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Beirut

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Protection of Jeita Spring

TECHNICAL REPORT NO. 1

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
—
General Recommendations from the Perspective of Groundwater Resources Protection

Ballouneh
January 2011

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

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List of Abbreviations

asl	Above mean sea level
AFD	Agence Française pour le Développement
AVSI	Italian NGO
BMZ	German Ministry of Economic Cooperation and Development
CDR	Council for Development and Reconstruction
CPT	Cone penetration test
DEMN	Digital elevation model
EIA	Environmental impact assessment
EIB	European Investment Bank
FAO	Food and Agriculture Organization
FC	Financial cooperation
GW	groundwater
IGN	Institut Geographique National
KfW	German Bank for Reconstruction and Development
LRA	Litani River Authority
MAPAS	Company operating Jeita Grotto
MCM	Million cubic meters
MoEW	Ministry of Energy and Water
SWE	Snow water equivalent
TC	Technical cooperation
UNDP	United Nations Development Program
UTM	Universal transverse mercator
WEBML	Water Establishment Beirut and Mount Lebanon
WW	Wastewater
WWTP	Wastewater treatment plant

Acknowledgements

In its effort to protect the water resources in the Nahr el Kalb catchment, the project *Protection of Jeita Spring* experienced great support not only at the political and institutional level but also from many municipalities and people in the catchment area.

We are especially grateful for the backing and support of the Council for Development and Reconstruction (CDR), namely its president, Nabil Jisr, Talaat Dada (deceased) and Eng. Ismail Makki (manager), the Ministry of Energy and Water (MoEW), namely H.E. Gebran Bassil and his staff, the Water Establishment Beirut and Mount Lebanon (WEBML), namely its president, Joseph Nseir, as well as George el Kadi (project manager), Maher Chrabieh (Director of the Dbaye treatment plant) and Dr. Paul Souaid (Director of the Water Laboratory at the Dbaye treatment plant).

Some of the technical installations could not have been achieved without the help of Jeita Grotto (MAPAS). Our sincerest thanks are extended to Dr. Nabil Haddad, Ayman Ibraheem, Najeeb Najeeb and all other staff who made it possible for us to conduct the tracer tests at Jeita.

Many mayors and staff of municipalities in the catchment saw the opportunities which the project hopes to provide in the near future as a chance for development. Among those which very actively assisted the project we would like to highlight the municipalities of Ballouneh (Dr. Pierre Mouzawak, Simon Daou, Tony Daou) and Jeita (Samir Baroud).

The hydrogeological investigations are conducted together with the University of Goettingen, Department of Applied Geology. Together with the project staff, Joanna Doummar planned and conducted the tracer tests and prepared the tracer test interpretation reports documented as annexes of this report. The project is very much indebted to her for her tireless support and significant input. Prof. Martin Sauter and Dr. Tobias Geyer, her supervisors, provided valuable advice for this work.

The project was made possible by grants of the German Government, allocated through the Ministry of Economic Cooperation and Development (BMZ). Our thanks therefore go to the staff of the BMZ, KfW and German Embassy. We experienced that this assistance is very much appreciated not only among the involved institutions and stakeholders but also the population living in the area.

0 Executive Summary

This report presents preliminary results of hydrogeological investigations of the Technical Cooperation (TC) Project Protection of Jeita Spring (implemented by BGR and CDR) relevant for the site selection of wastewater facilities in the Nahr el Kalb catchment (to be implemented by KfW and CDR as well as other donor agencies).

Most important in this respect are the results of two tracer tests conducted in April and August 2010. These tests show that mean groundwater flow velocity in the saturated part of the aquifer system in the Nahr el Kalb catchment is relatively fast (up to 800 m/h). Both tracer tests showed flow velocities in the unsaturated zone of around 30-45 m/h. The tests proved that there is a direct and fast hydrogeological connection between the initially proposed wastewater treatment plant in Nahr es Salib and Jeita spring. Previous tracer tests conducted at different places in the Nahr el Kalb catchment confirm these results.

The main consequence of these investigations is that decentralized wastewater treatment at locations in the river beds near the villages to be serviced will pose a severe risk to the water supply of the Greater Beirut area, based on Jeita spring, Kashkoush spring and several wells near those springs. The same is valid for a centralized wastewater treatment at the coast with wastewater conveyors constructed in the river beds. The risk of leakage from those pipelines and subsequent infiltration of insufficiently treated wastewater into the aquifer is very high and would most likely result in an bacteriological contamination of the drinking water resources even worse than it is now.

Based on these findings the TC project suggests to establish three main wastewater schemes in the Keserwan part of the Nahr el Kalb catchment, comprising :

Scheme 1 (Jeita, Shaile, Ballouneh, Daraya, Aajaltoun, Qleyyat, Rainfoun, Ashkout and Faitroun): conveyance of untreated wastewater largely by gravity to the coast at Zouk, construction of a WWTP at Zouk (pumping needed in some parts of villages ~ 15%).

Scheme 2 (Kfar Debbiane): construction of collector lines to the currently lowest point in the village, construction of a WWTP W of Kfar Debbiane on the mountain ridge; conveyance by gravity; local reuse of wastewater possible (requires pumping: > 150 m).

Scheme 3 (Mayrouba, Hrajel, Faraya): completion and repair/modification of existing collector lines to the lowest point of the village; establishment of WWTP there and reuse of treated WW (requires pumping: ~200 m) or no treatment plant but construction of

pipeline from Mayrouba to Faitroun; linkage with pipeline of scheme 1 (requires pumping: 150 m).

The proposed schemes would keep untreated wastewater at topographically high positions and thus reduce the pollution risk.

The areas most critical in terms of pollution risk for the Jeita spring are those overlying the underground course of the Jeita cave. A preliminary high-risk area has been delineated (later to be replaced by protection zone 2). Water resources protection in this area is most important. Therefore wastewater schemes in this area should have highest priority.

This pertains especially to the villages of Jeita, Shaile, Ballouneh, Aajaltoun, Daraya, Raifoun and Qleyyat (scheme 1).

1 Introduction

The work presented in this report was conducted in the framework of the German-Lebanese Technical Cooperation project *Protection of Jeita Spring*. The tracer tests were carried out and interpreted together with the Georg-August University Goettingen, Department of Applied Geology.

The German-Lebanese Technical Cooperation (TC) Project *Protection of Jeita Spring* is funded by a grant of the German Government (Ministry of Economic Cooperation and development, BMZ). Its aim is to "reduce important risks for the drinking water supply of Beirut through measures implemented in the Jeita catchment". On the German side, the project is implemented by the Federal Institute for Geosciences and Natural Resources (BGR). The project partners on the Lebanese side are the Council for Development and Reconstruction (CDR), the Ministry of Energy and Water (MoEW) and the Water Establishment Beirut Mount Lebanon (WEBML). Important components of the TC project are:

1. Integration of water resources protection aspects into the investment planning and implementation process in the wastewater sector;

2. Integration of water resources protection aspects into landuse planning and improved spring capture and water conveyance;

3. Establishment of a monitoring system.

Further details to the TC project are laid down in Annex 1.

The TC project commenced on 17.07.2010. Its first phase will last until 31.05.2012.

In parallel to the Technical Cooperation Project "Protection of Jeita Spring" a Financial Cooperation (FC) Project under the same name is implemented by KfW on the German and CDR on the Lebanese side. This project is funded by a loan of the German Government (BMZ). In the framework of this project, wastewater collection and treatment facilities will be established in the Nahr el Kalb catchment with the aim to reduce the pollution risk for the main source of drinking water supply for Beirut, the Jeita spring. Currently three phases for this project are planned with a financial volume of around 22.5 Mio EUR. According to the current planning the FC project is likely to commence in March 2011.

Both, the TC and the FC project will closely coordinate their activities to find the best possible solution for wastewater collection and treatment in the Nahr el Kalb catchment.

Concerning component 1, important tasks of the TC project are to:

1. Support CDR and other institutions concerning the concept and implementation of wastewater projects (location of WWTPs, design, collector lines, effluent discharge locations) in the Nahr el Kalb catchment and

2. Support CDR in the preparation of EIAs for wastewater projects, with regards to their impact on the water resources.

The intention of this report is to serve as a basis for decisions to be made by CDR and KfW concerning the concept and implementation of wastewater projects in the Nahr el Kalb catchment and to facilitate the work of the consultant of the FC project in this respect.

Most environmental impact assessments (EIA) for wastewater facilities do either not cover at all or insufficiently the issue of water resources protection, even though they should be designed to do exactly that. Also many areas lack a holistic approach and a clear concept for wastewater treatment. Often neighboring areas are not considered because of political or sectarian issues.

The wastewater schemes the TC project proposes are based on a holistic approach and look at the entire catchment. Their main aim is to provide sufficient protection for the water resources used for drinking purposes not only in the Greater Beirut area but also in the catchment itself. Therefore the people living in the catchment should have an interest themselves to protect "their" water resources.

2 General Characteristics of and Data Sources used for the Nahr el Kalb Catchment

2.1 Topography

The most current topographic maps date from 2005. The contour interval commonly is 20 m and is therefore not suitable for establishing a digital elevation model (DEM).

A preliminary DEM has been established, based on SRTM data (Shuttle Radar Topography Mission, February 2000; http://www2.jpl.nasa.gov/srtm/) with approx. 90 m * 90 m grid raster. This DEM (Figure 1) was e.g. used to delineate the surface water catchment area of Jeita spring using ArcGIS and to make initial proposals to KfW for WW facility site selection in 2008.

Another DEM used by the project is the ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radar; launched by NASA in 1999; http://www.gdem.aster.ersdac.or.jp/) with a horizontal resolution of 30 m * 30 m. However, despite the higher ground resolution, evaluations of the ASTER GDEM show a lower accuracy compared to the SRTM DEM (JACOBSEN, 2010).

Currently new, more precise topographic data are acquired using the TerraSAR-X (launched on June 15, 2007) – TanDEM-X (launched on June 21, 2010) radar satellites (http://www.dlr.de/eo/en/). BGR has applied to obtain and use these data for the entire project area. The new DEM will have a horizontal resolution of approx. 12 m * 12 m with a vertical accuracy of around 2 m. The new data would, among others, enable the project to determine the snow-water equivalent (SWE), thereby allowing an improved estimation of groundwater recharge and facilitate the establishment of a hydrological model. It is currently unknown when the new DEM will be ready for use. Due to its more accurate elevation this DEM could also be used to make a pre-planning of WW facilities in the Nahr el Kalb catchment.

Figure 2. exhibits the slope angle (gradient), derived from the SRTM DEM. Both, the DEM and the slope angle could be used for preliminary WW facility planning.

The map projection most widely used in Lebanon is:

Lambert conformal conic (Levant Lambert Zone or Syrian North Lambert Zone; in ArcGIS: Deir ez Zor Syria Levant, type 2). This projection was introduced by the French army for mapping of the Middle East. The ellipsoid used is: CLARK 1880 (IGN).

This map projection will be used in all maps prepared by the project together with geographic grid reference (DMS lat/long) or UTM Zone 36N.

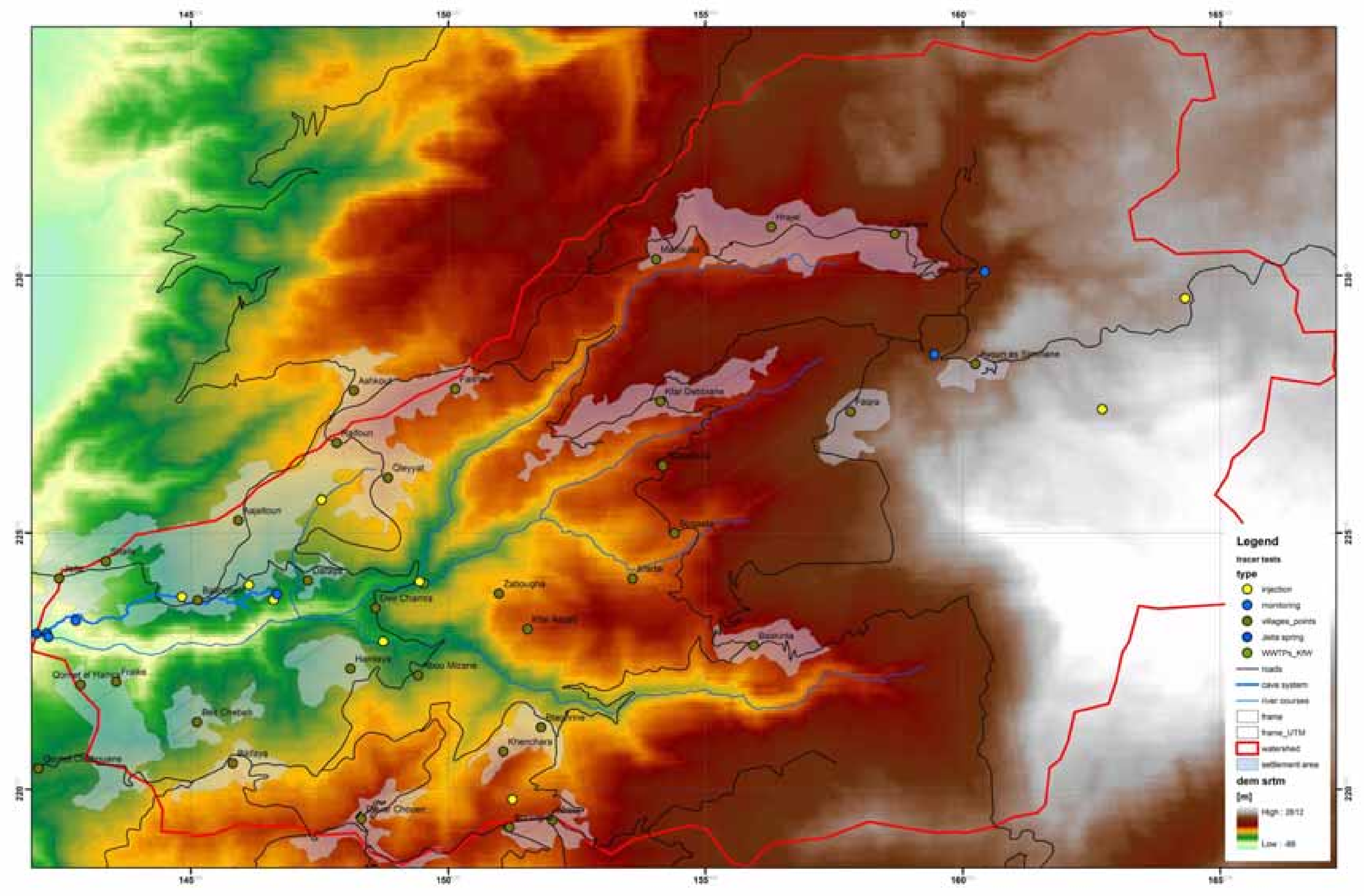

Figure 1: Digital Elevation Model of the Nahr el Kalb Catchment

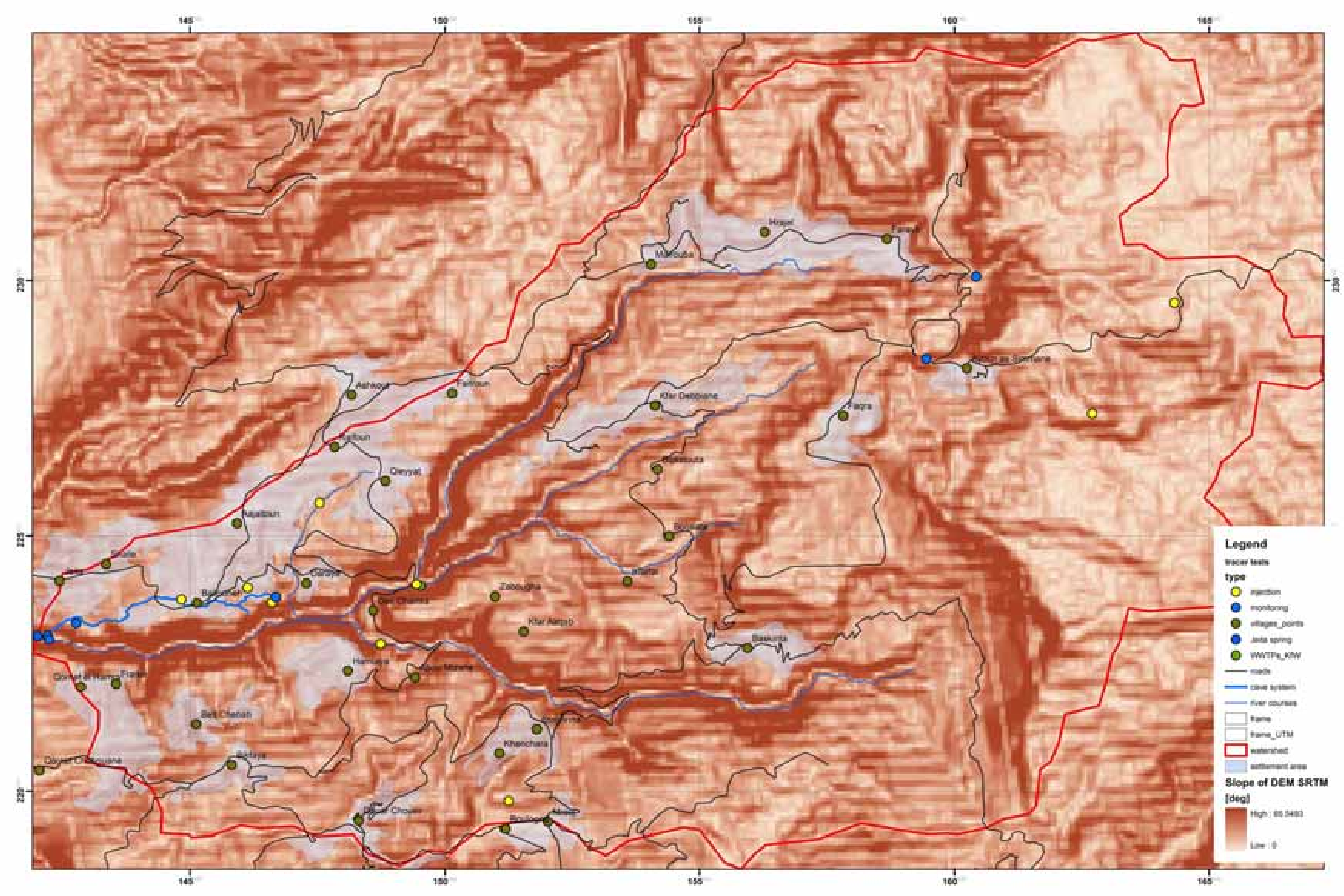

Figure 2: Slope determined from Digital Elevation Model of the Nahr el Kalb Catchment

2.2 Climate

There are only few reliable meteorological assessments for Lebanon. The most trustworthy appears to be that prepared by the Hydro-Agricultural Development Project for South Lebanon, prepared in 1973 in the framework of UNDP and FAO assistance to the Litani River Authority (LRA). It covers the period 1939 to 1970.

Currently there are only four stations in or near the Nahr el Kalb catchment (at: Kaslik, Hemlaya, Faqra, Qartaba; Figure 3). The TC project will establish another 6 stations (Table 1) so that rainfall distribution maps would become more reliable in the future, which will allow a more exact hydrological modelling. The new network will also cover snow fall and snow height measurements. The new stations are scheduled to be installed until June 2011.

Rainfall reaches from 900 mm/a at the coast to probably up to around 2,000 mm/a on the mountain plateau. According to the UNDP/FAO rainfall distribution map (Figure 4) average rainfall in the Nahr el Kalb catchment is 1,500 mm/a.

It is intended to transfer responsibility for the management of the new meteorological station to the National Meteorological Service.

Table 1: Proposed Meteorological Stations of Jeita Project

Name	E	N	Alt	Parameters
Full Weather Station W1 / LBC Antenna	35.840144°	33.965300°	2425	Precipitation Air temperature Wind velocity Wind direction Relative humidity Global radiation Barometric pressure Snow height
Rainfall Gauge R1 / Antonine International School (AIS)	35.680333°	33.957428°	800	Precipitation Air temperature
Rainfall Gauge R2 / Mar Sassine Monastery, Baskinta	35.801642°	33.941925°	1275	Precipitation Air temperature
Rainfall Gauge R3 / Kfar Debbiane municipality	35.771154°	33.986143°	1285	Precipitation Air temperature
Rainfall Gauge R4 / Dour Choueir water storage cistern	35.708116°	33.909213°	1263	Precipitation Air temperature
Rainfall Gauge R5 / Chabrouch Dam	35.83437°	34.02580°	1562	Precipitation Air temperature

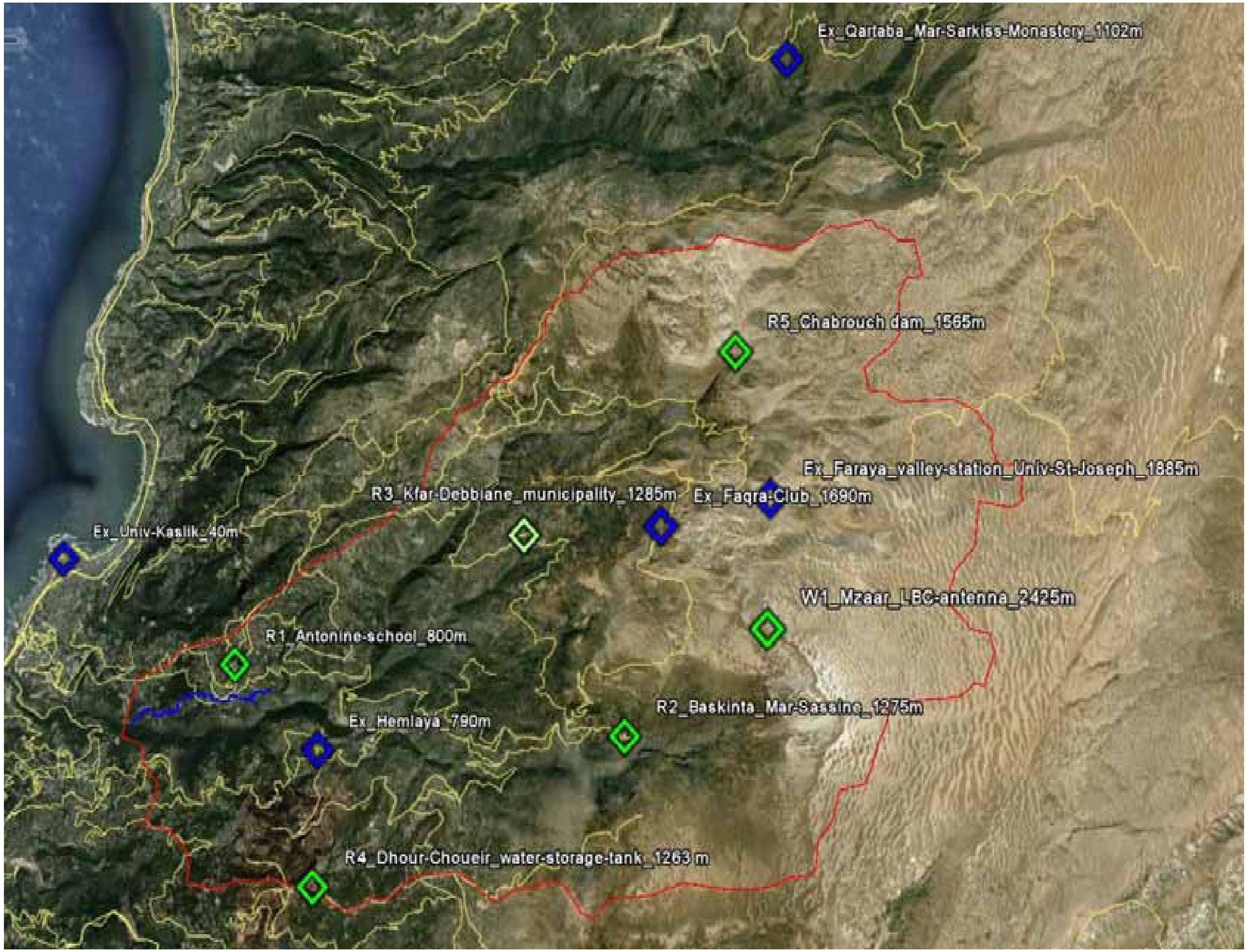

Figure 3: Meteorological Stations in the Nahr el Kalb Catchment (green: proposed; blue: existing)

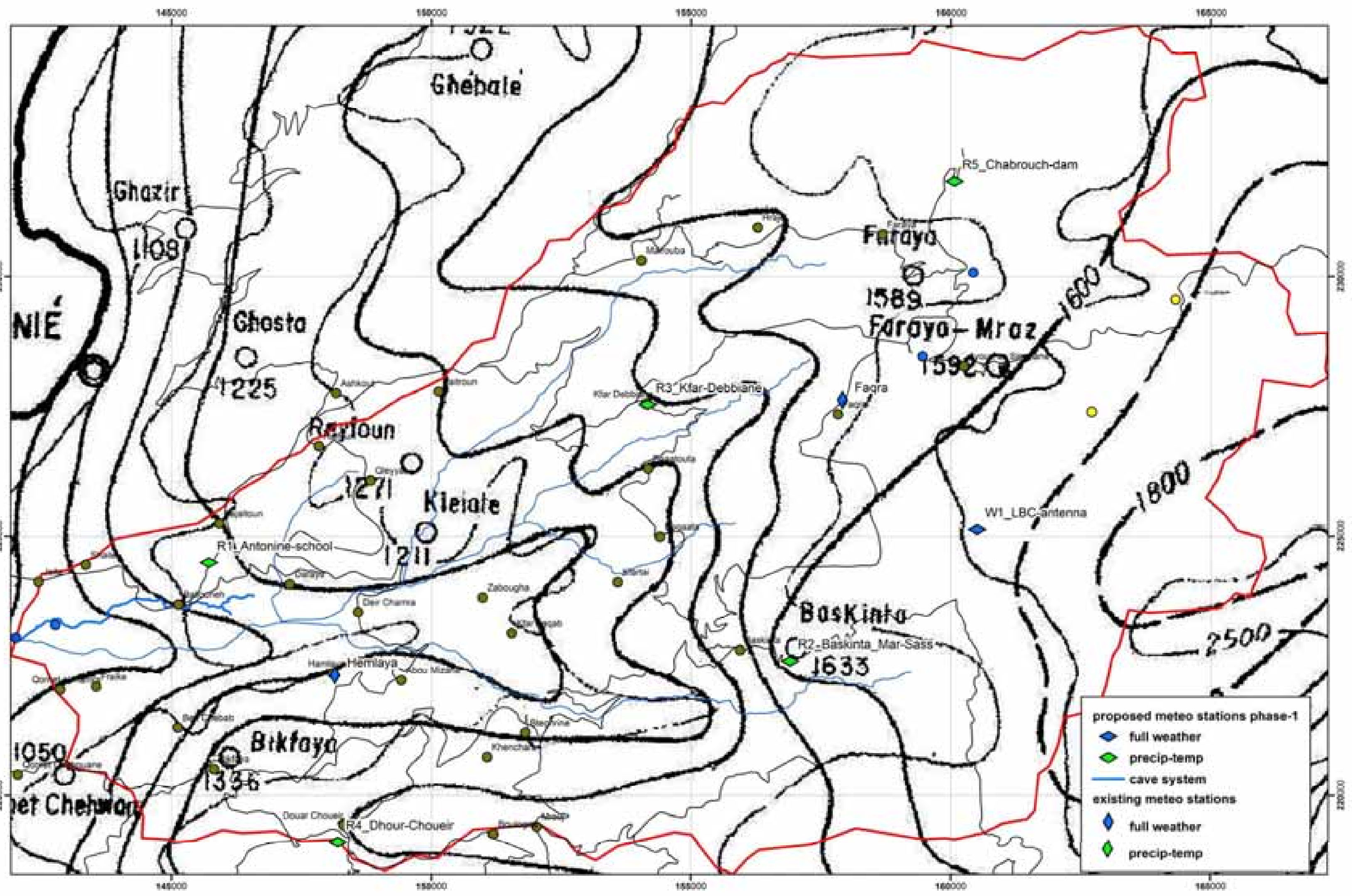

Figure 4: Rainfall Distribution (1939-1970) in the Nahr el Kalb Catchment (UNDP/FAO 1973)

2.3 Geology

The geology of the area has been mapped in the 1940s by French geologists (DUBERTRET 1955; Figure 6). This old map does not show all geological subunits of the Jurassic and Cretaceous and is not precise enough. A new geological mapping by the project is currently underway in the greater Nahr el Kalb catchment with the aim to present all geological units and subunits on the new map. At the same time tectonic features and karst features will be mapped. Based on the new geological map and additional geophysical soundings, structure contour maps for the main aquifer units are aimed to be prepared.

Both, the Cretaceous and the Jurassic limestones are highly karstified. The Jurassic, which is more karstified than the Cretaceous, is exposed in the lower part of the Jeita surface water catchment.

The standard lithostratigraphy used in Lebanon is shown in Figure 5.

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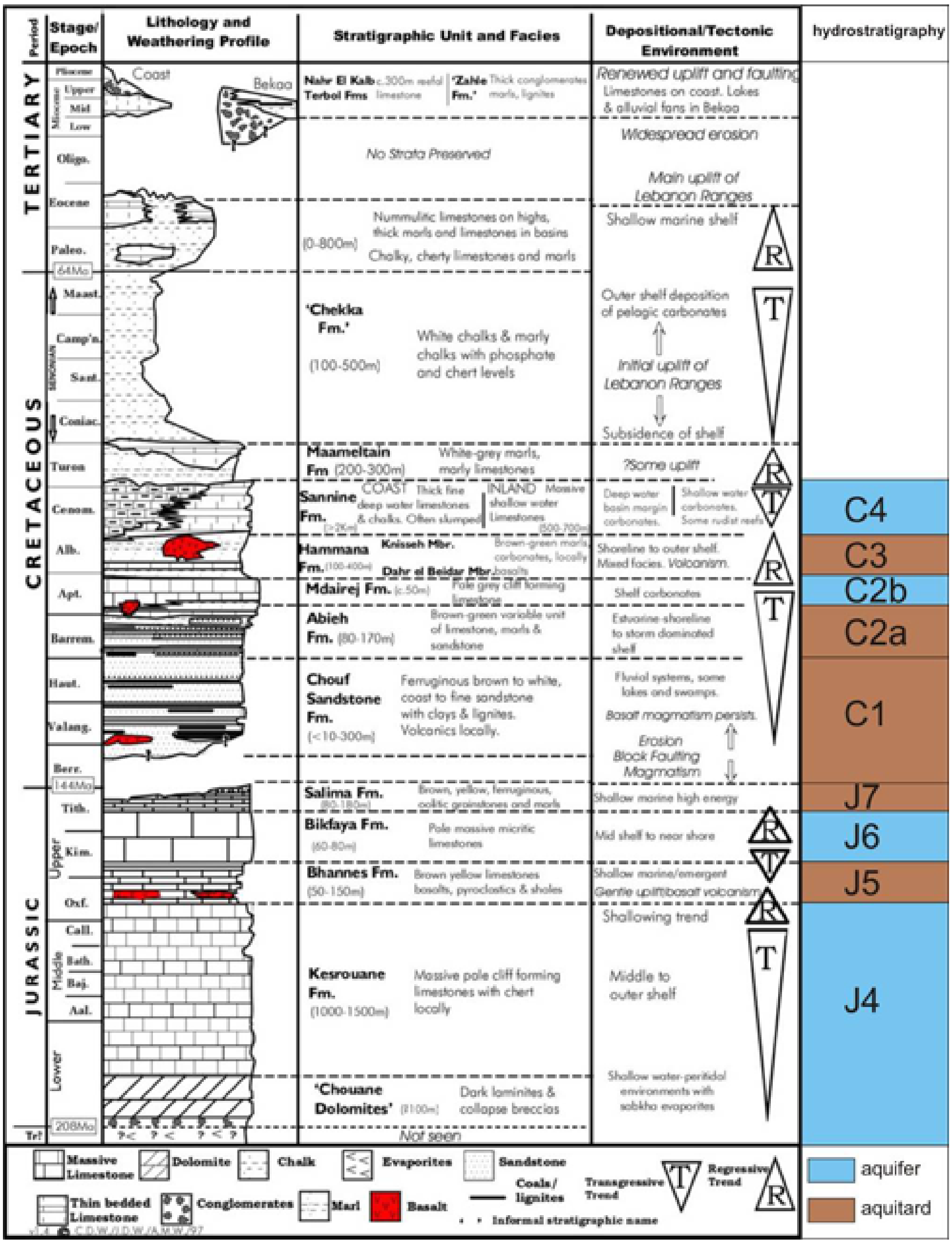

Figure 5: Lithostratigraphy and Hydrostratigraphy of Lebanon (modified after WALLEY, 2001)

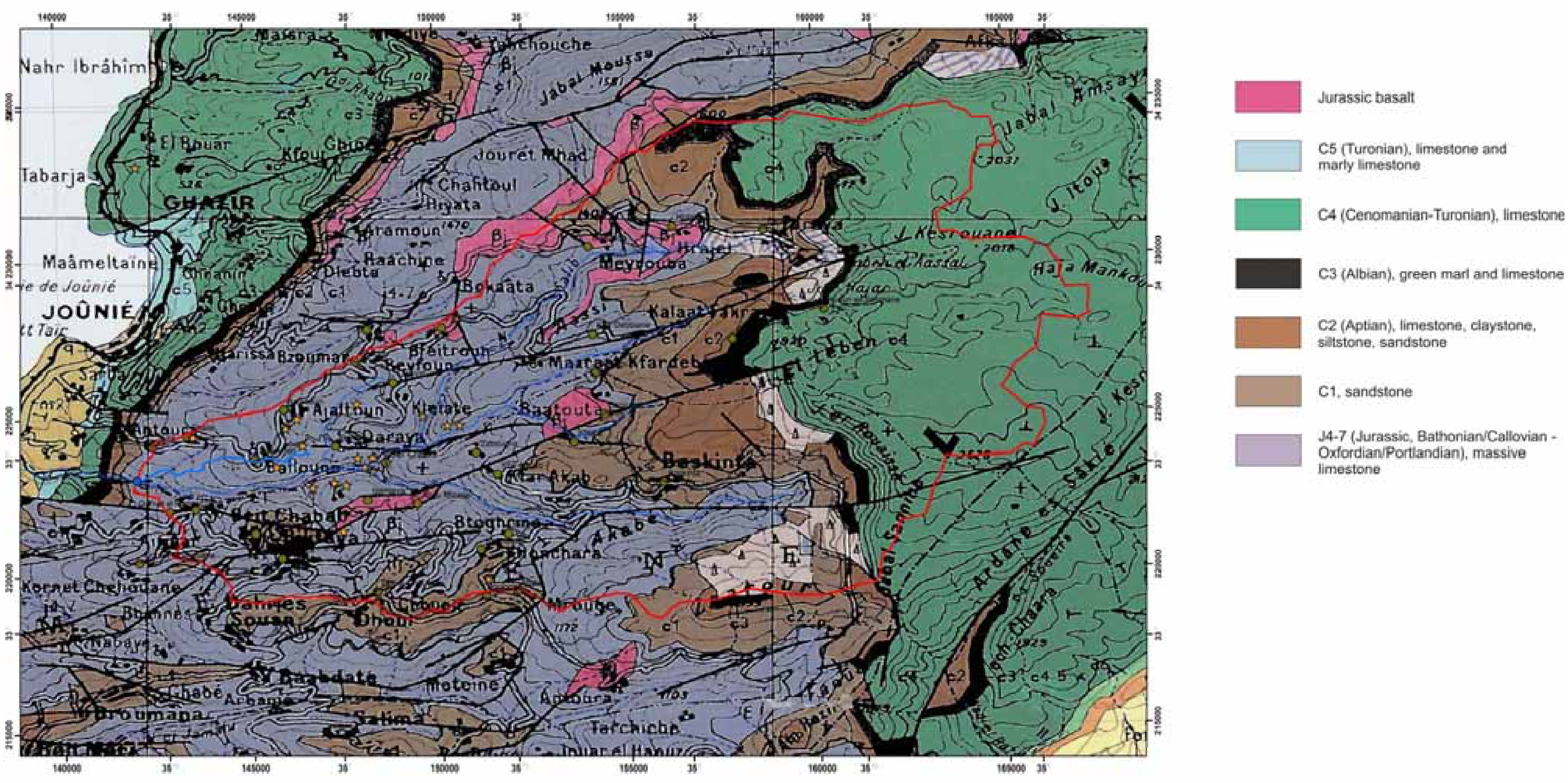

Figure 6: Geological Map - Sheet Beirut (adopted from DUBERTRET 1955)

2.4 Hydrology

Surface water runoff is currently monitored by Litani River Authority at four locations in the Nahr el Kalb catchment (blue symbols in Figure 7). The locations of those stations are not ideal and profiles, if ever existing, have never been cleaned over the past few years. The TC project aims to establish three new stations for continuous monitoring of water level and will establish correlation (rating) curves for runoff determination.

