6. TRACING EXPERIMENTS

6.1. ORGANISATION, INJECTION AND SAMPLING

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Within the three years of the research program 4 combined water tracing experiments with the classical hydrologic tracers were carried out to define the hydrodynamic behaviour of the karst systems as well as to localise underground connections. An overview of the tests performed is given in Tab. 6.1, the distribution of the various injection places and the main observation points is depicted in Fig. 6.1. One main focus of the research carried out was to define the variations in the hydrodynamic behaviour by means of repeated tracing experiments under different hydrological conditions. Details on the discharge behaviour of the main springs during the experiments performed are given in chapter 6.2. An overview of the basic data of the main sampling sites is given in Tab. 6.2. In the framework of chapter 6 the following abbreviations for the various laboratories conducting analyses will be used:

Abbreviations:

AGK: Applied Geology, University of Karlsruhe, Germany
GSF: Institute of Hydrology, GSF-Research Center, Germany
HMZ: Hydrometeorological Survey, Slovenia
IHG: Institute for Hydrogeology and Geothermics, Joanneum Research, Austria
IZRK: Karst Research Institute, Scientific Research Center, Slovenian Academy of Sciences and Arts
KÄSS: Laboratory Dr. habil. W. KÄSS, Germany
UBA: Federal Environmental Agency, Austria.

