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Artificial Tracer Test 4C - May 2012

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GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

PROTECTION OF JEITA SPRING - LEBANON -

- REPORT VI -

ARTIFICIAL TRACER TESTS- MAY 2012

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TABLE OF CONTENTS

LIST OF FIGURES

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 sixth report submitted as part of the cooperation mentioned above presents the analysis of tracer test 4C. Section 2 presents the methodology, and section 3 discusses the analysis of the results. Conclusions are presented in section 4.

2. METHODOLOGY

Fluorescein (Sodium fluorescein, BASF, CAS 518-47-8, $C_20H_{10}O_5Na_2$) was selected as it is considered nontoxic and can be considered as conservative tracer in carbonate aquifers. Concentration of tracer was monitored in three (3) springs Afqa, Yammouneh and Roueiss with field fluorometers (GGUN-FL30, Schnegg 2002). This equipment measures continuously dye concentration at the monitoring site at set intervals with incorporated photodiodes that detect emission of the used dyes and report data in millivolts. The limit of detection of the field fluorometer is dye at a concentration of 0.02 µg/l for fluorescein. Correction for the presence of background tracer concentration was also taken into account. The tracer used in the test is fluorescein (uranine; Orco) with uranine.concentration of 86%

Each fluorometer was calibrated using a solution prepared from the specific spring water to be monitored and a sample of the tracer used for the test value in order to obtain correct readings. Linear calibration curves for the field fluorometers were constructed based on different solutions with different concentrations (1 µg/l, 10 µg/l, and 100 µg/l) prepared for each of the monitored springs.

2.1.1. DISCHARGE

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.

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

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

Spring discharge of Afqa was measured by dilutions tests on 09 May 2012, providing an average discharge value of 21.4 m³/s (Figures 1, 2).

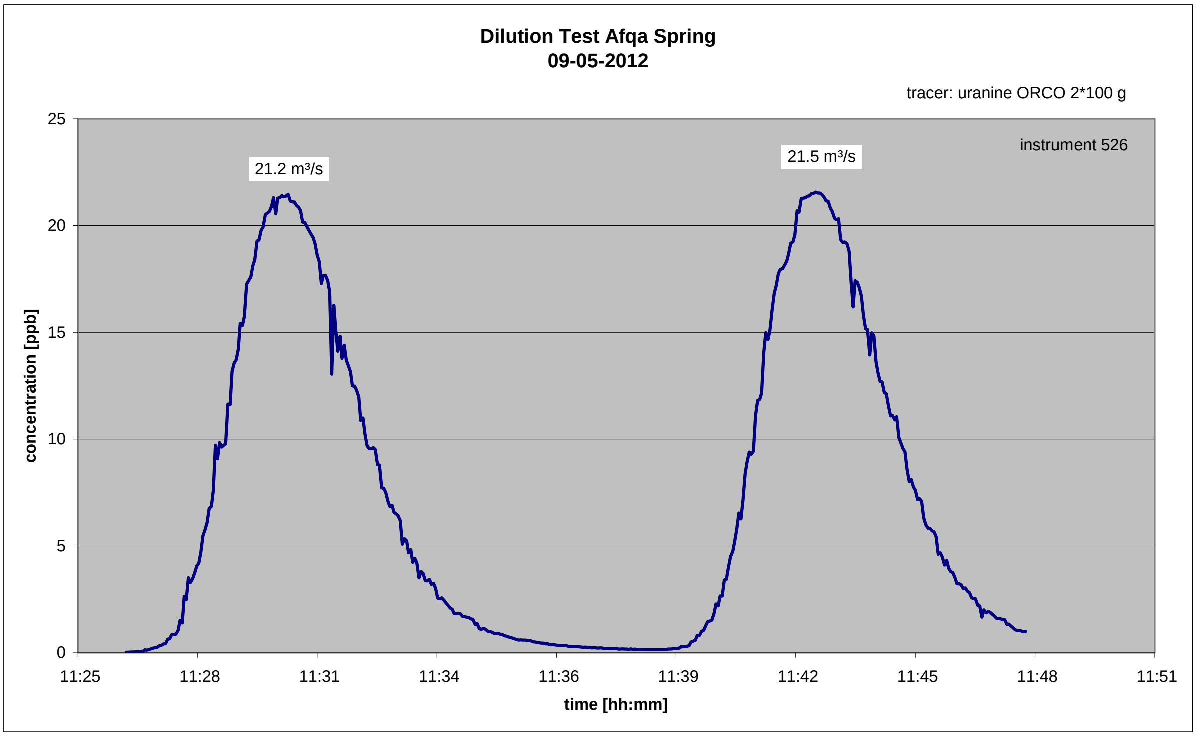

Figure 1: Dilution tests for discharge measurement of Afqa spring

Figure 2: Afqa Spring on 04.05.2012 09:30 a.m.