The TC project aims to determine where losses in streamflow occur along the Nahr es Salib/Nahr el Kalb by means of dilution tests.

Figure 7: Existing (blue) and Planned (green) Surface Water Gauging Stations

2.5 Hydrogeology

Based on the spring discharge measurements of the Jeita spring documented in the UNDP/MHER (1972) report 'Jeita – the famous karst spring of Lebanon', ACE (1988) and other related reports, the discharge of Jeita spring is assumed to be in the order of 160 MCM/a (80 – 290 MCM/a; Figure 8). During the water years 1966/67 – 1973/74 (the only time period for which flow records are available) monthly average discharge varied between 0.9 and 29.5 m³/s. End of the relatively dry year 2010 (end of November) a discharge of 1.0 m³/s was recorded by the BGR project (first significant rainfall/snow on

December 6, 2010). Highest discharge recorded until now reached 80 m³/s on February 21, 2011.

It is difficult to assess the level of accuracy of the previous flow records since it is not mentioned how exactly flow was measured. Under current conditions it is fairly difficult to measure flow continuously because of the lack of a suitable section or a well designed and calibrated weir where flow could be measured. **It is strongly recommended to install a structure for measuring spring discharge.** This would allow to more correctly assess the total flow of Jeita spring and address management options. **Presently only less than one third of spring discharge can be used.** Also much of spring discharge from Kashkoush spring is not being used.

Currently the project assesses flow of Jeita spring by means of continuous water level recordings (using an InSitu TROLL 9500 multiparameter probe with pressure transducer) at a fixed station, located 480 m upstream of the boat mooring (started beginning of August 2010). In order to correlate water level with flow, uranine dilution tests are conducted on average every two weeks. This is done in a similar way at all major springs in the Nahr el Kalb catchment: Jeita-Daraya tunnel (end of explored part of the Jeita cave; Figure 10), Kashkoush (Figure 11), Nabeh al Assal and Nabeh al Labbane. Water level responds immediately, i.e. within a few hours, to rainfall events at Daraya and Kashkoush.

In the upstream direction the Jeita cave has been explored to the Daraya tunnel. Flow at this location is assumed to be less than at Jeita. It is therefore inferred that Jeita spring receives some contribution between Daraya and Jeita from the northeast (Ballouneh, Aajaltoun, Raifoun, Qleyyat). This needs to be confirmed by dilution tests all along Jeita cave between Daraya and Jeita.

The mechanism of groundwater discharge from the Cretaceous aquifer is not yet fully understood. There are two main springs discharging from the Cretaceous, Nabeh al Assal and Nabeh al Labbane. While Nabeh al Labbane dries up at the end of the dry season (in 2010 at the beginning of September), flow at Nabeh al Assal is more constant (approx. around 6 MCM/a). It is assumed that there is a considerable amount of direct leakage through the Lower Cretaceous aquitard to the Jurassic aquifer because discharge of those two springs is relatively low. Compared to Assal spring, the lower temperature at Labbane spring indicates that its recharge area must be on average slightly higher than that of the former. This will be verified by isotope analyses.

The extent of the groundwater contribution zone to the Jeita spring has yet to be determined. Until now it is assumed that it might be similar to the surface water catchment of the Nahr el Kalb (Figure 6) but probably extending beyond it to the north and east, while the area to the south of Nahr el Kalb probably contributes to Kashkoush spring.

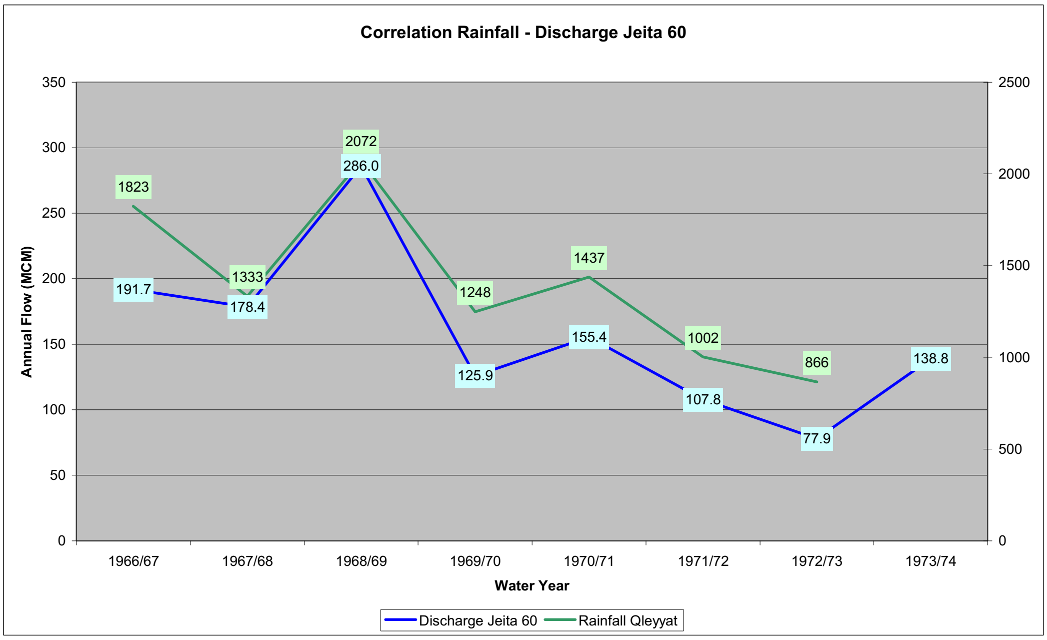

Figure 8: Average Annual Discharge of Jeita Spring during Water Year 1966/67 – 1973/74 correlated with Rainfall at Qleyyat (1070 m asl) (modified after ACE, 1988)

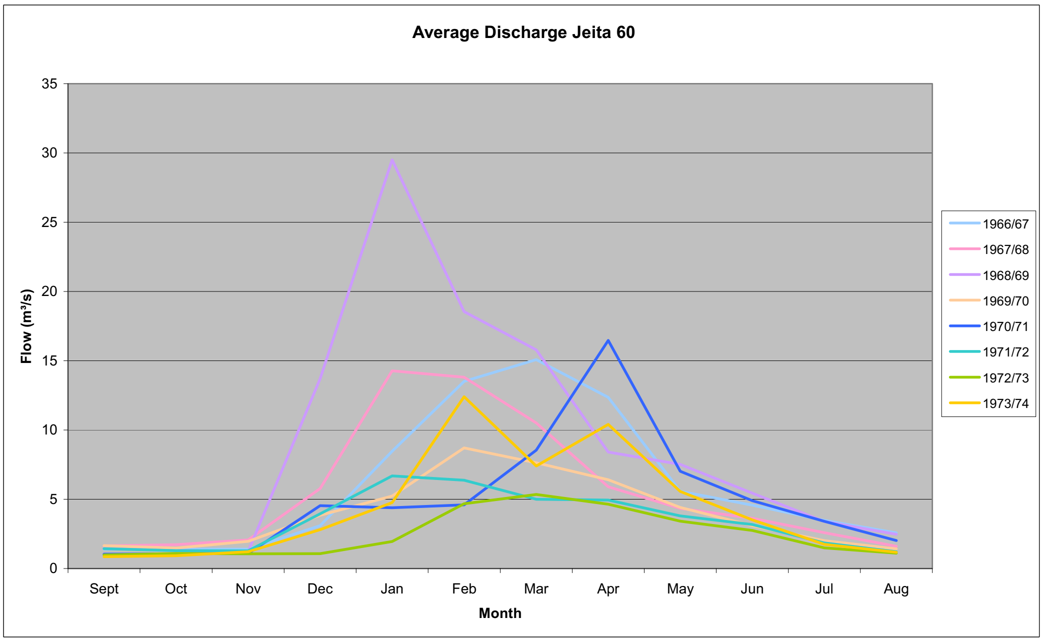

Figure 9: Monthly Average Discharge of Jeita Spring during Water Year 1966/67 – 1973/74
(modified after ACE, 1988)

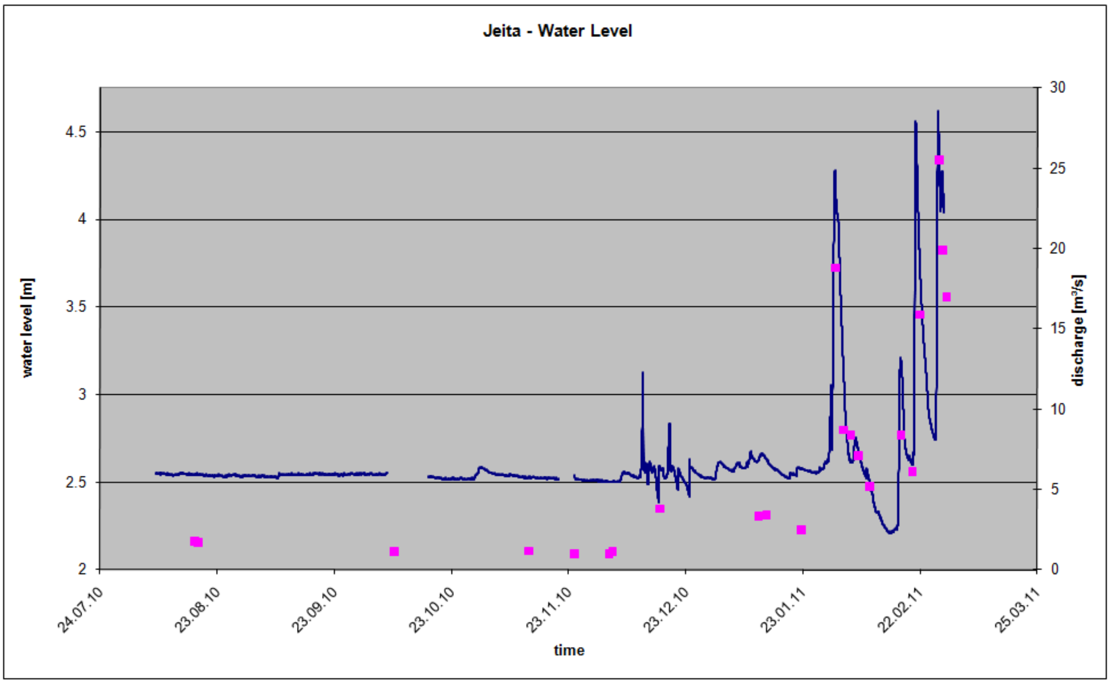

Figure 10: Water Level Fluctuations and Measured Spring Discharge in the Jeita Grotto

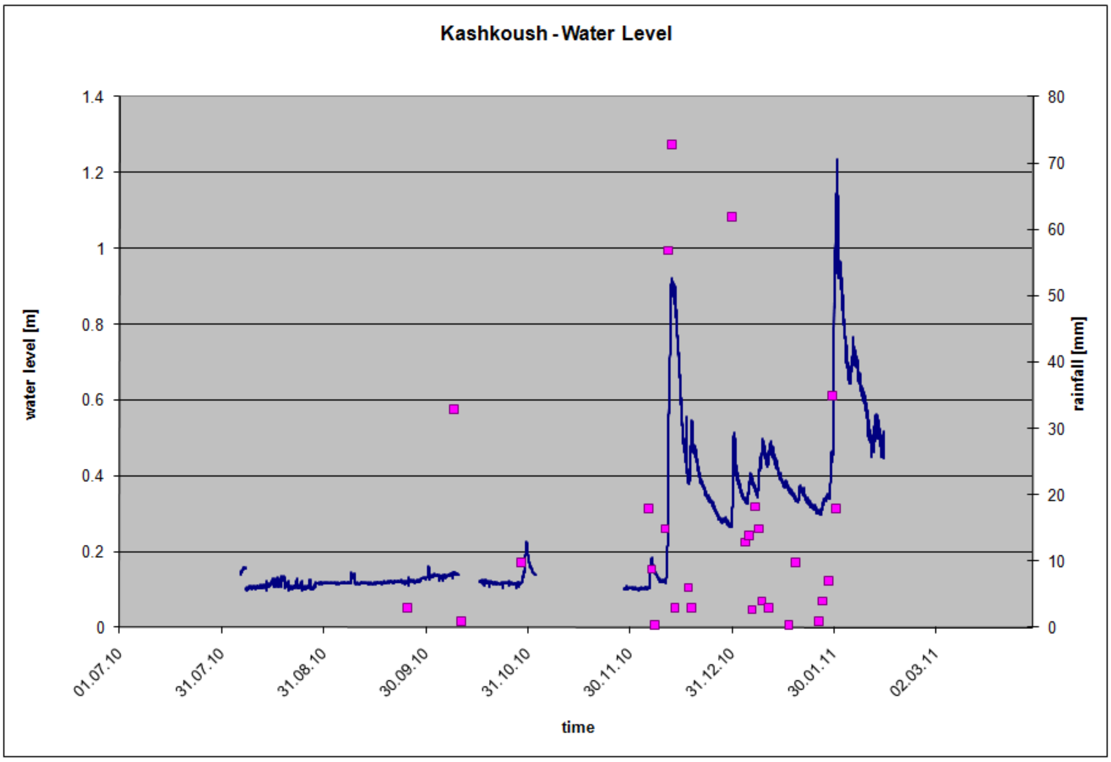

Figure 11: Water Level Fluctuations at Kashkoush Spring and Rainfall at Beirut Airport

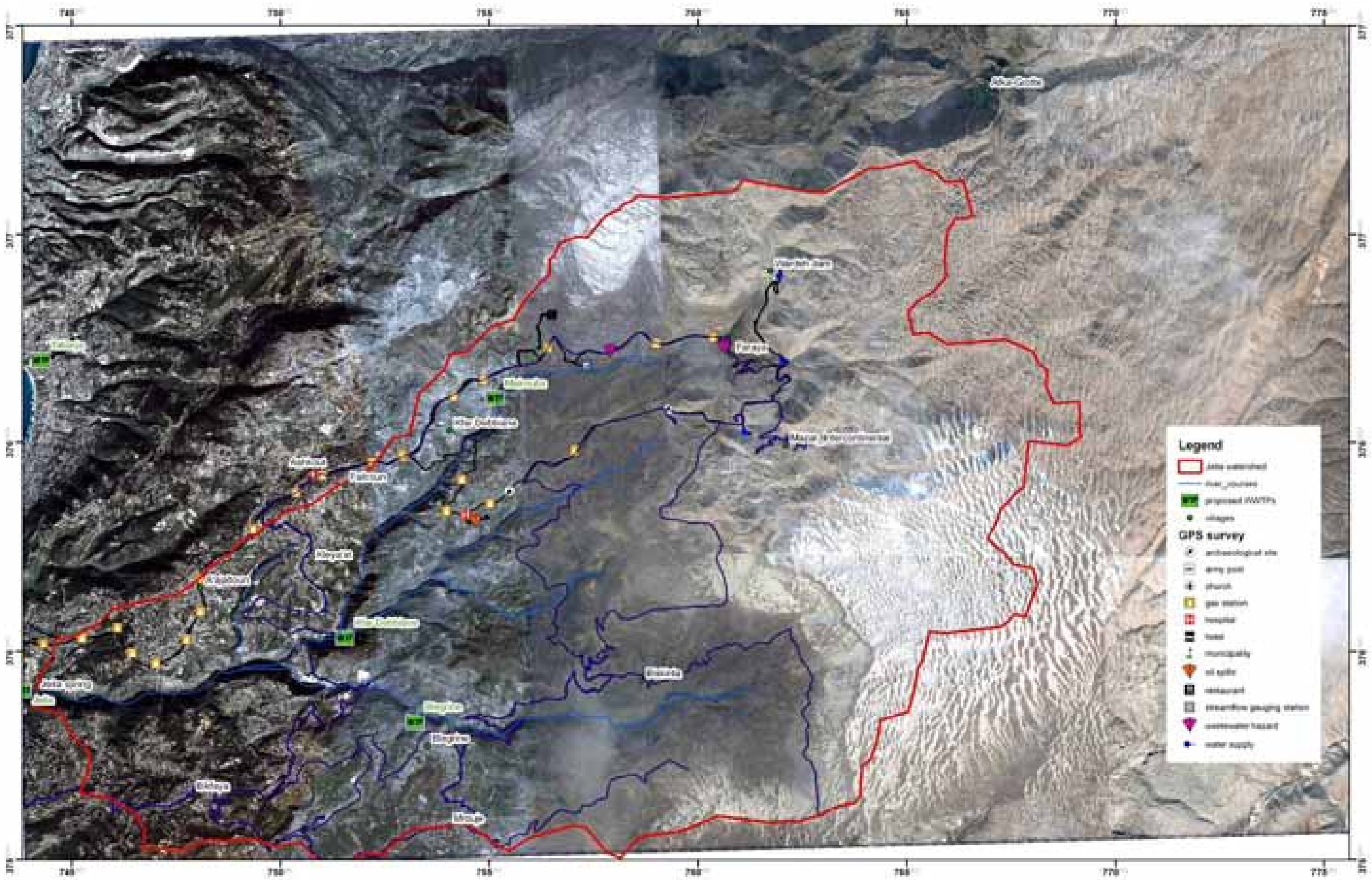

Figure 12: Surface Water Catchment of the Jeita Spring with Hazards to Water Resources

2.6 Pollution Risk

Various mappings of hazards to groundwater have been undertaken over the past two decades:

- Bahzad HAKIM (1993)
- Mark SAADEH (1994)
- Lina ABD EL NOUR (1998)
- AVSI (2009)

Besides wastewater, which is by far the most serious environmental threat, important hazards to groundwater are:

- uncontrolled waste dumping
- leakages of hydrocarbons from gas stations and fuel tanks for generators
- animal farms and
- quarries.

The project aims to update and improve the inventory of hazards to groundwater and assess the risk of groundwater contamination (Figure 12).

3 Current Planning for Wastewater Facilities

One part of the above mentioned project is to provide assistance to the Council for Development and Reconstruction (CDR), as one of the partners of BGR, as well as other relevant national institutions or donor agencies, among others the main German implementing agency for financial cooperation, the KfW Entwicklungsbank (KfW), the European Investment Bank (EIB) and the Italian Protocol, concerning the site searching for wastewater collection and treatment facilities in the groundwater contribution zone of the Jeita spring, herein referred to as the project area.

In this report we are focusing on the wastewater facilities to be implemented by CDR and KfW in the Financial Cooperation (FC) project also called *Protection of Jeita spring*. The first two phases of the FC project *Protection of Jeita spring* have already jointly been agreed upon, a third phase is currently negotiated.

In the framework of this FC project wastewater treatment plants and collector lines will be established in the project area. The project is scheduled to commence at the beginning of 2011. A consultant will carry out the detailed planning for the related facilities.

The current planning (BCT, 2008; KfW, 2008a, 2008b; Figure 14, Table 1) foresees three phases during which this project will be implemented (total duration 43 months; KfW, 2010):

1st phase (10/2010-12/2014):
First stage of a modular biological wastewater treatment plant (WWTP) and completion of the partially already completed secondary and tertiary (household) collector lines for the village of Jeita (5,000 inhabitants). The serviced area would cover 70% of the population of the village. Reuse of treated wastewater and sludge reuse are optional. According to current planning the WWTP would be located at the former hydroelectric power plant Hashash (Figure 13). The outcropping geological units in this area are the J6 (limestone), covered to the west by C1 (sandstone). The capacity of the first stage of the WWTP would be 480 m³/d.

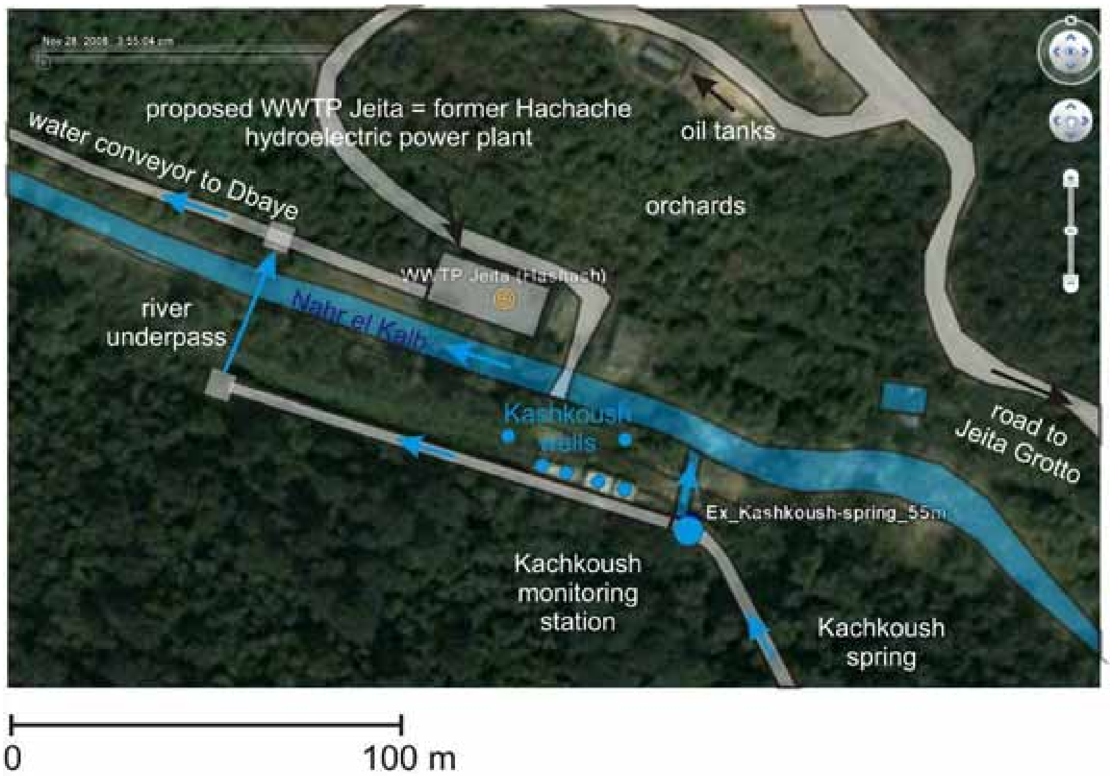

Figure 13: Proposed location of Jeita WWTP, also showing Jeita-Dbaye water conveyor and Kashkoush spring with water conveyor

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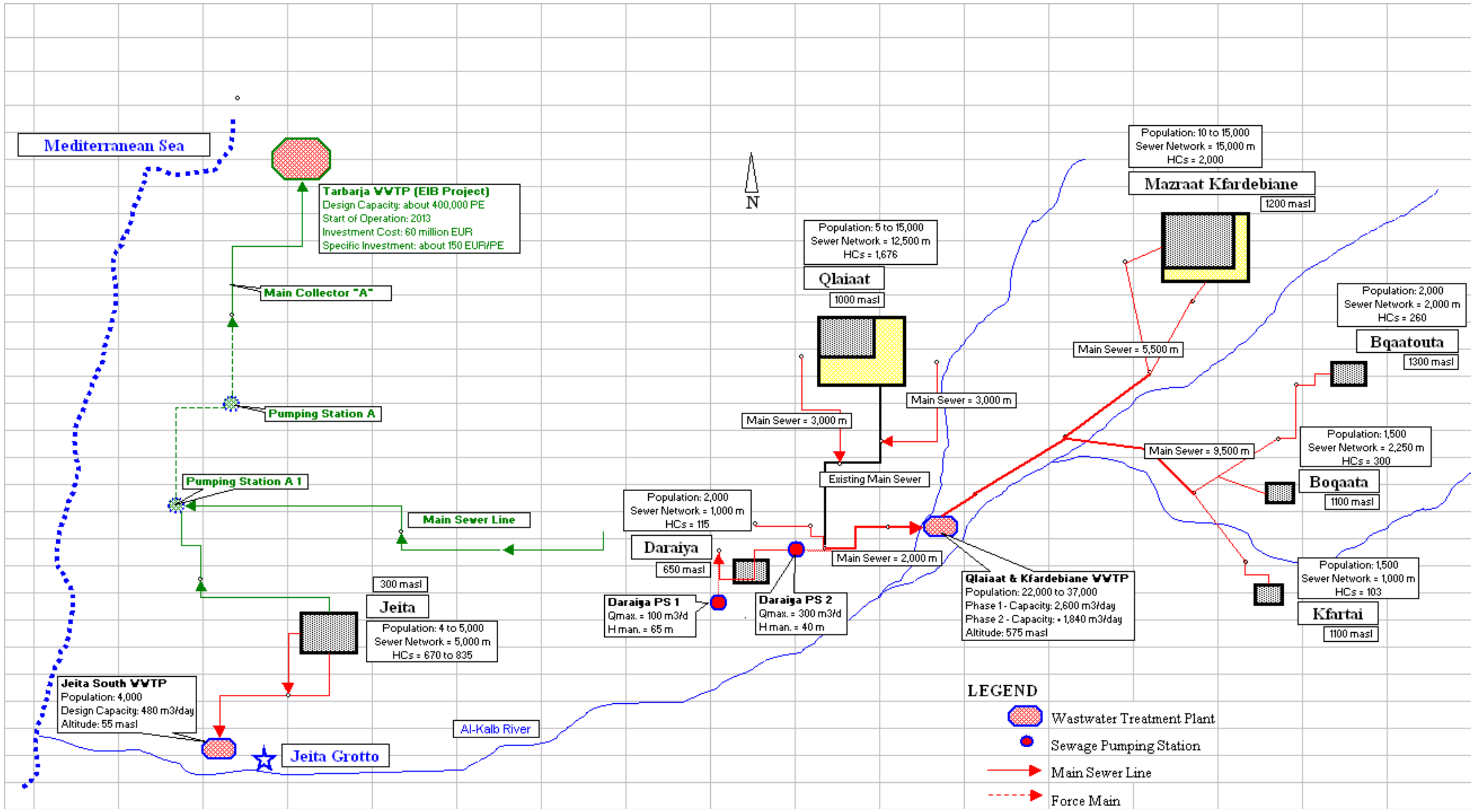

Figure 14: Proposed Schematic Layout of KfW project Protection of Jeita Spring (adopted from BCT, 2008)

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Table 2: Base data for KfW's wastewater project

(adopted from BCT, 2008)

No.	Project Towns	Priority	Contracted Water Supply			Water Consumption and specific Indicators in Winter						Water Consumption and specific Indicators in Summer					
			HCs	Total Water Supply	Average per HCs	Population	Water Cons.	Spec. Water Demand	Population per HCs	WW Generation at 80%	Service Coverage 2012 70%	Population	Water Cons.	Spec. Water Demand	Population per HCs	WW Generation at 80%	Service Coverage 2012 70%
			Nos.	m3/d	m3/d	Nos.	m3/d	l/c/d	Nos./HCs	m3/d	m3/d	Nos.	m3/d	l/c/d	Nos./HCs	m3/d	m3/d
1	Olaiaat	1	1.676	1.745	1,04	5.000	900	180	3			15.000	2.000	133	9		
2	Mazraat Kfardebiane	1	2.000	2.500	1,25	10.000	1.500	150	5			15.000	3.500	233	8		
3	Daraiya	2	115	122	1,06	2.000	200	100	17			2.000	300	150	17		
	Sub-TOTAL: 1 to 3		**3.791**	**4.367**	**1,15**	**17.000**	**2.600**	**153**	**4**	**2.080**	**1.456**	**32.000**	**5.800**	**181**	**8**	**4.640**	**3.248**
4	Bqaatouta	3	260	267	1,03	2.000	300	150	8			2.000	400	200	8		
5	Boqaata	3	300	330	1,10	1.500	200	133	5			1.500	300	200	5		
6	Kfartai	3	103	117	1,14	1.500	100	67	15			1.500	100	67	15		
	Sub-TOTAL: 4 to 6		**663**	**714**	**1,08**	**5.000**	**600**	**120**	**8**	**480**	**336**	**5.000**	**800**	**160**	**8**	**640**	**448**
	Sub-TOTAL: 1 to 6		**4.454**	**5.081**	**1,14**	**22.000**	**3.200**	**145**	**5**	**2.560**	**1.792**	**37.000**	**6.600**	**178**	**8**	**5.280**	**3.696**
7	Jeita	1	835	900	1,08	5.000	1.600	320	6			5.000	1.600	320	6		
	Sub-TOTAL: Jeita South		**668**	**720**	**1,08**	**4.000**	**1.280**	**320**	**6**	**1.024**	**717**	**4.000**	**1.280**	**320**	**6**	**1.024**	**717**
	GRAND TOTAL		**5.122**	**5.801**	**1,13**	**26.000**	**4.480**	**172**	**5**	**3.584**	**2.509**	**41.000**	**7.880**	**192**	**8**	**6.304**	**4.413**

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2nd phase (10/2010-12/2014):
First stage of wastewater treatment plant Kfar Debbiane, primary, secondary and tertiary collector lines for the village of Kfar Debbiane (10,000-15,000 inhabitants). [the high variation of the number of inhabitants is related to summer and winter tourism]

The proposed location of the WWTP would be SW of Kfar Debbiane and E of Daraya, in Nahr es Salib (Figure 15). The outcropping geological unit in this area is the J4 (limestone). The capacity of the first stage of this WWTP would be 2,600 m³/d.

Figure 15: Location of WWTP-2 Kfar Debbbiane and injection site 1 (uranine)

3rd phase (10/2010-12/2014):
Second stage of wastewater treatment plant Kfar Debbiane, primary, secondary and tertiary collector lines for the villages of Kleyyat (5,000-15,000 inhabitants) and Daraya (2,000 inhabitants); decentralized wastewater treatment measures in the villages of Bqaatouta (2,000 inhabitants), Boqaata (1,500 inhabitants) and Kfartai (1,500 inhabitants).

The WWTP of the first phase of the KfW project, destined for the village of Jeita, is planned to be located downstream of Jeita spring and can therefore not have an impact on the Jeita spring. This site is herein referred to as WWTP-1. The currently proposed location is near the former Harache hydroelectric power plant, adjacent to Nahr el Kalb (Figure 13). This plant was established in the 1950s. The Kashkkoush spring, also providing raw water for drinking purposes to the Dbaye treatment plant is located to the south of the river (400 m W of Jeita spring). The catchment of this spring has recently been improved (Gibb Cons./Kuwait Fund) so that now the water of the Kashkoush spring is diverted into the canal leading from Jeita to Dbaye.

Currently six drinking water supply wells (Kashkoush wells) are located next to Kashkoush spring. These wells are artesian during the rainy season.

The proposed WWTP-1 could have an impact on the water supply insofar as during certain times water from Jeita and Kashkoush is released into Nahr el Kalb and then again collected further downstream at the Mokhada dam. Furthermore there is fairly little space to safely establish a WWTP without putting the water supply at risk. The Water Establishment therefore opposes the plan to establish a WWTP near the former Hachache hydroelectric power plant.

The WWTP of the second phase of the KfW project, destined for the villages of Kfar Debbiane, Kleyyat and Daraya, is planned to be located near the confluence between hysic Salib and Nahr el Hardoun (Figures 15 and 16). This site is herein referred to as WWTP-2. The effluent of this WWTP would be discharged into the surface water, either into Nahr el Kalb or hysic Salib (tributary of Nahr el Kalb). There are three options for this effluent discharge (Figure 17):

Option 1: effluent discharge immediately downstream of the WWTP;

Option 2: effluent discharge at the confluence of hysic Salib and Nahr el Hardoun (pipeline 1 in Figure 16: 1.9 km);

Option 3: effluent discharge downstream of Jeita spring, e.g. at the Hachache hydroelectric power plant or further downstream (pipeline 2 in Figure 17: 8.2 km).