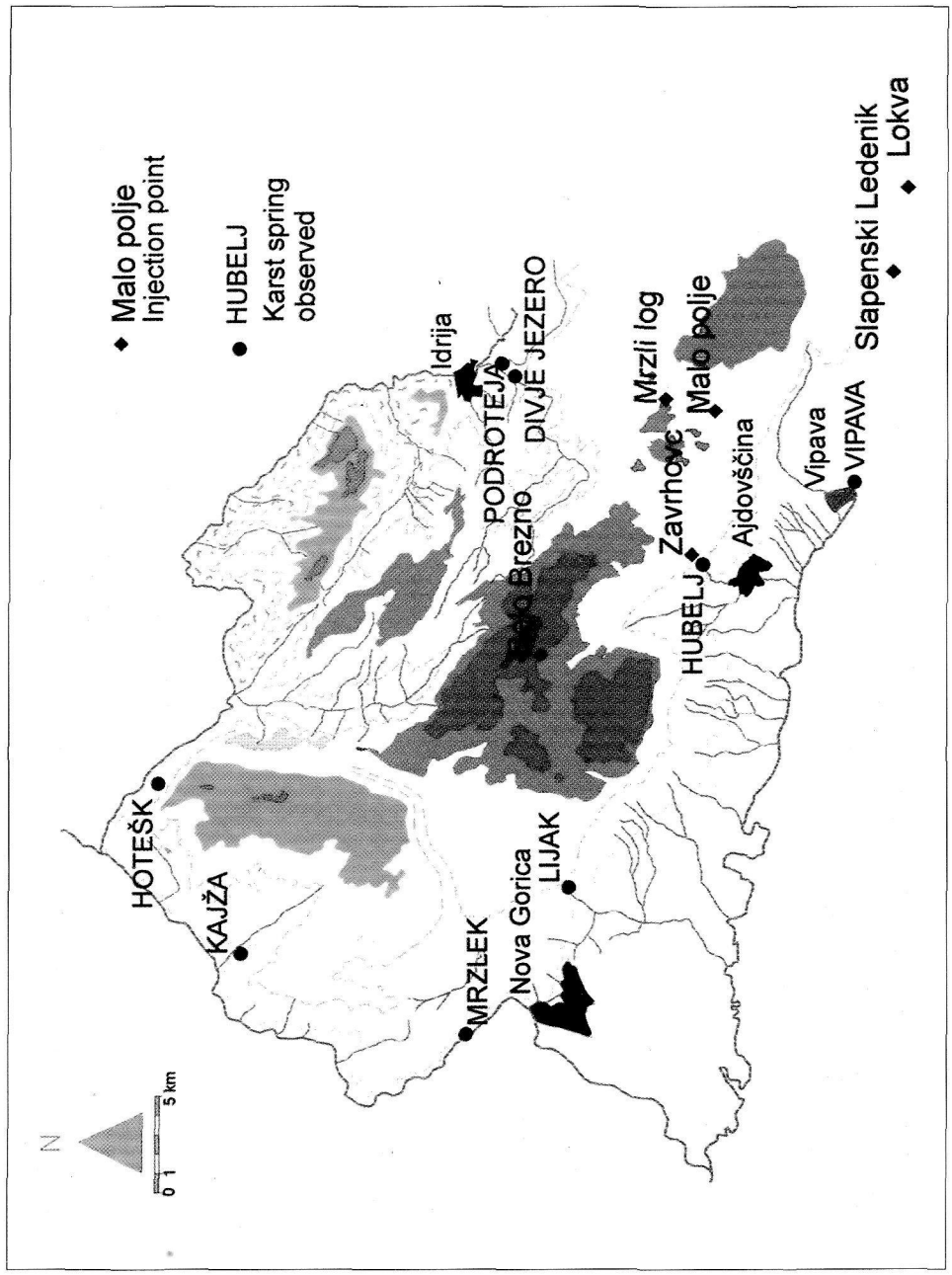

Fig. 6.1: Location map of the injection places and main observation points of the tracing experiments performed in the framework of the ATH research project from 1993 to 1996.

Tab. 6.1: Tracing experiments performed in the framework of the 7th SWT investigations in chronological order: date and time of injection, injection points with altitude, tracer type and amount, amount of pre and after flushing.

No.	date	time	injection place	altitude [m a.s.l.]	Tracer	amount /solution	Flushing pre [m^3]	Flushing after [m^3]
1	93/10/14	13:10	Belo brezno	1,200	uranine	5 kg / 30 l	*1)	7.0
		14:25	Zavrhovc	790	bacteriophages	4.1 • 10^{15} pfu / 16.5 l	1.5	3.5
2	94/04/16	10:25	Zavrhovc	775	lithium chloride	30 kg / 110 l	3.5	1.0
		10:30	Zavrhovc	775	bacteriophages	8.0 • 10^{15} pfu / 20.5 l		3.5
		13:10	Belo brezno	1,200	uranine	5 kg / 20 l	1.0	7.0
		11:00	Mrzli log	784	strontium chloride + pyranine	50 kg / 120 l + 5 kg / 40 l	1.0	6.0
		12:45	Lokva	464	uranine	7 kg / 100 l	*2)	
3	95/08/01	11:37	Belo brezno	1,200	uranine	7 kg / 30 l	2.0	3.0
		10:25	Zavrhovc	775	bacteriophages	6.6 • 10^{15} pfu / 26.0 l	3.5	3.5
		10:33	Malo polje	615	pyranine	8.5 kg / 120 l	1.5	4.5
4	95/10/26	11:45	Lokva	464	pyranine	8 kg / 100 l	*3)	
		11:45	Slapenski Ledenik	980	uranine	5 kg / 50 l	2.0	4.0

*1) *injection into a natural trickle stream of 0.2 l/s*
*2) *injection into the Lokva stream with an inflow of approx. 166 l/s*
*3) *injection into the Lokva stream by a gauged water level of 1.22 m*

Tab. 6.2: Basic data of the main sampling sites: altitude, distance from the relevant injection places (m) and the altitude differences (m). All data are taken from the official topographic maps.