2.1.2. EXPERIMENT

On May 4th 2012 at 12:00, 9.000 kg of uranine were injected in a doline at E 35.94441, N 34.05758, altitude 1798 m asl, in the highlands of Akoura (Upper Cretaceous plateau; Figure3). Snowmelt had started in mid April 2012 and around 80 % of snow was already molten at the day of injection. Daytime temperatures at the injection location reached 20°C, while temperatures fell during night to below zero. Snowmelt during daytime was therefore very intensive, reaching its maximum in the early afternoon hours. Because of the remote location a water tanker was not available for flushing. An amount of 0.5 m³ was transported in a 4*4 wheel car to the injection location for flushing (Figure 4). A 2.5 m * 1.5 m hole was dug into the remaining snow down to the natural ground (2.3 m; Figure 3). The hole was located near the deepest point in a doline. About 10 m from the hole, the snow had already been molten (Figure 5). The tracer substance was mixed in two 150 l barrels and injected at the bottom of the hole (Figure 6). The hole was then completely filled with snow and water. The doline was inspected before the winter and was chosen because of limited soil availability at the bottom of the doline.

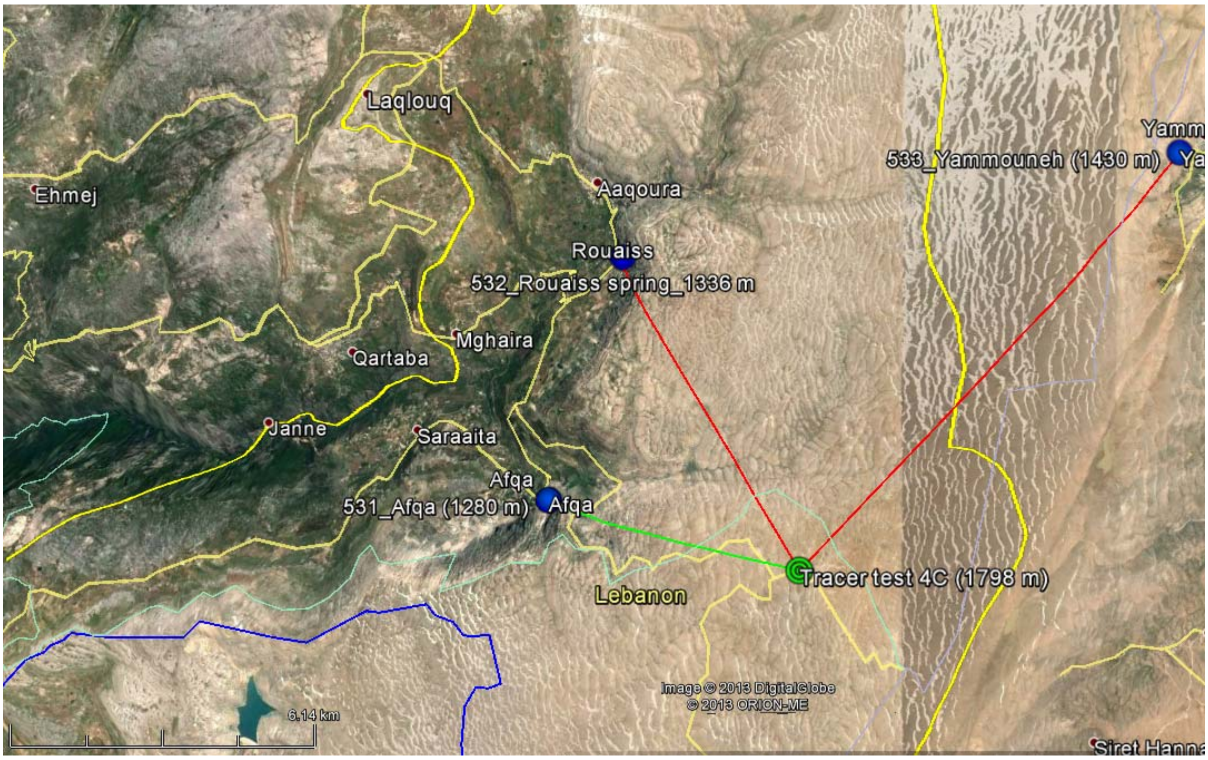

Figure 3: Tracer Injection Site Southeast of Akoura

Figure 4: Tracer Injection on 04.05.2012 in a Doline in the Upper Cretaceous Plateau