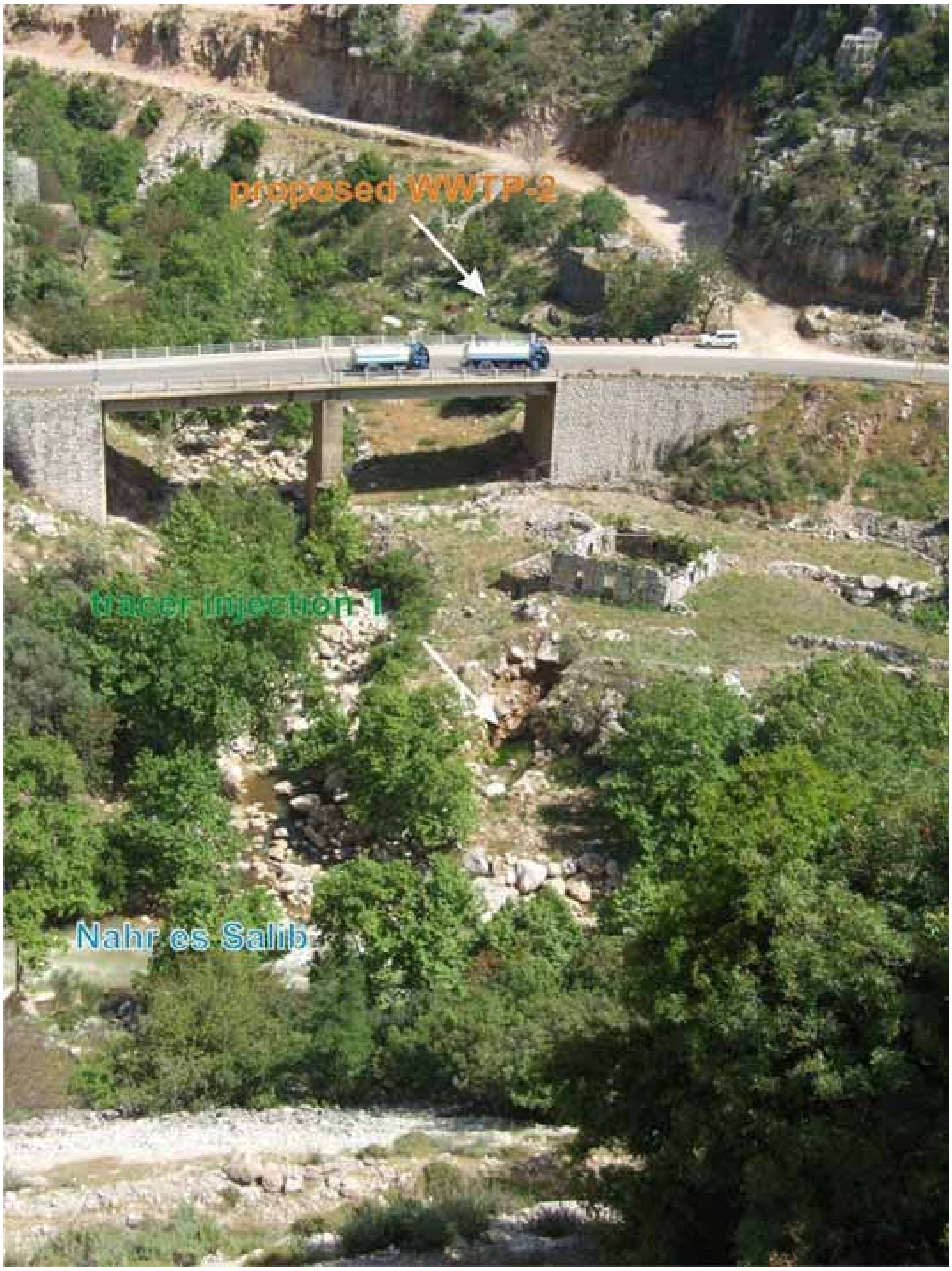

Figure 16: Proposed location of WWTP-2 Kfar Debbiane and tracer injection site 1

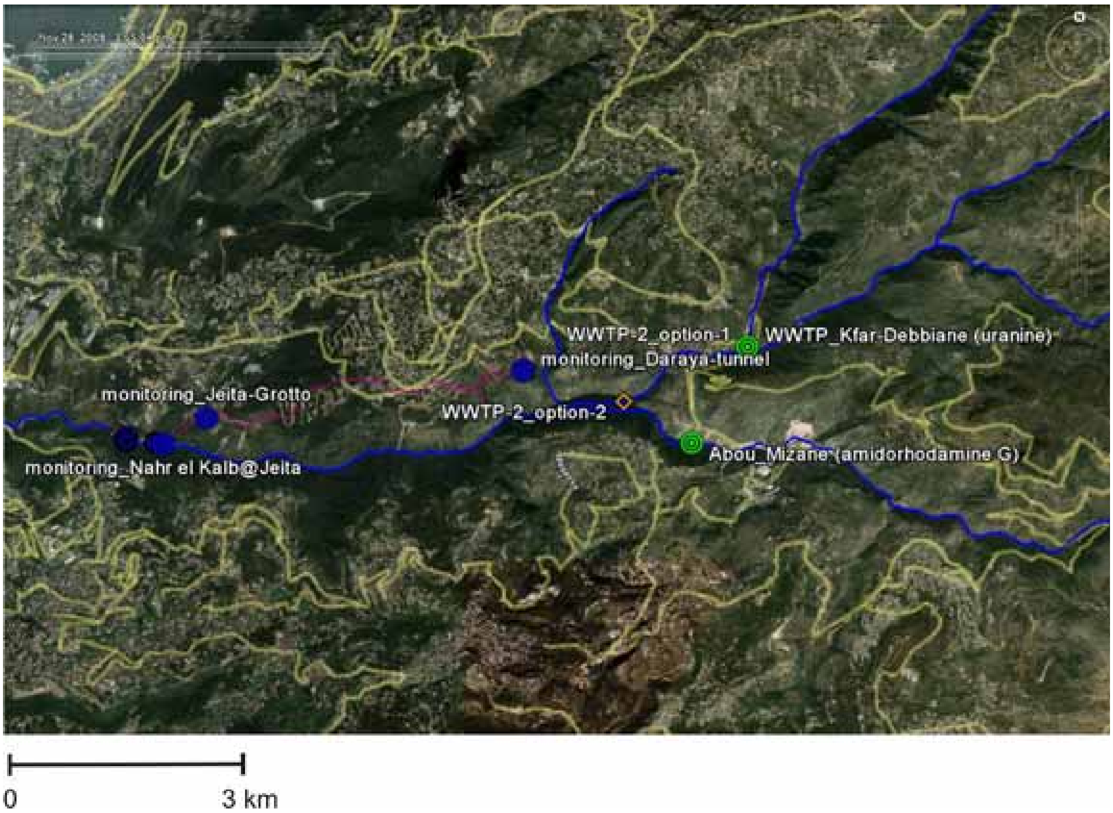

Figure 17: Options of effluent discharge from WWTP-2 Kfar Debbiane (WWTP-2 is located at option-1)

Tracer Tests 1 and 2 focused on determining the suitability of the then envisaged sites. However, based on the results of the hydrogeological investigations other options will need to be pursued. Therefore the current report not only documents the results of these investigations but also lists some of those options from the perspective of groundwater protection.

Option 3 is not feasible because the Nahr el Kalb is already a declared protection zone and would destroy the natural environmental habitat, apart from being overly costly.

4 Wastewater Master Plan

The overall objective of (ground-)water resources protection in a (ground-)-water catchment area, which is the objective of both, the TC and the FC project, can only be achieved if all individual sources of wastewater in the catchment area are covered by wastewater schemes so that no wastewater-related pollution risks remain. Due to the high degree of karstification, the rapid infiltration and the very fast travel times in the groundwater contribution zone of the Jeita and Kashkoush springs, wastewater pollution risks for all water sources used for drinking water supply in the entire groundwater catchment must be addressed. Because of the complexity of the matter it is suggested to prepare a wastewater master plan.

The wastewater master plan needs to provide all required base data and information concerning wastewater management in a catchment, by

- specifying the amounts of wastewater available at present and in the future (planning horizon), including their seasonal and spatial variability as well as their hysic-chemical composition;
- providing feasible options for wastewater schemes;
- establishing (investment) priorities concerning wastewater facilities (in order to minimize pollution risks; highest pollution risks first);
- addressing the issue of wastewater reuse (where, when, acceptability);
- addressing the issue of sludge management (feasibility and acceptability); and
- integrating environmental protection and conservation aspects, among others the need for water resources protection.

The purpose of the wastewater master plan is to help decision-makers taking the right investment decisions. The wastewater master plan has to integrate all other landuse planning aspects which might affect it, such as future infrastructure projects, residential, commercial and industrial zones and extensions thereof, mining areas, as well as nature or water protection or conservation zones. By adopting such an integrated wastewater planning in an entire catchment area investment needs in the wastewater sector can best be prioritized and overall investment costs be reduced.

It is emphasized that there may be considerable differences between the extent of the surface water catchment and the groundwater catchment (herein referred to as the groundwater contribution zone).

The objective of both, the TC and the FC projects “Protection of Jeita Spring”, is to protect the drinking water resources of the Greater Beirut area in the Nahr el Kalb catchment. These are covered by the:

- Jeita spring (33°56’37.17”N, 35°38’30.78”E);

- Kashkoush spring (33°56‘33.98“N, 35°38‘20.45“E);

- (currently) 11 wells in the Nahr el Kalb Valley near Jeita and Kashkoush springs; and

- (currently) 3 wells near the Mokhthada diversion station (33°56’43.93”N, 35°37’23.80”E; approx. 1.9 km downstream of Jeita spring).

The groundwater contribution zones of those sources have not yet been determined, however preliminary results of investigations conducted thus far indicate that:

The groundwater contribution zone of the Jeita spring probably extends over the northern part of the Nahr el Kalb surface water catchment and possibly beyond said zone to the north and east. The TC project will try to confirm this hypothesis by means of tracer tests.

The groundwater contribution of the Kashkoush spring probably extends over the southern part of the Nahr el Kalb surface water catchment area. The TC project will conduct tracer tests to confirm this hypothesis. Since Kashkoush spring provides up to 25% of the water supply of the Greater Beirut area, it is included in the investigations of the TC project.

The (currently) five wells near Jeita spring are drilled to up to 200 m into the J4 horizon of the Jurassic. It is assumed that the related groundwater contribution zone is more or less identical with that of Jeita spring.

The (currently) six wells near Kashkoush spring are drilled to up to 200 m into the J6 horizon of the Jurassic. It is assumed that the related groundwater contribution zone is more or less identical with that of Kashkoush spring. During the rainy season these wells become artesian.

Currently three wells near the Mokhtada diversion station are used for drinking water supply. They are drilled to depths of up to m and exploit the C4 aquifer of the Cretaceous.

Another important water source in this context is the Faouar Antelias spring (33°54’34.03”N, 35°36’41.18”E). Since 2009, water from this spring is conveyed to the Dbaye drinking water treatment plant. The extent of the Faouar Antelias groundwater contribution zone is currently unknown. It is assumed that is covers part of the southern surface water catchment (Metn side) of the Nahr el Kalb. If this hypothesis is confirmed, it might be included in the work of the TC project. Faouar Antelias spring currently contributes up to around 20% of the water supply of the Greater Beirut area. The spring emerges from the J4 aquifer of the Jurassic.

It is suggested to draft the wastewater master plan in cooperation with the Ministry of Energy and Water (MoEW), the Water Establishment Beirut and Mount Lebanon (WEBML), the Department of Landuse Planning (under the Ministry of Public Works) and the municipalities in the catchment.

5 Selection Criteria for Wastewater Facilities in Karst Areas

Generally a number of selection criteria need to be considered in the site selection and design of wastewater facilities. They have to encompass all components of the facilities, namely the collector lines, the treatment plant and the discharge facility. A comprehensive wastewater management plan needs to address the following issues:

- Wastewater management in those areas which cannot be serviced by the planned wastewater facilities;
- Sludge management; and
- Wastewater reuse.

The special conditions in the Mount Lebanon area are highly problematic with respect to water resources protection. Problems especially arise from elevated risks associated with :

- landslide and rockfall formation;
- soil stability;
- tectonic movements and earthquakes;
- open karst, i.e. direct infiltration and;
- high degree of karstification, i.e. rapid infiltration and fast flow in unsaturated and saturated zone;
- flooding.

A matrix of criteria suggested by the TC project Protection of Jeita Spring to be used for site selection and design of wastewater facilities in the Nahr el Kalb catchment and elsewhere in Lebanon is attached as ANNEX 2.

The matrix is divided into :

- General criteria;
- Geological and hydrogeological criteria; and
- Cost related criteria.

6 Aspects to be covered by the BGR-Project Protection of Jeita Spring

According to the operational plan and the agreement with CDR and KfW, the involvement of BGR in the selection and design process for wastewater facilities will focus on all relevant geological and hydrogeological aspects. Those are:

Table 3: Aspects to be covered by the TC-Project and Means of Investigation

Issue	Means	Subject of investigation
Geology, tectonics, karst features	DEM, geological mapping, mapping of tectonic existing faults, direction/dip of faults, mapping of karst features/degree of karstification	rock type, dip direction/angle: - suitability of underground as a geological barrier (→ reuse areas), - landslide risk - rockfall risk - risk of vertical/horizontal movements causing rupture of WW conveyor lines or damages to WWTP structures (sites on active faults bear an elevated risk of damage)
Hydrogeology	Tracer tests, hydrological model, water balance, DEM, geological structure contour maps (top/base of geol. Units), maps of GW vulnerability and GW hazards, delineation of GW protection zones	- GW flow direction, flow velocity in saturated zone (travel time/path; → GW vulnerability, pollution risk) - thickness of unsaturated zone, travel time through unsaturated zone (→ GW vulnerability, pollution risk) - infiltration, GW recharge (→ GW vulnerability, pollution risk) - GW vulnerability - GW hazard inventory/map (wastewater and other hazards) - assessment of pollution risks - GW protection needs (→ delineation of protection zones)
Hydrology	DEM, meteorological stations, surface water runoff stations, hydrological model (flow accumulation)	- risk of flooding

Those investigations are underway and will be completed at the end of the first phase of the TC project. It must therefore be clearly stated that not all results of the BGR investigations (TC project) will be immediately available for the selection and design process for wastewater facilities, needed for the first and second phase of the KfW/CDR FC project. A close coordination of the TC project with CDR, KfW and the FC consultant concerning the FC project is therefore needed.

Most of the above-mentioned investigations are also required for the EIAs of the WW facilities.

In order to proceed with the FC project in a timely manner, the TC project will have to work with scientifically based assumptions, sometimes using worst-case scenarios.

Issues, which cannot be addressed by the BGR project but should be covered by the KfW/CDR consultant are:

Table 4: Aspects to be covered by the KfW/CDR Consultant and Means of Investigation

Issue	Means	Subject of investigation
Earthquake probability	analysis of previous earthquake events (location, depth, strength/effect), DEM	- likelihood to affect the facilities (sites near zones with high probability of earthquakes bear an elevated risk of damage)
Stability of geological underground	geotechnical study (e.g. using cone penetration tests/CPT), DEM	unstable underground (e.g. landslide material or alluvium) may need special foundation

Also some tracer tests would have to be conducted by the KfW/CDR consultant, if required, e.g. the tracer test proposed for Kfar Debbiane.

7 Preliminary Results of Hydrogeological Investigations conducted by the TC-Project

Three groundwater tracer tests have thus far been conducted and some more are planned, in order to determine:

- the flow velocities in the unsaturated zone of the Cretaceous and Jurassic rock units
- the groundwater flow velocities in both, the Cretaceous and Jurassic aquifers
- the flow path and connectivity in both, the Cretaceous and Jurassic aquifers
- the hydraulic connection between the Cretaceous and Jurassic aquifer
- the role of prominent karst features (dolines, sinkholes)
- the role of prominent tectonic features (major fault zones)
- the seasonal variability of flow velocities and flow paths

- the groundwater contribution zone to the main springs (equivalent to protection zone 3)

Details concerning tracer tests 1 (1A and 1B) and 2 (2A and 2B) are laid down in the technical reports prepared together with the University of Goettingen (**Annexes 3 and 4**). The results of tracer test 3 (injection of 15 kg Ns-naphthionate and 10 kg uranine on November 13, 2010, in the Khenchara sinkhole: 35.740971° E / 33.915956° N) are not included in this report and will be documented in a separate report.

7.1 Summary of Tracer Test 1

7.1.1 Objective of Tracer Test 1

The objective of tracer test 1 was to determine the suitability of the proposed location for WWTP-2 (near Deir Chamra; compare chapter 3). Effluent discharge options 1 and 2 have been investigated within the framework of tracer test 1.

The purpose of tracer test 1 was to:

- determine whether there is a hydraulic connection between the effluent discharge points (options 1 and 2) and Jeita spring and/or Kashkoush spring;
- determine the flow velocity between the effluent discharge points (options 1 and 2) and Jeita spring and/or Kashkoush spring;
- determine the flow velocities in the saturated and unsaturated zones;
- determine restitution of tracer (which gives an indication about possible losses of tracer or flow along the flowpath);
- determination of amounts of flow at different points along the possible flow path (in this case at Jeita Grotto and at Daraya tunnel/siphon terminale; which give an indication about possible gains or losses of flow along the flowpath).

The layout of tracer test 1 is documented in Figure 18.

Figure 18: Schematic layout of tracer test 1

7.1.2 Injection Sites

The tracer injection sites were located as close as possible to effluent discharge points, option 1 (injection site 1***, Test 1A-1***) and option 2 (injection site 2***, Test 1A-2***).

Table 5: Characteristics of Injection Sites

Site	East Coordinate [geographic WGS84]	North Coordinate [geographic WGS84]	Altitude [m asl]	Remark
1 – WWTP-2 effluent discharge option 1	35.72076	33.95396	571	Preexisting hole: 3.7 – 7 m depth 5 – 14 m length 6.2 m width Holding capacity approx.: 210 m³
2 – WWTP-2 effluent discharge option 2	35.71466	33.94356	525	Hole prepared by project: 3. . depth 3. . length 3. . width Holding capacity approx.: 12 m³

Injection site 1, Test 1A-1 (Figure 19)
5,000 g of uranine (MKT) was injected on 19-APR-2010, 12:11 p.m.
Flushing: 40 m³ immediately after injection of tracer, 20 m³ 20 h later (20-APR-2010, 08:00 a.m.).

Injection site 2, Test 1A-2 (Figures 20 and 21)
5,000 g of amidorhodamine G (=sulphorhodamine G; ORCO) was injected on 22-APR-2010, 03:59 p.m.
Flushing: 40 m³ immediately after injection of tracer.

Both substances have no negative toxicological impact on human health. Amounts detected at the monitoring sites (maximum 1.7 ppb) were well below the limit of visibility (30 ppb).

Figure 19: Injection site 1, *Test 1A-1* (during injection of uranine)

Figure 20: Injection site 2*, Test 1A-2* (before preparation of site)

Figure 21: Injection site 2, *Test 1A-2* (during injection of amidorhodamine G)

Tracer test 1B was conducted between Daraya tunnel (seen monitoring stations, below) and Jeita (+500). On 28-APR-2010 11:42 424 g of uranine (MKT) was injected.

7.1.3 Monitoring Sites

Table 6: Characteristics of Monitoring Sites

Site	East Coordinate [geographic WGS84]	North Coordinate [geographic WGS84]	Altitude [m asl]	Remark
1 – Daraya tunnel/siphon terminal	35.69080	33.95142	~ 140	end of weir @ gallows
2 – Jeita Grotto	35.64858	33.94616	~ 65	500 m upstream of entrance
3 – Kashkoush spring	35.63783	33.94397	~ 55	control room @ ladder, 165 m downstream of spring
4 – Nahr el Kalb	35.64285	33.94324	60	river 20 m upstream pumping station

Monitoring site 1

After near-vertical passage through the unsaturated zone, flow in the saturated zone was assumed to be directed in westerly direction towards Jeita spring. The nearest place to the injection site where groundwater can currently be monitored is the so-called ‘siphon terminal’. It can be accessed from the ‘Daraya tunnel’ (described in HAKIM et al. (1988); Figure 22). The siphon terminal marks the eastern endpoint of the explored flow path in the Jeita Grotto (Figure 18). This monitoring location is referred to in this report as ‘Daraya tunnel’.

An Albillia GGUN FL30 fluorometer with optics I, II and V (Figure 23) was permanently installed at the end of the discharge monitoring weir (Figure 24) on 15-04-2010, 02:44 p.m. Data acquisition interval was set to 2 minutes. The recovery of recorded data from this station was 100%.

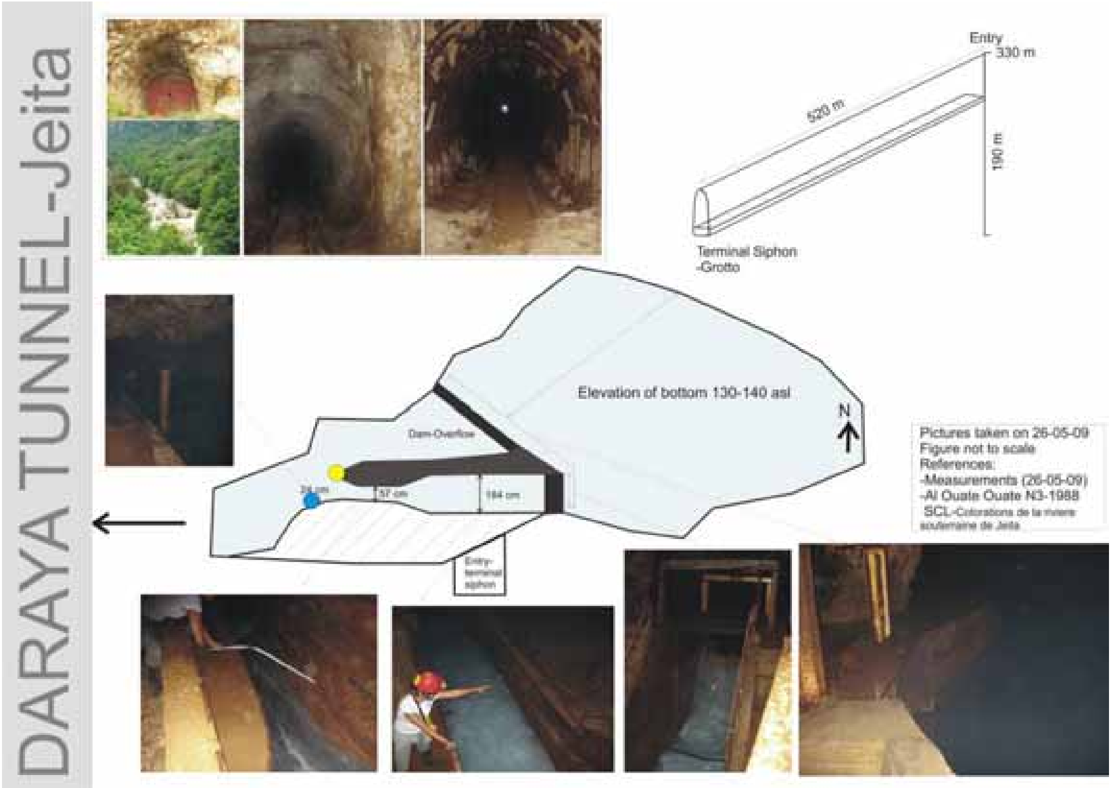

Figure 22: Daraya tunnel leading to siphon terminal, the endpoint of the explored part of Jeita Grotto

(🟡 fluorometer; 🔵 water level logger)

Figure 23: Albillia GGUN FL30 fluorometer used for detection of tracers

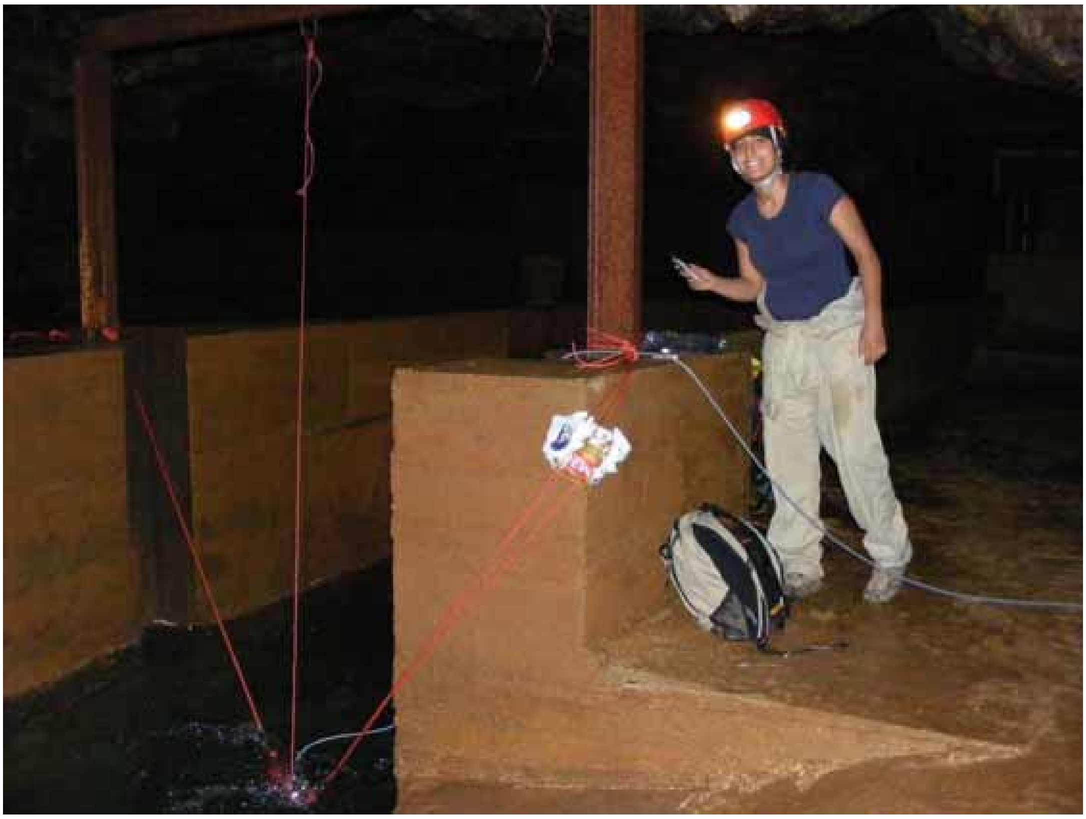

Figure 24: Monitoring of tracers at monitoring site 1 (siphon terminal / Daraya tunnel) with mobile Albillia fluorometer GGUN FL30

Monitoring site 2

The explored flow path in the Jeita Grotto (Figure 18) finally leads to the Jeita spring. This entire flow path is 5,600 m long. At 500 m from the emergence of the Jeita spring, some 200 m east of the point until where touristic visits are allowed, another Albillia GGUN FL30 fluorometer with optics I, II and V was permanently installed in the center of a 6 m wide section on 18-04-2010, 10:44 a.m. (Figure 25). Data acquisition interval was set to 2 minutes. Due to the failure of the CF data-card the recovery of recorded data from this station was incomplete (see below).

Manual samples were taken from 20-04-2010, 15:00 to 27-04-2010, 10:00 at a time interval of 1 hour.

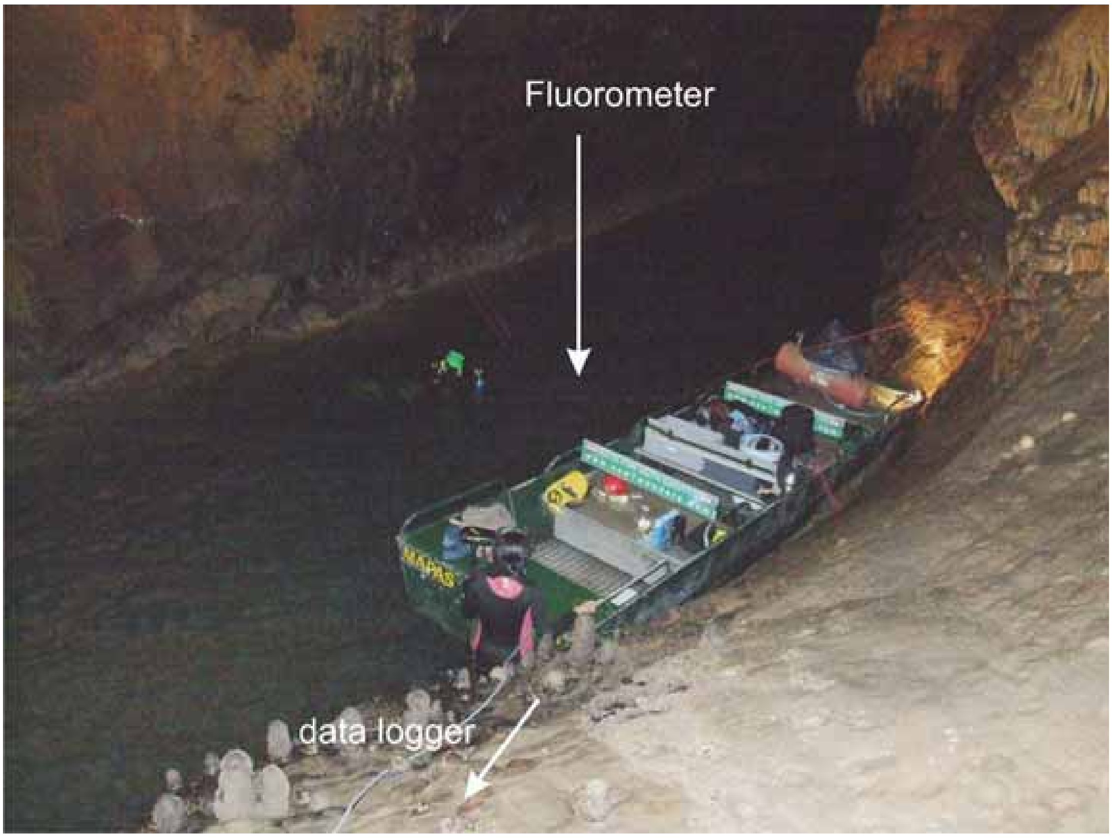

Figure 25: Monitoring of tracers at monitoring site 2 (Jeita Grotto) with mobile Albillia fluorometer GGUN FL30

Monitoring site 3

When preparing the concept for tracer test 1, it was assumed that another possible flow path from either of the injection sites might lead towards Kashkoush spring (Figure 26), located some 350 m downstream of Jeita spring. The monitoring site is located in the control room, which is 165 m NNW of the spring itself.

An Albillia GGUN FL30 fluorometer with optics I, II and III was permanently installed in the control room of the spring, on the northern side of a 2 m wide section on 22-04-2010, 10:11 a.m. Data acquisition interval was set to 2 minutes. The fluorometer was taken out on 27-04-2010, 07:02 a.m. to measure discharge at Nabeh al Assal, Nabeh al Labban and to measure the tracer content of the manual sample. During the monitoring period, recovery of recorded data from this station was 100%. The fluorometer was put back in position on 30-04-2010, 09:22 a.m. and recordings were continued at 2 minute intervals until 05-05-2010, 01:42 p.m.

Manual samples were taken at Kashkoush spring (near radar sensor in control room) from 20-04-2010, 15:00 to 27-04-2010, 10:00 at a time interval of 1 hour.

Figure 26: Location of monitoring site 3, Kashkoush spring

Monitoring site 4
Monitoring of the surface water at Nahr el Kalb is also important because, especially during high flow periods, part of the discharge from the groundwater system might occur as seepage in the lower Nahr el Kalb valley, near Jeita Grotto.

Therefore manual samples were taken from 20-04-2010, 15:00 to 27-04-2010, 10:00 at a time interval of 1 hour in Nahr el Kalb, 20 m upstream of the pumping station of WEBML (Figure 26). There was no influence from inflow of Jeita spring water into Nahr el Kalb at this location.

7.1.4 Results

From Test 1A-1, the injection of uranine at the proposed WWTP-2, the tracer uranine arrived at monitoring stations Daraya and Jeita (Figure 27) but not at Kashkoush. There are indications for an arrival of the tracer at Nahr el Kalb, however at low concentrations, which due to the high turbidity are not unambiguous. Test 1A-1 proved a direct hydrogeological connection between this location and Jeita spring (Annex 3). Although not all tracer arrived, probably due to the design of the injection point (injection in alluvial sediments of unknown thickness), this test shows that if treated wastewater would be discharged at this point it would arrive at Jeita spring. In case treatment is incomplete or wastewater must be bypassed for any reason, this would result in a severe contamination of Jeita spring so that the situation would be even worse than it is now.

Test 1A-2, injection of amidorhodamine G at Abu Mizane, was not successful. No arrival of tracer substance was recorded at any of the monitoring stations. The reason probably is the choice of injection site in alluvial sediments which are probably too thick and clayey and did not allow a quick infiltration of the tracer and percolation to the aquifer. It was intended to repeat this test. However, this could not be done until now.

For the above reason it is strictly recommended not to construct a WWTP at the intended location. In case the options of constructing a pipeline from the proposed WWTP-2 in Nahr el Kalb (options 1 or 2) are pursued it is advised to repeat Test 1A-2 (Abu Mizane) through the CDR/KfW consultant.

Table 7: Summary of Tracer Test 1A-1, Injection of Uranine at the Proposed WWTP-2

	Daraya	Jeita (+500) fluorometer	Jeita (boat mooring) manual samples
Flow (m^3/h)	3.6	5.6	5.6
distance from point of injection (m)	2700	7500	8000
first arrival (hours after injection)	44	50	51
mean arrival (hours after injection)	56	-	62
peak arrival (hours after injection)	59	64	64
restitution (%)	13	incomplete records	14

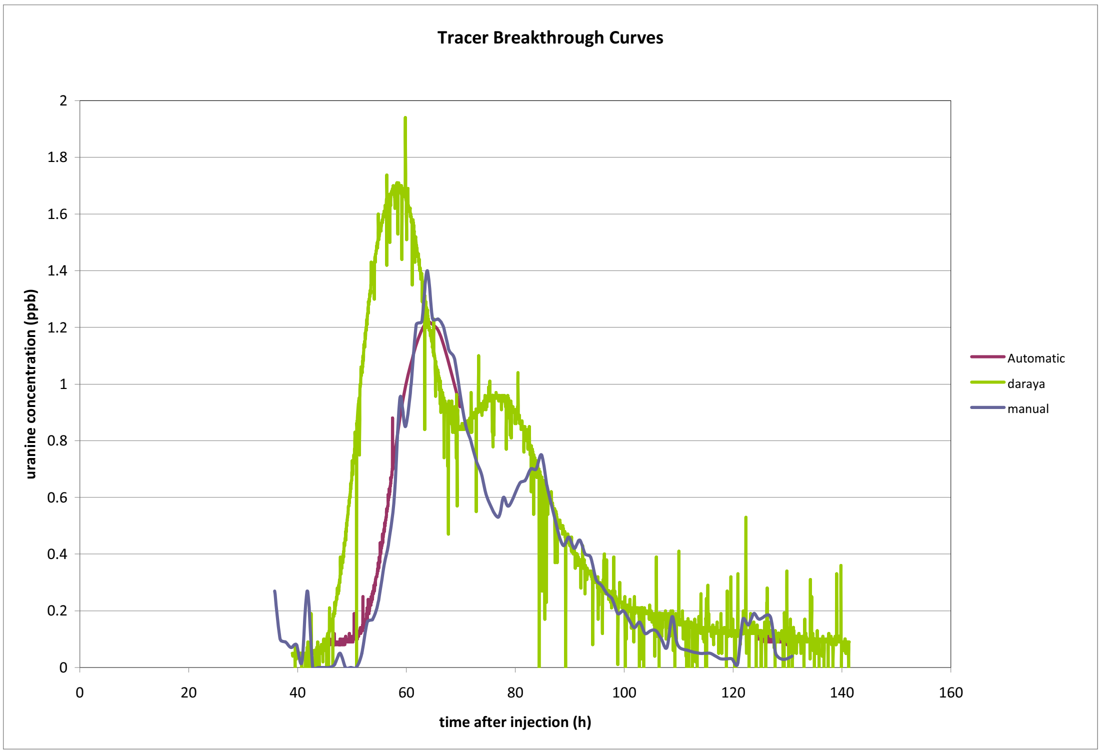

Figure 27: Tracer Test 1: Breakthrough Curves of Uranine Tracer Monitored at Daraya Tunnel, Jeita (+500 = automatic), Jeita (touristic entrance = manual)

Tracer Test 1B, injection of uranine at the end of the explored part of Jeita cave, at Daraya tunnel, showed a fast passage of groundwater in the saturated zone. Mean travel time between both points was 5 h 46 min (Figure 28). Mean flow velocity in the unsaturated zone thus was 630 m/h. Later tests conducted between those two points show that this travel time is highly varying throughout the year:

Table 8: Tracer Tests Conducted between Daraya Tunnel and Jeita

Date & Time	Flow (m^3/s)	Mean Travel Time (h:min)	Mean Flow Velocity (m/h)	Tracer & amount (g)
28-APR-2010	6.0	6:16	630	Uranine (424)
10-AUG-2010	1.7	11:10	354	Uranine (7)
17-AUG-2010	1.76	11:12	353	Uranine (10)
30-AUG-2010	1.43	11:29	344	Uranine (7)
24-NOV-2010	1.03	17:42	223	Uranine (10)
13-JAN-2011	3.4	7:14	546	Uranine (20)
31-JAN-2011	18.8	2:49	1882	Uranine (50)
02-FEB-2011	8.7	4:39	1140	Uranine (50)
04-FEB-2011	8.4	4:24	1205	Uranine (50)
06-FEB-2011	7.1	4:15	1247	Uranine (50)

Date & Time	Flow (m^3/s)	Mean Travel Time (h:min)	Mean Flow Velocity (m/h)	Tracer & amount (g)
09-FEB-2011	5.2	4:55	1078	Uranine (30)
17-FEB-2011	8.4	3:50	1383	Uranine (60)
20-FEB-2011	6.1	4:38	1144	Uranine (30)
21-FEB-2011	76	2:44		Uranine (100)
22-FEB-2011	15.9	4:12	1262	Uranine (60)
27-FEB-2011	25.5	2:47	1904	Uranine (100)
28-FEB-2011	19.9	3:04	1728	Uranine (55.84)
01-MAR-2011	14.8	3:14	1639	Uranine (51.75)
Min	1.0	2:47	223	
Max	25.5	17:42	1904	

The incomplete recovery of injected mass during Test 1B might indicate that part of the groundwater encountered at Daraya does not go to Jeita but takes another pathway. This hypothesis is, however, not supported by the flow measurements, which seem to indicate that flow is gained on the pathway from Daraya to Jeita. In order to solve this riddle, flow measurements and small tracer tests will be done along the flow path during the low flow period.

