REPUBLIC OF LEBANON
Council for Development and
Reconstruction
CDR
Beirut

FEDERAL REPUBLIC OF GERMANY
Federal Institute for Geosciences
and Natural Resources
BGR
Hannover

TECHNICAL COOPERATION

PROJECT NO.: 2008.2162.9

Protection of Jeita Spring

SPECIAL REPORT NO. 6

Artificial Tracer Test 5A - June 2011

Raifoun
February 2012

Artificial Tracer Test 5A - June 2011

Authors:	Joanna Doummar[1], Dr. Armin Margane (BGR), Dr. Tobias Geyer[1], Prof. Martin Sauter[1]
Commissioned by:	Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, BMZ)
Project:	Protection of Jeita Spring
BMZ-No.:	2008.2162.9
BGR-Archive No.:	xxxxxxx
Date of issuance:	February 2012
No. of pages:	15

---

[1] University of Goettingen/Germany

PROTECTION OF JEITA SPRING - LEBANON -

- REPORT IV -

ARTIFICIAL TRACER TESTS- JUNE 2011

JOANNA DOUMMAR (1), ARMIN MARGANE (2), TOBIAS GEYER (1), MARTIN SAUTER (1)

(1) Applied Geology, University of Göttingen, Goldschmidtstraße 3, 37077 Göttingen, Germany

(2) Federal Institute for Geosciences and Natural Resources (BGR), P.O. Box 51 01 53, 30631 Hannover, Germany

Submission of Final Report:	February 2012
Total Number of Pages:	15

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This report presents the results of the work undertaken in the Framework of the Cooperation between the Institute for Geosciences and Natural Resources in Germany (BGR) and Georg-August University in Göttingen as partial fulfillment of contract 10037409. The work is part of the German-Lebanese Technical Cooperation Project Protection of the Jeita Spring funded by the German Ministry of Economic Cooperation and Development (BMZ) and implemented on the German Side by the BGR. This is the fourth report submitted as part of the cooperation mentioned above.

This report presents the preliminary results of the tracer test conducted in June 2011 to delineate the potential hydrogeological connection if any, between point sources on the upper catchment area of the Jeita spring.

Section 1 provides the motivation and objectives of the tracer test. Section 2 discusses the methods, material and field work performed during this study. It includes a description of the various tracer tests performed in June 2011. The methods for analysis and the modeling tools used for the interpretation of the results are exposed in section 3, whereas, section 4 presents the results of the TBCs analysis. The latter mainly tackles aquifer dynamics and behavior as depicted in June 2011 and gives insights into the velocities and dispersivities in the Cretaceous system of the upper catchment area. Finally section 5 presents some conclusions and recommendations.

1.1 GENERAL

Jeita spring, located in the lower reaches of the Nahr el Kalb catchment, is an important karst spring located about 14 km northeast of Beirut in the Keserwan district. It constitutes the main water source for the Beirut Area and its northern suburbs for domestic use. In the Jeita karst aquifer, flow is governed by open channel flow/ full pipe hydraulics. Previously it was assumed that Jeita spring drains a catchment of about 288 km^2 extending east in the Lebanese Mountains (Figure 1-1; Bakic, 1970). The catchment of Jeita spring was defined mainly based on topographical boundaries, i.e. it was assumed that the groundwater catchment more or less coincides with the surface water catchment. Very little was known about hydrogeological connections between various locations in the catchment and the Jeita spring. The upper surface catchment area of Jeita spring, located above 1500 m asl, is drained by two springs: Assal and Labbane. The catchment of Afqa spring, discharging like Assal and Labbane springs from the Upper Cretaceous aquifer, was previously unknown. Assal and Labbane springs were according to previous studies believed to contribute to the discharge of Jeita spring, either through infiltration of surface water runoff into the Jurassic system or potential downward leakage from the Cretaceous system into the Jurassic aquifer. Afqa spring discharges into Nahr Ibrahim, located to the north of the Nahr el Kalb catchment.

