Nanos.*

area of Hubelj near Zavrhovc tried to explain the conditions in epikarst and vadose zone close behind the spring. Water tracing tests at Mrzli Log and Malo Polje should define the watershed area between Hubelj at the Vipava and Divje Jezero and the Podroteja at the Idrijca. Water tracing tests of the Lokva near Predjama and in shaft Slapenski Ledenik on Nanos Mt. should allow the comparison of mostly horizontal flow in epiphreatic zone and feeding of delta-shaped outflow from the aquifer into the Vipava springs with vertical drainage in a thick vadose zone.

### 7.2.2. Hydrometerological conditions during water tracing tests

On October 14, 1993 the first combined water tracing test was achieved after the initial autumn rain in September that followed a long dry period; practically there was no rainfall since January to the end of August 1993 (See hydrogramme of Hubelj and Lijak 1993). A week after the tracer was poured a distinct water pulse appeared after a heavy rain on October 21 to 25 (Otlica received 247 mm of rainfall); in the first half of November a new rain period followed with lower, but longer lasting water pulse up to the beginning of December; in the second half of December another rain and water pulse was recorded (See Chapter 6).

The second water tracing test was performed in spring, on April 16, 1994. The initial discharge of the Hubelj was twice as much as during the first tracing; already one day after the injection heavy rain increased the discharge in the springs; they slowly decreased through mid-May; after next rain from May 19 to 21 a distinctive water pulse occurred.

The third combined water tracing test was achieved during the summer drought on August 1, 1995. Dry weather continued since July to August 28, when in two days there was only 175 mm of rain on Nanos, 165 mm on Otlica and 118 mm on Lokve. The first abundant water pulse was followed by other five consecutive pulses in September, on September 4, 9, 15 and 20.

The fourth water tracing test was achieved during a dry autumn, on October 26, 1995. Slightly higher September waters flowed off, low discharges lasted from September 25 to October 30. After soft rain on October 30 and 31 (16.6 mm) the discharges in springs slightly increased for the first time; heavy autumn rain appeared between November 11 and 14 (188 mm) and between November 16 and 19 (193 mm on Otlica). Water pulses appeared in Lijak on November 12, 17 and 28 and on December 17 and 23, 1995.

Various amount of rainfall recorded at rain-gauge stations on Trnovski Gozd and Nanos differently influenced on height and distribution of water pulses in different springs. Smaller deviations of rain and discharge peaks are due to different permeability of single aquifers and different size of karst background of springs.

*Table 7.1 Overview of discharges at the beginning of water tracing tests.*

| Date | Q Hubelj | Q Vipava | Q Idrijca-Podroteja |
|---|---|---|---|
| October 14, 1993 | 2.8 | 8.1 | 18.1 |
| April 16, 1994 | 5.4 | 11.2 | 13.2 |
| August 1, 1995 | 0.5 | | 1.7 |
| October 26, 1995 | 0.6 | 1.7 | 2.7 |
| sQp 61-90 | 3.03 | 6.78 | 9.29 |

## 7.2.3. Underground water connection Belo Brezno - Hubelj

During the first water tracing test in 1993 the water pulse appeared in Hubelj after 155 hours and dye pulse after 190 hours after the injection. It means that rainfall accelerated the rinsing of tracer from Belo Brezno to Hubelj. Low concentrations and typical jagged concentration curve indicate, although the tracer was present in the spring for at least 1500 hours, partial and unhomogeneous outflow of rain from the area of Belo Brezno into Hubelj. According to our opinion the irregular concentrations are due to injection technique which was performed by separated pouring of dissolved tracer and by later adding of water from a lorry tank; such injection causes a sort of splashes of more or less diluted tracer from vadose to phreatic zone and it is recorded in different hourly or daily tracer concentrations in spring.

Due to low values in concentration curve (Fig. 6.21) it is difficult to read the true washing out, pushing or dilution of tracer by water pulses. It seems, that the very first appearance of tracer in spring together with the highest concentration is mostly due to normal outflow 150 hours after the injection and only partially to accelerated drainage influenced by the first water pulse. The second peak of concentration, after 285 hours, seems to be the result of tracer rinsing out of Belo Brezno after rain at the end of October; this tracer pulse is supposed to need 100 hours from the injection site to the spring (69 m/h); the second water pulse after rain in mid-November surely diluted the tracer in time from 600 to 800 hours after the injection. Increased concentration after 1100 hours might be the result of a new pulse due to rain in mid-November that washed off the tracer. This tracer pulse needed from 300 to 600 hours for its travel to spring (23 - 11.5 m/h). All these assumptions are, as it was said, rather doubtful due to modest secondary peaks of the dye pulse.