Table 9: Summary of Tracer Test 1B, Injection of Uranine at Daraya Tunnel

	Jeita (+500) fluorometer
flow (m^3/h)	5.6
distance from point of injection (m)	3950
first arrival (hours after injection)	5:30
mean arrival (hours after injection)	5:46
peak arrival (hours after injection)	5:42
restitution (%)	51

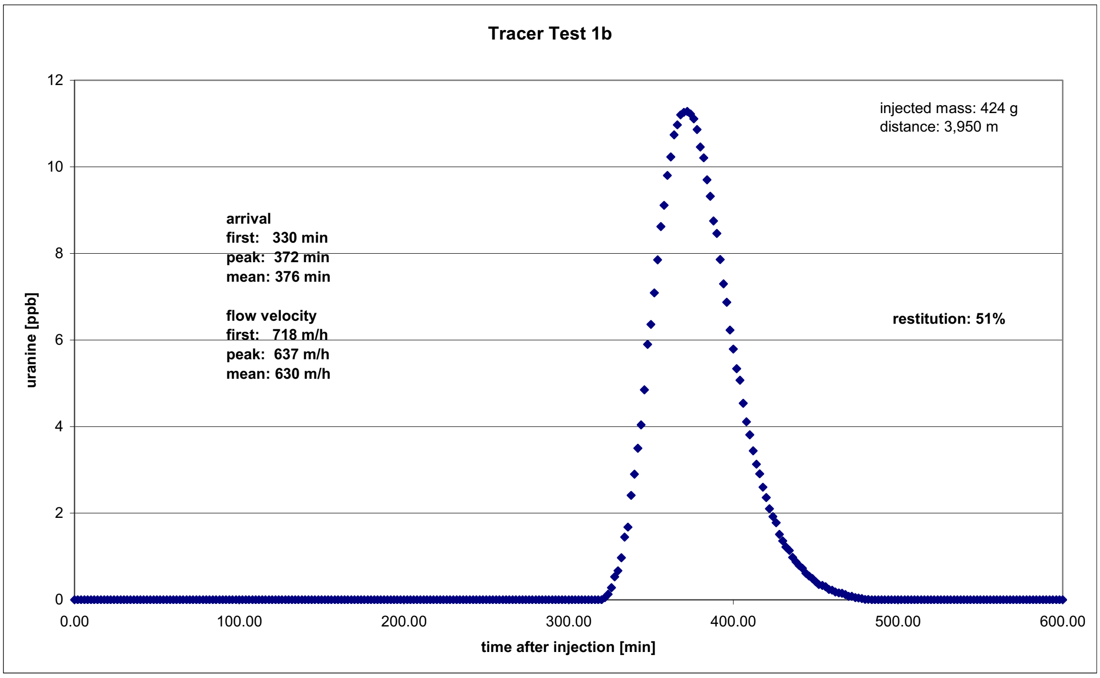

Figure 28: Breakthrough Curve of Tracer Test 1B

The arrival of uranine in Nahr el Kalb could indicate that (at certain times) some water leaves Jeita Grotto and enters Nahr el Kalb by an unknown pathway.

Detailed results of tracer tests 1A-1, 1A-2 and 1B are laid down in ANNEX 3.

7.2 Summary of Tracer Test 2

7.2.1 Injection Sites

The overall layout of tracer test 2 is shown in Figure 32. Three individual tracer tests were conducted during this test:

Table 10: Injection Sites of Tracer Test 2

Site	East Coordinate [geographic WGS84]	North Coordinate [geographic WGS84]	Altitude [m asl]	Remark
1 – Aajaltoun, fault zone (Test 2A-1)	35.70003	33.96811	853	Dug hole in alluvial sediments: 1.5 m depth

Site	East Coordinate [geographic WGS84]	North Coordinate [geographic WGS84]	Altitude [m asl]	Remark
				3 m length 3 m width Holding capacity approx.: 10 m³
2 – Ballouneh, cess pit (Test 2A-2)	35.67094	33.95063	652	Preexisting hole (cess pit for new house): 3 m depth 20 m length 3-4 m width
3 – Aajaltoun Valley (Test 2B), sinkhole Ras el Astar near housing project	35.68468	33.95321	654	Sinkhole (mapped by SCL)

Injection site 1, Test 2A-1 (Figures 29)
9,233 g of uranine (MKT) and 9,084 g of Na-naphthionate (MKT) were injected on 02-AUG-2010, 12:50.
Flushing: 60 m³ of water immediately after injection of tracer over approx. 75 minutes.
Injection site 2, Test 2A-2 (Figures 30)
5,749 g of amidorhodamine G (ORCO) was injected on 02-AUG-2010, 14:40.
Flushing: 60 m³ of water immediately after injection of tracer over approx. 75 minutes.

Injection site 3, Test 2B (Figures 31)
5,000 g of amidorhodamine G (ORCO) and Na-naphthionate (MKT) were injected on 20-AUG-2010, 11:40.
Flushing: 60 m³ of water immediately after injection of tracer over approx. 75 minutes.

Figure 29: Injection of Uranine during Test 2A-1 near Aajaltoun

Figure 30: Injection of Amidorhodamine G during Test 2A-2 in Ballouneh

Figure 31: Injection of Amidorhodamine G and Na-Naphthionate in a Sinkhole (Ras el Astar) during Test 2B near the Aajaltoun Valley Housing Project

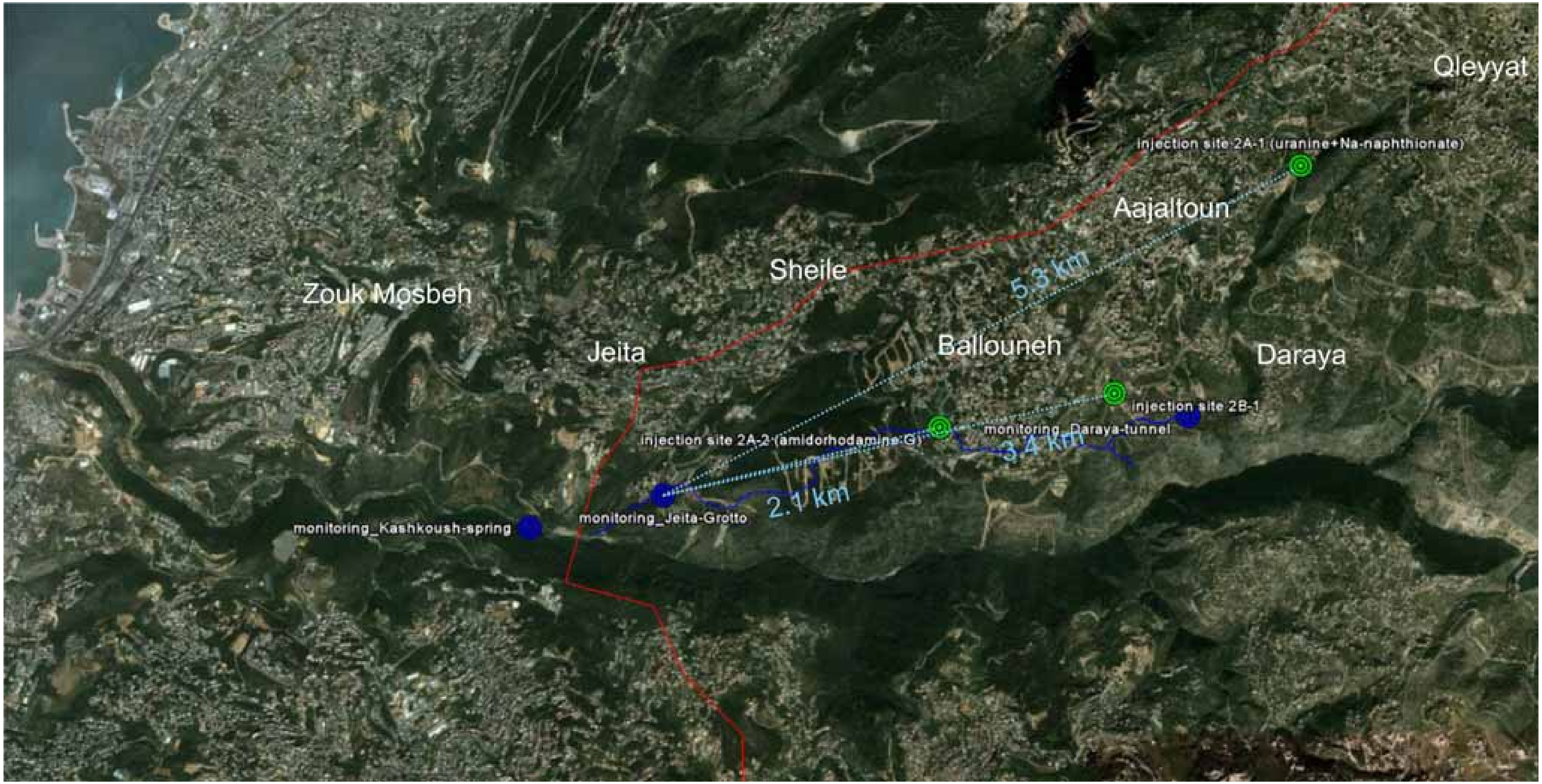

Figure 32: Setup of Tracer Test 2

7.2.2 Monitoring Sites

Table 11: Characteristics of Monitoring Sites

Site	East Coordinate [geographic WGS84]	North Coordinate [geographic WGS84]	Altitude [m asl]	Remark
1 – Daraya tunnel/siphon terminal	35.69080	33.95142	~ 140	end of weir @ gallows
2 – Jeita Grotto	35.64858	33.94616	~ 65	500 m upstream of entrance
3 – Kashkoush spring	35.63783	33.94397	~ 55	control room @ ladder, 165 m downstream of spring

For details of the monitoring sites compare Chapter 7.1.3 (Test 1). During Test 2A two fluorometers were installed at Daraya (instruments 526 and 532), two at Jeita (+ 500; instruments 525 and 533 on platform 1) and one at Kashkoush (instrument 531). For Test 2B instrument 526 was moved on 18-AUG-2010 to Jeita (+0 = touristic entrance). During Test 2A manual samples were taken at time intervals of 1 hour at all three sites. Monitoring was discontinued on 01-SEP-2010.

7.2.3 Results

Test 2A and 2B were conducted during the low flow period. No rain occurred during the monitoring period.

No tracer arrived at any of the three monitoring stations from injection sites 2A-1 and 2A-2. This, however, does not mean that there is no hydrogeological connection between the injection and the monitoring sites. The negative result is attributed to the extreme low flow conditions.

On the other hand Test 2B was successful. Both tracer substances arrived at Jeita (+500) after 16 h 40 min (first arrival). Test 2B thus proves a direct and fast hydrogeological connection of the Ras el Astar sinkhole to the Jeita spring. The Ras el Astar sinkhole is located approximately 240 m north of the trace line of the Jeita cave projected to the land surface and some 500 m downstream of the Daraya tunnel.

On 10-AUG-2010 a small tracer test between Daraya and Jeita was conducted. It showed, at a flow of 1.7 m³/s, a mean travel time of 11:10 h, resulting in a mean flow velocity of 354 m/h. With approximately 10 h 30 min travel time in the saturated zone (flow velovity in the upper part of the Jeita cave is higher than in its lower part), travel time in the unsaturated zone must thus be around 5 h during Test 2B.

Detailed results of tracer tests 2A-1, 2A-2 and 2B are laid down in ANNEX 4.

8 Previous Tracer Tests

Previous to the tracer tests conducted by the TC-project, two tracer tests were carried out in the Nahr el Kalb catchment.

8.1 Tracer Tests at Mayrouba

These tests were carried out between 1913 and 1923 in the upper part of the Jeita catchment in order to find out what share of the water discharging from the springs in the Cretaceous aquifer, Nabeh al Assal and Labban, infiltrates into the Jurassic aquifer. It was anticipated that when water from these springs was transferred to aqueducts supplying the villages in the upper part of the catchment, the amount available at Jeita spring might significantly decrease. These tests are documented in KARKABI (2009). The first tracer test had been conducted on September 6th, 1913 by Dr. Guiges from the French faculty of medicine. However documentation to this test has not yet been found. A second test was conducted on September 30th, 1913, when the amount of 20 kg uranine was released into Nahr es Salib (unknown location) by the 'concession'. The document reviewed by KARKABI (2009) indicates that the result was 'negative'. A third tracer test was conducted on November 6th, 1913, when the amount of 30 kg of uranine had been injected at Nabeh al Maghara in Mayrouba. Injection took place in Nahr es Salib near Mayrouba (exact location not mentioned) at 7 a.m. Water samples from Jeita spring were analyzed only for 25 hours (15 min intervals). The tracer, however, appeared (according to oral communication) on the morning of November 12th 1913, i.e. about 6 days after injection (exact first arrival time unclear).

On September 3, 1923, 43.6 kg of uranine was injected at 6 locations near Mayrouba, scattered over a stretch of 300 m along Nahr es Salib, which had been identified as places where losses in discharge occurred in or near the river. First reappearance of the tracer was noticed at 2 a.m. on September 10th, 1923, and remained visible until September 19th. Total restitution was given as 75%.

A comparable tracer test should be conducted for wastewater scheme 3, Mayrouba – Hrajel – Faraya (Chapter 9).

8.2 Tracer Tests at Siphon Terminal and Perte du Nahr es Salib

Altogether three tracer tests were conducted in the 1960 and early 1970s, as documented in HAKIM et al. (1988).

Two tracer tests have been conducted in July and September 1965, respectively, in the explored part of the Jeita Grotto to find out whether there are gains or losses along the course of the 'underground river'. During each of these tests 5 kg of uranine was injected at siphon terminal and at 2800 m upstream of Jeita spring, respectively. The result of this test had been negative, i.e. no gains or losses could be identified. First arrival of tracer was noticed 18 hours after injection.

A third tracer test had been carried out by means of injection of 5 kg of uranine at 300 m to the NNE of the confluence of Nahr el Salib and Nahr el Hardoun, thereafter forming Nahr el Kalb (148240 E, 224700 N, elevation: 440 m; Deir ez Zor, Syrian Levant 2) on July 12rd, 1971. This location is called perte de Nahr es Salib or perte de Deir Chamra. It had been noticed that during summer water completely infiltrated into Nahr es Salib at this location. Flow at the location of injection was 100 l/s, while discharge at Jeita spring was 2940 l/s. The straight line distance between these two points is 6150 m.

First reappearance or uranine was noticed on July 25th, 0:30 a.m., i.e. 29 hours and 30 minutes after injection. Water analyses were, however, done at rather long time intervals of 8 hours, only. Restitution was calculated as 24%. However, tracer restitution might be reduced because part of the tracer solution did not infiltrate at this location but was flowing into Nahr el Kalb.

9 Proposed Options for Wastewater Facilities

The current results of the hydrogeological investigations show that

- there is a direct hydrogeological link between Nahr es Salib and Jeita spring;
- groundwater moves very fast in the cave system (saturated zone);
- two thirds or more of the flow of Jeita spring come from the cave system east of Daraya;
- one third or less of the flow of Jeita spring enters the cave between Daraya (Jeita +4,800 m) and Jeita +500 m;
- infiltration in the unsaturated zone can be very fast, especially through sinkholes and where the high degree of karstification is high at the land surface;
- pollution risk therefore appears to be very high in the area over the cave system (projected from the trace line to the land surface) and approximately 500 m to each side (buffer zone); here measures to reduce the pollution risk should have a high priority with immediate effect;
- seasonal variations of flow velocities are high.

Concerning the planning of wastewater (WW) facilities in the Nahr el Kalb catchment the following facts have to be considered:

Construction of WW Facilities in High-Risk Areas

Protection zone 2 of Jeita spring can currently not yet be determined. It will comprise all areas with short travel times from land surface to Jeita spring. The above mentioned zone of high pollution risk will certainly be part of it.

Collection of wastewater for treatment outside this area should have highest priority in this zone. This zone comprises parts of the villages of Jeita, Ballouneh, Daraya, Aajaltoun, Qleyyat, Deir Chamra, Abu Mizane and Hemlaya.

Wastewater treatment plants, however, should not be located in this high-risk area. All wastewater related constructions in protection zone 2 have to avoid any leakage and infiltration into the underground. In this respect it is strictly recommended to surround wastewater collector lines and manholes by soil of low permeability (clay). The preliminary high-risk area is shown in Figure 33.

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

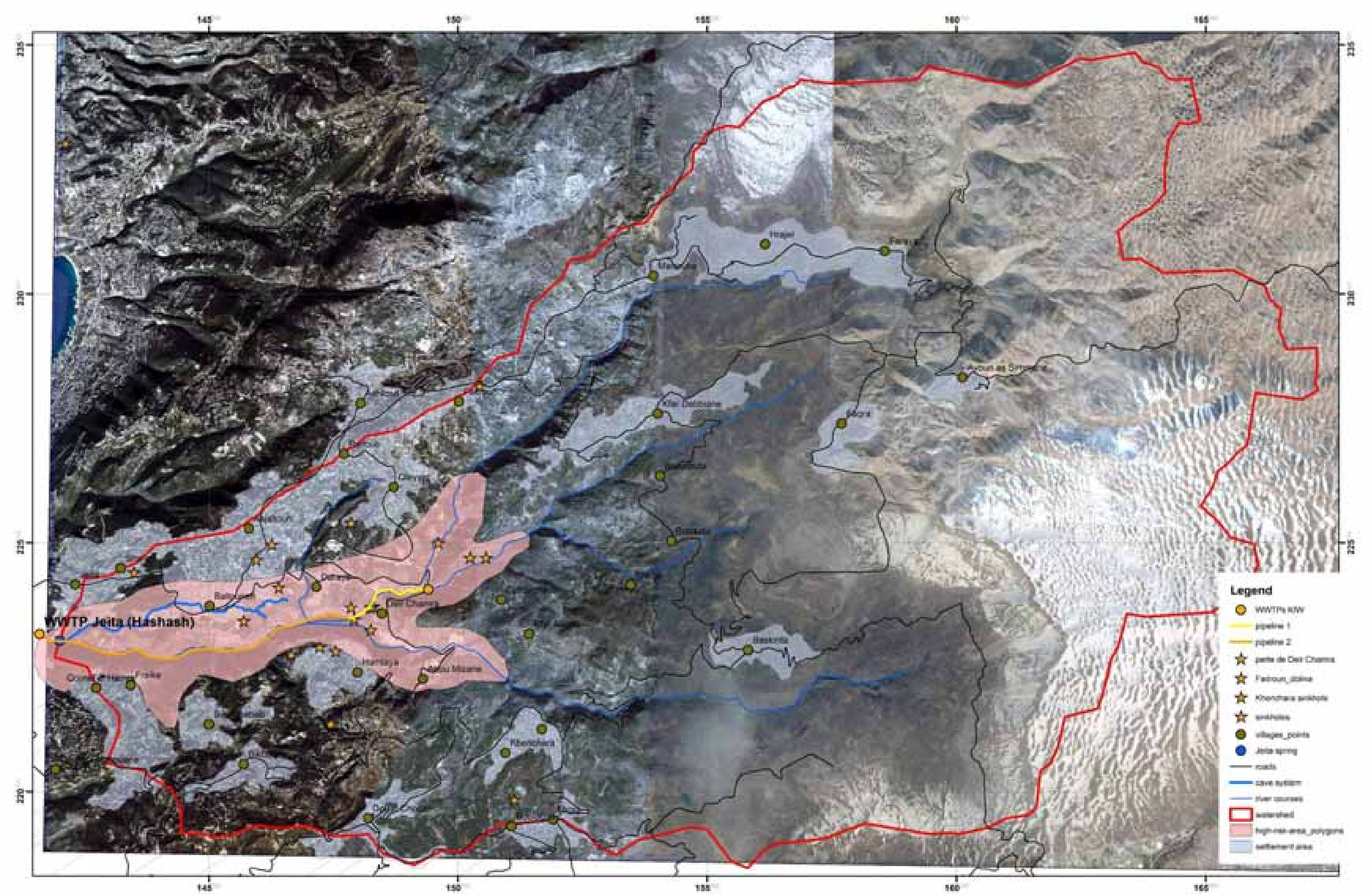

Figure 33: Area where the Pollution Risk for Jeita Spring is assumed to be high (preliminary)

Reuse of Treated Wastewater

Reuse of treated wastewater should only be allowed in villages where the thickness of the unsaturated zone is sufficiently high and/or the rock units underlying the areas where treated wastewater is considered to be reused are of low hydraulic permeability. This principally is only given at few residential areas, mainly located in the upper part of the Nahr el Kalb catchment, such as Kfar Debbiane, Boqaata, Bqaatouta, Kfartai, Baskinta, Faraya, Hrajel and Mairouba (often only the higher located parts of these villages). Detailed geological mapping by the BGR project is currently underway to determine the extent of areas where reuse of treated wastewater might be possible. A preliminary map of the potential area for reuse of treated wastewater is shown in Figure 34.

Sludge Management

At wastewater treatment plants (WWTPs) considerable amounts of sludge will accumulate. In case sludge should be used as fertilizer, it must be guaranteed that the chemical composition of the fertilizer is not hazardous to the environment. Sludge will need to be treated accordingly at a location where this is can safely be done without causing harm to environment and water resources (an additional EIA for this component will be needed).

In case sludge will not be used as fertilizer, sites for safe disposal will be needed. Such sites could only be built where disposal can safely be done without causing harm to environment and water resources (an additional EIA for this component will also be needed).

The project is currently preparing a best management practice guide (BMP) for wastewater management in Lebanon which will address reuse of treated wastewater and sludge management in Lebanon.

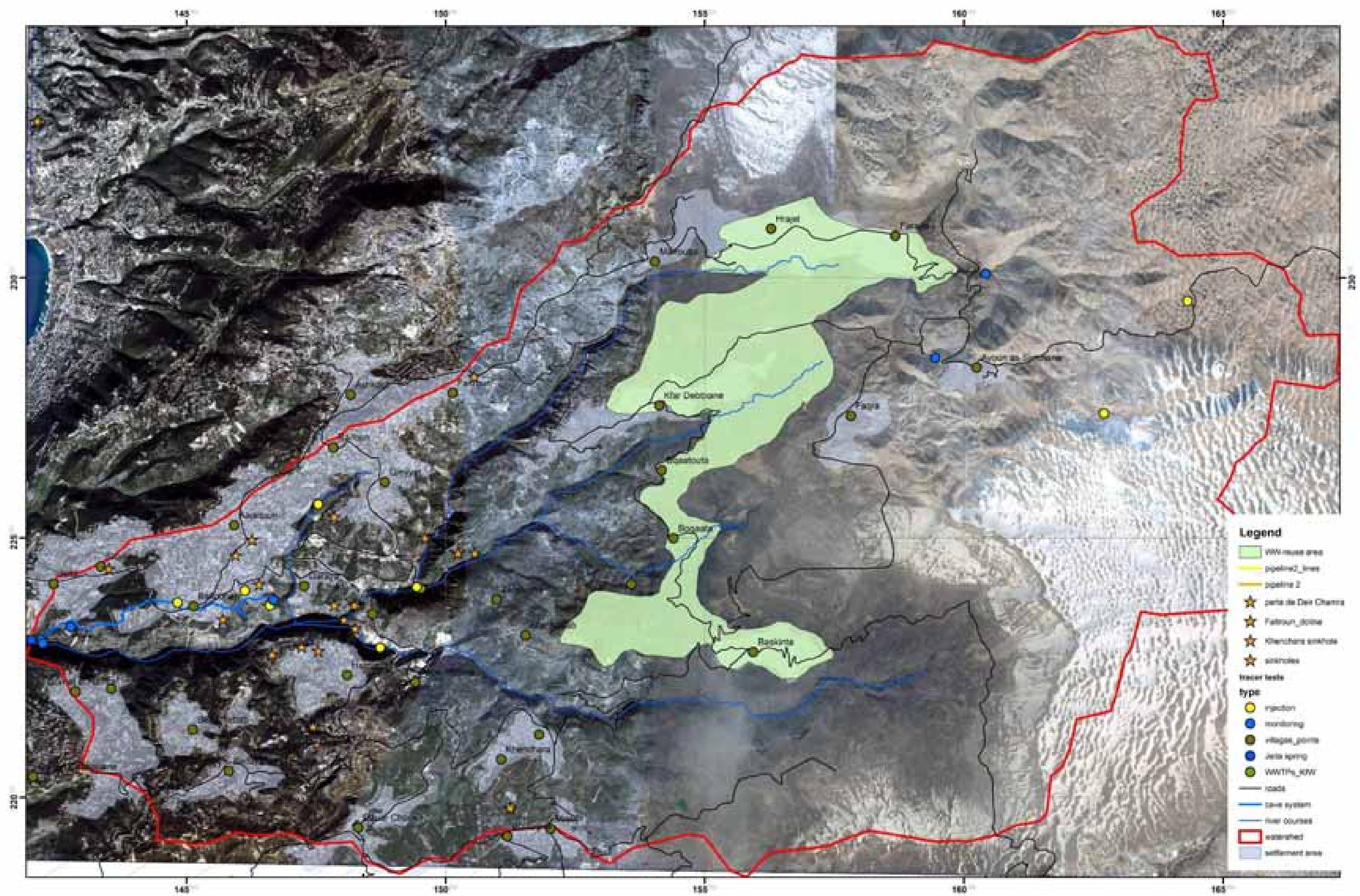

Figure 34: Proposed Area for Wastewater Reuse (preliminary)

Release of Treated Wastewater Effluent

After the treatment process wastewater is commonly released into a nearby watercourse. In case of overload or when certain components of the WWTP are not functional it may be necessary to bypass the treatment plant and release untreated wastewater. It must be made sure that treated wastewater is only released into the environment where it will not cause any harm to the environment and water resources and that a large enough storage for untreated wastewater is available so that bypassing will not be necessary under any circumstances. The selection of a safe effluent release location often is the most critical issue in the site selection process for wastewater facilities.

Option of a Wastewater Collector in Nahr el Kalb

Under the conditions prevailing in the Nahr el Kalb catchment, the option to collect all wastewater towards a topographically low point and convey it in the valley is objected by the author for the following reasons:

- the Nahr el Kalb valley constitutes a declared nature protection zone (Decree MinEnv);
- any leakage of untreated wastewater from such a pipeline will result in contamination of Jeita and/or Kashkoush spring;
- landslides or rock slides could severely damage the wastewater collector;
- although technically feasible, the construction of a wastewater conveyor along Nahr el Kalb valley would cause a severe environmental damage of this presently mostly untouched unique habitat;
- the collector would have to be built in a raised position, some 3 m above the bottom of the valley so that the construction could not be damaged by flashfloods; because of the almost vertical sidewalls of the valley this is not possible in many places;
- a service road, accessible all year round, and therefore also to be located in a raised position, would have to be built to allow for regular monitoring of leakage or damage and immediate repair.

Proposed Wastewater Schemes

Considering all of the above facts, collecting wastewater towards topographic low positions, i.e. to bring wastewater to Nahr el Kalb, bears the highest risk of groundwater pollution, is technically difficult and would be an environmental disaster. Decentralized wastewater treatment at locations in the river beds near the villages to be serviced will pose a severe risk to the water supply of the Greater Beirut area, based on Jeita spring, Kashkoush spring and several wells near those springs. The same is valid for a centralized wastewater treatment at the coast with wastewater conveyors constructed in the river beds. The risk of leakage from those pipelines and subsequent infiltration of insufficiently treated wastewater into the aquifer is very high and would most likely result in a bacteriological contamination of the drinking water resources even worse than it is now.

Therefore, from the perspective of optimal groundwater resources protection, the BGR project proposes three main wastewater schemes, which would keep wastewater at higher positions. Only for schemes two and three a wastewater reuse option could be considered.

Concerning the current planning of establishing a WWTP near the Kashkoush spring, it is recommended to drop this plan in favour of the suggested scheme 1. As mentioned above, WEBML is strongly opposing this plan because the WWTP would be too close to drinking water resources of Kashkoush spring, Kashkoush wells and the Jeita-Dbaye canal. Furthermore the Nahr el Kalb water is partly used for drinking purposes.

Scheme 1 (Jeita, Shaile, Ballouneh, Daraya, Aajaltoun, Qleyyat, Rainfoun, Ashkout and Faitroun)

The best option for the above mentioned villages would be to combine them into one single wastewater scheme (Scheme 1; Figure 35). Those villages are all located along the main road descending from Faraya to Zouk Mosbeh. The main wastewater collector should be constructed next to this road with smaller collector lines bringing all wastewater towards it. A WWTP should be built at the coast near the Zouk Power Plant, as is currently discussed for the EIB/AFD Keserwan wastewater project (LIBANCOSULT & HYDRATEC 2010).

In this respect it is strictly advised no to allow an extension of residential areas towards lower positions which could not be included later on into such a wastewater scheme, such as for example Ballouneh Park. Even when doing so some parts of this residential area will be difficult to service without installing pumping stations. Those areas are shown on Figure 36 but in terms of wastewater quantity should not constitute more than 15% of the total amount. Unfortunately many of these areas are located in or near the preliminary groundwater protection zone so that not properly addressing the issue of wastewater collection and treatment in them would pose a severe risk to the groundwater resources.

Wastewater should not be reused in this area since, from the perspective of pollution risk, it constitutes the most critical area and should have highest priority with regards to implementation of the WW scheme.

Concerning that part of the village of Jeita which lies within the Nahr el Kalb catchment and is considered a critical zone (Figure 36), collection of wastewater towards a point in Nahr el Kalb located downstream of Jeita and Kashkoush springs could be an option. However, because discharge of treated effluent into Nahr el Kalb upstream of Mokhada dam would be a risk for water supply (during late summer water from Jeita and Kashkoush springs is often diverted into Nahr el Kalb and then again diverted into the Jeita-Dbaye canal at Mokhada), discharge of treated effluent would have to be located downstream of Mokhada dam.

If this option is pursued it would be favorable to position the related WWTP on the way between Jeita and Nahr el Kalb. The reason for this is that in case of damage or leakage the impact on the drinking water resources would be less severe if the leaking wastewater would already be treated. The WWTP should not be located at Hachache because much of the valley in this area is already occupied by installations for drinking water supply (conveyor line Jeita-Dbaye, Kashkoush spring, Kashkoush wells). The valley is not large enough to house both, drinking water installations and a WWTP at the same location.

If the related WWTP would have to be located downstream of Mokhada dam a WWTP could be located either a) in Nahr el Kalb downstream of Mokhada or b) wastewater could be conveyed to the EIB/AFD WWTP at the EDL power plant in Zouk. The latter option would involve pumping. In any such case, the conveyors of untreated wastewater and drinking water in Nahr el Kalb would have to be strictly separated. It must technically be ensured that the wastewater conveyor cannot leak neither into Nahr el Kalb (because of the above-mentioned operation of the drinking water conveyance) nor into the Jeita-Dbaye drinking water conveyor.