Spring / Injection place altitude in m a.s.l.	Belo brezno 1,200	Zavr-hovc 1993: 790	Zavr-hovc 1994, 95: 775	Mrzli Dol 784	Malo Polje 615	Lokva 464	Slapen-ski Ledeni k 980
Hubelj 240	6,880 / 960	890 / 550	1,000 / 535	9,250 / 544	8,340 / 375		
Lijak 100	13,290 / 1,140						
Mrzlek 58	19,770 / 1,180						
Kajža 198							
Hotešk 195							
Podroteja 330				7,630 / 454	10,710 / 285		
Divje Jezero 350							
Vipava 99						12,490 / 365	7,600 / 881

6.1.1. First Combined Tracing experiment in October 1993

The two injection places of the first tracing experiment are located in the central part of the Trnovski Gozd plateau (ice cave Belo Brezno) and on the steep plateau border below Sinji Vrh close to the spring Hubelj (doline Zavrhovc) (Fig. 6.1). Injection was carried out on October 14 1993. The hydrologic conditions in the catchment area prior, during and shortly after the injection was characterised by a heavy precipitation event with a height of 60

mm on October 9 and 10, 1993 measured in the precipitation station Otlica. The next abundant rainfall was from October 21 to 25, with a maximum of 112.6 mm on October 22, hence altogether 247 mm of rain. At the time of injection the Hubelj discharge was 2.79 m^3/s. It started to increase on October 21 and attained its maximum the next day at 27.6 m^3/s. While the described hydrologic conditions are characteristic for the injection in Belo Brezno, for the tracing test in the doline near Zavrhovc (Fig. 6.1) low water conditions are prevailing.

Injection in the doline near Zavrhovc, October 14 1993

In the bottom of the doline at the farm Zavrhovc, 790 m a.s.l., distance from Hubelj 890 m, 16.5 l of phages solution (4.1×10^{15} pfu) were injected.

The selected doline is one of the series of deep dolines situated parallel to the steep plateau border below Sinji Vrh. In the grassy bottom of the doline a 5.5 m deep borehole was drilled through yellow-brown loam, mixed with some rubble in the lower part of the borehole. At the depth of 5 m, close to the rock, the borehole reached a 20 cm wide empty space. Experimentally, 1.5 m^3 of water was poured into the borehole and in 5 minutes it swallowed all the water. The phages solution was poured in at 14.25, injection lasted 3 minutes. Later 3.5 m^3 of water was added and all this water was promptly drained, after flushing lasted about half an hour.

Injection in Belo Brezno, October 14 1993

Belo Brezno is a smaller pothole, 40 m deep, lying south of the Golaki ridge in the area called Kozja Stena (compare chapter 2.5). The entrance of Belo Brezno lies at about 1240 m a.s.l., the pothole's bottom is at 1200 m a.s.l. The injection point is in 6880 m distance to the Hubelj spring, the altitude difference is about 910 m. The tracer was poured at the end of an oxbow passage continuing from the entrance part of the pothole towards the east. Over the oxbow passage wall about 0.2 l/s of water trickled down. The water disappeared among the rubble on the flat bottom. 5 kg of uranine were dissolved in 30 l of water. A closed barrel containing the solved tracer was lowered into the pothole and carried to the injection point. The dye was poured out at 13.10 and immediately disappeared among the rubble. By hoses the tracer was thoroughly washed by 7 m^3 of water. All the water disappeared by 13.45 giving the discharge of 3.9 l/s. The water drained off simultaneously.

Sampling

On the TBP the following main karst springs were sampled: Vipava, Hubelj, Lijak, Mrzlek, Hotešk, Kajža, Podroteja and Divje Jezero (Fig. 6.1). In the

vicinity of the Hubelj spring some smaller karst springs were included into the observation network: Skuk (520 m a.s.l.), Studenec near Gorenje (520 m a.s.l.). Using automatic samplers, partly put at disposal by the Federal Environmental Agency, Vienna, Austria, the Hubelj was sampled up to November 5, 1993 every two hours; later sampling was every 4 hours, and still later every 6 or 12 hours. Till the end of the observations one sample per day was taken. The springs Lijak and Mrzlek were sampled once per day. Unfortunately no sampling of the Mrzlek spring directly in the Soča river was possible due to technical reason. Therefore only samples of the Mrzlek pumping station are available. While water samples from the springs Hotešk, Kajža, Studenec near Gorenje and Skuk were only taken once per day at the beginning of the observation time, main observation was carried out by active charcoal detectors changed once per week. Observation of a possible tracer recovery in the springs Podroteja and Divje Jezero was solely done by activated charcoal adapters.

