Gorenje

Observation period: 16.4, 12:15 - 24.5., 13:50
Amount of samples: 50
Highest value: 19 µg/l Sr
Lowest value: 9 µg/l Sr
Medium value: 13,5 µg/l Sr
Standard deviation: 1,88
Variance: 3,53
Result: No Sr-passage

Hubelj

Observation period: 16.4., 12:00 - 25.5., 1:00
Amount of samples: 232
Highest value: 9 µg/l Sr
Lowest value: 2 µg/l Sr
Medium value: 4,96 µg/l Sr
Standard deviation: 1,42
Variance 2,04
Result: No Sr-passage

6.6. MATHEMATICAL MODELING WITH THE MULTI-DISPERSION-MODEL (A. WERNER & P. MALOSZEWSKI)

6.6.1. Introduction

Numerous tracer experiments have been carried out within the research program of the 7[th]SWT on the Trnovski Gozd plateau (Slovenia). The area between the springs Mrzlek, Lijak and Hubelj (Fig. 6.1) formed one main focus of the investigations of the ATH. In the following the mathematical interpretation of the uranine tracer experiments of the input location Belo Brezno (Fig. 6.1, Tab. 6.1) will be described. At this place one tracer test was performed in each of the years 1993, 1994 and 1995 (compare chapter 6.3.2). Therefore it was possible to evaluate mathematically experiments with different hydrological boundary conditions. The main output was the karst spring Mrzlek in a distance of 19.8 km to the injection point and not the nearby located Hubelj spring (6.9 km distance). As described previously current discharge measurements of the Mrzlek spring are not available, due it's outlet in the dammed Soča river.

6.6.2. The Multi-Dispersions-Model (MDM)

The Multi-Dispersion-Model (MDM) was used for the evaluation. This model was developed by MALOSZEWSKI et al. (1992) for the interpretation of tracer tests in Styria. The MDM is an extension of the classical convection-dispersion model after LENDA & ZUBER (1970). The resulting breakthrough curve of a tracer experiment is seen as the outcome of different flow paths. Step by step the breakthrough curves of the individual flow paths and the parameter of convection (mean transit time) and dispersion (dispersivity) processes are determined. The mathematical background of this model was illustrated detailed in the report of the 6th SWT (MALOSZEWSKI et al. 1992). The following solution is valid for every flow path:

$$C_i(t) = \frac{M_i}{Q_i} \frac{1}{t_{0_i}\sqrt{4\pi\, P_{D_i}\left(\frac{t}{t_{0_i}}\right)^3}} \cdot \exp\left[-\frac{\left(1-\frac{t}{t_{0_i}}\right)^2}{4P_{D_i}\left(\frac{t}{t_{0_i}}\right)}\right] \qquad (1)$$

with C_i = tracer concentration
M = tracer mass
Q = discharge
t_0 = mean transit time

$$P_D = \frac{D}{v\,x} = \frac{\alpha}{x}$$

P_D = dispersion parameter
D = dispersion
v = mean flow velocity
α = dispersivity
i = index of the flow path

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

$$C(t) = \sum_{i=1}^{N} C_i(t) \qquad (2)$$

The discharge Q is normally necessary for a full calculation. Unfortunately this information was not available because of the location of the spring at the bottom of a river. However, it is possible to normalize the solution (1) to the maximal concentration.

In the past the MDM was used for the interpretation of tracer tests in different karst areas (MALOSZEWSKI et al. 1994; BARCZEWSKI et al. 1996; LÖHNERT et al. 1996; WERNER et al. 1997a; 1997b).

6.6.3. The Tracer Tests of the Injection Place Belo Brezno

Three different tracer experiments were selected for the mathematical interpretation. The ice cave Belo Brezno was the injection place for all of these tests. The injection was performed at the lowest point in this cave. An additionally injection of water should ensure that the tracer was flush out direct in the saturated zone.