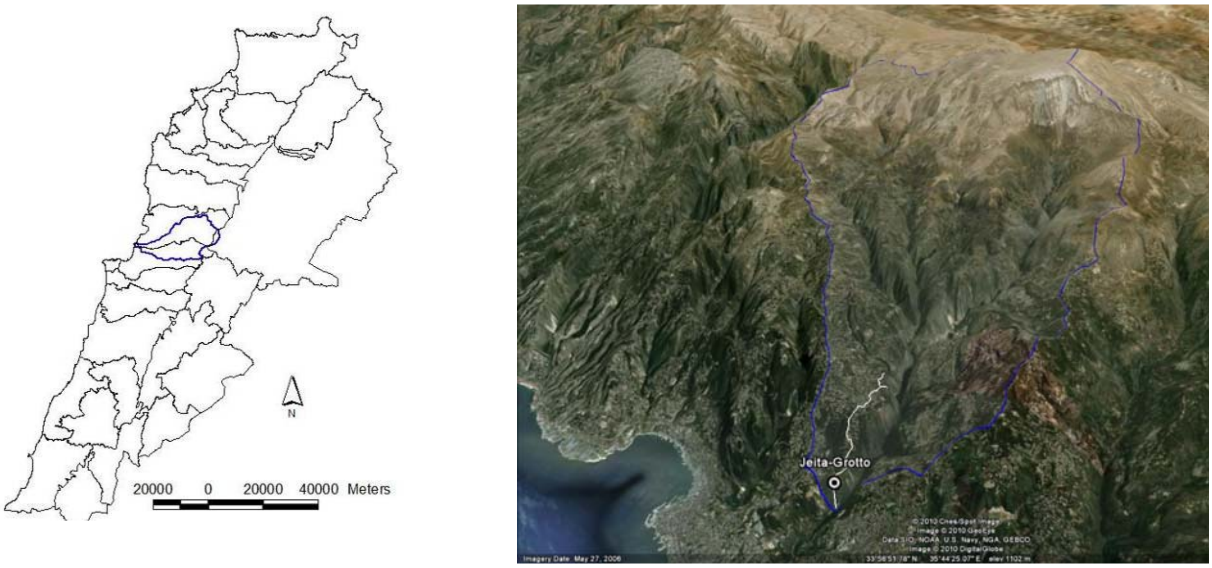

Figure 1-1 **Location of Jeita Spring and Catchment(blue line) in Lebanon (Google Earth)**

1.2 OBJECTIVES OF THE ARTIFICIAL TRACER TESTS

The main goal of the artificial tracer tests was to investigate hydrological connections between rapid and slow recharge point sources on the catchment area/subcatchment areas suspected to contribute to the total recharge of Jeita spring.

The objectives of the tracer test were to:

- Identify a potential hydrogeological connection between the injection site and the Jeita spring and eventually other springs existing on the catchment. This tracer test was done to better delineate the northern boundary of the catchment area, since it was assumed that due to the geological structure the northern boundary of the groundwater catchment considerably extends beyond the surface catchment boundary.
- Characterize hydrodynamic flow and transport parameters of the Jeita Aquifer system (flow velocities; mean and maximum, transit times, longitudinal dispersivities, mass restitution, etc…) during low flow periods.

2. FIELD WORK AND METHODOLOGY

2.1 MATERIALS

The tracer uranine (sodium fluorescein, acid yellow 73, BASF, CAS 518-47-8, $C_{20}H_{10}O_5Na_2$) was selected as it is considered non- toxic. Uranine, sensible to photochemical decay, is only highly adsorptive under increasing acidity (Ford and Williams, 2007) and can be considered as conservative tracer in carbonate aquifers.

Concentration of tracer was monitored in the springs with field fluorometers (GGUN-FL30 serial numbers 525, 531, 533; Schnegg, 2002). This equipment continuously measures dye concentration at the monitoring site at specific intervals with incorporated photo diodes, able to detect emission at wave lengths of dyes of interest in this study. The field fluorometers, which detect signals as millivolts, were calibrated for uranine, with solutions with known concentration of uranine prepared with the tested waters. Uranine has a spectrum of luminescence ranging between 490 nm and 524 nm. In the presence of one tracer, the calibration file allows a direct conversion of electrical signal into concentration in micrograms per liter. In the presence of two or more tracers, the lamps are calibrated for up to three dyes; therefore, based on a system of three linear equations, the electrical signal is transformed into three signals representative of concentrations of both tracers (Schnegg, 2002). The limit of detection of the field fluorometer is dye at a concentration of 0.02 µg/l for uranine (Schnegg, pers. comm.). Correction for the presence of background tracer concentration was also taken into account. It is worth noting that the threshold of tracer detection signal limit for the field fluorometer is 1000 µg/l, beyond this limit, samples need to be also diluted until achieving a detectable signal.

2.2 FIELDWORK

2.2.1 Injections

Tracer test (5A) was undertaken on the **June 27, 2011**, under low-flow conditions. The site, located at an elevation of 1239 m asl, has the coordinates N 34.0037°, E 35.7325°. The location was flushed with 60 m^3 of water each over 50 min (with water tanks).Therefore the rate of flushing was about 20 l/sec (1.2 m^3/min), which is a sufficient rate to ensure percolation of the tracer into the underground. The point of injection is located outside the previously delineated catchment area (Bakic, 1972) and approx. 1 km northwest of the limits of the northern surface water divide.