6.1.2. Second Combined Tracing experiment in April 1994

Injection was carried out on April 16, 1994 at four points: Belo Brezno, the doline near Zavrhovc, in Mrzli Log and in the Lokva stream below Predjama Castle (Tab. 6.1 and Fig. 6.1). In respect to evaluate the variability of the hydrodynamic behaviour under different hydrologic conditions the two injection points used in the first combined experiment (Belo Brezno, Zavrhovc) were chosen again.

Abundant rainfall appeared on April 10 and 11 (67.3 mm - Otlica) and April 17 and 18 (64.2 mm). During the injection the Hubelj discharge was measured as 5.41 m^3/s and Vipava 11.9 m^3/s. Due to rainfall in the catchment areas the Hubelj and Vipava discharge increased the following two days up to a maximal value and then gradually decreased during the whole month. The next precipitation event occurred in May 19 to 21 with a height of 190 mm. Caused by those rainfall, and as described in detail in Chapter 3, both the Vipava and even more the Hubelj discharge increased. After two days the discharge already started to decrease and it was decreasing up to September.

Injection in the doline near Zavrhovc, April 16 1994

Unfortunately, the drilling efforts into the doline's bottom at the same place such as in October 1993 were not successful. The water used for the preflushing did not flushed away. Therefore the tracer was injected into the bottom of a nearby, rocky doline covered with vegetation below the Zavrhovc farm house (775 m a.s.l). Testing of the swallow capacity was done with 3 m^3 of water poured onto the rocks in the border of the doline bottom at 10.00.

The water drained off. On the preceding day 30 kg LiCl were dissolved in 110 l of water and at 10.20 to 10.25 poured on the same spot. It was washed by 1 m^3 of water. At 10.30 20.5 l of phages solution (8 x 10^{15} pfu) were poured and washed by 3.5 m^3 of water. The water drained off promptly.

Injection in Belo Brezno, April 16 1996

The injection was carried out at the same place as in 1993. At the time of the injection the surface was covered by 30 - 60 cm of snow, melting intensively. All over the cave the drippings were strong. 5 kg of uranine were dissolved in 20 l of water. A closed barrel with tracer was lowered into the pothole and transported to the point planned for the injection. The tracer was poured out at the bottom of the cave at 13.10, at the end of an oxbow continuing from the entrance part of the pothole towards the east. Over the oxbow passage wall some 0.5 - 1 l/s of water trickled down. The water disappeared among the rubble. The majority of the dye washed by 7 m^3 of water was drained off within 15 minutes.

Injection in Mrzli Log, April 16 1996

Mrzli Log is a big karst depression, about 1 km long and 70 m deep, partly formed in limestone and partly in dolomite (Fig. 6.1). The bottom is flat, covered by dolomitic debris in which the shallow bed of a periodical stream is incised. The riverbed overgrown by grass ends in shallow alluvial dolines. In one of them a swallow-hole is opened. The tracers were poured into that.

The tracer, 50 kg of $SrCl_2$ was dissolved in 120 l of water quickly and completely. The second tracer, 5 kg of pyranine, was dissolved separately in 40 l of water and later added to the $SrCl_2$ solution. In the swallow-hole the water from a fireman tanker was poured for 5 minutes (about 1 m^3) at the beginning and at 11.00 both tracers were poured in it. The solution quickly drained off. The remains were washed by the remaining quantity of water (about 6 m^3). Water disappeared promptly.

Injection in the Lokva below Jama Cave (Predjama), April 16 1996

The uranine tracer was injected into the ponor of Lokva stream, which sinks at the northern border of the Pivka basin below the Predjama Castle. The ponor lies at 464 m a.s.l. and is 12990 m distant from the Vipava springs. The water level on the gauging site at the time of the injection was 129 cm, the discharge established by the curve 0.166 m^3/s (validity of the curve until 31.3.1994). Uranine was dissolved in about 100 l of water. The tracer was poured into the flow from 12.45 to 12.50. 15 minutes after the injection all the dye was washed off the riverbed.