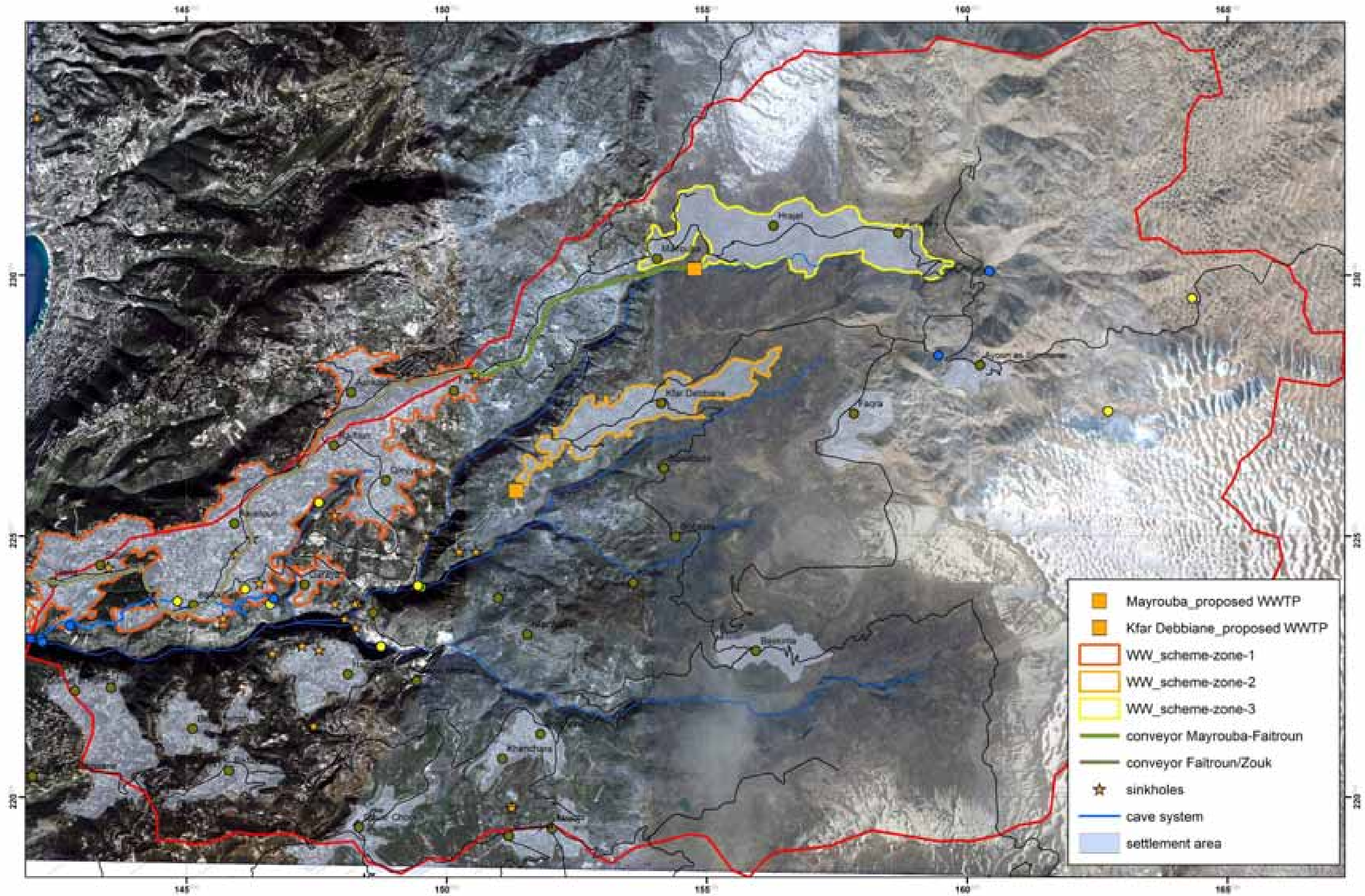

Figure 35: Proposed Wastewater Schemes in the Nahr el Kalb Catchment (Keserwan District only)

Figure 36: Critical Areas for Wastewater Treatment in Proposed Wastewater Scheme 1

In some municipalities wastewater collector lines (principal and secondary) have already been constructed (e.g. in Jeita). However, those may not fit with the new wastewater scheme. It is known that for instance in Jeita connections between pipelines and manholes were deliberately widened/damaged because the diameters did not fit, so that the wastewater networking is leaking. Such problems may exist in many places because the collector lines were built in several phases over a longer time period by different contractors.

Therefore before implementing any new wastewater scheme an inventory and inspection of the already existing network would first have to be done and the option of repair or modification thereof would have to be integrated in the new schemes.

Scheme 2 (Kfar Debbiane)

Conveying untreated wastewater from Kfar Debbiane to the proposed principal wastewater conveyor on the Faraya – Zouk Mosbeh road is not an option because it would involve pumping stations at several locations and thus be overly costly. In order to do so wastewater would first have to be pumped up to the main road in Kfar Debbiane (Figure 37, point 1: 1200 m asl), from there it must be pumped up to the highest point on this road at 1245 m asl (point 2), then it would flow by gravity down to the bridge crossing Nahr es Salib at 1130 asl (point 3). From there it would have to be pumped up to the roundabout near the al Husn and al Nassira monasteries at 1240 m asl (point 4) from where it could finally be connected to the principal collector of scheme 1.

The village of Kfar Debbiane is principally located near the area where treated wastewater may be reused and from the perspective of groundwater resources protection it would be optimal to reuse treated wastewater there (the thickness of the unsaturated zone is considered to be more than 500 m). The municipality is favoring this option but it would be important to have a commitment from the water users as well.

A suitable location for a WWTP in this respect would be available in the valley SE of the village (Figure 37; E 35.789547° / N 33.987030° / 1260 m asl).

However, the lowest point of this reuse command area is located at an elevation of approximately 1240 m asl while the lowest point of Kfar Debbiane currently is at 1130 m asl. The municipality plans to extend the village towards the W to even lower elevations of approximately 1000 m asl. Thus, treated wastewater would have to be pumped up from there to the reuse command area.

Considering all of the above facts, the best solution for Kfar Debbiane would be to treat wastewater in Kfar Debbiane. From the perspective of groundwater resources protection effluent discharge should be at locations as high as possible. Point 5 (E 35.740141° / N 33.969868° / 1110 m asl) shown on Figures 37 and 38 offers the most suitable solution in this respect. However, before selecting this location a tracer test should be done there in order to make sure that travel time to Jeita spring is long enough to incapacitate all microbiological constituents. Residential areas should not spread beyond this point to lower elevations because they may later on not be possible to be served with this WWTP. The distance of the proposed site from Jeita spring is about 10 km.

Part of the WW collector lines have already been constructed through funds allocated by the MoEW in collaboration with the municipality. However, this network is incomplete and was laid down on the assumption that the WWTP would be built at the location shown on Figure 37 (previously proposed WWTP: E 35.759546° / N 33.978715° / 1150 m asl).

For any new wastewater scheme the already existing network would first have to be inventoried, inspected and repaired or modified.

Reuse of treated wastewater downstream of the proposed WWTP is not an option because of the contamination risk.

The village of Bqaatouta has about 2000 inhabitants (KfW 2008a) and ranges in elevation between 1260 and 1400 m. Wastewater may be conveyed to the proposed Kfar Debbiane WWTP, however, this might need pumping because the lowest point on the road connecting the two villages is located at 1245 m (in the valley separating the villages) and this road then ascends to around 1300 m in Kfar Debbiane. This conveyor would have a total length of 7.4 km. The elevation profile for this conveyor is shown in Figure 39 (basis: Googel Earth with SRTM data). Because houses in Bqaatouta are dispersed over a large area, the better option may be to use septic tanks or small-scale bioprocess wastewater treatment systems for up to 100 persons each such as those locally produced and already installed at some places in the Nahr el Kalb catchment (e.g. in Jeita Grotto; www.polytech.cc, info@polytech.cc).

For the villages of Boqaata (max. 1500 inhabitants) and Kfartay (max. 1500 inhabitants), also originally intended to be included in the KfW proposal (KfW 2008a), the spacing between houses is even larger, so that building a wastewater network for these comparatively small villages must be considered uneconomic. Also here, the use of septic tanks or small-scale bioprocess wastewater treatment systems should be considered.

Options involving small septic tanks would require the availability of wastewater trucks emptying the septic tanks on a regular basis (approx. once a month) and taking the sewage to a WWTP where this kind of wastewater could be treated.

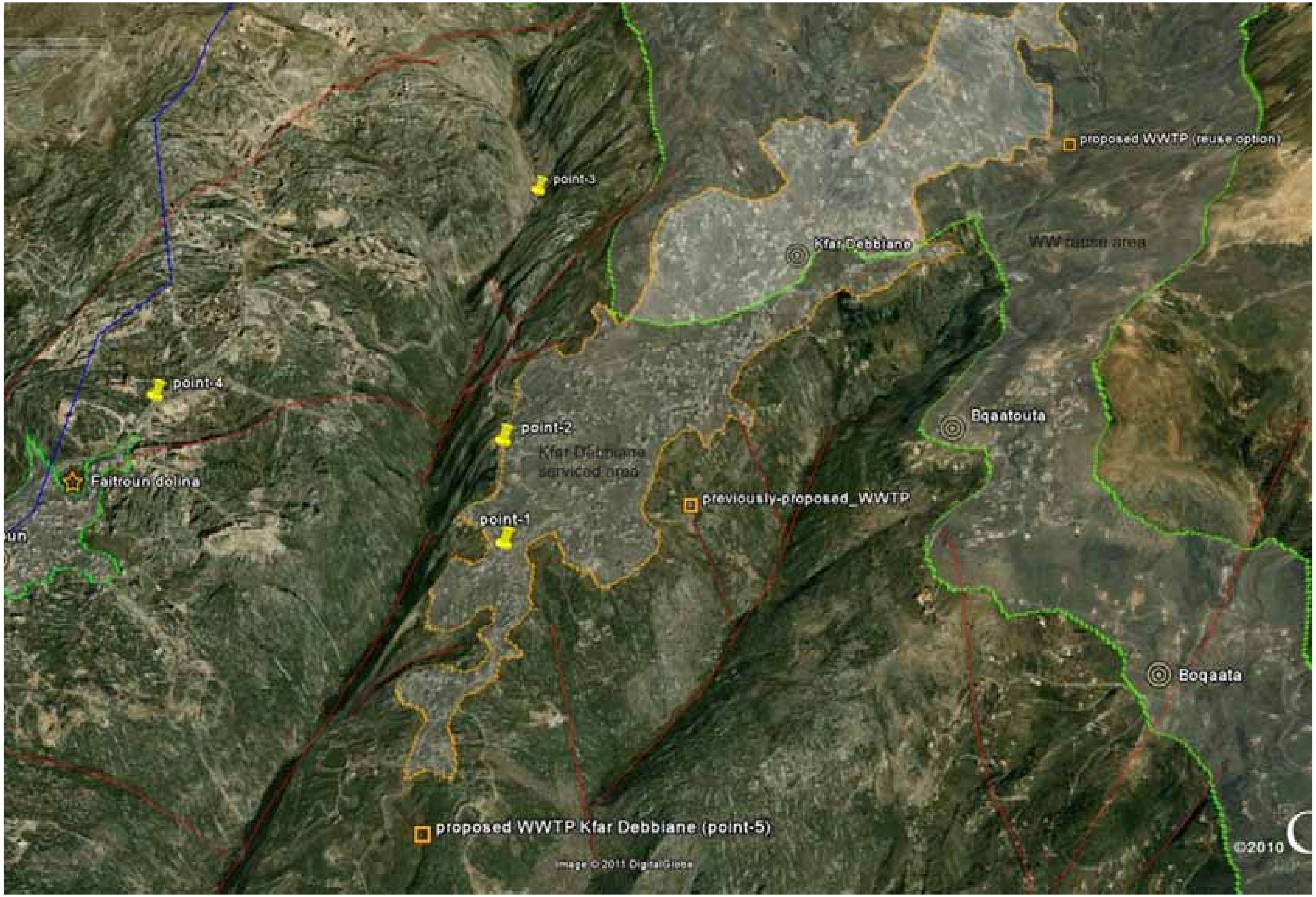

Figure 37: Wastewater Scheme Kfar Debbiane

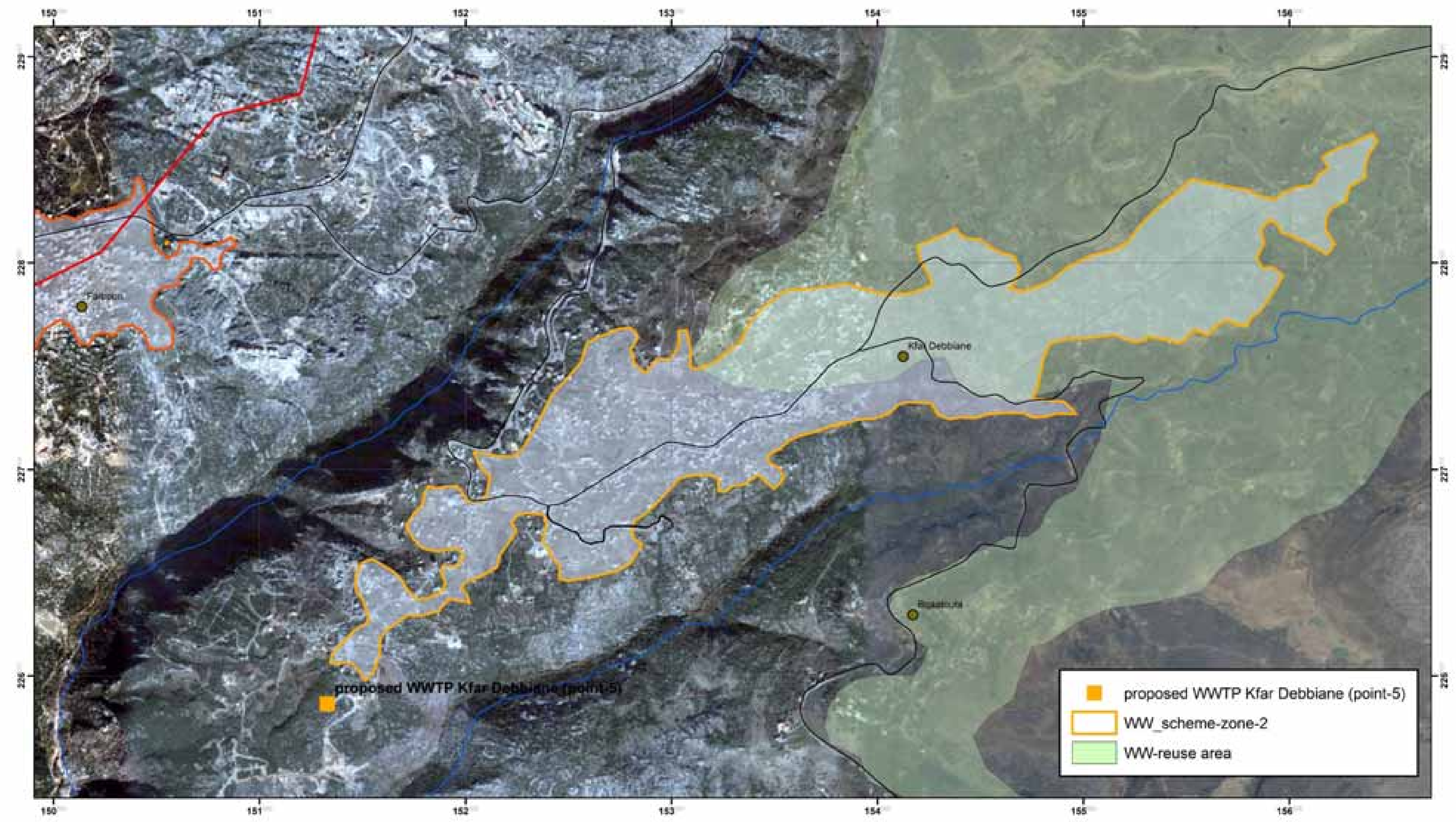

Figure 38: Proposed Location for Wastewater Treatment Plant in Kfar Debbiane

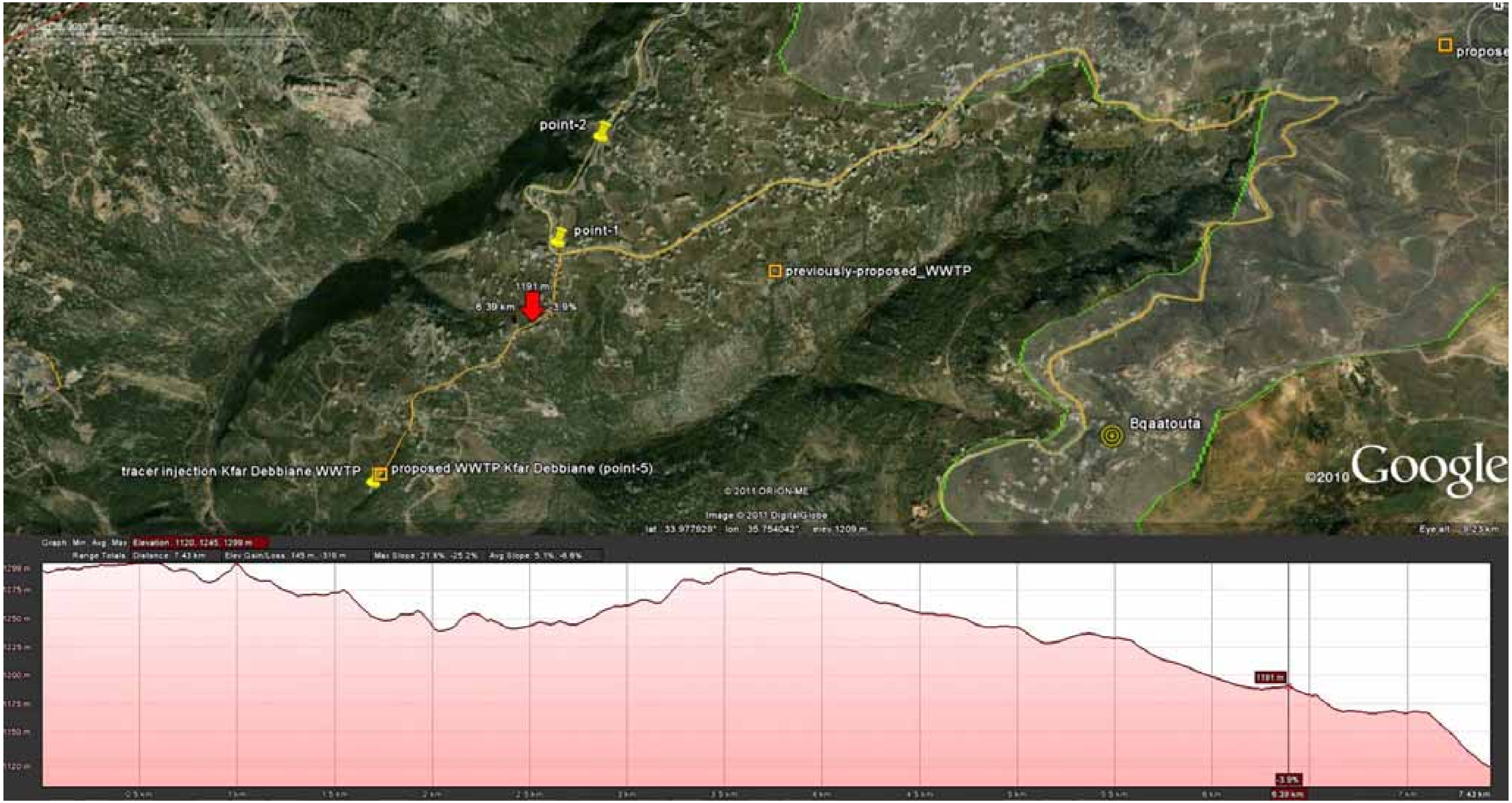

Figure 39: Trace Line and Elevation Profile along WW Conveyor Bqaatouta – Kfar Debbiane WWTP (left to right)

Figure 40: Map showing the Location of the Villages of Boqaata and Kfartay and the large Spacing between Houses

Scheme 3 (Mayrouba, Hrajel, Faraya)

Option-1

Also in much of this area (Figure 41) treated wastewater could principally safely be reused, since much of the area is located on less permeable rock units of the Lower Cretaceous and the Jurassic basalt. However, implementing the reuse option would require a commitment not only from the municipality but chiefly from the water users.

MoEW has started to construct a wastewater collector, which brings all wastewater to Nahr es Salib. This collector line follows the course of Nahr es Salib from Faraya (beginning of canal, point-1: E 35.822336° / N 34.014215° / approx. 1300 m asl) down to Hrajel (end of WW canal, point-2: E 35.794251° / N 34.010979° / approx. 1200 m asl). Thereafter it continues as a pipeline in the river bed approximately to the administrative boundary to Mayrouba, where it ends (assumed end of collector, point-3: 35.787839° / N 34.010240° / 1180 m asl). Currently thus untreated wastewater is released into the river bed (total length of collector line: 3.8 km).

The highest point of the area to be serviced is at 1430 m asl, the lowest at 1170 m asl (restaurant). In light of the topography there are not too many options for locating a WWTP site. Based on this criteria the optimal site would be at the place shown in Figure 41 (E 35.777179° / N 34.009530° / 1180 m).

However, as mentioned in Chapter 8.1, tracer tests had been conducted in Nahr es Salib near Nabeh al Maghara (November 1913) and Mayrouba (September 1923), close to the suggested site. During the first test the tracer arrived after around 6 days at Jeita spring. The second test was also positive and had a very high restitution, i.e. most of the tracer arrived at Jeita and not anywhere else. This means that treatment at this location must be ensured to meet the quality standards at all times.

Therefore the construction of a WWTP at this location would require the implementation of treated wastewater reuse. This, however, would require pumping the treated wastewater up to about 1350 m asl.

An alternative could be the conveyance of treated wastewater through a canal down to areas where it could safely be reused. There already exists an irrigation canal taking water from Nahr es Salib down to Jeita. However, farmer would possibly object to the idea adding treated wastewater to this canal, so that another canal would have to be built. Moreover, as shown in Figure x, there is no such reuse area downstream of Mayrouba.

If treated wastewater is to be discharged into Nahr es Salib at Mayrouba, it must be guaranteed that this water meets the standard for discharge of treated wastewater into rivers. A bypassing of untreated wastewater could not be accepted. Therefore the capacity of the WWTP must be large enough to treat all wastewater now and in the future at all times. Besides a generator to provide all needed energy for the treatment process at least one standby generator would have to be available.

Option-2

Another option would be to link the wastewater system of this scheme with scheme-1. For this purpose no WWTP would be built at the proposed WWTP site but a pipeline would have to be built from there to Faitroun (5.3 km) to connect scheme-3 with scheme-1. Untreated wastewater would have to be pumped up around 150 m to the main road (Figure 41).

The wastewater collection facilities already in place will need some intensive repair and modification, especially the stretch between the end of the canal (point 2) and the final end of the pipeline in the river bed (point 3).

It is recommended to reuse treated wastewater on the nearby irrigation areas (shown on Figure 41). For this purpose it would, however, have to be pumped up.

Figure 41: Wastewater Scheme Mayrouba – Hrajel – Faraya

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Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

ANNEX 1: Tasks of the Technical Cooperation Project "Protection of Jeita Spring

according to operational plan, dated 22 October, 2010

Output/Product 1: **Integration of water resources protection aspects into the investment planning and implementation process in the wastewater sector**
A1.1: Support of CDR and other institutions concerning wastewater projects (location of WWTPs, design, collector lines, effluent discharge locations)
KfW provides project with proposals for WWTP facilities (up to three preliminary site selections)
project determines suitability of proposed WWTP facilities for the KfW project, makes proposals for alternative solutions
CDR, KfW and project agree on (up to three) suitable sites for WWTP facilities
advise CDR on detailed site investigation (ToR; investigation carried out by KfW consultant)
review detailed investigation report and report back to CDR / KfW on quality of investigation and suitability of site
A1.2: Support of CDR concerning the preparation of EIAs for wastewater projects, with regards to their impact on the water resources
review existing EIAs, make proposal for improved EIAs, contribute to relevant chapters if applicable EIB, KfW, Italian Protocoll)
prepare standard outline and instructions for hydrogeological (HG) parts of EIAs together with CDR
after preliminary site selection for CDR/KfW site(s) prepare MoU with CDR concerning project role in EIA preparation
conduct and prepare HG parts of EIAs for CDR/KfW site(s) as per MoU
review draft EIAs for CDR/KfW site(s) and reach agreement on conclusions of report(s)
provide advice to CDR and consultants working for CDR/KfW in the acceptance procedure of EIAs (HG parts only)
support CDR in conducting seminars concerning the preparation of EIAs (water and protection related aspects only)
A1.3: Preparation of best practice guidelines (BMPs) for the implementation of wastewater projects with special consideration of the aspect of ground and surface water protection
review international and regional best management practice and related guidelines
prepare related best management practice guideline (BMP) together with CDR based on regional experience
sign MoU with CDR concerning implementation of BMP
promote implementation of best practice guidelines / seminar (disseminate information)

Output/Product 2: Integration of water resources protection aspects into landuse planning and improved spring capture and water conveyance
A2.1: GW vulnerability map, inventory of hazards to groundwater, determination of the GW pollution risks
compile relevant data (soil, climate, characteristics and thicknesses of rock units, mapping of karst features)
prepare vulnerability map and related report
prepare inventory and map of hazards to water resources and related report
assess risks of groundwater pollution
prepare monitoring concept for high-risk pollution hazards
inform concerned municipalities about related pollution risks and required changes in landuse practices
provide advice to municipalities concerning required changes in landuse planning (sensitive areas, how to avoid pollution)
A2.2: Delineation of groundwater protection zones
prepare detailed digital terrain model
collect information required for geological / tectonic / karst feature maps (using satellite images, aerial photographs, etc.)
collect information through field work
prepare structure contour maps (base of aquifers / aquitards) and cross sections
prepare geological / tectonic / karst feature maps
conduct tracer tests and prepare related reports
compile data on extent of cave system
determine range of influence (including its temporal variability) on cave system
determine groundwater flow paths and travel times in saturated and unsaturated zones
establish all relevant components of the water balance
compile groundwater quality and flow data
compile isotope data (groundwater residence time)
compile hydrogeological information and prepare hydrogeological report
delineate protection zones 1 / 2 / 3 and prepare related report(s) (information then also used in landuse planning)
prepare list of landuse restrictions in protection zones 1, 2, 3
prepare MoU concerning acceptance of protection zone delineation
provide information on extent of GW protection zones to landuse planning institutions (dissemination of information)
A2.3: Support of the relevant governmental institutions in implementing the proposed protection zones and urgent protection measures
prepare information material on the need for groundwater protection for different campaigns (schools, universities, churches, media) (flyers, broshures, posters, internet site)

Output/Product 2: Integration of water resources protection aspects into landuse planning and improved spring capture and water conveyance
establish information point at Jeita spring (with KfW) on GW protection for Jeita spring
implement information and awareness measures on groundwater protection and support local NGOs in awareness raising initiative targeting children and youth
conduct jour-fixe meetings with environmental fund of GTZ
A2.4: Proposal for an improved capture of the Jeita Spring with the aim to reduce the risk of pollution
review current status and pollution risk of spring capture
prepare proposal for improved spring capture; prepare ToRs and negotiate institutional arrangements for construction, operation & maintenance costs
A2.5: Proposal for an improved water conveyance system from the Jeita Spring to the Dbaye treatment plant with the aim to reduce the risk of pollution
investigate status of conveyance system and potential pollution risks
prepare proposal for improved conveyance system

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

Output/Product 3: **Establishment of monitoring system**
A3.1: Establishment of a monitoring network concerning water quality and available amount of water at strategic points in the catchment
arrange stakeholder meeting for GW monitoring (LRA, MoEW, CDR, WEBML)
plan and establish monitoring network for groundwater quality at all major springs (early-warning system)
plan and establish monitoring network for amount of groundwater flow at all major springs (optional)
plan and establish climatic monitoring network (to be transfered to National Meteorological Service)
plan and establish monitoring network for surface water runoff (optional)
provide advice for the establishment of a monitoring network for effluent quality at WWTP discharge sites
A3.2: Establish database for water quality/quantity data
prepare hard and software for database
compile and analyze existing data
training the laborartory staff of WEBML in the use of database
institutionalize use of database
A3.3: WEBML response system
review of water quality control and response system at Dbaye treatment plant and identify gaps
review possibilities to respond to peaks of pollution from different sources (change of treatment technique or change of water source)
propose and develop appropriate response system
agree with WEBML on implementation
implement system
test system using fake alert
capacity building on response system for Dbaye treatment station staff

ANNEX 2: Criteria for Site Selection and Design of Wastewater Facilities in the Nahr el Kalb Catchment

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source	Responsibility
General Criteria							
number of inhabitants to be serviced (capacity)	xxx	xxx	xxx		financial feasibility	municipalities	KfW
WW facilities used for domestic, industrial, commercial WW	x	x	xxx	xx	integration of industrial and commercial WW will require special treatment	decision/agreement needed which to include	KfW
planned extension of residential /industrial / commercial areas (landuse plan)	xx	xx	xx		WW planning must be coordinated with landuse planning authorities	municipalities / Landuse Planning Dept.	KfW
population growth rate	xx	x	xx			municipalities / Landuse Planning Dept.	KfW
planning horizon	x	x	xx				KfW

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source	Responsibility
material to be used (by law / regulation; appropriate ?)	xx	xx	xx		material must be appropriate to support geological/tectonic stresses, temperature, pressure, etc.	determine appropriate material for each condition	KfW
existing network (location / diameters / material / design)	xxx	x	xx		previous concepts must fit with new concepts	compile location/condition/diameter/material of existing network	KfW
character of WW (composition, including seasonal variability)		xx	xxx		amount of sludge; reuse potential of sludge (limited if industrial WW is treated and treatment method does not ensure complete removal of all hazardous substances)	chemical analyses	KfW
topography (which (parts of) villages can be connected / combined ? Where have primary / secondary collector lines to be laid down ? pumping required ? when / where ? Can collector lines follow roads / existing	xxxx	xxx	xxx	xx	pumping costs should be minimized / avoided	establish detailed DEM, determine optimal trace lines of primary/secondary conveyors; discuss with municipalities	KfW & BGR (DEM)

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source	Responsibility
infrastructure ?)						(land ownership)	
land ownership (need for expropriation ?)	xx	xx		xx		cadastre map (not up-to-date)	KfW
local acceptance	x	xx		xx	must be discussed with involved mayors of municipalities	local awareness campaigns	KfW
existing (nature / groundwater /surface water / forestry / wildlife) protection / conservation zones	xxxx	xxxx	xxxx			compile info from all related agencies	KfW & BGR (GW protection zone)
existing infrastructur (roads; access / accessibility)	xxx	xx	xx			compile related info	KfW
availability & amount of energy to be needed	xxxx	xxx	xxxx		effluent discharge by gravity or pumping required for reuse ?	compile/assess related info	
Geological and Hydrogeological Criteria							
geology (rock type, underground as a barrier, dip direction/angle)	xx	xx			if natural geological barrier is existing, it should be used	geological mapping	BGR

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source	Responsibility
stability of geological underground	xxx	xxx	xxx		unstable underground (e.g. landslide material or alluvium, may need special foundatation	geotechnical study (e.g. Using cone penetration tests/CPT)	KfW (& BGR)
landslide / rockfall probability / likely effect	xxx	xxx	xxx		damages by landslides or rockfalls must be avoidded	geological mapping	BGR
tectonics (existing faults, direction)	xxxx	xxxx	xxxx		sites on active faults bear an elevated risk of damage	geological mapping	BGR
earthquake probability (likelihood to affect the site)	xxxx	xxxx	xxxx		sites near zones with high probability of earthquakes bear an elevated risk of damage	analysis of previous earthquake events (location, depth, strength/effect)	KfW (& BGR)
groundwater flow direction / flow velocities	xx	xxx		xxx	high GW flow velocities (even if only seasonal) bear a high pollution risk	tracer tests	BGR/Uni GÖ / KfW
thickness of unsaturated zone / flow velocity in unsaturated zone	xxx	xxx	xxx	xxxx	leakage loss from network; reuse possibility	tracer tests	BGR/Uni GÖ GÖ / KfW

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source	Responsibility
infiltration / GW recharge	xx	xx	xx	xxx	unhindered infiltration into the underground (aquifer) at high GW recharge rates bear a high risk of pollution	water balance/hydrologic al modelling	BGR/Uni GÖ
karst features (degree of karstification)		xxx		xxxx	high karstification near WW facilites bear a high pollution risk; flow paths in karst system are often not sufficiently known	geological mapping	BGR
risk of downstream water resources to become polluted		xxxx		xxxx			BGR
distance / travel time to water source (used for drinking purposes)	xxx	xxx	xxx	xxx	the higher the travel time the lower the pollution risk	tracer tests	BGR/Uni GÖ
risk of flooding	xxx	xxx	xxx	x	WWTP and collector lines must be protected against flooding	DEM, hydrological model	KfW & BGR
Cost related Criteria							

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source	Responsibility
method of treatment (primary / secondary / tertiary)			xxx	xxx	can existing regulations / guidelines for effluent (reuse) quality be maintained at all times ?		KfW
reliability of treatment			xxx	xxx			KfW
storage capacity (bypass in case of overload ?)		xx	xx	xx	must be large enough to guarantee that bypassing untreated WW will not be necessary		KfW
possibility / need for treated WW reuse		xx	xxx	xxx	discharge location must be high enough to use as little energy as possible for reuse		KfW & BGR (where could it safely be reused)
sludge management / reuse of (treated) sludge for agriculture		xx	xx	xx	can existing regulations / guidelines for quality of (organic) fertilizer be maintained at all times ?	analysis of sludge content; determine sites for sludge application; determine treatment of sludge and related feasibility	KfW & BGR (where could it safely be applied)

Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment
General Recommendations from the Perspective of Groundwater Resources Protection

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source	Responsibility
costs for primary collector lines							KfW
costs for secondary collector lines							KfW
costs for household connections							KfW
costs for WWTP construction							KfW
costs for effluent discharge pipeline / canal							KfW
overall costs for construction (available funds)					including equipment, laboratory and staff for continuous monitoring of treated WW quality		KfW
annual costs for maintenance and operation (available budget)					including continuous monitoring of treated WW quality and sludge mgmt.		KfW

xxxx - killing arguments
xxx - very important arguments
xx - important arguments
x - less important arguments

ANNEX 3: Results of Tracer Test 1

PROTECTION OF JEITA SPRING - LEBANON -

- SPECIAL REPORT -

ARTIFICIAL TRACER TESTS - APRIL 2010

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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 undertaken 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.

About 67% of the area in Lebanon consists of karstified (6,900 km^2) rock sequences. The project area is the Jeita karst catchment drained by the Jeita spring. It is considered one of the most important springs in Lebanon, which provides the Capital Beirut with water for domestic use.

One part of this project is to provide assistance to the Lebanese Council for Development and Reconstruction (CDR), as one of the partners of BGR, as well as other relevant national institutions or donor agencies, among others the main German implementing agency for financial cooperation, the KfW Entwicklungsbank (KfW), the European Investment Bank (EIB) and the Italian Protocol, concerning the site searching for wastewater collection and treatment facilities in the groundwater contribution zone of the Jeita spring, herein referred to as the project area.

The KfW project - Protection of Jeita spring - is planning to establish wastewater treatment plants and collector lines in the area. One treatment plant is planned to be constructed on the catchment area of the Jeita spring. Prior to the installation of the latter, it is primordial to understand the groundwater flow dynamics within the karst system in order to depict the impact of such a potential source of contamination on the Jeita spring.

In addition of being used to acquire various transport parameters in karst aquifer such as peak concentration, velocities, dispersivities, persistence of the tracer in water, and percentage of recovery, tracer tests are also adopted in various studies as to simulate a substitute potential pollutant such as fecal bacteria (Orth et al., 1997, Autckenhaler, 2002; Göppert and Goldscheider, 2007). A good knowledge of transport in a karst aquifer helps define adequate management, remediation or prevention measures.

This report presents the results of the tracer test conducted in April 2010 to delineate the hydrogeological connection between the location of a potential WWTP and the Jeita spring. Section 1 provides a description of the study area, Section 2 discusses the methods, material and field work performed during this study. It includes a description of the various tracer tests performed in April 2010, Section 4 presents the analytical results, whereas Section 5 presents the modeling results. The latter mainly tackles aquifer dynamics and behavior as depicted in April 2010 and gives insights into the velocities and dispersivities in the Jurassic Jeita system. Finally Section 6 presents some conclusions and recommendations.