Figure 5: Hole for Tracer Injection near deepest Point of the Doline

Figure 6: Tracer Injection in Melting Snow

For automatic tracer arrival monitoring, four field fluorometers with data loggers were deployed respectively in Afqa (1280 m, instruments 531, 536), Rouaiss (1336 m, instrument 532), and Yammouneh (1430 m, instrument 533). Monitoring was done from 03.05.12 10:12 to 14.05.12 08:44 (263 h). Unfortunately logging of data was interrupted in instrument 536 on 11.05.2012 at Afqa spring, therefore the more complete data for Afqa (instrument 531) are used. Also at instrument 531 a data gap of 41 hours (06.05.12 23:02 - 08.05.12 16:16) occurred.

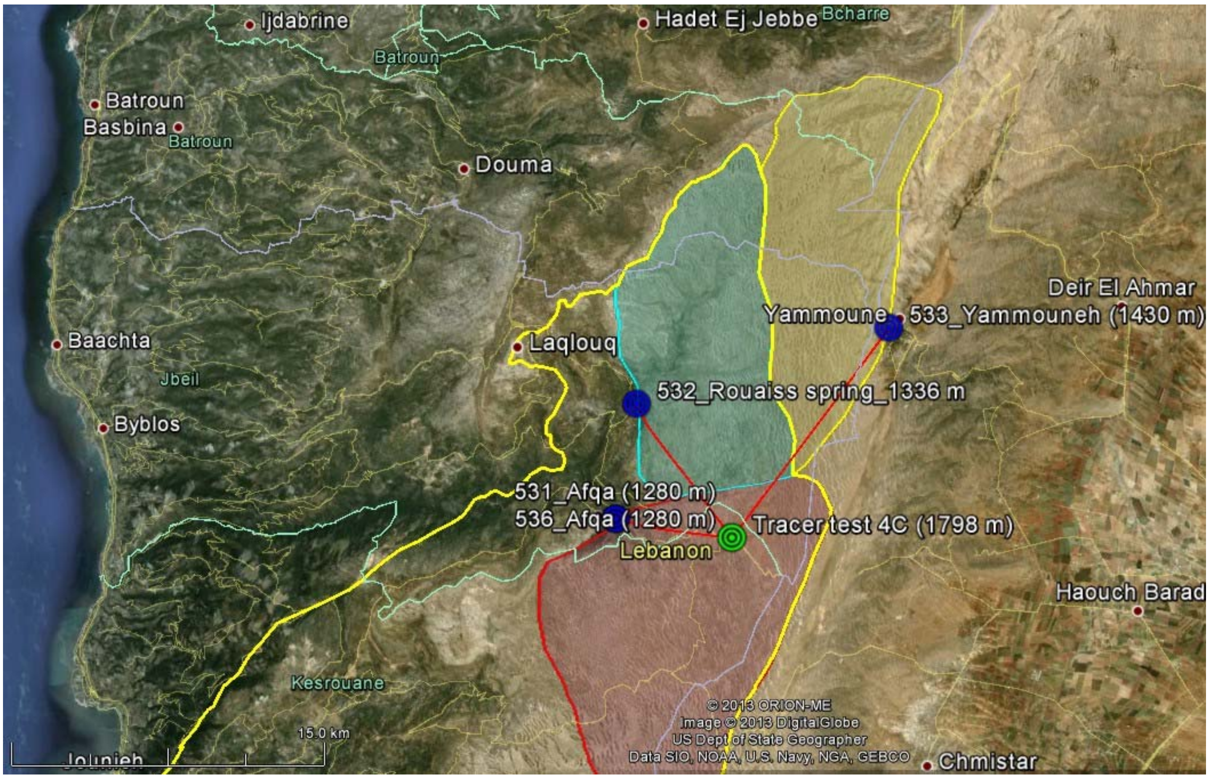

Figure 7: Locations of Tracer Injection and Monitoring

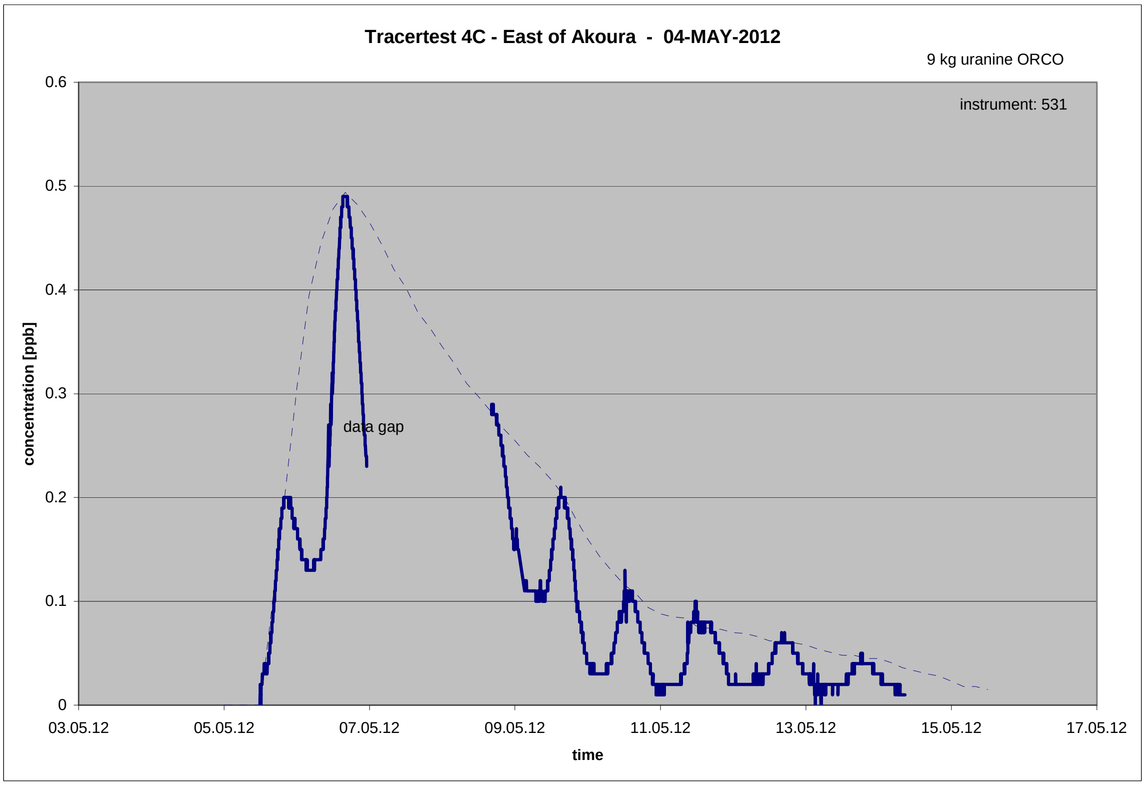

Figure 8: Tracer Monitoring at Afqa Spring

2.1.3. DATA ANALYSIS

Tracer concentration data were plotted versus time to reconstruct a Tracer Breakthrough Curve (TBC). Tracer breakthrough curves (TBCs) were analyzed with the methods of moments and numerically with the software CXTFIT- Stanmod (Toride et al., 1999). The software allows the numerical calculation of various transport parameters by fitting a simulated curve with the observed tracer breakthrough curve. The analysis of the data allows calculating the mass of injected tracer recovered at the spring (M) based on the total spring discharge, the mean velocity at which the tracer travels from injection to observation point (vm).

2.1.3.1. Tracer recovery

Recovery R was calculated based on the TBC, upon integration of the concentration C(t) multiplied by flow data Q(t) over the tracer restitution period, from its first detection until end of tailing based on Equation 2 (EPA, 2002). Recovery is the ratio of massive flux over the injected mass (M)

$$R = \frac{1}{M} \int_{t=0}^{\infty} C(t)Q(t)dt \qquad \textbf{(2)}$$

2.1.3.2. Flow velocities

The mean flow velocity (Equation 3) was calculated based on the mean residence time (td). Maximum velocity was calculated based on the time of first 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, 2002)

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

3. RESULTS AND ANALYSIS

Uranine was only detected in Afqa cave located 5107 m downstream from the injection point. The discharge of the Afqa spring was estimated by dilution measurements, whereby approximate discharge during experiment flow conditions reached 21.4 m^3/s on 9 May 2012 (Figure 1). Two tracer breakthrough curves were retrieved with two fluorometers (531, Figure 9; and 536, Figure 10).