The second water tracing test in April 1994 recorded, by twice higher waters, understandably lower concentrations of Uranine in Hubelj but they appear in separated peaks. The first traces after 70 to 90 hours are probably due to previous water tracing as similar last trace was still recorded at the end of January. More distinctive traces of Uranine appeared after 400 hours at relatively constant low discharge. After 600 hours after the injection there are no traces of Uranine recorded. Also at this second water tracing a higher water pulse flushed a major part of Uranine from Belo Brezno towards Mrzlek. Rate of returned tracer in Hubelj was even hundred times smaller than it was at the first test.

The concentration curves of the third water tracing in Belo Brezno at very low waters in August 1995 do not essentially differ from the previous two. There are separated tracer peaks, only the initial part resembles more to a short pulse, with intermediary dilution; that would be the result of unhomogeneous tracer pouring. The first traces appeared in Hubelj after 140 hours, tracer reached its peak after 180 hours and its end after 204 hours. Some tiny traces were recorded after 320, 440 and 500 hours and after an abundant water pulse after 650 hours all the traces of Uranine practically disappeared. The rate of returned tracer is in this case twice as small as at the second tracing (0.01 %).

Low concentrations and sporadic appearance of Uranine during all the three tracing tests indicate an impeded drainage, some sort of splashing from Belo Brezno towards Hubelj. Apparent velocities of the first appearance and apparent peak of the dye pulse are in this case even less reliable than at other springs. If we do not take into account the first trace at the second water tracing after 70 hours but we consider as the first the appearance after 400 hours then it is shown that the fastest outflow occurs at the lowest waters and at the lowest concentrations, and slower outflow at higher waters when concentrations are higher too. Disproportion in amount of tracer between medium and high waters indicates different drainage in epikarst and maybe even in phreatic zone during different hydrometeorological conditions. In all the three cases the basic drainage was oriented from Belo Brezno towards Mrzlek.

## 7.2.4. Underground connection Belo Brezno - Mrzlek

As karst waters from Mrzlek spring flow directly into the Soča a direct comparison between dye and water pulses is not possible in this spring. For comparison we used hydrogrammes of Hubelj and partly of Lijak. Hubelj and Lijak hydrogrammes are pretty similar considering the fact that in Lijak overflow pulses were recorded only and lower part of the hydrogramme reflects water table lowering in the borehole near Lijak. Water level in it reacts concordantly to emptying and filling of the common aquifer (JANEŽ 1992; PETRIČ 1993). Differences are partly due to different distribution and quantity of rainfall to the eastern and western side of Trnovski Gozd and partly to different accumulation capacities of both parts of the common aquifer.

At the first water tracing in Belo Brezno a typical dye pulse appeared in Mrzlek with highest concentration at its beginning; after 216 hours a computed velocity was 92.4 m/h; in Hubelj the velocity was 35 m/h. Similar as in Hubelj also in Mrzlek water pulse outran the dye pulse for about 60 hours. Rain after 150 hours since the injection pushed the dye pulse out of underground and thus diluted its initial part; it is seen in conical start of a concentration curve. The second rain after 500 to 600 hours since the injection diluted Uranine in Mrzlek where Uranine outflowed constantly for about 1000 hours in total.

After the second water tracing in Belo Brezno a nice dye pulse appeared in Mrzlek. The concentration curve is regular due to rainfall soon after the Uranine injection that washed the tracer into phreatic outflow zone of the karst aquifer. The first appearance of tracer after 168 hours, which means about 100 hours after the water pulse peak, and dye pulse peak after 318 hours, give rather realistic velocities of underground flow (120 and 60 m/h) at medium high waters. Smaller secondary Uranine concentration peak between May 5 and 6 is probably influenced by soft rain that pushed a part of tracer from underground but did not cause dilution. Without a proper effect to dye pulse was also rain about May 20; smaller dilution appeared only at low waters in the next ten days.