Table 2-1 Injections Points

INJECTION POINT	COORDINATES (ALTITUDE) (m)	INJECTION TIME	FLUSHING VOLUME (m^3)	COMMENTS
Test 5A	35.7325° E 34.0037° N (1239)	27.06.2011 (13:00)	60 (over 15 min) rate of flushing: 20 l/s	9373 grams of Uranine (Infiltration rate was relatively favorable to ensure good percolation of the tracer)

2.2.2 Observation points

Four field spectrofluorometers with dataloggers (525, 526, 531 and 533) were deployed for automatic sampling at:

- Jeita spring (entrance; 525, 533),
- "siphon terminale" (Daraya Tunnel, 531) and
- Hrash spring (526).

Manual samples were not collected for the purpose of this tracer test, as field fluorometers were checked constantly every 24 hours. A detailed description of the observation points is provided in Table 2-2.

Table 2-2 Observations Points

OBSERVATIONS POINTS	LATITUDE LONGITUDE Z(masl)	LINEAR DISTANCE TO INJECTION (m)	SAMPLING	TIME SPAN	SAMPLING INTERVAL	COMMENTS
Jeita Grotto (Entrance)	35.646168° E 33.945592° N 70	10500	Automatic	30.06.2011-17.07.2011	2 min- 5 min	GGUN-FL30 525, 533
Jeita Grotto Daraya Tunnel	35.688063° E 33.950619° N 140	7000	Automatic	30.06.2011-17.07.2011	2 min	GGUN-FL30 531
Hrash Spring	35.644910° E 33.968780° N 231	9000	Automatic	30.06.2011-17.07.2011	2 min	GGUN-FL30 526

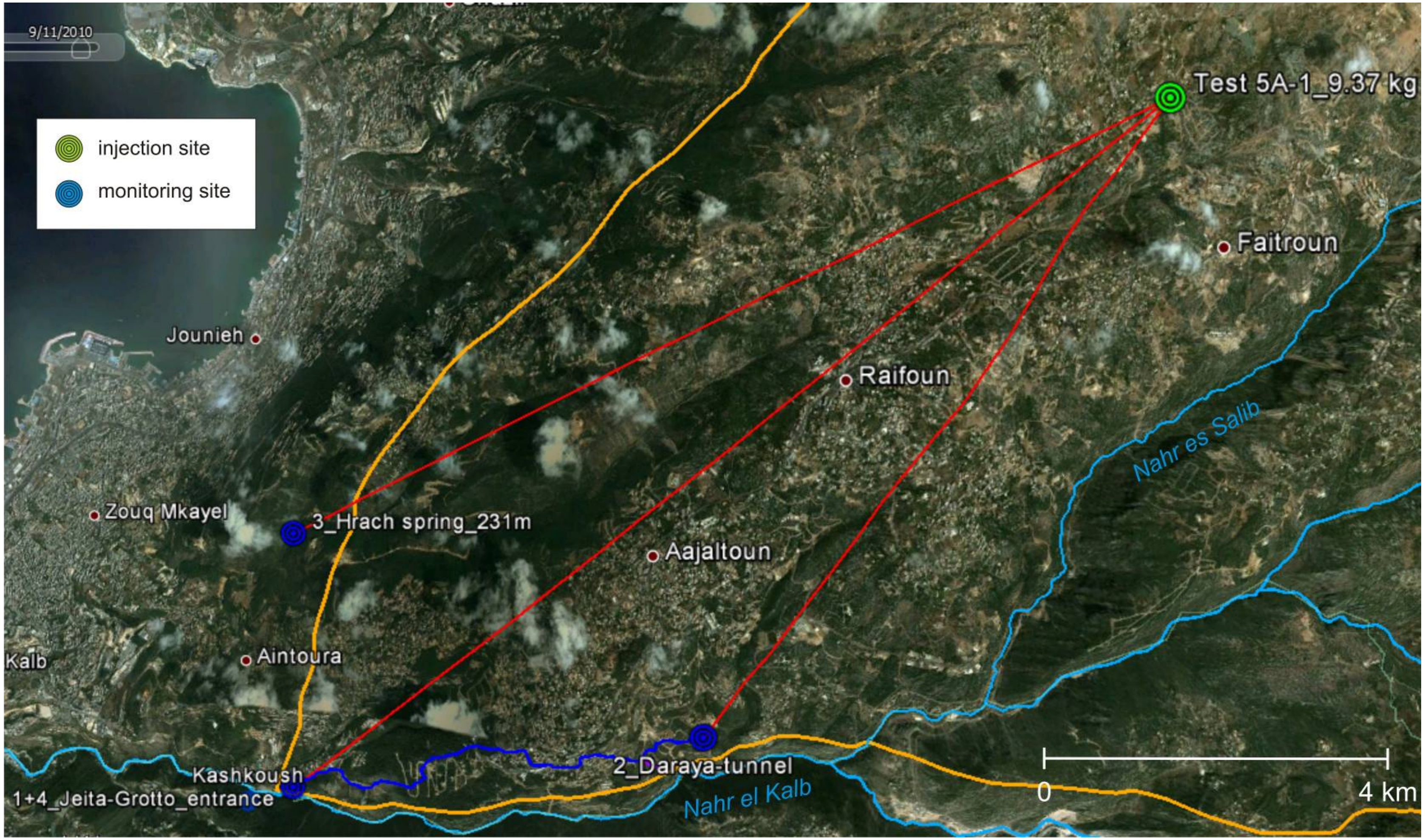

Figure 2-1 **Map showing the Set-Up (Injection Points and Observation Points) of Tracer Test 5A undertaken on June 27, 2011 (Google Earth)**