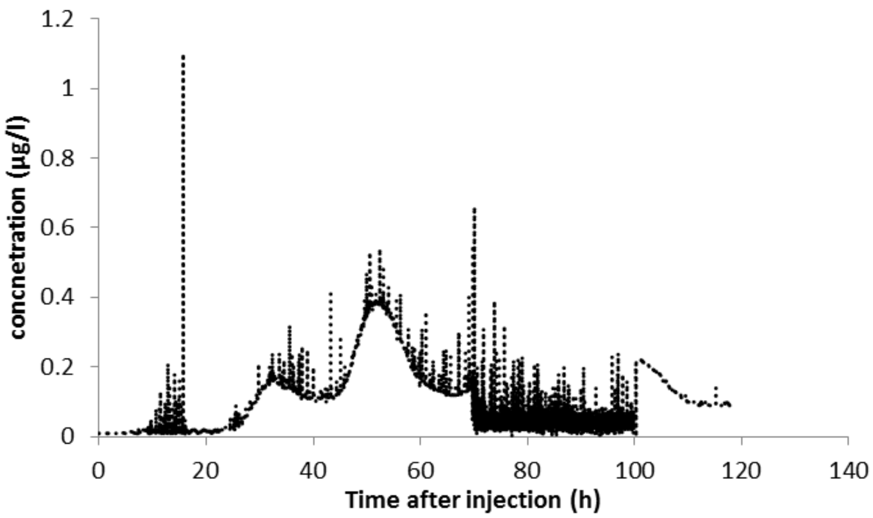

Figure 9: Tracer Breakthrough Curve restituted at Afqa Spring (536) showing two Restitution Peaks and a fluctuating Tailing

Fluorometer 536

The first tracer arrival was detected in Afqa spring with the fluorometer 536, 22.5 hours following injection. The peak concentration reached 0.4 µg/L 33.3 hours after injection (Figure 9). The TBC is characterized by two consecutive peaks indicating the arrival of two uranine pulses to the spring. Further peaks, as observed in fluorometer 531 could not be registered due to failed registration in the data logger.

Maximum velocity, which is the velocity of first arrival, is calculated to be about 226 m/h. Mean flow velocity is calculated based on mean transit time (td), which is the time where half of the tracer had elapsed at the observation point. It corresponds to 32 hours for the first peak and 56 hours for the second peak. Respective mean velocities over the monitored distance (5107 m) are therefore estimated to be about 160 m/h and 90 m/h. First and second peak are the results of different flushing of the tracer in the system. The first transit time corresponds to the flow induced by flushing, whereas the second and consecutive peaks (second peak occurred 25 hours after the first peak) occur because of additional flushing after daily snowmelt events. Due to data gaps after the second peak, the consecutive snowmelt events cannot be evaluated for fluorometer 536.

Dispersion for the first peak is estimated at 1850 m^2/h, whereas it is about 1160 m^2/h as estimated from the second peak. Therefore longitudinal dispersivities are within the range of 11.5-13 m.