Sampling

Hubelj was sampled for two weeks every two hours, for one week every four hours, then every 6 hours, and since May 25 two times per day. Studenec near Gorenje and Skuk, Podroteja and Divje Jezero were sampled until the end of April twice per day, and later daily. Hotešk and Lijak were sampled daily, Mrzlek 4 times per day in April and later 2 times per day.

The 7 main sampling locations of the Vipava (compare Fig. 4.12) have been equipped with automatic samplers and with data logger as far it was technically possible (compare Chapter 3.6). The sampling stations are listed in the Tab. 6.3.

Tab. 6.3: Sampling stations at the Vipava spring group with their logging equipment and the different laboratories responsible for their sampling site. Abbreviations refer to the list given in chapter 6.1.

No.	Name	Fluorimetric Analysis	Chemical Analysis	Datalogger
Vipava 4/1	Pri Kapelici	UR (KÄSS)		HMZ: Cond, T
Vipava 4/2	Pod Lipo	UR (HMZ)	CHEM (HMZ)	
Vipava 4/3	Perhavčeva Klet	UR (IHG)		IHG: Cond, T
Vipava 4/4	Vipavska Jama	UR (GSF)		HMZ: Cond, T
Vipava 4/5	Pod Skalo	UR (GSF)		HMZ: Cond, T
Vipava 4/6	Pod Farovžem A	UR (GSF)		HMZ: Cond, T
Vipava 4/7	Pod Farovžem B	UR (HMZ)		IHG: Cond, T, P
Vipava 4/8		UR (IHG)		IHG: Cond, T

All the springs and the common flow of Vipava were observed. The springs Pri Kapelici 4/1, Pod Lipo 4/2, Perhavčeva Klet 4/3, Pod Farovžem 4/7 and common flow 4/8 were sampled for 9 days every two hours and then for 10 days every 4 hours; subsequent sampling was every 6 hours. The springs Pod Skalco 4/5, Pod Farovžem 4/6 and Vipavska Jama 4/4 were at first sampled three times per day and later once per day.

The sampling interval was established individually for distinct periods of time from April 16 to 26 every 2 hours, April 26 to May 3 every 4 hours, from May 3 to May 13 every 6 hours and from May 14 to June 6 every 12 hours. After June 6 1994 the sampling was daily or according to the progress in the breakthrough process at longer intervals.

6.1.3. Third Combined Tracing Experiment, August 1995

Injection

While the water tracing tests in 1993 and 1994 were carried out at medium or high waters, the tracing in 1995 was done at prevailing low water conditions. Since the last half of June and up to the last week in August only little rain fell. The discharge of the Hubelj was rather constant, exhibiting a slow decrease. At the time of injection, the discharge was 0.514 m^3/s. On August 16, 1995 the minimal annual discharge was reached (compare Chapter 6.2). Also the Vipava discharge constantly decreased from the first week in July up to the last days in August; the minimal annual discharge was measured on August 8, 1995. In such conditions on the 1st of August repeated injection was carried out at ice cave Belo Brezno as well as in the doline near Zavrhovc (the same as in 1994). As an additional injection place the doline Malo Polje was selected (Tab. 6.1, Fig. 6.1).

Injection in the doline near Zavrhovc, August 1 1995

The tracer was injected, as in 1994, into the bottom of a rocky doline, covered with vegetation below the Zavrhovc farm, 775 m a.s.l. From 10.21 to 10.25, 3.5 m^3 of water from a fireman tanker was poured in the rocky bottom of the doline. At 10.25 26 l of phages dilution (6.6 x 10^{15} pfu) was injected. The injection was finished in 3 minutes. The remaining quantity of water (3.5 m^3) was poured in the doline in 6 minutes until 10.34.