(orange line: assumed groundwater catchment of Jeita spring)

2.3 DISCHARGE MEASUREMENTS

Flow rate measurements were mainly performed based on the dilution gauging methods using uranine. The dilution method relies on calculating the discharge rate based on a tracer breakthrough curve (TBC). The integration of the concentration over time allows the estimation of the discharge rate as shown in Equation 1.

$$Q = \frac{M}{\int c(t)dt} \tag{1}$$

Where
Q is the discharge rate [L³/T]
M is the injected salt or dye tracer mass [M]
c is concentration [M/L³]
t is time [T]

The spring discharge at the various discharge points were measured at different intervals during the tracer test period. The discharge rates are shown in Table 2-2. Discharge rates are very important for the calculation of restitution rates are the springs. The degree of uncertainty in the measurements reaches about ±0.1 m^3/sec due sometimes to incomplete dilution and short distance tests during discharge measurements using the dilution methods.

Table 2-2 Discharge Rates Measured at the Positive Observations Points

OBSERVATION POINT	METHOD	DATE	DISCHARGE RATE	COMMENTS
Jeita spring	Dilution with uranine	30.06.2011	2.9 m^3/s	±0.1 m^3/sec
Jeita spring	Dilution with uranine	13.07.2011	2.4 m^3/s	±0.1 m^3/sec
Jeita spring Daraya Tunnel	Dilution with uranine	13.07.2011	2.2 m^3/s	±0.1 m^3/sec

3. EVALUATION AND MODELING

Tracer breakthrough curves (TBCs) were analyzed graphically, using Excel sheets, and numerically with the software CXTFIT- Stanmod (Toride et al. 1999). The *Advection-dispersion Model (ADM)* was adopted for the modeling of the TBC. The software allows the calculation of various process parameters based on fitting with observed tracer breakthrough curves. These are tracer recovery (*R*), restitution “key” times (*t*), flow velocities (*v*), longitudinal dispersion (*D*), dispersivity (α), and Peclet numbers.

3.1 PARAMETERS

3.1.1 Tracer recovery

Tracer concentration data were plotted versus time to reconstruct a tracer breakthrough curve. Recovery *R* was calculated based on the TBC, upon integration of the concentration multiplied by flow data over the tracer restitution period, from its first detection until end of tailing based on Equation 2 (EPA/600/R-02/001, 2002).

$$R = \frac{1}{M}\int_{t=0}^{\infty} c(t)Q(t)dt \quad (2)$$

Recovery rates provided in this study are valid only in the case where the tracer is considered to be conservative and to have been totally conveyed into the saturated zone, rather than being partially trapped in the unsaturated zone or in soil superficial layers as a result of poor flushing.

3.1.2 Flow velocities

Mean (v_m), maximum (v_{max}), and peak (v_p) flow velocities were calculated respectively based on the mean residence time, the time of first detection, and time of peak detection. The mean residence time represents the time where half of the recovered tracer mass has elapsed at the observation point. It is calculated by (EPA/600/R-02/001, 2002):

$$t_d = \int_{t=0}^{\infty} \frac{c(t)Q(t)tdt}{c(t)Q(t)dt} \quad (3)$$

3.1.3 Longitudinal dispersivity and dispersion

The shape of the dye hydrograph provides an indication of the longitudinal dispersion of the tracer, as the retrieved TBC is one-dimensional. As a matter of fact, variance of the TBC allows the estimation of dispersivity (α) and longitudinal dispersion (D_L), neglecting molecular diffusion as shown in Equation 4. Dispersion portrayed by the variance of the TBC is due to variation in velocities during transport. It usually reflects the degree of heterogeneity of the flowpath. The longitudinal dispersion is highly positively correlated with the effective velocity and dispersivity.

$$\mathrm{D_L} = \alpha_L \cdot \mathrm{v_m} + \mathrm{D}^* \quad (4)$$

D_L being the longitudinal dispersion coefficient [L^2/T]
α_L being the dispersivity of the tracer [L]
v_m being the effective velocity calculated based on mean residence time [L/T]
D^* being the molecular diffusion coefficient (neglected in this case) [L^2/T]

3.2 MODELING (1-D ADVECTION-DISPERSION MODEL (ADM))

The ADM was used to analyze the Tracer Breakthrough Curves (TBC) resulting from the tracer test undertaken in June 27, 2011. The ADM, governed by Equation 5, is based on the variation of the concentration of tracer with time as inversely proportional to the flow rate at the observation point, the reciprocal of the Peclet number (P_D). The Peclet number (ratio of distance over longitudinal dispersivity, or the ratio of longitudinal dispersion to distance and mean velocity) shows the respective contribution of each of the advection and diffusion in the transport mechanism. It is defined by the ratio of the linear distance over the dispersivity. A peclet number that is greater than 6.0 characterizes mass transfer dominated by advection processes rather than diffusion processes (EPA/600/R-02/001, 2002).