The third water tracing test with Uranine in Belo Brezno at low waters confirmed the results of the previous two tests. Also in this case a major part of used Uranine (60-70 %) flowed into Mrzlek. The first trace appeared after 630 hours together with the beginning of water pulse after more than one month of dry weather. The peak of water pulse outran the peak of dye pulse for about 100 hours; this means that similarly as at the first tracing it was rain that pushed the tracer out of underground. Obviously tracer almost reached spring thus one may reckon with real apparent velocity of low waters in phreatic zone to be from 20 to 25 m/h.

After the first rain at the end of August, another five rainy periods followed in September provoking corresponding water pulses. At the same time they were recorded in Lijak and Hubelj and we suppose that they correspond to water pulses in Mrzlek. After the first dye pulse two secondary peaks appeared; the first after 880 (1000) hours and the second after 1030 (1200) hours since the injection. Both secondary dye pulses are connected with washing and pushing of tracer in Vast karst aquifer. A trace of Uranine was recorded in Mrzlek still after 3600 hours or five months; till now this is the longest water tracing in the High Karst of the western Slovenia.

## 7.2.5. Underground connection Belo Brezno - Lijak

During the first water tracing test it was still possible to sample the water in the Lijak borehole and near it, later the borehole breached and thus data for comparison are missed. In 1993 Uranine appeared in Lijak after 214 hours since it was injected in Belo Brezno; it is practically the same time as it was required for Hubelj and Mrzlek and it was undoubtedly influenced by the already known water pulse. The Uranine concentration curve in Lijak is practically identical to the Mrzlek curve, only maximal concentration is slightly lower. Thus already known hydraulic connection of Lijak and Mrzlek was confirmed; in the first one only high waters flow on the surface while the second one permits a permanent outflow from common aquifer. A short lasting water pulse drained about 10 % of Uranine which was present in the karst groundflow of Lijak up to 2800 hours since the injection although five distinctive overflow pulses occurred in this time; in Mrzlek the tracer was present 1400 hours only. Probably a part of low water remains in Lijak, as it cannot flow directly to Mrzlek without an additional hydraulic pressure. At water tracing in 1994 we did not record Uranine in Lijak and in 1995 it occurred only in a sample belonging to the sixth water pulse of September 19, 1995.

### 7.2.6. Underground connection Zavrhovc - Hubelj

Drainage through 550 m thick vadose karst zone, only 1 km distant from the Hubelj spring, was traced three times by phages (See Chapter 6.4) and once by LiCl (See Chapter 6.5).

After the first tracing on October 14, 1993 at medium waters and after a wet season (See Table 6.14) the tracer travelled by 37,7 m/h (for its first appearance) and 22.3 m/h during the peak. Such drainage was undoubtedly provided by rainfall that previously watered the epikarst zone (from October 7 to 13 there was 75.6 mm of rain); after the injection there was at first a soft rain (October 15-19 28,6 mm) followed by two periods of abundant showers (October 21-25 251,3 mm and November 3-9 388 mm, gauged on Otlica). Concentration curve is jagged, typical of tracing in a vadose zone with unhomogeneous watering, but it indicates a characteristic tracing pulse and also traces of secondary rinsing of phages after an abundant water pulse (See Fig. 6.31)

At the second water tracing test there was still more water. On Otlica 177 mm of rain was recorded from April 1-15, and after the injection, between April 16 and 20, another 85,7 mm. Correspondingly higher were also discharges in the Hubelj spring. Without considering slightly changed injection location, the flow velocities through epikarst zone were very similar. The first trace was 14 hours late, the concentration peak appeared 9 hours earlier giving slightly higher velocity (25,9 m/h) than at the first tracing. The tracer concentration curve is even more jagged, but the concentrations are 25 times lower (See Fig. 6.32) and correspondingly lower is also the rate of returned tracer (0,78 % and 0,012 %).

At the same time as phages also LiCl was poured at the same site into epikarst zone. Rather typical dye pulse appeared in the spring between April 20 and 26; the first appearance was after 80 hours and the peak after 100 hours since the injection giving slightly lower velocity (18,5 to 15,6 m/h). The secondary LiCl pulse was recorded in Hubelj between May 19 to 25; it was due to abundant rain as the discharges in Hubelj increased to 31,5 $m^3/s$.