Injection in Belo Brezno, August 1 1995

The injection point was the same as in the years 1993 and 1994 (Photos 14 and 15). From 11.18 to 11.32 2 m^3 of water from the fireman tanker was

Photo 14: Tracer injection at Belo Brezno, 1995 (Photo by J. Kogovšek).

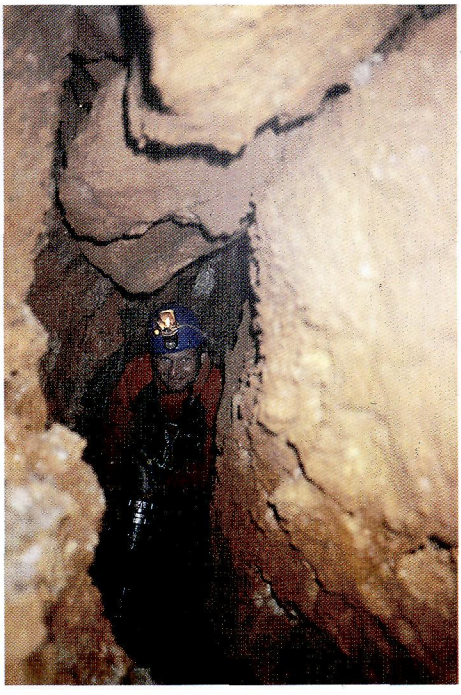

Photo 15: Tracer injection at Belo Brezno, work in the shaft (Photo by A. Mihevc).

poured in the pothole. At 11.37 7 kg of uranine dissolved in 30 l of water was poured at the bottom of the cave at the same point as in 1993 and 1994. The remains were washed by remaining water (3.5 m^3) till 11.55.

Injection near Malo Polje, August 1 1995

This injection point was used for the first time. The village Malo Polje lies 2 km NE from Col. It is in the northern edge of an almost 1 km long karst depression. The injection point was in the middle of the depression in a doline located some metres E from another doline filled with rubbish (Photo 16). The injection doline lies about 660 m a.s.l.

8.5 kg pyranine was dissolved in about 120 l of water. The tracer dissolved quickly and completely. From 10.05 to 10.30 1.5 m^3 of water from a fireman tanker was poured in the swallow-hole, which was artificially enlarged some days prior the day of injection. At 10.35 the tracer was poured into the swallow-hole. The remains of the solution were washed with water at 10.55 and at 11.05 all the remaining water (4.5 m^3) was emptied in the swallow-hole.

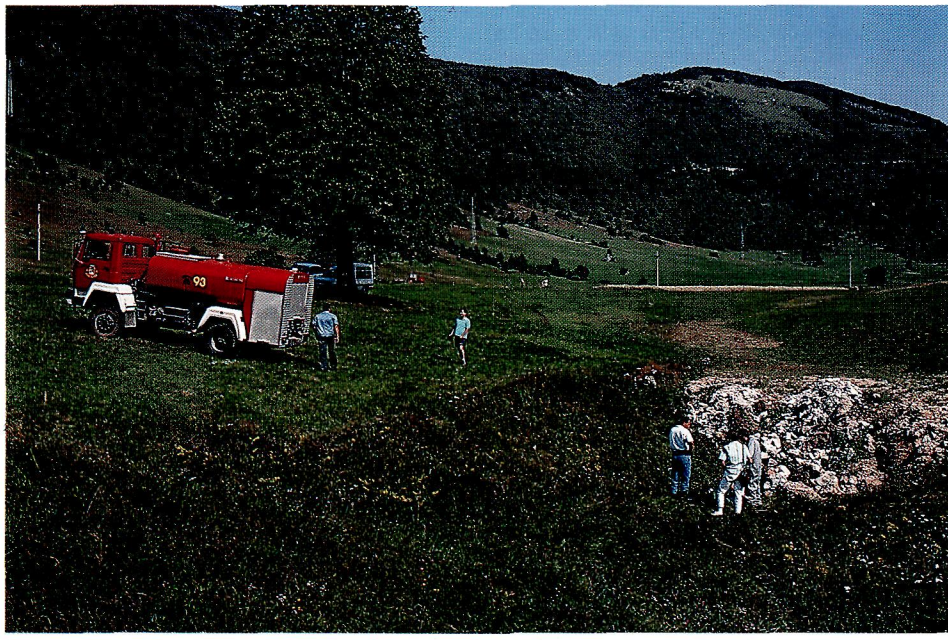

Photo 16: Swallow-hole, point of tracer injection at Malo Polje, 1995 (Photo by J. Kogovšek).