This parameter has an implication on the dependence of each of the velocity and dispersivity on the physicochemical characteristics of the tracer, which are relatively insignificant where advection plays an important role in mass transport processes (EPA/600/R-02/001, 2002).

$$C(t) = \frac{M}{Qtm\sqrt{4\pi P_D\left(\frac{t}{t_m}\right)^3}}\exp\left(-\frac{\left(1-\frac{t}{tm}\right)^2}{4P_D\frac{t}{tm}}\right) \tag{5}$$

The software Stanmod (CXTFIT) was used for the modeling of TBCs resulting from a conservative tracer Dirac pulse test using the Advection-Dispersion Model (ADM). The latter does perform automatic runs. Initial estimates for fitting parameters have to be introduced in the model. Observed values are input as concentration in micrograms per liter (µg/l) as a function of time in hours. At the beginning of the modeling, the maximum and minimum ranges were significantly high. With an iteration number often set to 50, the system returns a best fit for the observed values. Upon refinement of the curve, range between maxima and minima was reduced to a one final set of dispersion and mean velocity. The *massive flux* required by the model is the integral of the concentration as a function of time (*ʃC(dt)*).

4. RESULTS OF THE TRACER TEST

Tracer breakthrough curves (TBC) were retrieved in the Jeita spring at the touristic entrance (fluorometers 525 and 533) and at the siphon terminale (Daraya tunnel, 531). Tracer was not restituted in the Hrash spring (526). The tracer test undertaken on June 27, 2011, was therefore positive delineating a connection between the injection point and Jeita spring. Graphical interpretation of the TBC is presented in Table 4-1.

Even though true distances are usually more sinuous and therefore greater (Field, 2000, Göppert and Goldscheider, 2007), linear distances between the injection point and the observation point are usually considered for velocity calculations, i.e. the calculated flow velocity is a lower bound of the average flow velocity. Since the tracer arrived to the spring at siphon terminale, it is considered that the tracer traveled through a linear distance of 7 km until arrival to the siphon terminale, then circulated within the cave over a distance of 5.3 km. Therefore the total distance over which velocities were estimated is 12.3 km from the injection point to the Jeita spring at the touristic entrance of the cave.

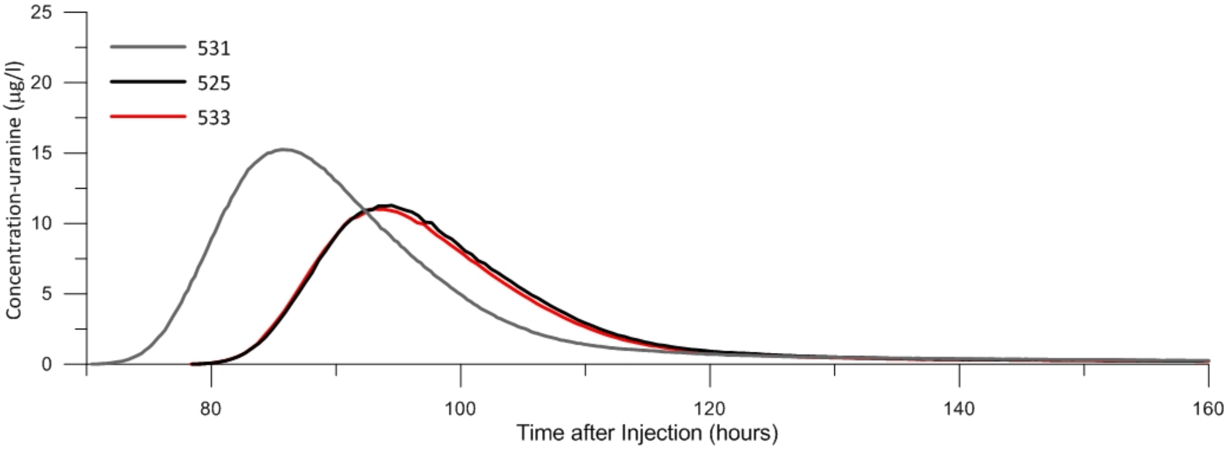

Figure 4-1 Observed TBCs restituted in Jeita Spring at the Siphon Terminale (Daraya tunnel, 531) and at the Touristic Entrance of the Cave (525) and (531)

Table 4-1 **Graphical Interpretation of the TBC´s resulting from the Tracer Tests (June 2011)**