1.1 GENERAL

The Jeita Spring is an important karst spring located north to Beirut in Jounieh area. It constitutes the main water source for the Beirut Area and its northern suburbs for domestic use. Governed by open channel flow/ full pipe hydraulics, the Jeita Spring drains a catchment of about 288 km^2 extending east in the Lebanese Mountains (Figure 1-1). The catchment of the Jeita spring is defined to date mainly based on topographical boundaries. Very little is known about the connection between various locations on the catchment and the Jeita Spring.

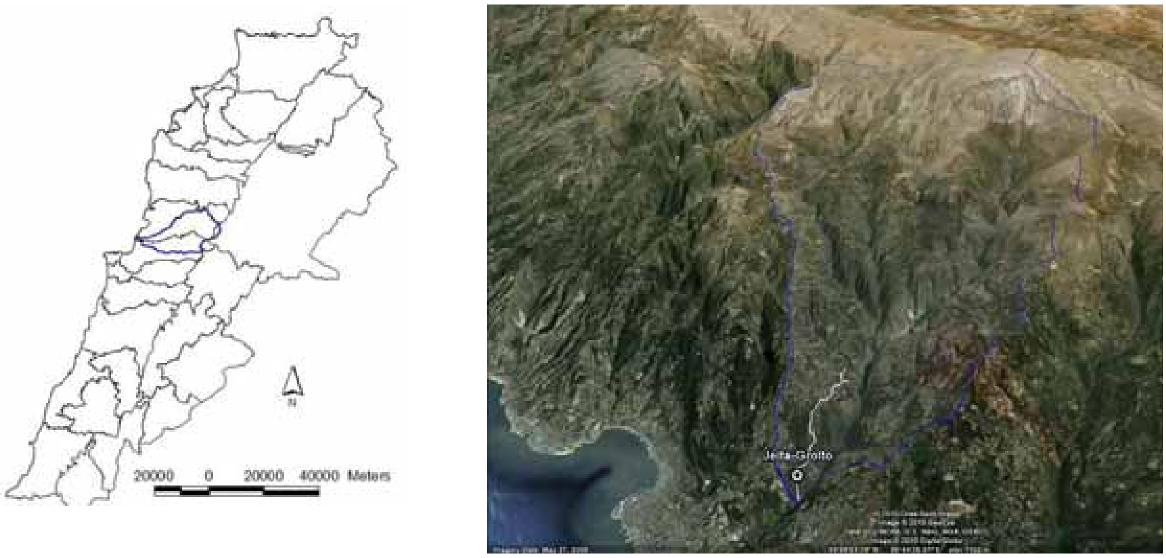


Figure 1-1 Location of Jeita Spring and Catchment in Lebanon (GoogleMaps)

The total yearly precipitation on the Jeita Catchment is estimated at about 407 Mm^3, out of which only about 52.3 % are infiltrated, whereas about 15 % and 32.7 % are lost in surface runoff and evapotranspiration respectively.

The Jeita cave is developed in limestone of Jurassic age over a total length (including subsidiaries) of 9000 m. The topography of the grotto was established underground as well as on the surface. The Jeita Cave is also accessible from a tunnel located downstream to Ballouneh Village, about 4500 m east to the Jeita Spring.

1.2 OBJECTIVES OF THE TRACER TEST

The main goal of the artificial tracer tests was to investigate the impact of the construction of a WWTP on the Jeita catchment area. The tests were applied to

- Identify a potential hydrogeological connection between the injection site (potential waste water treatment plant location and the potential wastewater release point) and the Jeita spring and eventually other springs existing on the catchment
- Characterize hydrodynamic flow and transport parameters of the Jeita Aquifer system (flow velocities; mean and maximum, transit times, longitudinal dispersivities, mass restitution, etc…)

An additional tracer test was conducted within the cave over a distance of 4800 m to assess water velocities, dilution effects and potential tracer mass losses only within the cave. This information is crucial for interpretation of all further tracer tests performed on the catchment.

2. FIELD WORK AND METHODOLOGY

2.1.1 Materials

The tracers Fluorescein (Sodium fluorescein, BASF, CAS 518-47-8, $C_{20}H_{10}O_5Na_2$) and Amidorhodamin G ($C_{25}H_{26}N_2O_7Na$; Figure 2-1) were selected as they are considered non toxic. Both tracers can be measured simultaneously on-site with low detection limits. Fluorescein, 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. Geyer et al. (2007) reported that Amidorhodamin G is considered as a reactive tracer, showing slight retardation with respect to Fluorescein. However for the purpose of this tracer test, Amidorhodamin G will also be regarded as a conservative tracer.

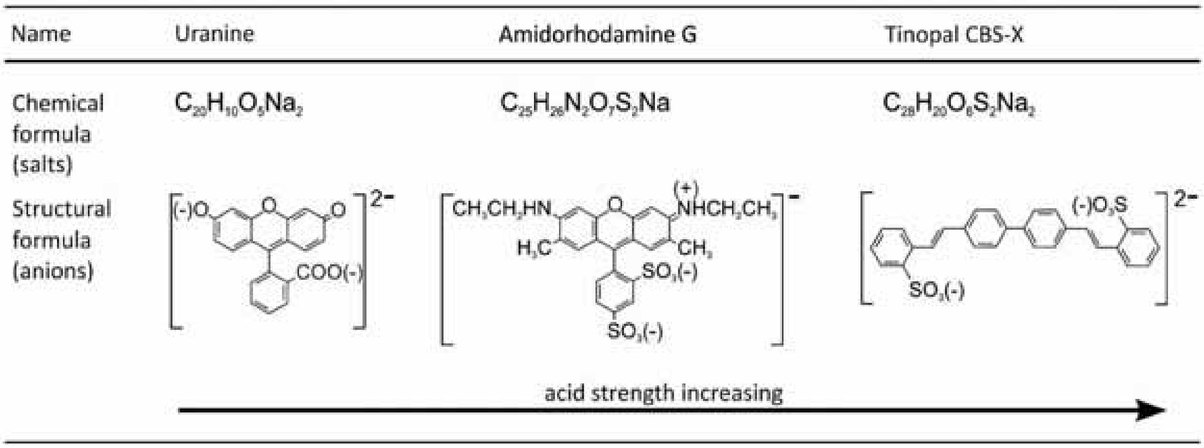


Figure 2-1 Chemical structures of the selected tracers (from Geyer et al. 2007).

Concentration of tracer was monitored in the springs and stream with field fluorometers (GGUN-FL30 serial numbers 524, 525, 526, Schnegg 2002). This equipment measures continuously dye concentration at the monitoring site every 2 minutes with two incorporated lamps 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 Fluorescein and Amidorhodamin G. The dissimilarity and lag between the luminescence wavelengths of both Fluorescein and Amidorhodamin G enables the distinction between both dye types during analysis and hinders the significance of overlaps. Fluorescein has a spectrum of luminescence ranging between 490 nm and 524 nm, whereas that of Amidorhodamin G extends between 535 nm and 552 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 tracers, the lamps are calibrated for both dyes; therefore, based on a system of two linear equations, the electrical signal is transformed into two 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 fluorescein and 0.2 µg/l for Amidorhodamine G. The detection of tracer in water samples taken manually or with the automatic sampler was performed at a later stage using the field fluorometer GGUN-FL30 (serial number 524) activated for both Fluorescein and Amidorhodamin G at a sampling rate of 10 sec). 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.

2.1.2 Fieldwork

2.1.2.1 Injections

A tracer test was undertaken on the 19th of April (at 12:11) under relative low flow conditions. Five kilograms of the fluorescent dye Fluorescein were injected in the vicinity of the location of the PWWT into an artificially 10-m dug hole. The tracer, injected directly into a bucket was flushed with a total volume of 40 m^3 of water (from water tanks for about two hours; Figure 2-1). The pit hole was flushed with additional 20 m^3 on the next day (20th April 2010 at 8:11 am) 20 hours after the first flushing. On the 22nd of April 2010, five kilograms of Amidorhodamin G (AG) were injected in Abou Mizane in a drilled hole (of about 3-m diameter) during a rain event, and flushed with a total volume of 20 m^3 over about 1 hour. The favorable weather conditions and difficult accessibility of the tanks to the Injection pit hindered the appropriate flushing. Therefore, the pit was flushed only 15 hours after the first injection with additional 40 m^3. However it is to be noted that the infiltration rate was relatively low, which did not allow a good percolation of the AG. On the 28th of April 2010, 424 grams of fluorescein were released in the Jeita underground river at the "siphon terminal" of the Daraya Tunnel.

Table 2-1 Injections Points

INJECTION POINT	X,Y,Z (LAMBERT, m)	INJECTION TIME	FLUSHING VOLUME (m^3)	COMMENTS
Injection Point (1) Deir Chemra	149387 224042 555	19.04.2010 (12:11) 19.04.2010 (8:11)	40 20	Infiltration rate was relatively favorable to ensure good percolation of the tracer
Injection Point (2) Abu Mizane	148115 223315 450	22.04.2010 (15:59) 22.04.2010 (08:00)	20 40	During heavy rain event Infiltration rate was relatively low to ensure good percolation of the tracer
Daraya Tunnel (3)	146135 223503 140	28.04.2010	In flowing water	Turbidity rose after injection to about 48 NTU

Figure 2-1 **Fluorescein Injection and Flushing in Deir Chemra pit hole on April 19th, 2010 (12:11)**

Figure 2-2 **Amidorhodamin G Injection and Flushing in Abu Mizane pit hole on April 22nd, 2010 (15:59)**

Figure 2-3 Fluorescein Injection in the Jeita Underground River on April 28th, 2010 (11:42)

2.1.2.2 Observation points

Field spectrofluorometer with dataloggers were installed in the Jeita spring 500 m inside the cave and in the Siphon terminal (4800 m from the cave touristic entrance) and in the Qachqouch Spring for automatic sampling. Manual samples were collected from Jeita and Qachqouch springs and Nahr El Kalb River every hour (**Error! Reference source not found.** and Figure 2-4).

Table 2-2 Observations Points

OBSERVATIONS POINTS	X,Y,Z (LAMBERT, m)	SAMPLING	TIME TIME SPAN	SAMPLING INTERVAL	COMMENTS
Jeita Grotto (+500m)	142603 223385 95	Automatic	17.04.2010-11.05.2010	2 min	GGUN-FL30 serial number 525
Jeita Grotto Beginning of the Touristic Section (+0m)	142233 223115 90	Manual	19.04.2010-27.04.2010 (13:00)	1 hour	Analyzed on the 28.04.2010 with GGUN-FL30 serial number 524
Jeita Grotto Daraya Tunnel	146135 223503 140	Automatic	15.04.2010-12.05.2010	2 min	GGUN-FL30 serial number 526
Qachqouch Spring	141946 223006 60	Automatic	19.04.2010-04.05.2010	2 min	GGUN-FL30 serial number 524

OBSERVATIONS POINTS	X,Y,Z (LAMBERT, m)	SAMPLING	TIME TIME SPAN	SAMPLING INTERVAL	COMMENTS
Qachqouch Spring	141946 223006 60	Manual	19.04.2010-27.04.2010 (13:00)	1 hour	Analyzed on the 28.04.2010 with GGUN-FL30 serial number 524
Nahr El Kalb	142115 222989 50	Manual	19.04.2010-27.04.2010 (13:00)	1 hour	Analyzed on the 28.04.2010 with GGUN-FL30 serial numbers 524

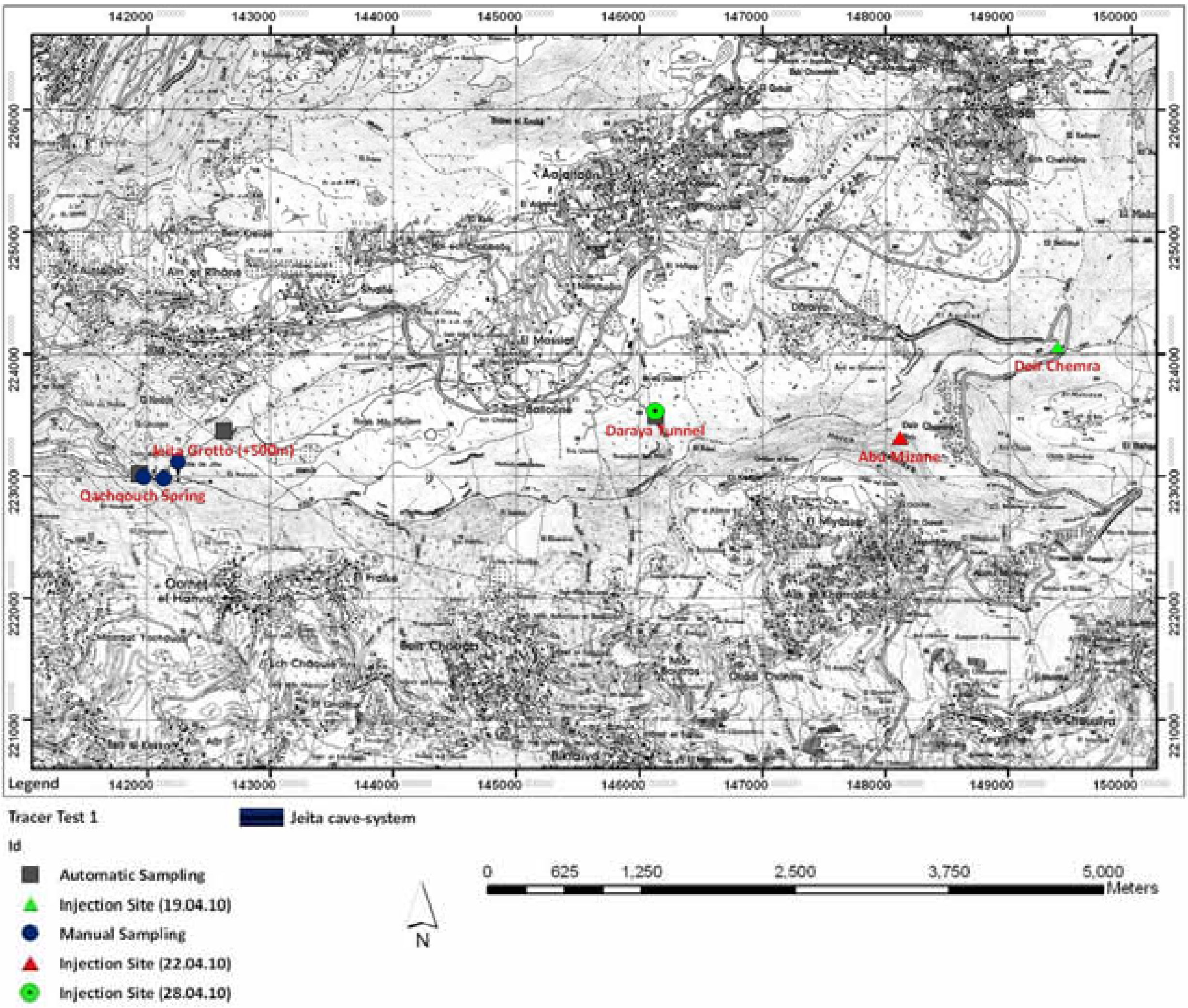


Figure 2-4 **Location of Observation Points downstream to the Injection points during the tracer test undertaken in April 2010**

2.1.3 Discharge Measurements

Flow rate measurements were mainly performed based on the dilution gauging methods using salt and Fluorescein. The dilution method relies on calculating the discharge rate based on a tracer breakthrough curve (TBC). In the case of salt, a TBC of Electrical Conductivity is measured and translated to salt concentration with the help of a calibration function. The integration of the concentration over time allows the estimation of the discharge rate as shown in Equation 1.

A Calibration curve (rating curve, Equation 2) of salt concentration as a function of conductivity was constructed for the Daraya and Qachqouch Springs prior to discharge measurement.

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

Where
Q is the discharge rate [L^3/T]
M is the injected salt or fluorescein mass [M]
c is concentration [M/L^3]
t is time [T]

$$c = a[EC] + b \qquad (2)$$

EC is the Electrical conductivity
a is the slope of the linear relationship between C and EC
b is the intersection of the calibration curve with the y axis

The spring discharge at the various discharge points were measured at different intervals during the tracer test period. It was measured only once in the Jeita Cave to avoid interference with the large scale tracer tests. 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 0.4 m^3/sec due sometimes to incomplete dilution and short distance tests during discharge measurements using the dilution methods.

The discharge flow rates were measured during tracer tests at the various observation points namely, Jeita Spring at 500m inside the cave and in Daraya Tunnel as well as Qachqouch spring and Nahr El Kalb River.

Table 2-2 Discharge Rates Measured at the Observations Points

OBSERVATION POINT	METHOD	DATE	DISCHARGE RATE	COMMENTS
Jeita Grotto (+500m)	Dilution with fluorescein	17.04.2010	5.6 m^3/sec ±0.4 m^3/sec	
Jeita Grotto Daraya Tunnel	Dilution with fluorescein and salt (velocity estimation)	15.04.2010 23.04.2010 25.04.2010 28.04.2010	3.2-3.6 m^3/sec ±0.4 m^3/sec	Fluorescein dilution was not successful due to relatively short distance (14 m) and consequent incomplete dilution
Qachqouch Spring	Dilution with fluorescein and salt	20.04.2010 24.04.2010 25.04.2010 04.05.2010	1.4-1.5 m^3/sec ±0.1 m^3/sec	Salt dilution method was not successful due to the short distance (20 m) Fluorescein dilution was performed on a distance of 166.5 m
Nahr El Kalb	Dilution with fluorescein	04.05.2010		

2.2 EVALUATION AND MODELING

2.2.1 Parameters

Tracer breakthrough curves (TBCs) were analyzed graphically, using Excel sheets, and numerically with the software CXTFIT- Stanmod (Toride et al. 1999). Two model approaches, the *Advection-dispersion Model (ADM)*, and the *two region non equilibrium model (2RNEM)* were adopted for the modeling of the TBC, especially in the presence of overlaps in the tracer breakthrough curve and to reproduce tailing in most of the retrieved TBCs. 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.

2.2.1.1 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 3 (EPA/600/R-02/001, 2002).

$$R = \frac{1}{M}\int_{t=0}^{\infty} c(t)Q(t)dt \qquad (3)$$

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.

2.2.1.2 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)

$$t_d = \int_{t=0}^{\infty} \frac{c(t)Q(t)tdt}{c(t)Q(t)dt} \qquad (4)$$

2.2.1.3 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 5. 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.

$$D_L = \alpha_L \cdot v_m + D^* \qquad (5)$$

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]

2.2.2 Modeling

2.2.2.1 1-D advection-dispersion model (ADM)

The ADM governed by Equation 6, 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).

$$C(t) = \frac{M}{Qtm\sqrt{4\pi P_D\left(\frac{t}{t_m}\right)^3}}\exp\left(-\frac{\left(1-\frac{t}{tm}\right)^2}{4P_D\frac{t}{tm}}\right) \qquad (6)$$

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 (*∫C(dt)*).

The fitting allows to inversely estimate the mean velocity and dispersion (Göppert and Goldscheider, 2007). This model is however unable to account for tailing observed in TBCs. This phenomenon can generally be described by mass-transfer between mobile and immobile fluid regions, flow channeling and multi-dispersion.

2.2.2.2 Two region Non equilibrium model (2RNEM)

The two region non-equilibrium model is based on the assumption that the solute is present under two forms of fluid regions, a mobile fraction, such in the conduits and main flow direction pathways, and an immobile fraction, which is hosted in dead end passages and sediments pools (Field and Pinsky, 2000, Geyer et al., 2007). The latter fraction is thought to be released slowly with time, which explains in some cases, the tailing observed in most of the tracer breakthrough curves.

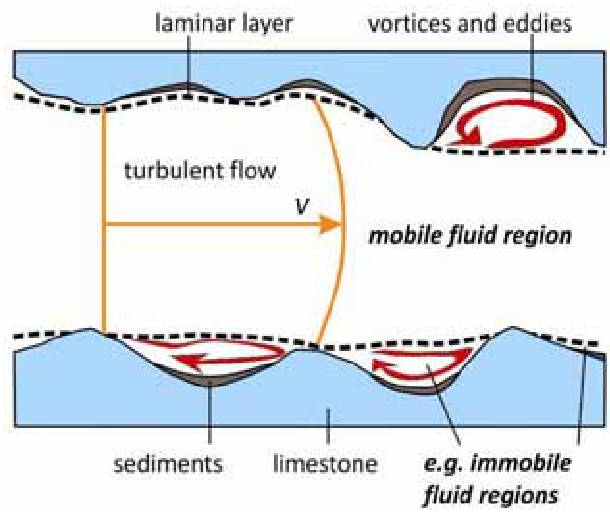


Figure 2-5 Conceptual model of flow within a karst conduit (from Geyer et al. 2007).

This Two region Non equilibrium model accounts for conservative transport processes, including advection, dispersion and mass transfer between the immobile and mobile phase. The corresponding equations are (Toride et al. 1999)

$$\theta_m \frac{\partial c_m}{\partial t} = D \frac{\partial^2 c_m}{\partial x^2} - v \frac{\partial c_m}{\partial x} - \omega (c_m - c_{im})$$

$$(1-\theta_m) R \frac{\partial c_{im}}{\partial t} = \alpha (c_m - c_{im}) \quad (7)$$

Where v is the average velocity [L/T]
D is the dispersion coefficient [L^2/T]
θ_m is fraction of the mobile fluid phase [-]
ω is the first order mass transfer coefficient [1/T]
c_{im} and c_m are the respective concentration of mobile and immobile fluid phase [M/L^3]
x is the space coordinate [L]
t is time [T]

In a first approach, fluorescein and amidorhodamin G are assumed as conservative tracers in this study. Therefore reactive transport processes like e.g. ion exchange, complexation and decay will be neglected.

Tracer injection is simulated by a Dirac pulse, i.e. tracer injection period is negligible compared to the observed tracer travel time. Calibration with CXTFIT can be performed inverse, i.e. the model iterates, based on transport preset parameters, in order to reproduce observed tracer. The parameters that are adjusted for the model are β, ω, velocity *v* and dispersion *D*.

3. RESULTS OF THE TRACER TEST

The first tracer test undertaken on April 19th, 2010 was positive as fluorescein was detected in the Jeita spring at various points, as well as in the Nahr El Kalb River. The tracer test undertaken on April 22nd, 2010 was negative, as amidorhodamine G was not detected in any of the observation points. The tracer test within the cave performed on April 28th, 2010 was also successful.

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. Distances were defined as follows and didn't account for turtuosity or change in altitude, except in the Jeita cave:

- The distance between the Injection point and the Daraya tunnel was a straight line distance of about 2700m.
- The distance between the Injection point and the Jeita spring (+ 500 m) is about 7500 m accounting for 2700 m until the Daraya tunnel and additional 4800 m within the cave between the Daraya siphon terminal and the observation point.
- The distance between Injection point and the Jeita spring (at the touristic entrance) is about 8000 m.
- The distance within the cave was calculated based on the cave trace and accounts for turtuosity.

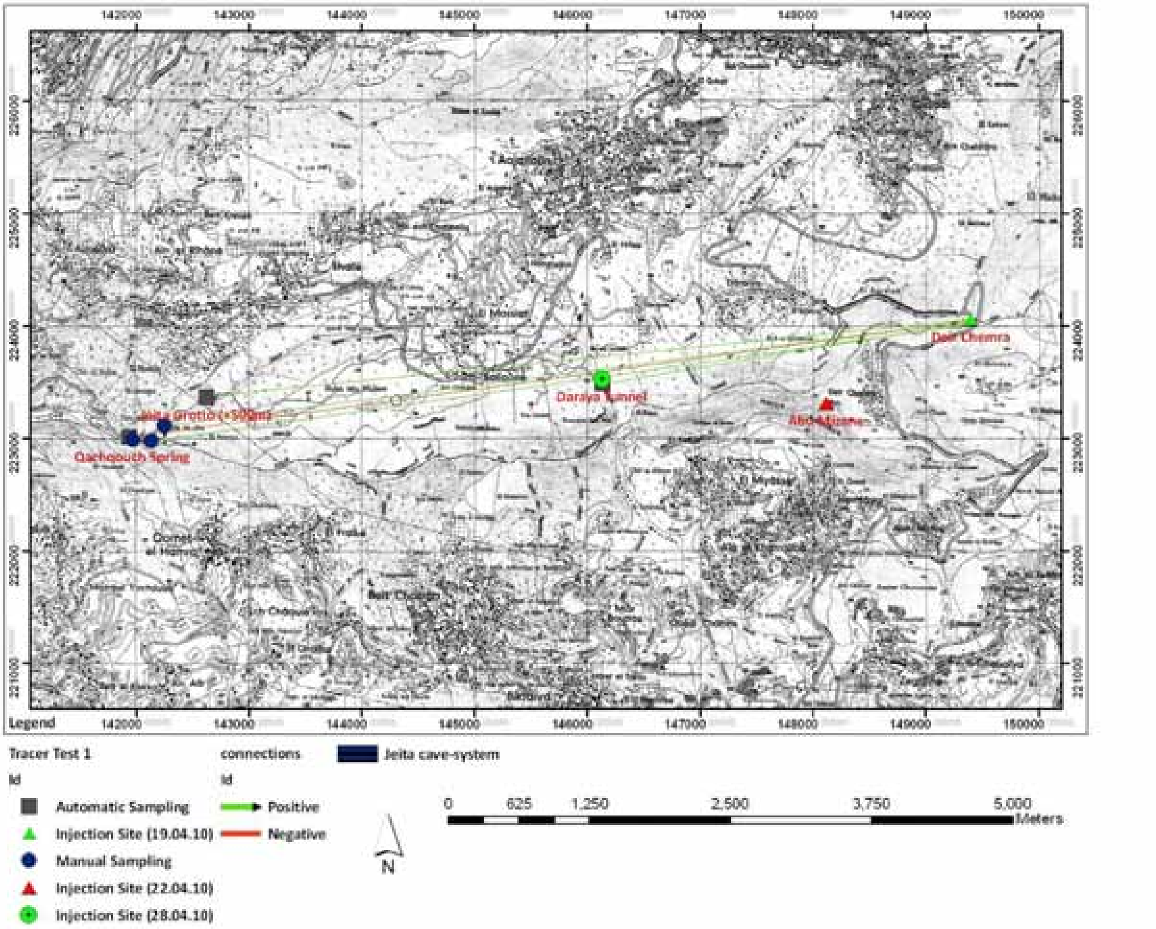


Figure 3-1 **Connections between the observation and injection points**

3.1 TRACER BREAKTHROUGH CURVES- TRACER TEST 1 (FLUORESCEIN)

Fluorescein was detected in the Jeita spring at the Daraya Tunnel, and at both locations within the cave, as well as in Nahr El Kalb River. However, no tracer was detected in Qachqouch Spring. Therefore a hydrogeological connection exists between the injection site at Deir Chemra and the Jeita Spring.

The following section discusses the fluorescein Breakthrough curves retrieved at the Jeita Spring. Connections between Injection point and observation points are shown in Figure 3-1.

3.1.1 Jeita Cave: Siphon Terminal- Daraya Tunnel

The tracer was detected in the Jeita Spring at daraya locality about 46 hours after the injection. The peak concentration reached 1.8 µg/L 57 hours after injection (Figure 3-2). The shape of the restitution curve is rather irregular, since it shows two peaks. The first peak being a result of the first injection, the second peak reaching 0.88 µg/L is believed to result from the flushing undertaken 20 hours after the first injection. As a matter of fact, the difference between the first and second peak is about 20 hours. The tailing started 100 hours and persisted 140 hours after injection. Tailing extended consequently for about 40 hours from the end of fluorescein recession.

Based on discharge rate under prevailing flow conditions (3.6 m^3/sec), approximately 650g of fluorescein were restituted in the Jeita Spring at the Daraya Tunnel, which represents 13% of the total injected mass of fluorescein.

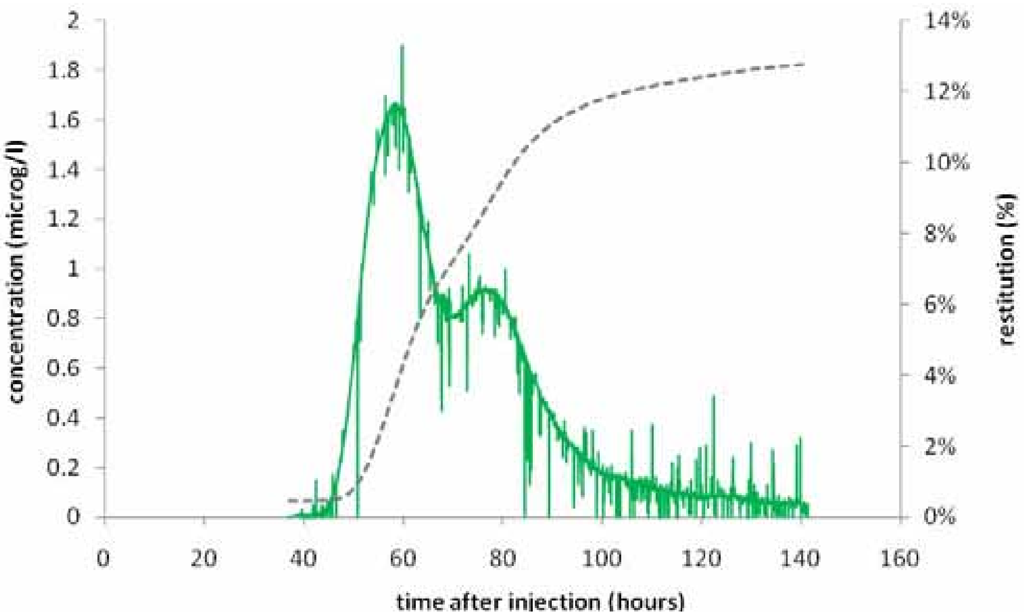


Figure 3-2 **Fluorescein restitution curve (TBC) in Jeita cave at the siphon terminal (Daraya Tunnel) showing an extensive tailing, a peak of about 1.8 µg/L, and a recovery of about 13%. The second peak is due to the flushing occurred 20 hours after the first injection.**

3.1.2 Jeita Cave: 500 m Inside the Cave from Entrance of Touristic Section

The tracer was detected in the Jeita Spring 500 m inside the cave from the entrance of the touristic section about 50 hours after the injection. Due to a malfunctioning of the field fluorometer the rest of the curve was not saved on the datalogger, as a result of which, the shape of the restitution curve is not complete. The tracer arrived about 50 hours after the injection. The recorded peak reached 1.2 µg/L appeared 63 hours after injection. Restitution cannot be calculated from the incomplete curve. It is worth noting that the tracer started to appear at the Jeita cave (+500m) 6 hours after its first detection in the Daraya section.

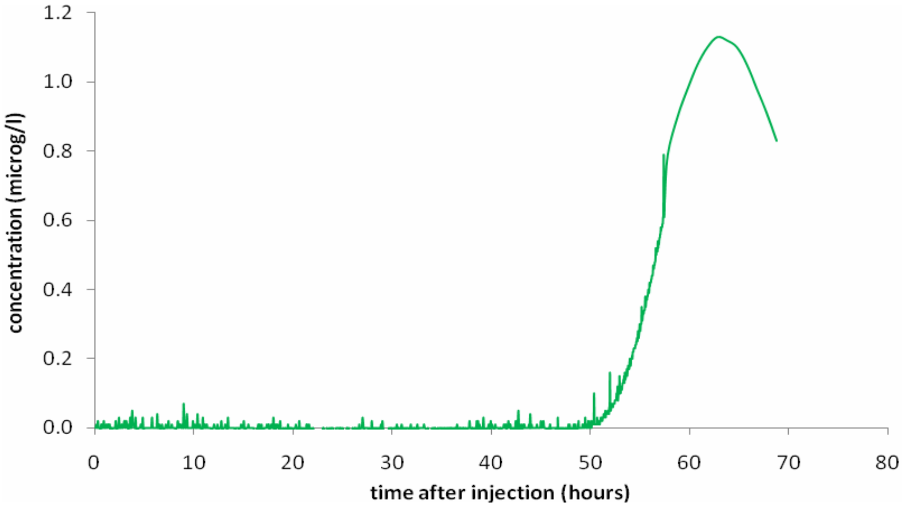


Figure 3-3 **Fluorescein restitution curve (TBC) in Jeita cave 500 m inside the cave from the tourist entrance, a peak of about 1.2 µg/L. the curve is incomplete because of a malfunctioning of the fluorometer**

3.1.3 Jeita Cave: Tourist Entrance

The tracer was detected in the Jeita Spring at the spring outlet at the touristic entrance about 50 hours after the injection. The peak concentration reached 1.2 µg/L 57 hours after injection (Figure 3-2). Like in the Jeita spring at the Daraya Tunnel, the TBC shows two peaks. The first peak being a result of the first injection, the second peak reaching about 0.75 µg/L is believed to have resulted from the second flushing undertaken 20 hours after the first injection. Conclusions about tailing could not be given in the case of the TBC reconstructed from manual sampling because of insufficient sampling period.

Retardation and decay were neglected in calculation as fluorescein is considered a relatively conservative non degradable tracer. Based on discharge rate under prevailing flow conditions, approximately 700g of fluorescein were restituted in the Jeita Spring outlet at the touristic entrance, which represents 14% of the total injected mass of fluorescein.

Fluorescein was detected in the samples collected hourly from the Nahr El Kalb River at the water authority pumping station (Figure 3-5). Measured concentrations reached about 1 µg/L. It is suspected that there are various inflow points into the Nahr El Kalb River, including inflow from the Jeita spring. Therefore restitution rates cannot be calculated from the TBC. On the other hand, fluorescein was not detected in the Qachqouch spring, neither in the samples collected manually nor by the field fluorometer.