Sampling

At the beginning Hubelj (Photo 17) was sampled four times per day for analyses of tracer and isotopes (see Chapter 5). Later it was sampled twice per day and at the end of sampling once per day. In the smaller karst springs Studenec near Gorenje and Skuk in vicinity of the Hubelj water samples were taken once per day for one month and later activated charcoal adapters were changed once per week.

Activated charcoal adapters were changed in Kajža and Hotešk at the beginning of the observation twice per week and later once per week. Podroteja and Divje Jezero were observed by taking water samples either once or two times per day; later the sampling was two times per week. Sampling of Vipava was at springs Pod Lipo 4/2 and Pod Farovžem 4/7 once per day.

This time it was possible to sample the karst spring Mrzlek in both the pumping station and directly in the spring on the right bank of the Soča river. Mrzlek pump station was sampled from July 27, 1995, up to January 4, 1996, by an automatic sampler WTW PB 10/T. Mrzlek spring was sampled from July 27, 1995, up to January 4, 1996, by an automatic sampler Endress+Hauser asp-port. The sampling frequency and missing samples of Mrzlek spring and pump station are given in the Table 6.4. In principle momentary samples should be taken. Due to technical problems for two time intervals only average daily samples were available.

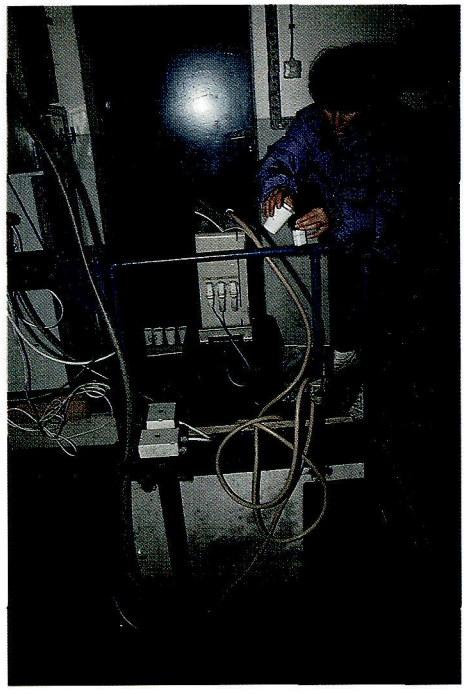

Photo 17: Water sampling devices at Hubelj spring (Photo by J. Kogovšek).

Tab. 6.4: Sampling schedule for the Mrzlek spring and the Mrzlek pump station during the third combined tracer test in 1995.

Sampling point	**Date**	**Sampling intervals**
Mrzlek spring	27.7.-29.7.95	1 per day
	8.8-18.8.95, 24.8.-7.9.95	4 per day
	19.8-23.8.95	average daily samples
	8.9.-30.9.95	2 per day
	3.10.-4.1.96	1 per day
	29.7.- 8.8.95, 19.- 26.10, 23.-28.11., 5.- 5.12., 18.- 21.12., 30.12.95 - 1.1.96	automatic sampler out of function
Mrzlek pump station	27.7.-7.8.95	average daily samples
	8.8.-18.8.95, 28.8.-7.9.95	4 per day
	8.9.-10.9.95	2 per day
	19.-27.8., 11.-29.9., 1.10., 9.10., 24.10.-31.1.95	1 per day
	26.8., 30.9., 2.-8.10., 10.-23.10., 26.10., 5.11., 27.11., 2.12., 3.12., 16.12., 21.12.95	automatic sampler out of function

6.1.4. Fourth Combined Tracing experiment, October 1995

Injection

In October 26, 1995 an additional tracing test was done at the Lokva near Predjama repeating the experiment performed during high water flow conditions in spring 1994 and in the pothole Slapenski Ledenik on Nanos (see Chapter 2.5) at prevailing low waters (Tab. 6.1, Fig. 6.1).