OBSERVATION POINT	PEAK (µg/l)	TRACER FIRST ARRIVAL (hours)	MAXIMUM VELOCITY (m/hours)	PEAK CONCENTRATION TIME (hours)	VELOCITY TO PEAK CONCENTRATION (m/hours)	RESTITUTION (%)
Jeita Spring (siphon terminale, Daraya tunnel; 531) 7000 m	15.03	70.37	99	87.03	80	26.3
Jeita Spring (touristic entrance; 533) 12300 m	10.72	78.3	157	92.2	133	25.2
Jeita Spring (entrance; 525) 12300 m	10.95	78.47	157	92.33	133	26.2

4.1 TRACER BREAKTHROUGH CURVES AT SIPHON TERMINALE

Uranine was first detected in 531 at the siphon terminale about 70 hours after injection. The maximum peak observed in 531 is 15.03 µg/L and was reached 87 hours after injection. The peak velocity calculated over a distance of 7000 m is 99 m/hour. Based on the discharge rate (2.2 m^3/s) under prevailing flow conditions, a recovery of approximately 26 % of uranine was achieved. A tailing over about 50 hours is observed in the Tracer Breakthrough Curve (TBC). This behavior is prominent in a karst aquifer, due to the immobile regions present in the aquifer, where parts of tracer are retained and released gradually with time.

Based on the modeling of the TBCs using the ADM model with CXTFIT (Figure 4-2), the mean velocity over a distance of 7000 m between the injection point and the spring at the siphon terminale is 79 m/hour. The estimated Peclet number is 279 reflecting the prevailing advective component of the transport through the karst system. Longitudinal dispersion is about 1990 m^2/h yielding a longitudinal dispersion of 25 m. The estimated values are given with a mean square error of 0.4 µg/l, the coefficient of correlation between observed and modeled values being 0.974.

4.2 TRACER BREAKTHROUGH CURVES IN THE JEITA SPRING (ENTRANCE OF THE CAVE)

Uranine was detected in both fluorometers, 525 and 533 in Jeita spring at the entrance of the cave about 78 hours after injection. The maximum peaks observed in 525 and 533 are 10.95 and 10.72 µg/L, respectively, yielding velocities to peak concentration (v_p) of 133 m/hour. The discrepancies in the observed peak concentrations are due to slight differences in the calibrations (2%), which is acceptable for the purpose of the study. The peak velocity as calculated in both TBC is 157 m/hour. Based on the discharge rate (2.9 m^3/s) measured under prevailing flow conditions, a recovery of approximately 25-26 % of uranine was achieved. A tailing over about 50 hours is observed in the Tracer Breakthrough Curve (TBC). As portrayed in the TBC retrieved at siphon terminale, this behavior is prominent in karst aquifers, due to the immobile regions present in the aquifer, where parts of tracer are retained and released gradually with time. The TBC can be analyzed with the Two Non Region Equilibrium Model (2NREM) provided with CXTFIT to estimate the portion of tracer mobile phase, and reproduce a better fit especially with respect to the observed tailing, however, such an analysis is beyond the scope of the following work.

Based on the modeling of the TBCs using the ADM model with CXTFIT (Figure 4-3), the mean velocity over a distance of 12300 m between the injection point and the spring at siphon terminale is about 127-128 m/hour. Peclet numbers range between 320-331, reflecting the prevailing advective component of the transport through the karst system. Longitudinal dispersion ranges between 4750-4860 m^2/h yielding a longitudinal dispersion of 37-38 m. The estimated values are given with a mean square error of 0.14-018 µg/l. The coefficient of correlation between observed and modeled values is highly acceptable and is on average 0.975.

Given the velocities observed between the injection point and the spring at the Daraya Section, and those estimated between the injection point and the Jeita spring over an entire distance of 12300 m, the velocity inside the cave over a distance of 5300 m is estimated to range between 700-705 m/hour. A dilution effect is observed in the TBC at Jeita spring (525, 531) in comparison to the one observed at siphon terminale. An amount of 700 l/s (0.7 m^3/s) are inflowing additionally to the system between those two points.