The experiments were carried out under the following hydrological conditions:

	Karst water level	Number of Rain Events
• 1993	very high	many
• 1994	high	very few
• 1995	very low	no, first after 500 h

The main outcome of the injected tracers was the Mrzlek spring. In the Hubelj spring it was only possible to detect very low concentrations with an episodic behavior (compare Chapter 6.3.2). A further detection of the uranine was only possible in the Lijak spring. The activity of this periodical spring strongly depend on the karst water levels. More details about the performance of the experiments, the sampling and the results are given in the chapters 6.1, 6.2 and 6.3.

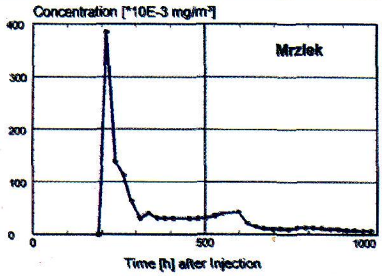
6.6.3.1. The First Tracer Test (1993)

This tracer test was carried out in the autumn 1993. The water level of the karst system was very high due to a longer precipitation period. The resulting breakthrough curve (Fig. 6.39) of the Mrzlek spring could be divided in different single peaks. However, these four peaks were not the result of the individual flow paths but of the multiple flow of one or two paths.

Due to the high karst water level the tracer was transported very fast into the saturated zone. This leads to a quick transport. The less values for the dispersivity (Peak I and II) are typical for the transport in the conduit system of a karstic aquifer. However, a smaller part of the tracers was hold in the unsaturated zone and flush out a short time later by following rain events. The higher values for the dispersivity and mean transit times of the Peak III and IV show this behavior.

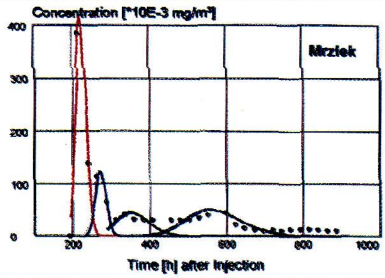
Due to the high karst water level the Lijak spring was active during this tracer test. The determined values are comparable with the results for the Mrzlek spring. Therefore the Lijak drained probably the same part of the karst system.

MRZLEK
Uranine



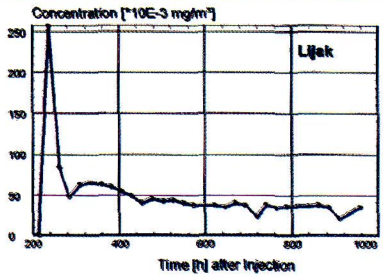
Hydrologic Situation:
- very high karst water levels
- multiple intensive rain events

Tracer Experiment
- Input: Belo Brezno
- Tracer: 5 kg Uranine
- Date: 10/14/1993



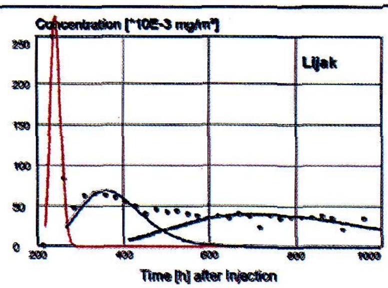
	Peak 1	Peak 2	Peak 3	Peak 4
t_0 [h]	222	272	359	572
v [m/h]	89	73	55	35
α_L [m]	35	28	137	122

LIJAK
Uranine



Hydrologic Situation:
- very high karst water levels
- multiple intensive rain events
- periodic spring

Tracer Experiment
- Input: Belo Brezno
- Tracer: 5 kg Uranine
- Date: 10/14/1993



	Peak 1	Peak 2	Peak 3
t_0 [h]	245	381	823
v [m/h]	54	35	16
α_L [m]	15	49	654

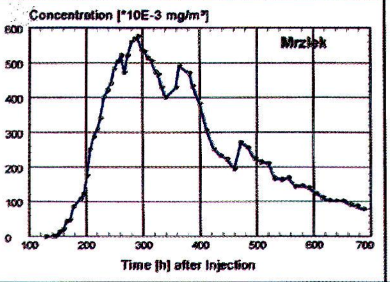
Fig. 6.39: Evaluation of the first tracing experiment from autumn 1993.