Injection in the Lokva below Jama Cave (Predjama), October 26 1995

8 kg of pyranine was injected into the Lokva stream like in 1994. The swallow-hole lies at 464 m a.s.l. and its distance to the Vipava springs amounts up to 12,990 m. The water level on the gauging station was at the time of the injection 122 cm. 8 kg of pyranine was dissolved in about 100 l of water. The tracer was poured in the stream in the time from 10.05 to 10.15. Water only slowly flushed the tracer.

Injection in Slapenski Ledenik on the Nanos plateau, October 26 1995

Slapenski Ledenik is a shaft, 112.4 m deep, lying on the east side of the Nanos plateau. The entrance is located about 1000 m a.s.l. At the depth of 35 m, the shaft divides into two branches (see Chapter 2.5).

5 kg of uranine was dissolved in about 50 l of water. The tracer dissolved quickly and completely. 2 m^3 of water from the fireman tanker was poured in the western branch of the shaft, at the depth of 45 m. At 11.45 the tracer was injected. 10 minutes after the injection all the dye was washed off in the hole. The remaining quantity of water (4 m^3) was washed in the hole until 12.30.

Sampling

In the spring Vipava 4/2 and Vipava 4/7 automatic sampler WTW PB 20/S was installed and in the spring Vipava 4/5 the sampler WTW PB 10/T. All springs were sampled from October 25 1995, up to June 2 1996. Sampling for such a long period of time was performed due to the expectation of a long duration of the uranine concentration wave. Additional, possible tracer recoveries after the snow melt or during the spring high waters can give valuable information on the hydrodynamic characterisation of the Vipava. The sampling frequency and missing samples of Vipava springs are given in the Tab. 6.5.

Tab. 6.5: Sampling in the Vipava springs during the forth tracing experiment in 1995.

SAMPLING POINT	DATE	SAMPLING METHOD
4/2, 4/5, 4/7	25.10.95 - 21.12.95	4x per day
4/2, 4/5, 4/7	22.12.95 - 01.03.96	3x per day
4/2, 4/5, 4/7	02.03.96 - 02.06.96	1x per day
4/5	28.10.95 - 30.10.95	automatic sampler out of function
4/2, 4/7	29.10.95 - 03.11.95	automatic sampler out of function
4/5, 4/7	06.12.95 -11.12.95	automatic sampler out of function

6.2. DESCRIPTION OF THE HYDROLOGICAL SITUATIONS DURING THE TRACING EXPERIMENTS

(N. TRIŠIČ & J. POLAJNAR)

6.2.1. The Hubelj Spring in the Time of the First Tracing Experiment (October 14 to December 31, 1993)

The values of discharges of the Hubelj were above average in the time of tracing experiment, if compared to the average over many years for the same period (October, November, December 1961-90). The mean discharge was by one third higher in the time of the tracing experiment than the mean discharge of the period. The highest discharge in the time of tracing experiment was higher by 2-times than the mean of extremes of the maximum high discharges in the period, and the lowest discharge was equal to the mean of extremes of the minimum low discharges in the period.

At the injection of the tracer on October 14, 1993, the initial discharge of 2.786 m^3/sec was only one half of the average mean discharge in the time of tracing experiment. On October 22, the high water wave followed with the highest discharge of 29.13 m^3/sec, which is more than the mean of extremes of the maximum high discharges in the period. By the end of October, the discharge of the Hubelj decreased below the value of discharge at the time of injection of the tracer, and on November 9, the second minor high water wave occurred with the highest discharge which was lower than the mean of extremes of the maximum high discharges in the period.