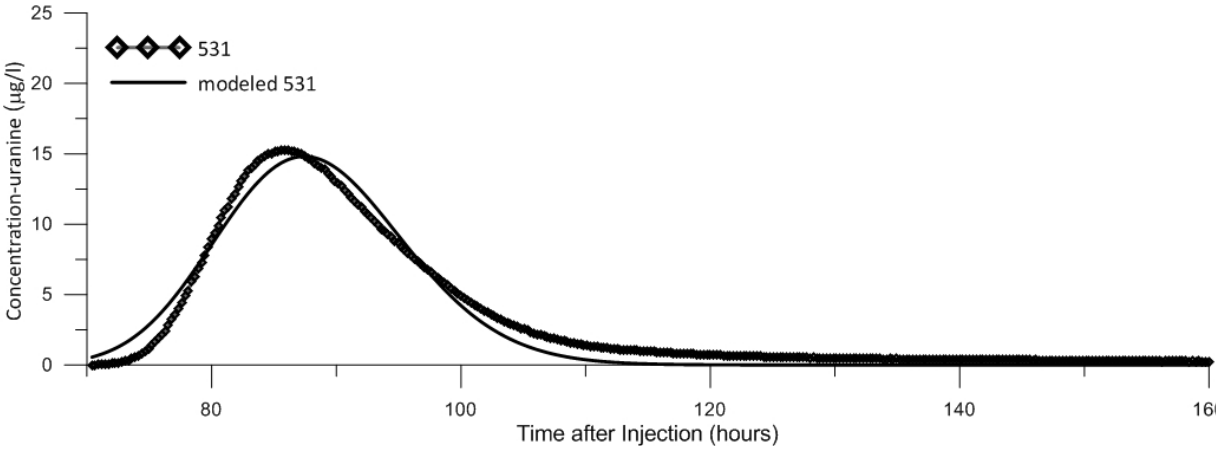

Figure 4-2 **Observed and modeled TBC restituted in Jeita Spring (Siphon Terminale; 531)**

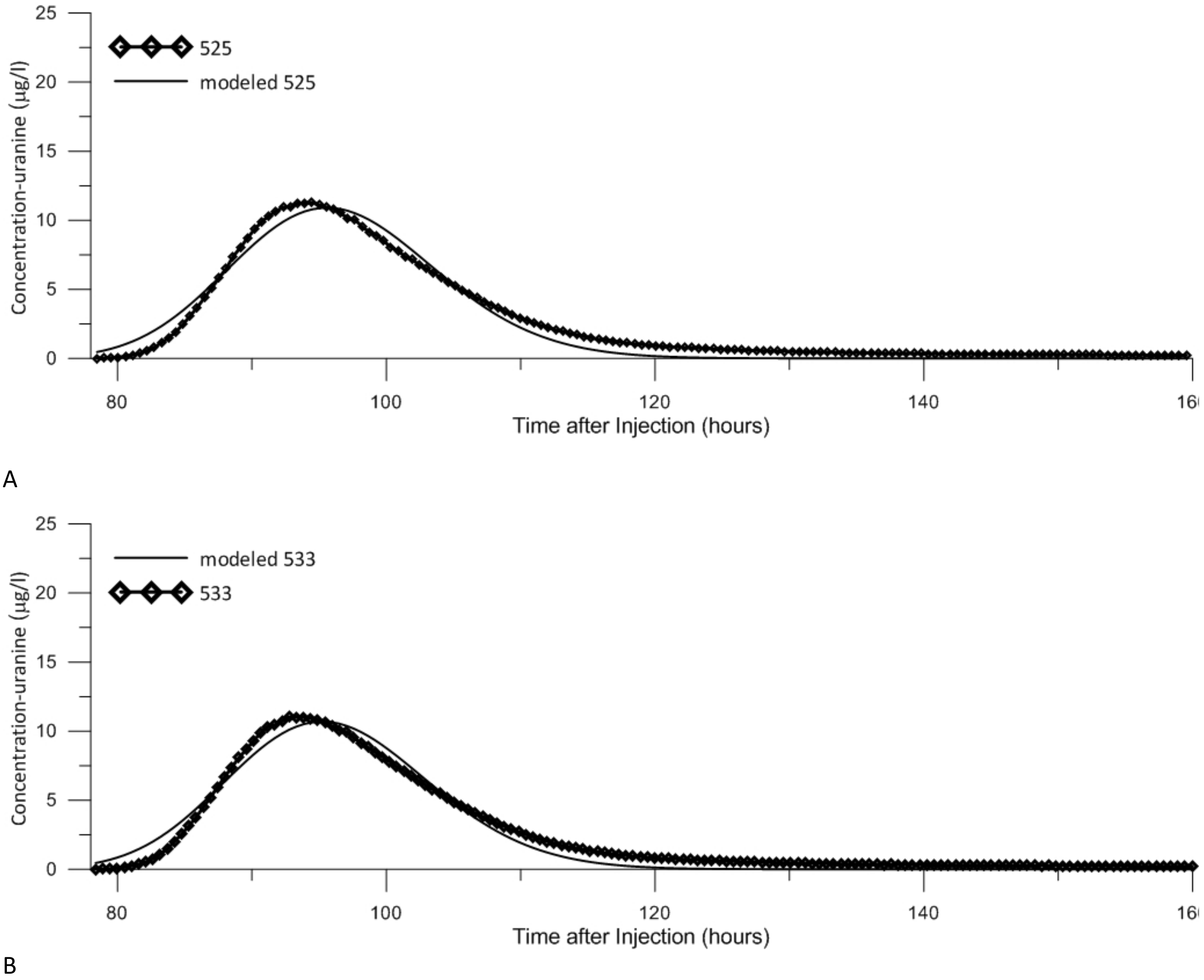

Figure 4-3 Observed and modeled TBCs restituted in the Jeita Spring in A) fluorometer 525 and B) Fluorometer 531