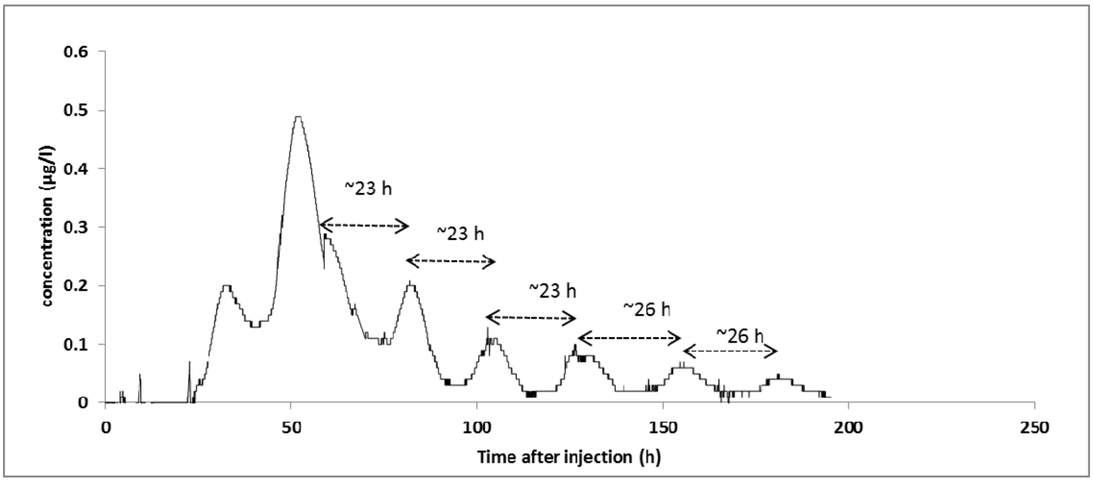

Figure 10: Tracer Breakthrough Curve restituted at Afqa Spring in Fluorometer 531 showing multiple Restitution Peaks due to a periodic Snowmelt occurring on the Recharge Area

Fluorometer 531

The TBC obtained from Fluorometer 531 shows similar results. Tracer arrival is first observed in Afqa spring around 23 hours after injection. The first and second peaks observed in the above curve (Figure 10) match the peaks of the TBC observed in Figure , therefore similar transport parameters can be inferred. The total tracer mass recovered from the TBC is 1.2 kg, which is equivalent to 14 % of the total injected mass.

The tracer breakthrough curve restituted with the fluorometer 531 shows multiple peaks resulting from periodic snowmelt events occurring on the recharge area. Each peak is reflective of the flushing of the tracer remaining in the injection point by melting snow, and the subsequent response of the spring to one daily snowmelt event as the time lag between the different peaks ranges between 23 and 26 hours (Figure 10). If snowmelt is considered to start around 8:00 AM, then the transit time to peak for each snowmelt event ranges between 30 and 35 hours, which corresponds to the mean transit time estimated from the first peak. The variation of transit times results from varying intensities of snowmelt events. Field observations during this time showed that temperatures largely differed from one day to the other. Additionally, the variance of the restituted peak is closely related to the extent of flushing and dispersion of the tracer remaining in the injection point. A spring hydrograph showing the discharge at the spring as a result of snowmelt event is required for a better assessment of the observed peaks, and quantitative interpretation of the tracer breakthrough curve. Unfortunately the existing spring discharge measurements by Litani River Authority (LRA) cannot be used for this purpose as the Afqa station urgently requires repair (MARGANE, 2012a, 2012b).

4. CONCLUSIONS

A tracer experiment was undertaken on May 04th, 2012, where 9 kg of Sodium fluorescein (Uranine) were injected in highlands of Akoura upstream to Afqa spring. Based on the results, a hydrogeological connection was established between the injection point and the Afqa spring located 5107 m downstream to it, as the latter was the only spring were the tracer was detected. The tracer was not detected in any of the other observation points namely Yammouneh and Rouaiss springs.

Based on the tracer breakthrough curve observed at the spring and the discharge measured by the dilution method, the total mass recovered is estimated at about 1.2 kg from the complete TBC (Fluorometer 531), which constitutes only 14 % of the total injected mass. The tracer traveled at a mean velocity of about 90 m/h as estimated from the mean transit time of the first peak. These velocities are typical for karstified aquifers. Longitudinal dispersivities are within the range of 11.5-13 m as calculated from estimated dispersion and mean velocities. The presence of multiple peaks indicates the remobilization of the tracer at the injection point as a result of daily snow melts. However a better assessment of melting times or recharge from snow melt equivalent can only be performed if a high resolution spring hydrograph is provided along with the TBC.

5. REFERENCES

EPA (2002): The QTRACER2 program for tracer-breakthrough curve analysis for tracer tests in karstic aquifers and other hydrologic systems. Report no. EPA/600/R-02/001; Washington, D.C.

MARGANE, A. (2012a): Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley. – Technical Cooperation Project 'Protection of Jeita Spring', Advisory Service Document No. 1-1, 62 p.; Raifoun.

MARGANE, A. (2012b): Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley – Addendum No. 1. – Technical Cooperation Project 'Protection of Jeita Spring', Advisory Service Document No. 1-1, 42 p.; Raifoun.

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. 1483-1488 pp.