The third water tracing with phages at Zavrhovc was achieved during the summer drought when epikarst zone above Hubelj was without rain, worth mentioning, from mid-June to the end of August 1995. From June 16 to August 1 there was only 77 mm of rain on Otlica, it rained only three times (from 10 to 15 mm) in the season, when evapotranspiration is the highest. From August 1 to August 26 there was 105,7 mm of rain, a real rain, 165,5 mm, started from August 27 to 29, having an impact on Hubelj discharge also. The first trace after the injection of phages on August 1, 1995 appeared after 661 hours on August 29, the peak of dye pulse only 12 hours later; apparent velocity is thus 2.3 m/h. Secondary trace appeared on September 11, after rain on September 4 and 8. The phages travel through dried epikarst zone was practically blocked for four weeks, until heavy rain provoked the tracer pulse; concentrations were very low and the rate of returned tracer only 0,001 %. Water tracing in epikarst zone requires special preparation and suitable conditions, the results are important for planning the protection of karst aquifers.

## 7.2.7. Underground connection Mrzli Log - the Podroteja and Divje Jezero

On April 16, 1994 during the second combined water tracing Pyranin was injected into an ouvala Mrzli Log between Križna Gora and Javornik above Črni Vrh. According to morphological properties this area should belong to the Hubelj recharge area (9,2 km). The water tracing test did not confirm this assumption as Pyranin appeared in a dye pulse of Podroteja (7,6 km) after 300 to 600 hours and after 822 hours it was recorded in Divje Jezero also. The connection corresponds to geological setting. Apparent tracer velocity in Podroteja was 24,7 m/h and the peak of pulse 20,1 m/h. Outflow velocity (9,2 m/h) into Divje Jezero is truly apparent as during low waters Divje Jezero does not drain karst water from a common aquifer; the tracer there was recorded as a short outflow during water pulse on May 19 only. During this water pulse it did not appear any more in Podroteja as Pyranin could not be detected even 200 hours earlier due to dilution.

## 7.2.8. Underground connection Malo Polje - the Podroteja and Divje Jezero

For the third combined water tracing in summer 1995 Malo Polje near Col was chosen as it lies on would-be watershed between Podroteja and Hubelj; it is 8,3 km far from Hubelj and 10,7 km from Podroteja. This tracing by Pyranin also did not confirm the supposition of the connection with Hubelj; the tracer appeared in three separated peaks in low concentration in Podroteja and Divje Jezero after 740 to 830 hours with apparent velocity from 13 to 14 m/h. The tracer appeared in both springs after 100 hours after the peak of the first high water pulse, while during the second, substantially lower pulse tracer was no more recorded. Probably this case indicates a trace of secondary washing while true base outflow from Malo Polje is not proved. Water tracing in epikarst watershed zone requires more tracer and a more sensitive one.

## 7.2.9. Underground connection Lokva (Predjama) - the Vipava (P. HABIČ, V. ARMBRUSTER)

In April 16, 1994 during the second combined water tracing test among the others also the sinking stream Lokva near Predjama was dyed. The permanent springs of the Vipava from V-1 to V-7 and common at water gauge station V-8 were monitored. Hydrological conditions were similar as in the catchment area of other springs in the area of Trnovski Gozd. Two days after the injection at relatively high waters (11,2 $m^3/s$) a water pulse occurred with peak at 25,2 $m^3/s$. Later water decreased constantly. After 450 to 500 hours on May 6 a low water pulse, peak 6,3 $m^3/s$, occurred; after 800 hours since the injection a more abundant water pulse occurred on May 20 with first peak at 26.7 $m^3/s$ and on May 21 with 22,6 $m^3/s$. The first traces of Uranine appeared in the Vipava after 69 to 74 hours, varying in different springs, and the first peak after 80 to 103 hours. The velocities of the first tracer appearance are between 175 to 185 m/h. In some springs the second peak was more distinctive, between 140 to 166 hours since the injection, velocities from 78 to 126 m/h (See Fig. 6.21 - 6.26). Water pulse accelerated the washing of tracer somewhere in the middle between swallow-hole and spring and at the same time it washed off the retained tracer from the ponor area. Thus two tracer pulses appeared in the springs. The first had higher concentrations only at the common gauge station V-8 and in the spring V-3; the first peak in the spring V-7 was rather diluted, although higher than the second one. The springs V-1, V-2, V-4, V-5 and V-6 had higher concentrations in the second pulse which was certainly much more prominent in all the springs.

The differences in the concentration curves between single springs are