6.6.3.2. The Second Tracer Test (1994)

This tracer experiment was also performed during high karst water levels, but after the injection no rain events were observed for the first 470 h (Fig. 6.40). A natural flush out of the tracer by the rain events like 1993 was not possible. The lower flow velocities and the higher values for the dispersivity (Peak II) in comparison to the experiment of 1993 are the result of a delayed entry in the saturated zone. Because of the missing rain events the tracer was hold back in the unsaturated area. The following transport in the conduit system of the saturated zone is also very quickly. The third peak is caused by the rain events after 470 h.

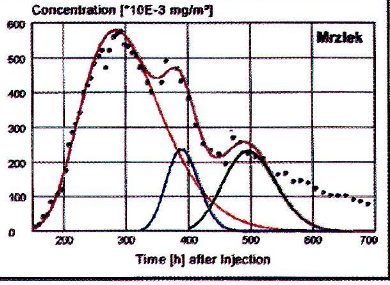
No tracer was detected in the Lijak spring because during the experiment the karst water level was decreased. The discharges of the Lijak spring were in the beginning about 5 ml/s and within two days they were fall down to values of less than 10 l/s.

MRZLEK
Uranine



Hydrologic Situation:
- high karst water levels
- until 470 h: no rain events
- after470 h: several rain events

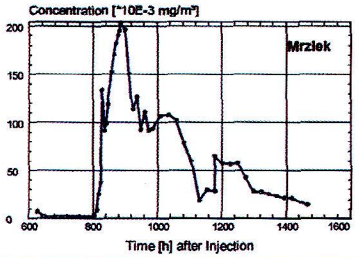
Tracer Experiment
- Input: Belo Brezno
- Tracer: 5 kg Uranine
- Date: 04/16/1994



	Peak 1	Peak 2	Peak 3
t_0 [h]	307	393	502
v [m/h]	64	50	39
α_L [m]	495	44	71

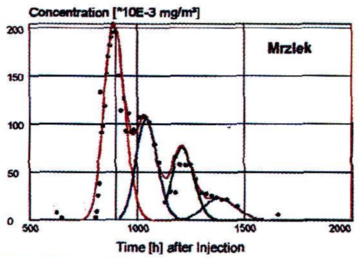
Fig. 6.40: Evaluation of the second tracing experiment from spring 1994.

MRZLEK
Uranine



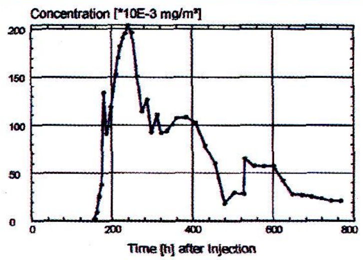
Hydrologic Situation:
- Very low karst water levels
- Till 650 h: no intensive rain events
- after 650 h: intensive rain events

Tracer Experiment
- Input: Belo Brezno
- Tracer: 7 kg Uranine
- Date: 08/01/1995

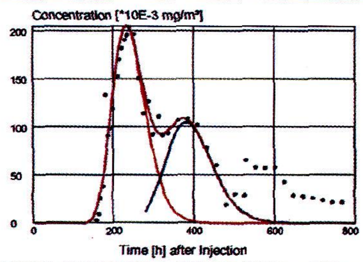


	Peak 1	Peak 2	Peak 3	Peak 4
t_0 [h]	897	1046	1212	1389
v [m/h]	22	19	16	14
α_L [m]	28	22	17	28

MRZLEK
Uranine



Corrected Interpretation:
- Effective Input after 650 h



	Peak 1	Peak 2
t_0 [h]	245	395
v [m/h]	81	50
α_L [m]	299	222

Fig. 6.41: Evaluation of the third tracing experiment of summer 1995.

6.6.3.3. The Third Tracer Test (1995)

This experiment was carried out during a dry period in the summer of 1995. (Fig. 6.41)The karst water level was very low during the whole experiment. No larger rain events were detected during the first 650 h of this tracer test.

The evaluation of the experiments (Fig. 6.42 above) shows great mean transit times but only very less dispersivity values. Therefore it can be assumed that the tracer was first hold in the epikarst. The following intensive rain events (after ca. 650 h) flush out the tracer into the saturated zone. The less dispersivity values show then the same transport behavior in the conduit system as in the years before.