Table 4-2 **Summary of the Modeling Results of the Tracer Test (5-A) undertaken on June 27, 2011**

PARAMETERS	SYMBOL	UNITS	SIPHON TERMINALE (JEITA SPRING) (531)	JEITA SPRING (533)	JEITA SPRING (525)
Distance	D	m	7000	12300	12300
Discharge	Q	m^3/sec	2.2	2.9	2.9
ADVECTION DISPERSION METHOD (ADM)					
Mean velocity	v	m/hour	**79.2**	**128**	**127**
Mean transient time	t_m	hours	88.38	96.09	96.85
Dispersion	D	m^2/hour	1990	4750	4860
Dispersivity	A	M	25.1	37.1	38.3
Peclet number	P_D	-	279	331	321
Massive flux	M	µg•h/l	276	199	199
Restitution rate	R	%	23.32	22.17	22.95
Statistical parameters					
Coefficient of correlation	R^2	-	0.974	0.974	0.976
Mean square error	MSE	µg/l	5.36E-04	3.36E-02	1.41E-01

5. CONCLUSIONS

Based on the tracer test undertaken on June 27, 2011, a hydrogeological connection was established between the injection point (5-A) and Jeita spring at various points within the cave (siphon terminale) and at the outlet. No tracer was retrieved in Hrash spring located outside, west of the assumed groundwater catchment.

The total transit time of the tracer during the tracer test conducted on June 27, 2011, was about 96 hours. Similar hydrodynamic parameters can be deduced from the TBC retrieved in fluorometers 525 and 533 at the Jeita spring entrance, notably with regards to mean velocity (about **128 m/hour**) and average longitudinal dispersivity (**38 m**). The recovery rate is about 26 % in the entire system. The mean velocity of the tracer over the distance of 7000 m is about 79 m/hour, with a longitudinal dispersivity of 25 m. The tailing in the TBCs is prominent due an important portion of immobile phase released with time.

Velocities within the cave are of the range of **700 m/h** as calculated based on the behavior of the tracer between siphon terminale and Jeita spring at the touristic entrance.

Assuming a velocity of 700 m/h over the entire length of the cave (5300 m), then the mean transit time of the tracer in the cave is about 7.5 hours, which is common value under the prevailing discharge conditions.

Based on dilution effects observed in the TBC retrieved respectively in Jeita spring at siphon terminale and at the entrance, an additional inflow of about **700 l/s** (0.7m^3/s) can be inferred.

6. REFERENCES

- Auckenthaler A, Huggenberger P, 2003.Pathogen Mikroorganismen in Grund und Trink Wasser. Transport Nachweissmethoden Wassermanagement. Birkhauser. p 80-91
- Bakic, M., 1972. Jeita the Famous Spring of Lebanon, United Nation Development Report. UN. Beirut. 1-149 pp
- EPA/600/R-02/001, 2002. The QTRACER2 program for tracer-breakthrough curve analysis for tracer tests in karstic aquifers and other hydrologic systems. Washington, D.C.: U.S. EPA.
- Field M.S, and Pinsky P.F. 2000. A two region non equilibrium model for solute transport in solution conduits in karstic aquifers. Journal of contaminant hydrogeology 44, 1, p 329-351
- Field M.S., and Nash S.G., 1997. Risk assessment methodology for karst aquifers: (1), estimating karst flow parameters. Environmental monitoring and Assessment. 47, 1, p 1-21
- Ford D., Williams D.W., 2007. Karst hydrogeology and geomorphology. Unwin Hyman, Boston
- Geyer T., Birk S., Licha T., Liedl R., and Sauter M., 2007. Multi tracer approach to characterize reactive transport in karst aquifers. Groundwater. Vol 45, 1. p 36-46
- Göppert N and Goldscheider N. 2008. Solute and colloid transport in karst conduits under low and high flow conditions. Groundwater, 46, 1 p. 61-68.
- Perrin J., and Lütscher M. 2008. Inference of the structure of karst conduits using quantitative tracer tests and geological information: example of the Swiss Jura. Hydrogeology Journal. 16: p. 951–967
- Schnegg P.A, 2002. An inexpensive field fluorometer for hydrogeological tracer tests with three tracers and turbidity measurement. Groundwater and Human development. Ed. E Bocanegra, D Martine, and H Massone. Mar del Plata, Argentina. p. 1483-1488
- Toride, N., F.J. Leij, and M.T. van Genuchten. 1999. The CXTFIT code for estimating transport parameters from laboratory or field tracer experiments. U.S. Salinity Laboratory Agricultural Research Service, U.S. Department of Agriculture Riverside, California. Research Report 137.