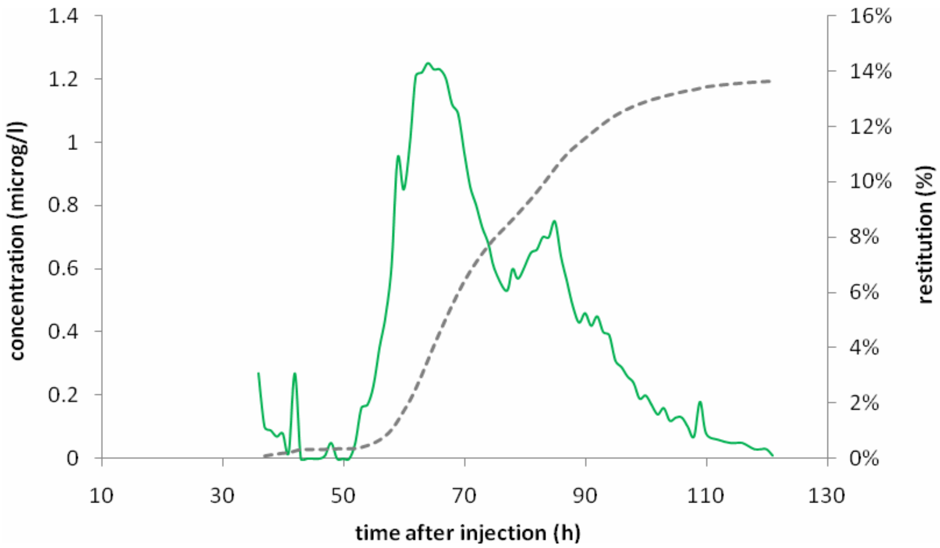


Figure 3-4 **Fluorescein Restitution Curve (TBC) in Jeita cave at the entrance of the tourist section based on manual collected samples. The second peak is due to the flushing occurred 20 hours after the first injection**

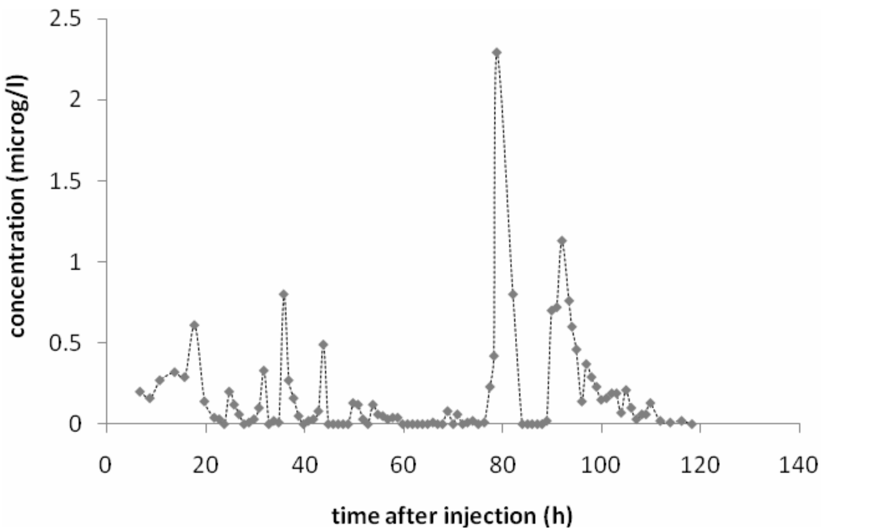


Figure 3-5 **Fluorescein Concentrations detected in the Samples collected in Nahr El Kalb River**

3.2 TRACER BREAKTHROUGH CURVES- TRACER TEST 1-B (FLUORESCEIN)

During the tracer test undertaken within the cave fluorescein was detected at the Jeita Spring 500 m inside the cave about 5.37 hours after the injection. The peak concentration reached about 11 µg/L 6 hours after injection (Figure 3-6).

Based on discharge rate under prevailing flow conditions (5.6 m^3/s), approximately 216 g of fluorescein were restituted in the Jeita Spring outlet at the touristic entrance, which represents about 51% of the total injected mass of fluorescein. Such low restitution rates within the cave between Daraya and the Jeita Spring are contradictory with the results of the first tracer test, which shows no losses within cave.

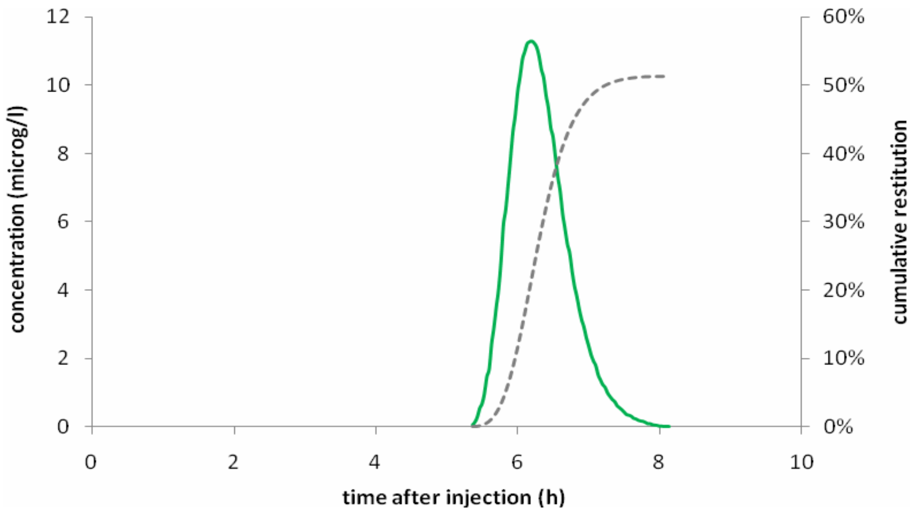


Figure 3-6 Fluorescein Breakthrough Curve (TBC) resulting from the Injection in the Jeita cave at the daraya Tunnel recovered at the Jeita Spring (500 m inside the cave)

3.3 COMPARISON OF RESULTS AND SYNOPSIS

The first tracer arrivals are detected 43, 48.8 and 49.8 hours after the tracer injection respectively in the Jeita spring at the Daraya Tunnel, at 500m inside the cave and at the cave outlet. Variance of the three TBC is relatively similar, which implies a similar dispersion coefficient of the three TBC.

Based on peak times of detection of 57.2, 63.8 and 64.8 hours in the Jeita spring at the Daraya Tunnel, at 500m inside the cave and at the cave outlet, the peak flow velocity of groundwater is considered to be 47 m/hour between injection point and Daraya System and about 120 m/hour under low flow conditions between the injection point and the Jeita spring including the Daraya tunnel. Velocities and restitution rates interpreted graphically from the TBC are shown in Table 3-1.

Velocities within the cave appear to be very high. Based on tracer first arrival time, the maximum velocity reaches about 900 m/d, whereas peak velocity calculated based on the time of peak concentration is about 786 m/d.

Table 3-1 Velocities and Restitution Rates deduced graphically from the TBC

OBSERVATION POINT DISTANCE FROM INJECTION POINT	TRACER FIRST ARRIVAL (hours)	MAXIMUM VELOCITY (m/hours)	PEAK CONCENTRATION TIME (hours)	PEAK VELOCITY (m/hours)	RESTITUTION (%)
TRACER TEST (FLUORESCEIN) - 19. APRIL 2010- DEIR CHEMRA					
Jeita Grotto (+500m) 7500m	48.8	153	63.8	117.5	-
Jeita Grotto Beginning of the Touristic Section (+0m) 8000m	49.8	160.6	64.8	123.5	13
Jeita Grotto Daraya Tunnel 2700m	43	62.7	57.2	47.2	13
Qachqouch Spring					NEGATIVE
Nahr El Kalb	Suspected to be 75	Various peak tracer detected however no conclusions about velocities or restitution rates can be given			
TRACER TEST (AMIDORHODAMINE) – 22 APRIL 2010 – ABU MIZANE					NEGATIVE
TRACER TEST (FLUORESCEIN) – 28 APRIL 2010 – WITHIN THE CAVE					
Jeita Grotto (+500m) 4800m	5.3	905	6.1	786	51

4. MODELING RESULTS

A summary of all modeling results of the tracer tests performed in Deir Chamra and within the cave is presented in Table 4-1 . The quality of the model fits was assessed by estimation of the coefficient of correlation (R^2) and the mean square error (MSE). All fitting were achieved with coefficients of correlation exceeding 0.95 and a mean square error generally not exceeding 10^{-3} micrograms per liters, as portrayed in Table 4-1.

Table 4-1 Summary of the Modeling Results of the Positive Tracer Tests Undertaken in April 2010 (Deir Chemra and Jeita Cave)

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO DARAYA TUNNEL		JEITA GROTTO (+500M)	JEITA GROTTO BEGINNING OF THE TOURISTIC SECTION (+0M)	
TRACER TEST (FLUORESCEIN) - 19. APRIL 2010- DEIR CHEMRA							
Distance	D	m	2700		7500	8000	
Discharge	Q	m^3/sec	3.6		5.6	5.6	
ADVECTION DISPERSION METHOD (ADM)							
Mean Velocity	v	m/hour	45.1	43.8	**116**	**120**	**121**
Mean transient time	t_m	hours	60	62	66	66	67
Dispersion	D	m^2/hour	851	1230	**3410**	**5070**	**783**
Dispersivity	A	m	18.9	28	44.5	41.9	6.5
Peclet number	P_D	-	143.1	95.9	169	191	1230
Massive Flux	M	µg•h/l	29	16.8	17.3	21.5	11.5
Restitution Rate	R	%	11.9		6.98	13.32	
Statistical parameters							
Coefficient of Correlation	R^2	-	0.974	0.943	0.992	0.966	0.890
Mean Square Error	MSE	µg/l	6.98E-03	4.20E-03	4.82E-04	7.96E-03	4.45E-03
TWO REGION NON EQUILIBRIUM MODEL (2NREM)							
Mean Velocity	v	m/hour	**45.6**	**36.4**	**114**	**109**	**118**
Mean transient time	t_m	hours	59	74	65.8	73.4	67.8
Dispersion	D	m^2/hour	722.0	614.0	**5040**	**2900**	**916**

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO DARAYA TUNNEL		JEITA GROTTO (+500M)	JEITA GROTTO BEGINNING OF THE TOURISTIC SECTION (+0M)	
Partition coefficient	β	-	0.8	0.804	0.93	0.869	0.903
Mass transfer coefficient	ω	1/hour	2.39E-01	2.39E-01	1.7E-01	1.12E-04	1.97E-04
Dispersivity	α	m	15.8	16.9	44.2	26.6	7.8
Peclet number	P_D	-	170	160	170	301	1030
Massive Flux	M	µg•h/l	27.0	21.4	21.5	28.3	5
Restitution Rate	R	%	12.5%		8.68%	13.44%	
Statistical parameters							
Coefficient of Correlation	R^2	-	0.984	0.985	0.967	0.973	0.925
Root mean Square Error	RMSE	µg/l	4.80E-03	1.13E-03	1.87E-03	6.86E-03	1.19E-03

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO- DARAYA TUNNEL
TRACER TEST (FLUORESCEIN) – 28 APRIL 2010 – WITHIN THE CAVE			
Distance	d	m	4800
Discharge	Q	m^3/sec	5.6
ADVECTION DISPERSION METHOD (ADM)			
Mean Velocity	v	m/hour	**766**

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO-DARAYA TUNNEL
Mean transient time	t_m	hours	6
Dispersion	D	m^2/hour	6970
Dispersivity	α	m	9.1
Peclet number	P_D	-	528
Massive Flux	M	µg•h/l	10.81
Restitution Rate	R	%	51.44
Statistical parameters			
Coefficient of Correlation	R^2	-	0.9897
Mean Square Error	MSE	µg/l	1.62E-01
Degree of uncertainty	U	µg/l	
TWO REGION NON EQUILIBRIUM MODEL (2NREM)			
Mean Velocity	v	m/hour	760.0
Mean transient time	t_m	hours	6.3
Dispersion	D	m^2/hour	2380
Partition coefficient	β	-	0.92
Mass transfer coefficient	ω	1/hour	3.11
Dispersivity	α	M	3.1
Peclet number	P_D	-	1530
Massive Flux	M	µg•h/l	
Restitution Rate	R	%	51.44

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO-DARAYA TUNNEL
Statistical parameters			
Coefficient of Correlation	R^2	-	1.0
Root mean Square Error	RMSE	µg/l	6.17E-03

4.1 TRACER BREAKTHROUGH CURVES- TRACER TEST 1 (FLUORESCEIN)

4.1.1 Jeita Cave: Siphon Terminal- Daraya Tunnel

The TBC recovered at the Jeita cave in the Daraya section was modeled using both the Advection Dispersion Model (ADM) and the Two Non Equilibrium Model (2RNEM). For modeling purposes the two peaks were regarded as results of two injections and peaks were modeled separately. According to both models mean flow velocities ranged between **43 and 45 m/day**. As a result of different infiltration rates triggered with the second flushing, variance in the second peak is greater, showing a more important dispersive component. Dispersion values vary between **850 and 1530 m^2/hour** respectively for the first and second peak.

Mean transit time between the Injection point and Daraya Tunnel (a total distance of 2700m and an altitude difference of about 400 m) resulted to be about 60 hours.

Since tailing is relatively pronounced in the second peak, it was modeled using the 2NREM model (Figure 4-1). The mobile phase proportion is estimated to be 80%. Mean velocity calculated with the 2NREM model is about 36 m/h accounting for the large observed tailing.

The summation of the two modeled peaks with both models is shown in Figure 4-2. It is to be noted that tailing is best fitted with the 2NREM.

Peclet numbers ranges between 160 and 170, reflecting the prevailing advective component of the transport through the karst system. Recovery rates reaching not more than 13% obtained with the CXTFIT fall in the same range of that calculated by manual integration.

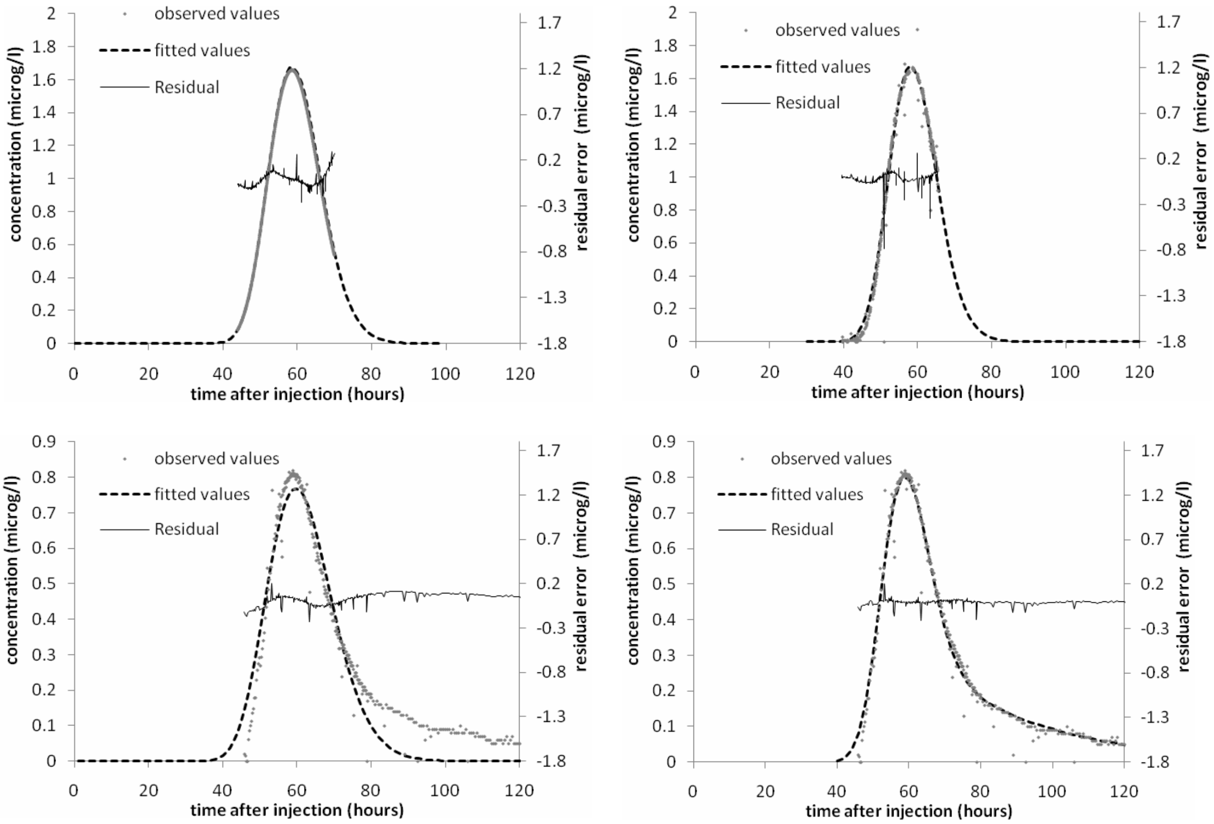


Figure 4-1 First and second peak of the Daraya TBC modeled respectively with ADM and 2NREM

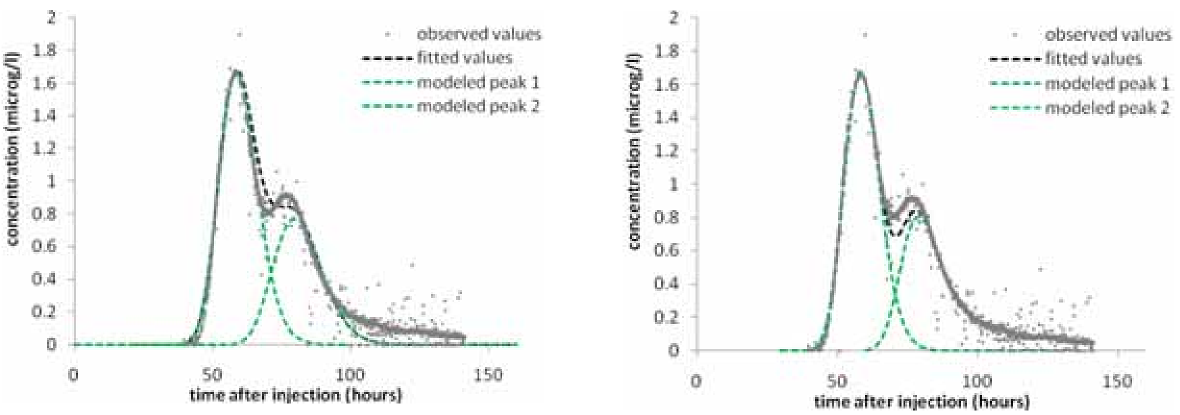
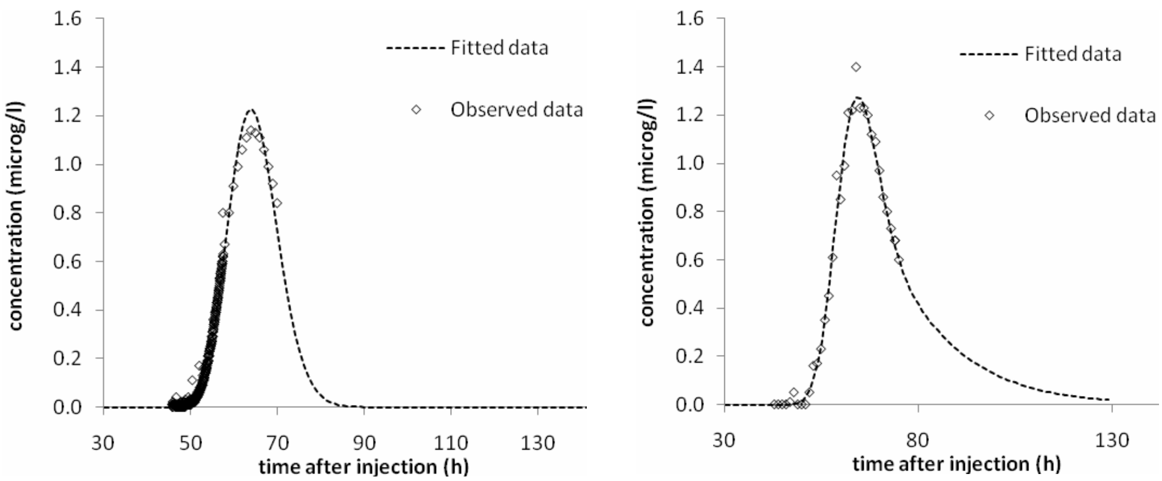


Figure 4-2 Summation of the first and second peaks of the Daraya TBC modeled respectively with ADM and 2NREM

4.1.2 Jeita Cave: + 500m

The incomplete curve TBC restituted at the Jeita Spring 500m inside the cave by the fluorometer was simulated with the Advection Dispersion Model (ADM) and the Two Non Equilibrium Model (2RNEM; Figure 4-3). Since the curve is not complete on the tracer recession limb, the 2NREM modeled parameters are not fully reliable, especially that the tailing is missing. According to the ADM mean velocity is **114 m/day**. The calibrated value for dispersion is **5040 m^2/hour**. The mean transit time over a total distance of 7500 m was calculated to be about 66 hours.

Peclet numbers are higher than 100, reflecting the prevailing advective component of the transport. Recovery rate obtained with the CXTFIT are not representative of the total recovery rate. The massive flux was regarded in this case as a fitting parameter.



a b

Figure 4-3 Fitted data of the Jeita (+500m) TBC modeled with ADM (a) and 2NREM (b)

4.1.3 Jeita Cave: Touristic Entrance

The TBC reconstructed from manual samples collected at the cave entrance was modeled using both the Advection Dispersion Model (ADM) and the Two Non Equilibrium Model (2RNEM). Like for Daraya TBC, for modeling purposes the two peaks were regarded as results of two injections. Therefore, during modeling every peak was modeled separately, the second injection being performed 20 hours after the first Injection. According to the ADM model, mean velocities ranged between **120 and 121 m/h**. Dispersion values vary between **5070 and 7830 m^2/h** respectively for the first and second peak. As a result of different infiltration rates triggered with the second flushing, variance in the second peak is greater, showing a more important dispersive component.

Mean transit time between the Injection point and this observation point (a total distance of 8000 m and an altitude difference of about 500 m) resulted to be about 66-67 hours.

In order to account for the tailing, the TBC was modeled using the 2NREM. In the latter case, modeled mean velocities ranged between **109 and 118 m/hour**. Modeled dispersion values ranging between **916 and 2900 m^2/hour** appears to be lower than the values obtained with the ADM model. The fitted mobile phase proportion ranges between **87% and 90%**. Peclet numbers are higher than 100, reflecting the prevailing advective component of the transport. Recovery rates obtained with the CXTFIT fall in the same range of that calculated by manual integration. The total restituted mass was considered as a fixed parameter, whereas the massive flux for each of the peaks was regarded as a fitting parameter.

Figure 4-4 and Figure 4-5 show the summation of the two peaks in an attempt to reproduce the entire observed TBC. As depicted in Figure 4-5, with the 2NREM model tailing is best accounted for and fitted values match to a good extent the observed values.

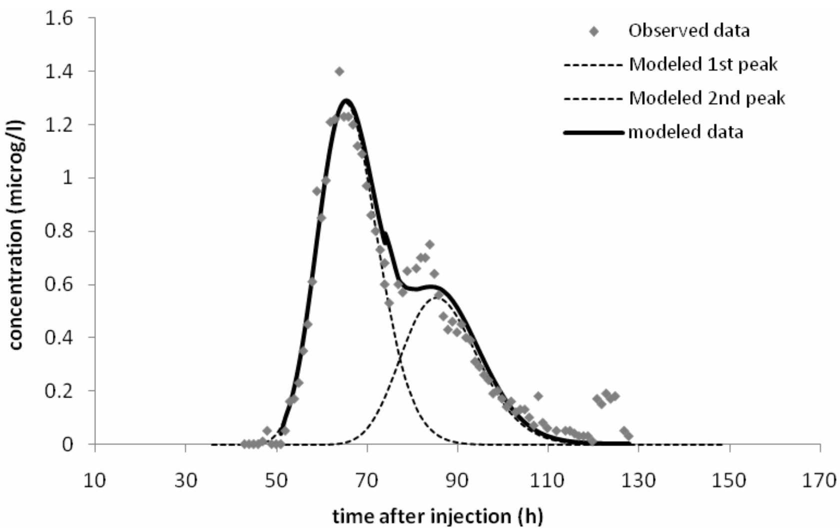


Figure 4-4 Fitted data modeled with ADM for the Jeita (+0m) TBC. The modeled curve is the sum of the modeled first and second peaks

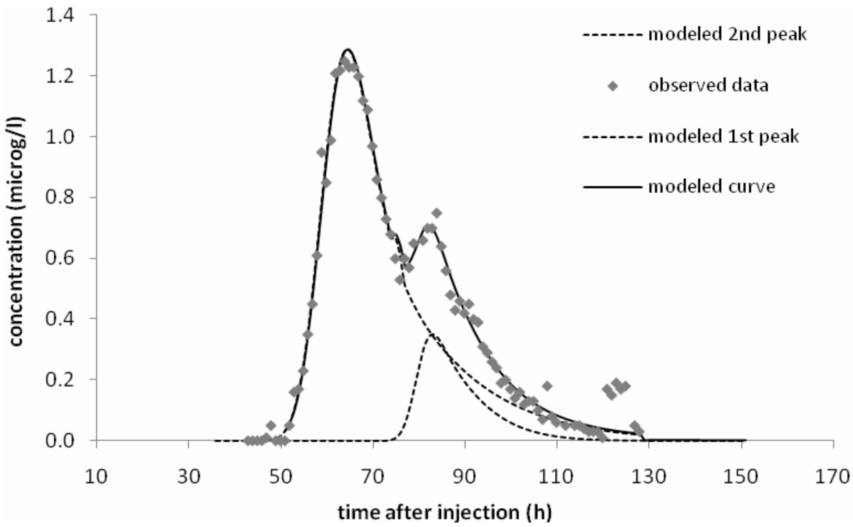


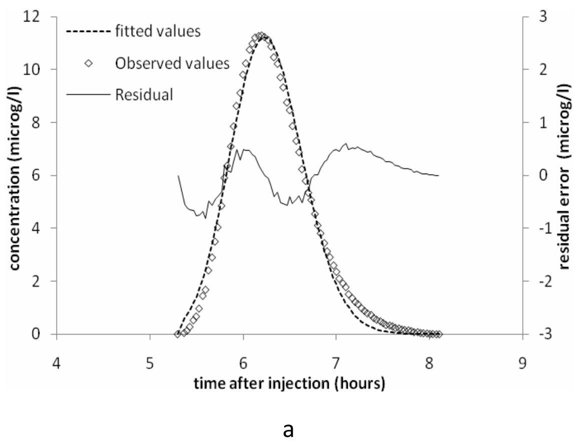
Figure 4-5 **Fitted data modeled with 2NREM for the Jeita (+0m) TBC. The modeled curve is the sum of the modeled first and second peaks**

4.2 TRACER TEST 1-B (FLUORESCEIN)

The TBC resulting from the tracer test undertaken within the cave was modeled using both the Advection Dispersion Model (ADM) and the Two Non Equilibrium Model (2RNEM, Figure 4-6). According to the ADM model, mean velocity was about **766 m/hour**. Dispersion reached **7000 m^2/hour**, which results in longitudinal dispersivity of about **9 m**. Such high values for dispersion obtained in the ADM model are due to the attempt of the model to account for the tailing. Mean transit time between the Injection point and this observation point (a total distance of 4800 m) resulted to be about **6.3 hours.**

The modeled mean velocity with the 2NREM Model is about **760 m/hour**, whereas the modeled Dispersion value reaches about **2380 m^2/h** yielding a longitudinal dispersivity of about **3.1 m**. The mobile phase proportion is about **92%**.

Peclet numbers are higher than 100, ranging between 528 (ADM) and 1530 (2NREM) reflecting the prevailing advective nature of the transport. Recovery rates obtained with the CXTFIT fall in the same range of that calculated by manual integration. The total restituted mass was regarded as a fixed parameter during modeling.



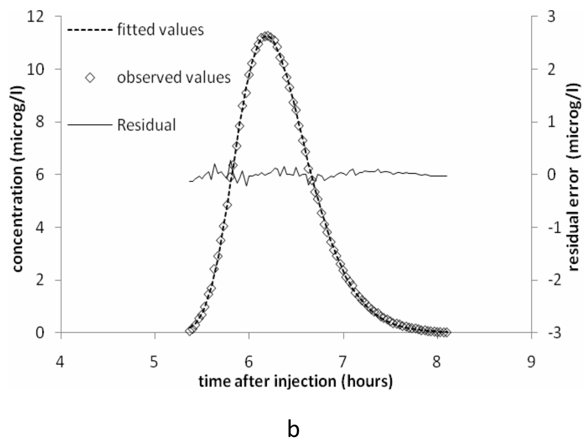


Figure 4-6 **Fitted data modeled with ADM (a) and 2NREM (b) for the TBC resulting for the tracer test 1b**

5. DISCUSSION AND CONCLUSIONS

Based on the tracer test undertaken on April 19th, 2010, a hydrogeological connection was established between an injection point in Deir Chemra at the potential location of the waste water treatment plant and the Jeita Spring at various points within the cave and at the outlet. Furthermore, tracer was also detected in the Nahr El Kalb River. The detected tracer in the River might have been channeled into the River through springs existing along the river, or an overflow from the Jeita cave itself.

Velocities within unsaturated zone depicted from the tracer behavior between the injection point and the Daraya tunnel ranges between 43 and 45 m/hour, yielding mean transient times of 60 hours. The mean transit time of the tracer between the injection point and the Jeita cave is about 66 hours, which imply a transit time of 6 hours within the cave, or a velocity of about 800 m/hour.

Velocities within the cave range between 760 and 766 m/hour, which are in accordance with the velocities calculated from the first tracer test. These velocities are considered relatively high but physically common velocities in karst systems. Longitudinal dispersivity within the cave ranges between 3m and 9 m depending on the adopted model.

Restitution rates in the first tracer test did not exceed 14 % in all the observation points namely, the Daraya tunnel and the Jeita Spring. Conclusions cannot be given about the remaining tracer quantity, which is probably trapped in the unsaturated zone, and released at very low rates.

The fluorescein concentrations observed in the TBC retrieved at the Jeita spring are lower than the ones observed in the Daraya TBC, due to dilution processes occurring in the cave because of additional $2m^3/s$ inflow at some location within the cave.

No tracer loss was detected between Daraya and Jeita outlet, as in both observation points tracer restitution was about 13-14 %. However the tracer test performed within the cave shows a loss of 49% in the tracer mass. This discrepancy can be explained either by inaccuracy in the input mass, high turbidities, or the tracer behavior. A portion of fluorescein might have remained stuck at the beginning of the Daraya section, and was not released with time. It is also worth mentioning that turbidity values at the time of tracer restitution were relatively high, exceeding 48 NTU, which might have hindered the fluorescein fluorescence. It is therefore advised to repeat the tracer test within the cave to rule out any possible losses.

Even though AG was not detected in any of the observation point, a hydrogeological connection between the injection point at Abu Mizane and the Jeita spring cannot be ruled out. The AG test could have been negative as a result of poor infiltration rates during injection and poor conditions of the injection hole.

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ANNEX 4: Results of Tracer Test 2

GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

PROTECTION OF JEITA SPRING - LEBANON -

- REPORT -

ARTIFICIAL TRACER TESTS - AUGUST 2010

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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 undertaken 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 second report submitted as part of the cooperation mentioned above.

This report presents the preliminary results of the tracer test conducted in August 2010 to delineate the hydrogeological connection between point sources in the 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 August 2010, Section 3 presents the results of the TBCs analysis. The latter mainly tackles aquifer dynamics and behavior as depicted in August 2010 and gives insights into the velocities and dispersivities in the Jurassic Jeita system. Finally Section 5 presents some conclusions and recommendations.

1.1 GENERAL

The Jeita Spring is an important karst spring located north to Beirut in Jounieh area. It constitutes the main water source for the Beirut Area and its northern suburbs for domestic use. Governed by open channel flow/ full pipe hydraulics, the Jeita Spring drains a catchment of about 288 km^2 extending east in the Lebanese Mountains (Figure 1-1). The catchment of the Jeita spring is defined to date mainly based on topographical boundaries. Very little is known about the connection between various locations on the catchment and the Jeita Spring.

Figure 1-1 Location of Jeita Spring and Catchment in Lebanon (GoogleMaps)

The total yearly precipitation on the Jeita catchment is estimated at about 407 Mm^3, out of which only about 52.3 % are infiltrated, whereas about 15 % and 32.7 % are lost in surface runoff and evapotranspiration respectively.

The Jeita cave is developed in limestone of Jurassic age over a total length (including subsidiaries) of 9000 m. The topography of the grotto was established underground as well as on the surface. The Jeita Cave is also accessible from a tunnel located downstream to Ballouneh Village, about 4500 m east to the Jeita Spring.

1.2 OBJECTIVES OF THE TRACER TEST

The main goal of the artificial tracer tests was to investigate hydrological connections between rapid and slow recharge point source in the catchment area/ subcatchment areas suspected to contribute to the total recharge of the Jeita Spring. These areas are as follows:

1) A north south trending fault zone located north to the Jeita cave trace, where a 3 m * 2 m * 2 m hole was artificially drilled in the heavily fractured valley,

2) A pit located in a construction site destined for future waste water discharge for a building in Ballouneh Area,

3) A sinkhole located about 250 m north from the cave trace. The sinkhole “Houet Ras el Astar” was discovered by The SCL (Spéléo Club du Liban; personal communication).

The Objectives of the tracer tests were mainly to:

- Identify a potential hydrogeological connection between the injection site and the Jeita spring and possibly other springs existing in the catchment
- Characterize hydrodynamic flow and transport parameters of the Jeita Aquifer system (mean and maximum flow velocities and transit times, longitudinal dispersivities, mass restitution, etc…) during low flow periods in comparison to high and medium flow periods.

Additional tracer tests were conducted within the cave over a distance of 4800 m to assess water velocities, dilution effects and potential tracer mass losses only within the cave. This information is crucial for interpretation of all further tracer tests performed in the catchment.

2. FIELD WORK AND METHODOLOGY

2.1.1 Materials

The tracers Fluorescein (Sodium fluorescein, BASF, CAS 518-47-8, $C_{20}H_{10}O_5Na_2$) and Amidorhodamin G (=Sulphorhodamine G; CAS 5873-16-5; acid red 50; $C_{25}H_{26}$ N_2O_7Na) and Na-Na-Naphtionate ($C_{20}H_8O_3N$ S Na) were selected as they are considered non toxic. Both Fluorescein and Amidorhodamin G tracers can be measured simultaneously on-site with low detection limits. Na-Naphtionate has a high background value in the Jeita waters varying between 4 and 8 µg/l. Fluorescein, 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. Geyer et al. (2007) reported that Amidorhodamin G is considered as a reactive tracer, showing slight retardation with respect to Fluorescein (Figure 2-1).

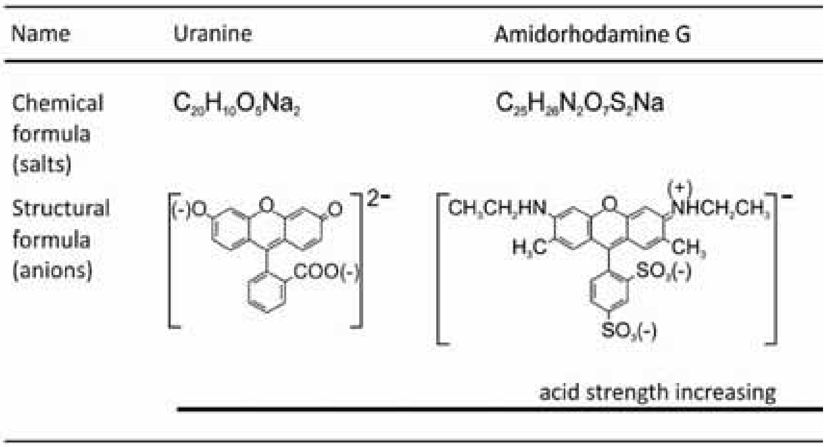


Figure 2-1 Chemical structures of the selected tracers (modified from Geyer et al. 2007)

Concentration of tracer was monitored in the springs and stream with field fluorometers (GGUN-FL30 serial numbers 524, 525, 526, 532, 533, 531; Schnegg 2002). This equipment measures continuously dye concentration at the monitoring site every 2 minutes with two incorporated lamps 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 Fluorescein, Amidorhodamin G, and Na-Naphtionate. The dissimilarity and lag between the luminescence wavelengths of both Fluorescein and Amidorhodamin G enables the distinction between both dye types during analysis and hinders the significance of overlaps. Fluorescein has a spectrum of luminescence ranging between 490 nm and 524 nm, whereas that of Amidorhodamin G extends between 535 nm and 552 nm, while that of Na-Naphtionate extends from 325 nm to 420 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 the 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 fluorescein and 0.2 µg/l for Amidorhodamine G. The limit of detection of Na-Naphtionate is usually 0.07 µg/l. However it is worth noting that the concentration of Na-Naphtionate in Jeita waters was relatively high reaching 8 ppb. 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.