A fictive input after 650 h (28.8.) was simulated for comparison. The evaluation (Fig. 6.42 above) shows mean transit times in the order of the other experiments. The high dispersivity values are caused in the distribution of the tracer in the epikarst during the first hours.

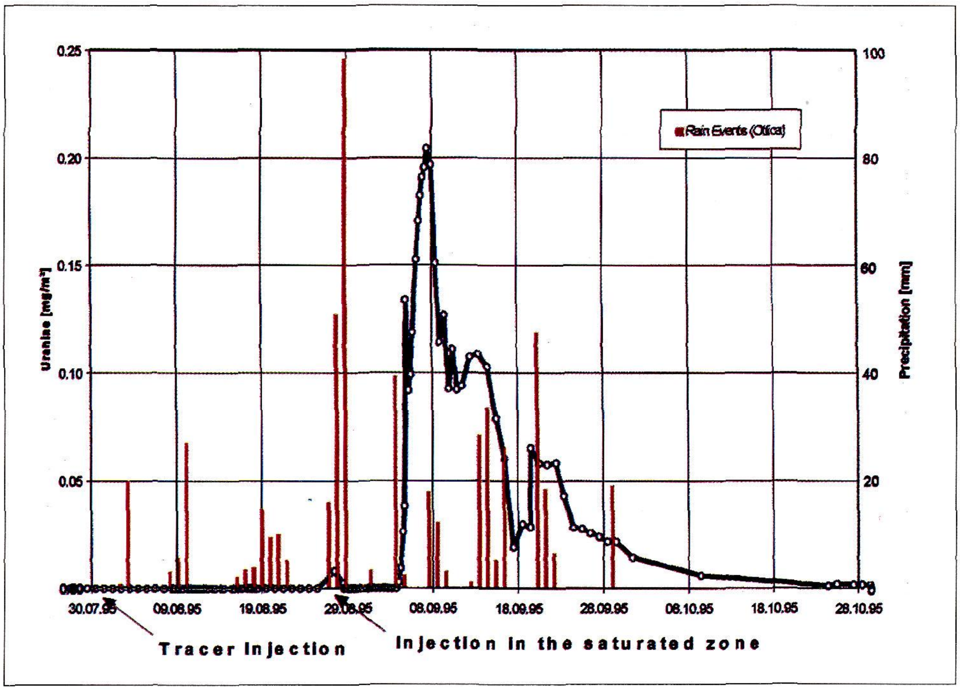


Fig. 6.42: Breakthrough curve of the third tracer experiment (summer 1995) and precipitation heights recorded in the precipitation station Otlica.

6.6.4. Conclusion

The evaluation shows that the transport behavior in the **saturated zone** is mainly independent of the hydrological conditions and the karst water level (Tab. 6.23) The flow velocities are between 60-90 m/h and the dispersivity values are very low (20-30 m). The transport takes place in the conduits of a good developed karst system. The number of flow paths or better flow systems can not determine unequivocal. Due to the rain events the multiple flow of one or two ways is probably.

Tab. 6.23: Overview of the results (for the first two Peaks) determined with the Multi-Dispersion-Model.

Tracer test /Year	Spring	Mean transit time [h]		Dispersivity [m]	
		Peak I	Peak 2	Peak 1	Peak 2
First / 1993	Mrzlek	222	272	35	28
	Lijak	245	381	15	49
Second / 1994	Mrzlek	307	393	495	44
Third / 1995	Mrzlek	897	1046	28	22
	Mrzlek (corrected.)	245	395	299	222

The differences in the breakthrough curve of the tracer experiments are caused in the location of the injection place in the **unsaturated zone**. Depending on the karst water level and/or rain events it was possible that the injected tracer was totally hold back (1995). The additional injection of water was not enough for a full input of the tracers into the saturated zone. The epikarst processes are difficult to understand. They are recognizable on the high dispersivity values (> 100 m) and the long mean transit times. The migration processes in the epikarst are also responsible for the episodic tracer detection in the Hubelj spring.

A further quantitative evaluation is not possible because of the missing discharge values of the Mrzlek spring. The performed normalization can lead to deviations of the determined parameters. However, these differences are normally not very large (WERNER 1997).