2.1.2 Fieldwork

2.1.2.1 Injections

Two tracer tests were undertaken on the **2nd of August 2010** under extreme low flow conditions. The injection points were an artificially drilled hole (Ajaltoun hole; Figure 2-2) along the "Fault zone" in Ajaltoun area and an artificially drilled pit, respectively. The latter is supposed to serve for waste water discharge of a building in construction (Nassar pit). The holes were flushed with about 5 m^3 of water prior to tracer Injection. About 10 kg of Na-Naphtionate and Fluorescein were injected In the Ajaltoun hole and 5 kg of AG were injected in the Nassar pit. Both sites were flushed with 60 m^3 of water each over a period ranging between 2-3 hours (with water tanks). However it is to be noted that the infiltration rate was very low in the Nassar Pit, which did not allow any percolation of the AG. The latter tracer test was considered not successful. On the **30th of August 2010**, the Ajaltoun hole was flushed with additional 40 m^3 of water in an attempt to accelerate the flow, and achieve retrieval of the injected tracer.

Figure 2-2 Injection of 10 kg of Na-Naphtionate and Fluorescein into the Ajaltoun artificially dug hole

On **the 20th of August 2010**, 5 kg of Na-Naphtionate and 5 kg of AG were injected into a doline in the area of new Ajaltoun (sinkhole Ras el Astar; Figure 2-3). This sinkhole was explored by the SCL, and is peported to be about 22 m deep.

Figure 2-3 Injection of 5 kg of Na-Naphtionate and Amidorhodamine G into the sinkhole "Ras el Astar" in New Ajaltoun

On the **27th of August 2010**, the sinkhole was flushed with additional 40 m^3 in order to depict whether quantities of tracer remained stuck in the doline especially that the sinkhole is apparently used as a waste dump and is clogged partially with waste.

On the **28th of April 2010**, 50 grams of AG were released in the Jeita underground river at the "siphon terminal" of the Daraya Tunnel.

It is worth noting that 7 g and 10 g of fluorescein were released respectively on the **10th of August 2010** and the **17th of August 2010** at the "siphon terminal" as a result of discharge dilution measurements in Daraya. The results observed at the level of the installed fluorometer near the cave entrance are also regarded for analysis.

Table 2-1 Injections Points

INJECTION POINT	COORDINATES LAMBERT - UTM (Z) (m)	INJECTION TIME	FLUSHING VOLUME (m^3)	COMMENTS
Ajaltoun hole	147 515 226 005 36 749452.38 37 61910.24 (854)	02.08.2010 (12:11)	60	10 kg of Fluorescein and Na-Naphtionate Infiltration rate was relatively favorable to ensure good percolation of the tracer
		17.08.2010 (09:00)	40	Flushing of the hole

Nassar Pit	144 603 223 808 36 746818.14 37 59902.28 (652)	02.08.2010 (12:11)	60	5 kg of AG Infiltration rate was very low to ensure percolation of the tracer- Failed
Ras El Astar Sinkhole	146 033 224 109 36 748102.40 37 60197.83 (656)	20.08.2010 (11:40)	60	5 kg of Na-Naphtionate and AG
		27.08.2010 (15:40)	40	Flushing of the sinkhole
Daraya Tunnel	146135 223503 36 748257.41 37 59654.21 (140)	17.08.2010 (13:40)	-	50 g of AG
		10.08.2010 (16:00)	-	7 g
		17.08.2010 (13:00)	-	10 g

2.1.2.2 Observation points

During the first two tracer tests, two Field spectrofluorometer with dataloggers were installed in the Jeita spring 500 m inside the cave (525,533) and in the Siphon terminal (532,526) 4800 m from the cave touristic entrance) and one was installed in the Qachqouch spring (531) for automatic sampling. Manual samples were collected between 02.08.2010 and 20.08.2010.

During the tracer tests undertaken with the cave, one fluorometer (525) was installed 715 m inside the cave, upstream to a potential additional inlet. Fluorometer 533 was installed 500 m upstream of the cave entrance.

During the tracer test investigating Ras El Astar sinkhole, fluorometer 526 was installed at the cave entrance, whereas fluorometer 533 was kept at 500 m inside the cave. A detailed description of the observation points is provided in Table 2-2.

Figure 2-4, Figure 2-5 and Figure 2-6 show the set ups of the three tracer tests undertaken during low flow periods respectively on the 2nd, 17th, and 20th of August 2010.

Table 2-2 Observations Points

OBSERVATIONS POINTS	X,Y,Z (LAMBERT, m)	SAMPLING	TIME SPAN	SAMPLING INTERVAL	COMMENTS
Jeita Grotto (+500m)	142603 223385 95	Automatic	17.04.2010-11.05.2010	2 min- 5 min	GGUN-FL30 serial number 525

OBSERVATIONS POINTS	X,Y,Z (LAMBERT, m)	SAMPLING	TIME SPAN	SAMPLING INTERVAL	COMMENTS
Jeita Grotto (+715m)	142603 223385 95	Automatic	17.08.2010 (14:00)- 18.08.2010 (10:00)	2 min	GGUN-FL30 serial number 525
Jeita Grotto Beginning of the Touristic Section (+0m)	142233 223115 90	Automatic	17.08.2010 -30.08.2010	2 min	GGUN-FL30 serial number 526
Jeita Grotto Daraya Tunnel	146135 223503 140	Automatic	02.08.2010- 17.08.2010	2 min	GGUN-FL30 serial number 526
Jeita Grotto Daraya Tunnel	146135 223503 140	Automatic	02.08.2010- present	2 min	GGUN-FL30 serial number 532
Qachqouch Spring	141946 223006 60	Automatic	02.08.2010- present	2 min	GGUN-FL30 serial number 531

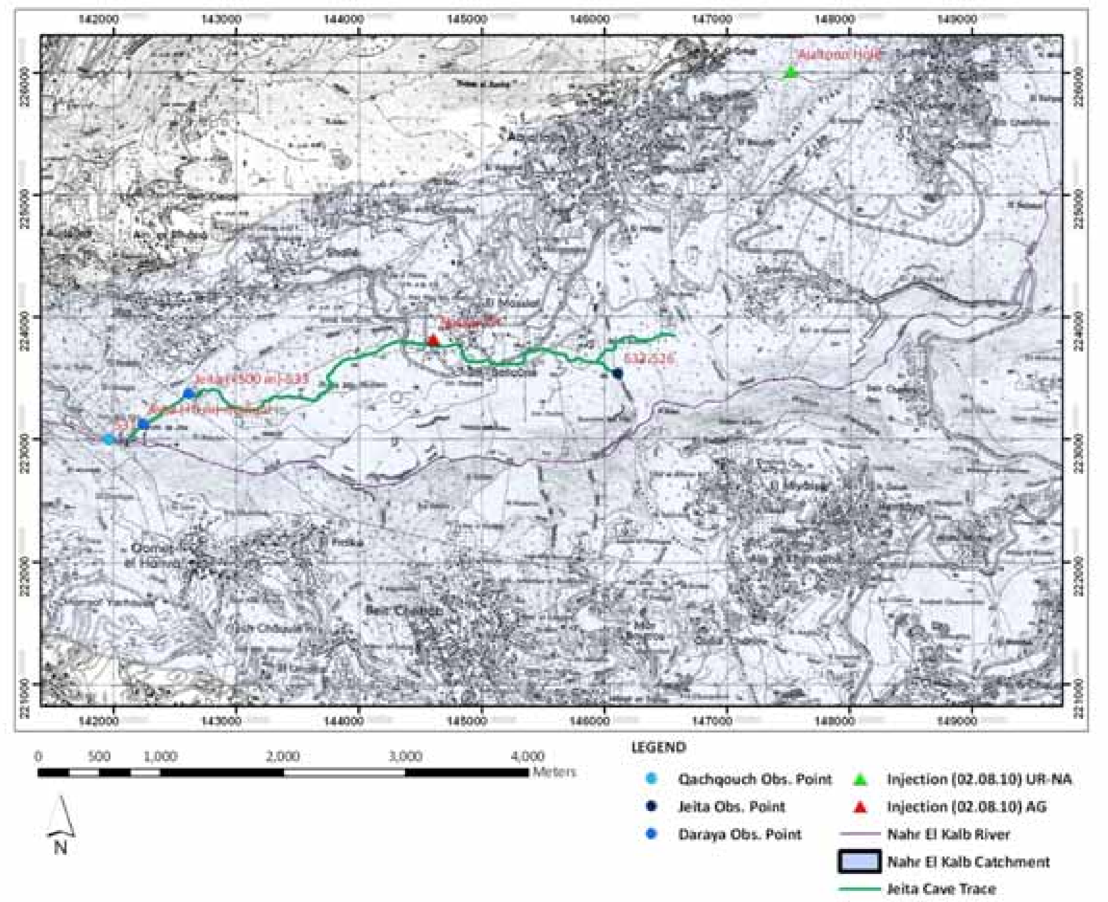


Figure 2-4 Map showing the Set-Up (Injection Points and Observation Points) of Tracer Test 1 undertaken on August 2nd 2010

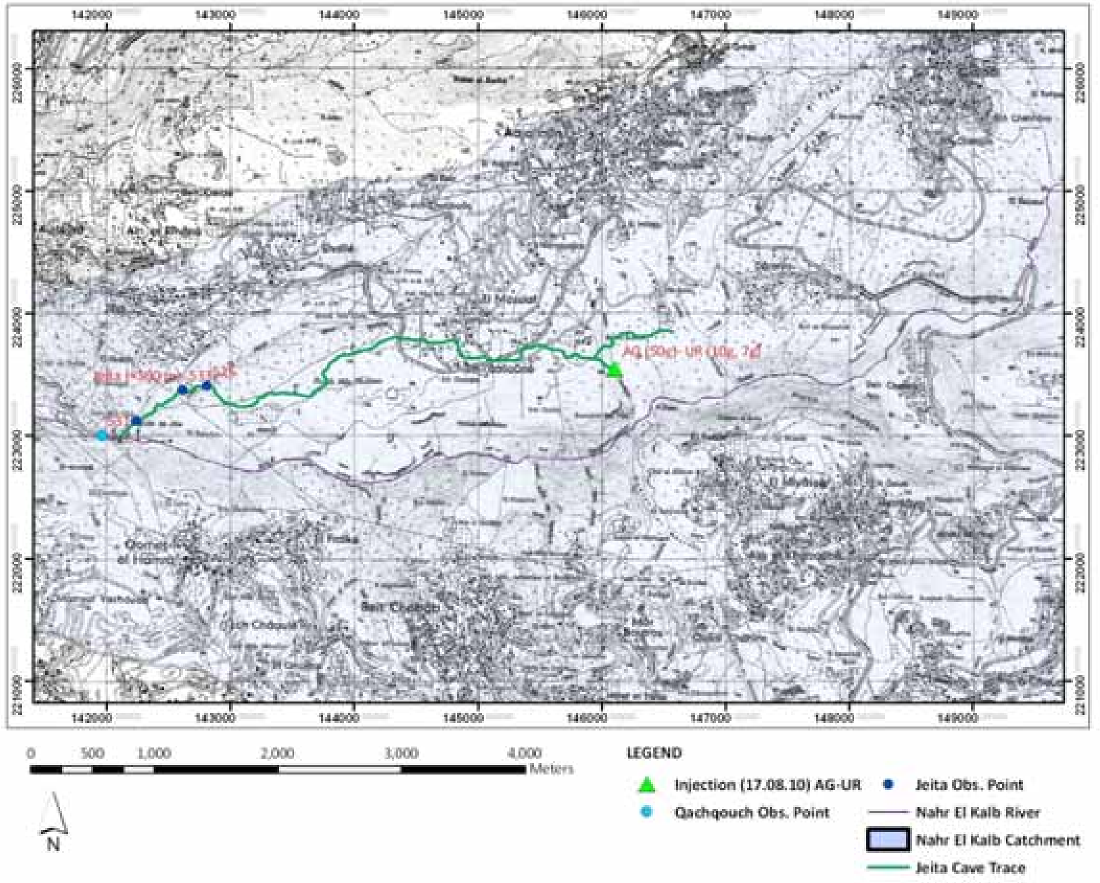


Figure 2-5 **Map showing the Set-Up (Injection Points and Observation Points) of Tracer Test 2 undertaken on the 17th of August 2010**

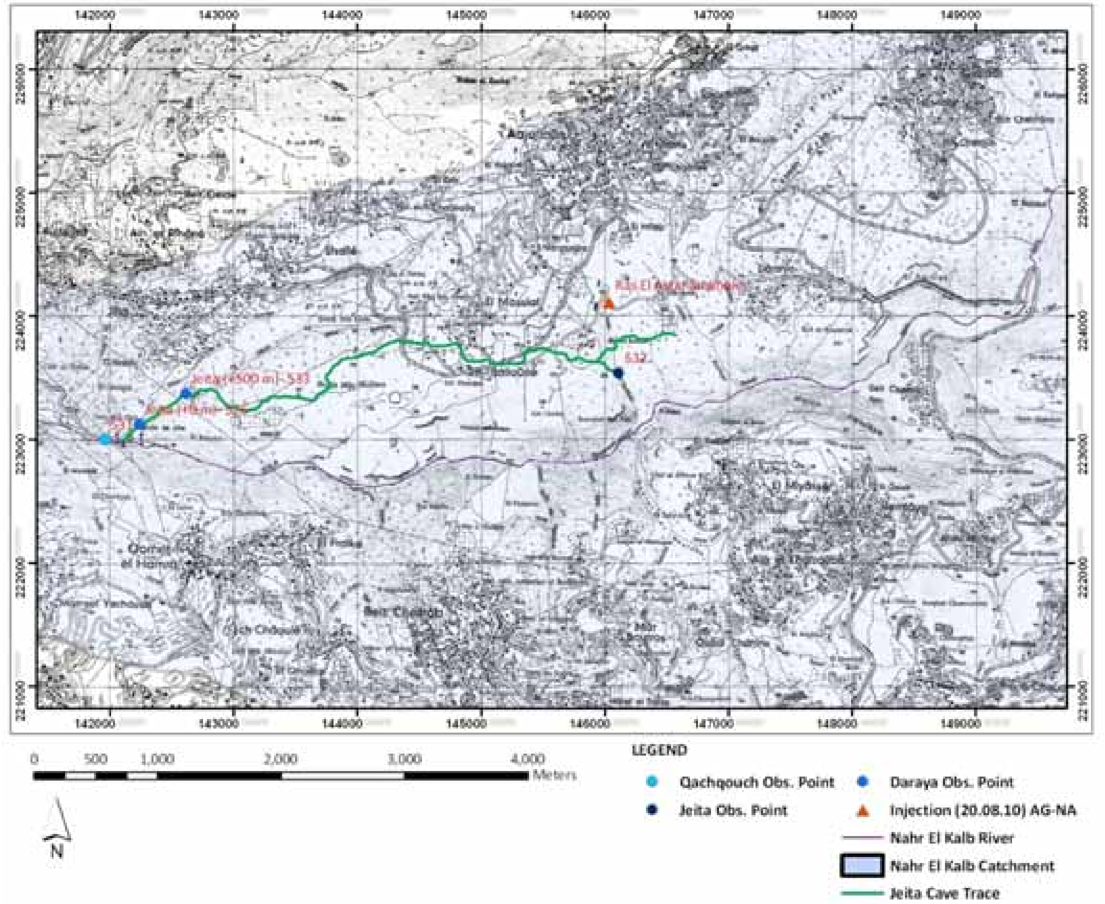


Figure 2-6 Map showing the Set-Up (Injection Points and Observation Points) of Tracer Test 3 performed on the 20th of August 2010

2.1.3 Discharge Measurements

Flow rate measurements were mainly performed based on the dilution gauging methods using salt and Fluorescein. The dilution method relies on calculating the discharge rate based on a tracer breakthrough curve (TBC). In the case of salt, a TBC of electrical conductivity is measured and translated to salt concentration with the help of a calibration function. The integration of the concentration over time allows the estimation of the discharge rate as shown in Equation 1.

A Calibration curve (rating curve, Equation 2) of salt concentration as a function of conductivity was constructed for the Daraya tunnel and Qachqouch spring prior to discharge measurement.

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

Where
Q is the discharge rate [L^3/T]
M is the injected salt or fluorescein mass [M]
c is concentration [M/L^3]
t is time [T]

$$c = a[EC] + b \qquad (2)$$

EC is the Electrical conductivity
a is the slope of the linear relationship between C and EC
b is the intersection of the calibration curve with the y axis

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 0.1-0.3 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 Grotto	Dilution with fluorescein	10.08.2010 18.08.2010	Obsolete results	Fluorescein dilution was not successful due to relatively short distance (14 m) and consequent incomplete dilution
Jeita Grotto	Dilution with Salt	10.08.2010 18.08.2010	1.9 m3/s ±0.3 m^3/sec	
Jeita Grotto Daraya Tunnel	Dilution with fluorescein	09.08.2010 17.08.2010 30.08.2010	Obsolete results	Fluorescein dilution was not successful due to relatively short distance (14 m) and consequent incomplete dilution
Jeita Grotto Daraya Tunnel	Dilution with Salt	09.08.2010 17.08.2010 30.08.2010	1.0 m^3/sec ±0.1 m^3/sec	The salt measurements fall within appropriate ranges, when Compared with velocity measurement regarded as representative of the maximum discharge.

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). Two model approaches, the *Advection-dispersion Model (ADM)*, and the *two region non equilibrium model (2RNEM)* were adopted for the modeling of the TBC, especially in the presence of overlaps in the tracer breakthrough curve and to reproduce tailing in most of the retrieved TBCs. 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 PRELIMINARY EVALUATION

3.1.1 Parameters

Tracer breakthrough curves (TBCs) were analyzed graphically, using Excel sheets, and numerically with the software CXTFIT- Stanmod (Toride et al. 1999). Two model approaches, the *Advection-dispersion Model (ADM)*, and the *two region non equilibrium model (2RNEM)* were adopted for the modeling of the TBC, especially in the presence of overlaps in the tracer breakthrough curve and to reproduce tailing in most of the retrieved TBCs. 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.

3.1.1.1 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 3 (EPA/600/R-02/001, 2002).

$$R = \frac{1}{M}\int_{t=0}^{\infty} c(t)Q(t)dt \qquad (3)$$

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.

3.1.1.2 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)

$$t_d = \int_{t=0}^{\infty} \frac{c(t)Q(t)tdt}{c(t)Q(t)dt} \qquad (4)$$

3.1.1.3 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 5. 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.

$$\mathrm{D_L} = \alpha_L \cdot \mathrm{v_m} + \mathrm{D}^* \qquad (5)$$

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

3.2.1.1 1-D advection-dispersion model (ADM)

The ADM governed by Equation 6, 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).

$$C(t) = \frac{M}{Qtm\sqrt{4\pi P_D\left(\frac{t}{t_m}\right)^3}} \exp\left(-\frac{\left(1-\frac{t}{tm}\right)^2}{4P_D\frac{t}{tm}}\right) \quad (6)$$

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 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 (*∫C(dt)*).

The fitting allows to inversely estimate the mean velocity and dispersion (Göppert and Goldscheider, 2007). This model is however unable to account for tailing observed in TBCs. This phenomenon can generally be described by mass-transfer between mobile and immobile fluid regions, flow channeling and multi-dispersion.

3.2.1.2 Two region Non equilibrium model (2RNEM)

The two region non-equilibrium model is based on the assumption that the solute is present under two forms of fluid regions, a mobile fraction, such as in the conduits and main flow direction pathways, and an immobile fraction, which is hosted in dead end passages and sediments pools (Field and Pinsky, 2000, Geyer et al., 2007). The latter fraction is thought to be released slowly with time, which explains in some cases, the tailing observed in most of the tracer breakthrough curves.

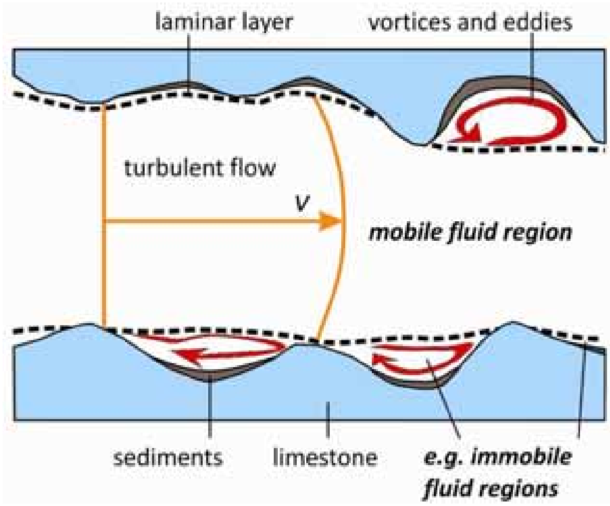


Figure 3-5 Conceptual model of flow within a karst conduit (from Geyer et al. 2007).

This Two region Non equilibrium model accounts for conservative transport processes, including advection, dispersion and mass transfer between the immobile and mobile phase. The corresponding equations are (Toride et al. 1999)

$$\theta_m \frac{\partial c_m}{\partial t} = D \frac{\partial^2 c_m}{\partial x^2} - v \frac{\partial c_m}{\partial x} - \omega(c_m - c_{im})$$

$$(1-\theta_m) R \frac{\partial c_{im}}{\partial t} = \alpha(c_m - c_{im}) \qquad (7)$$

Where v is the average velocity [L/T]
D is the dispersion coefficient [L²/T]
θ_m is fraction of the mobile fluid phase [-]
ω is the first order mass transfer coefficient [1/T]
c_{im} and c_m are the respective concentration of mobile and immobile fluid phase [M/L³]
x is the space coordinate [L]
t is time [T]

In a first approach, fluorescein and amidorhodamin G are assumed as conservative tracers in this study. Therefore reactive transport processes like e.g. ion exchange, complexation and decay will be neglected.

Tracer injection is simulated by a Dirac pulse, i.e. tracer injection period is negligible compared to the observed tracer travel time. Calibration with CXTFIT can be performed inverse, i.e. the model iterates, based on transport preset parameters, in order to reproduce observed tracer. The parameters that are adjusted for the model are β, ω, velocity *v* and dispersion *D*.

4. RESULTS OF THE TRACER TEST

The first two tracer tests undertaken on the 2nd of August were negative. The latter does not rule out the connection between the Injection points and the Jeita cave. The tracer test undertaken on Ras El Astar Sinkhole was positive delineating a connection between the sinkhole and the Jeita cave. The tracer however did not appear in the Daraya Tunnel. The results of the tracer test performed within the cave will also be discussed hereafter. 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. Distances were defined as follows and didn't account for turtuosity or change in altitude, except in the Jeita cave, where the flowpath is known:

- The distance between the Daraya Tunnel and Jeita Cave (525; +715 m inside the cave) was estimated at 4585 m.
- The distance between the Daraya Tunnel and the Jeita spring (+ 500 m) is about 4800 m.
- The distance between Ras El Astar Sinkhole and the Jeita spring (at the touristic entrance; 526) is about 6500 m, whereas the distance between the sinkhole and the Jeita Spring (at 533; + 500 m) is about 6000 m.
- The distance within the cave was calculated based on the cave trace and accounts for turtuosity.

4.1 TRACER TEST (02ND OF AUGUST 2010)

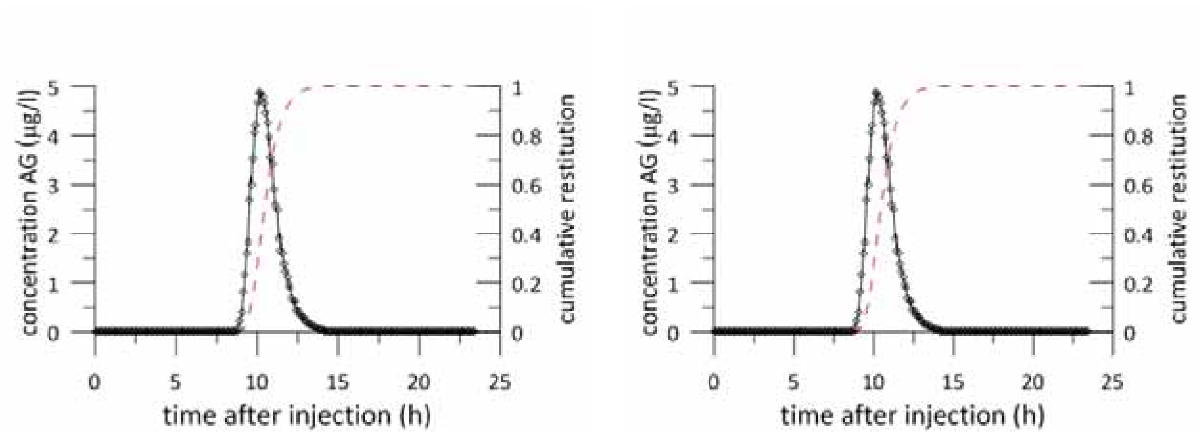
The tracer tests undertaken in Ajaltoun and Nassar Pit in Ballouneh resulted in being negative, as no tracer was retrieved in any of the observation points. The samples collected manually between August 02nd 2010 and August 20th 2010 revealed no presence of any of the tracers. The fluorometers installed at the various observation points did not detect arrival of any tracer substance.

4.2 TRACER BREAKTHROUGH CURVES- TRACER TEST (WITHIN THE CAVE)

The tracer (50 g AG) injected within the cave on the 17th of August was retrieved at fluorometers 525 (+ 715 m) and 533 (+500 m). Below is a detailed description of the results.

The AG started to appear 8.8 hours and 9.4 after injection respectively in 525 and 533. Mean residence times are calculated to be respectively 10 and 11 hours in 525 and 533. Consequently, velocities within the cave range between 420-440 m/h on the 17-18 of August 2010. No prominent tailing is observed. According to discharge rates prevailing at that time, the complete mass of injected AG was retrieved in both fluorometers. The maximum concentration observed is about 4.5 µg/L (533; Figure 4-1) and 4.86 µg/L (525; Figure 4-1). Dilution with respect to 525 is observed in the fluorometer 533 (Figure 4-2) located downstream to a potential inlet. If considered that complete restitution occurred at the the fluorometer 533, the dilution results from additional volume in the range of 80 L/s.

A similar result is also obtained from the retrieved TBC resulting from the injection of 10 g of uranine in Daraya tunnel shortly before injecting the AG. Based on modeling of the obtained curve, longitudinal dispersivities within the cave are in the range between 10-12 m.



A B

Figure 4-1 TBC of Amidorhodamine G released in Daraya on the 17th of August 2010 respectively in fluorometers 525 (a) and 533 (b)

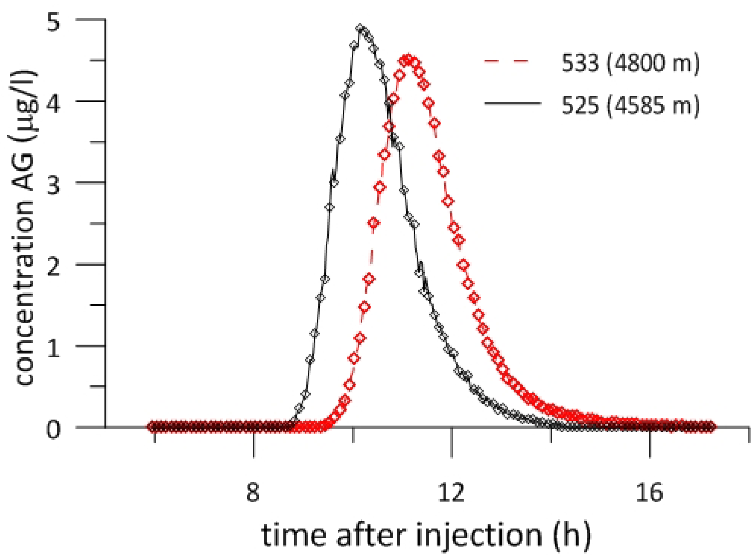


Figure 4-2 **TBCs of Amidorhodamine G released in Daraya on the 17th of August 2010. Note the lower concentration retrieved in 533 due to a potential dilution between 525 and 533.**

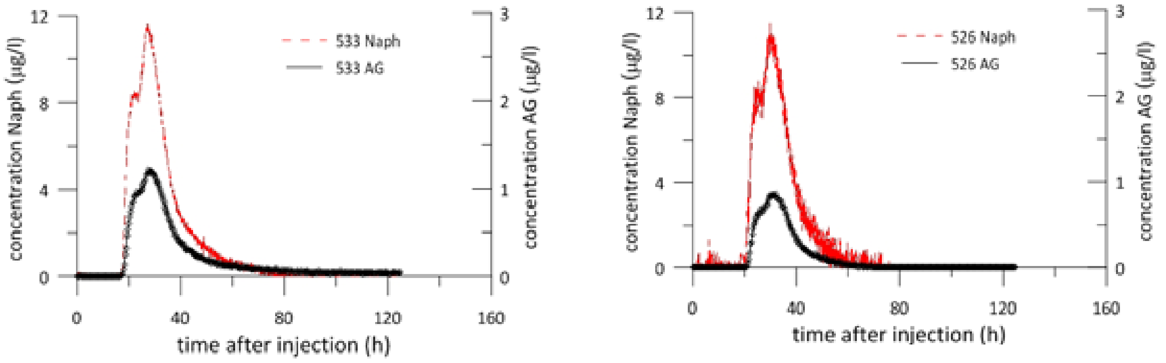
Table 4-1 **Graphical Interpretation of the TBC´s resulting from the Tracer Tests (August 2010)**

OBSERVATION POINT DISTANCE FROM INJECTION POINT	TRACER FIRST ARRIVAL (hours)	MAXIMUM VELOCITY (m/hours)	PEAK CONCENTRATION TIME (hours)	PEAK VELOCITY (m/hours)	RESTITUTION (%)
TRACER TEST (AJALTOUN ARTIFICIAL HOLE) – 02 AUGUST 2010 – AJALTOUN					**NEGATIVE**
TRACER TEST (NASSAR PIT)- 02 AUGUST 2010- BALLOUNEH					**NEGATIVE**
OBSERVATION POINT DISTANCE FROM INJECTION POINT	**TRACER FIRST ARRIVAL (hours)**	**MAXIMUM VELOCITY (m/hours)**	**PEAK CONCENTRATION TIME (hours)**	**PEAK VELOCITY (m/hours)**	**RESTITUTION (%)**
TRACER TEST (AMIDORHODAMINE) - 17 AUGUST 2010- DARAYA-JEITA					
Jeita Grotto (+715m; 525) 4585m	8.8	521	10.1	453	100
Jeita Grotto (+500m;533) 4800m	9.4	510	11.2	428	100
Qachqouch Spring					**NEGATIVE**
TRACER TEST (FLUORESCEIN) – 17 AUGUST 2010 – WITHIN THE CAVE					
Jeita Grotto (+715m;525) 4585m	9.1	503	10.06	455	29
Jeita Grotto (+500m;533) 4800m	9.5	505	10.86	441	37
TRACER TEST (AMIDORHODAMINE)- 20 AUGUST 2010- RAS EL ASTAR SINKLHOLE					
Jeita Grotto (+500m;533) 6000m	15.6	384	Peak 1: 22 Peak 2: 26.7	272 224	2.97
Jeita Grotto (+0m;526) 6500m	19.2	338	Peak 1: 25 Peak 2: 30.7	260 211	1.80
TRACER TEST (NA-NAPHTIONATE)- 20 AUGUST 2010- RAS EL ASTAR SINKLHOLE					
Jeita Grotto (+500m;533) 6000m	14.7	442	Peak 1: 21 Peak 2: 26.6	285 225	22.42

Jeita Grotto (+0m;526) 6500m	18.4	353	Peak 1: 23.8 Peak 2: 29.3	273 221	22.43

4.3 TRACER BREAKTHROUGH CURVES- TRACER TEST RAS EL ASTAR SINKHOLE

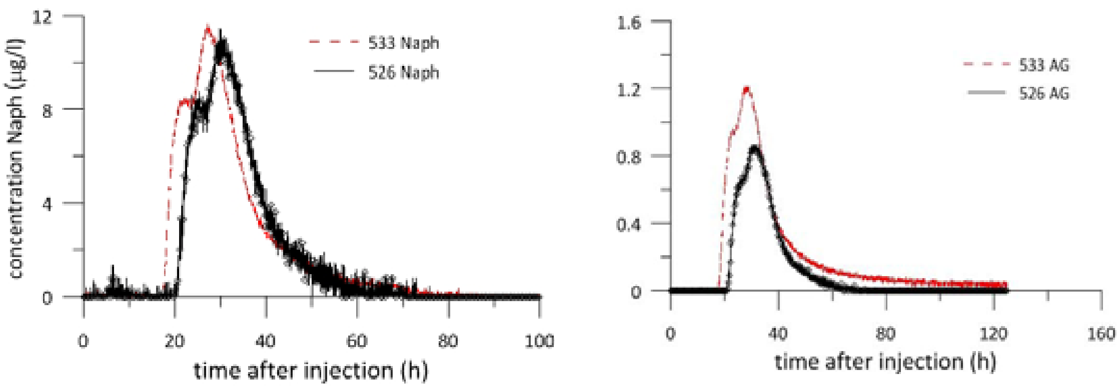
The tracers AG and Na-Naphtionate were first detected in 533, after about 15.6 hours, then in 526, after about 19.2 hours after injection. The maximum peak of Na-Naphtionate observed in 533 is about 11.29 µg/L, whereas a peak of 11 µg/L was depicted in the TBC curve at 526.



A B

Figure 4-3 TBCs of Amidorhodamine G and Na-Naphtionate injected in the Ras El Astar Sinkhole on the 20th of August 2010 respectively in fluorometers 533(a) and 533 (b)

Based on discharge rate (1.6 m^3/s) under prevailing flow conditions, approximately 148 g of AG and 1200 g of Na-Naphtionate were restituted in the TBC retrieved at 500 m inside the cave (533), whereas only 80 g of AG and 1200 g of Na-Naphtionate were retrieved at the Jeita Spring outlet at the touristic entrance (526): This slight variation of peak concentration and total restituted massive flux as portrayed in Figure 4-1 may be the result of dilution occurring between 526 and 533 and/or an error in the calibration.

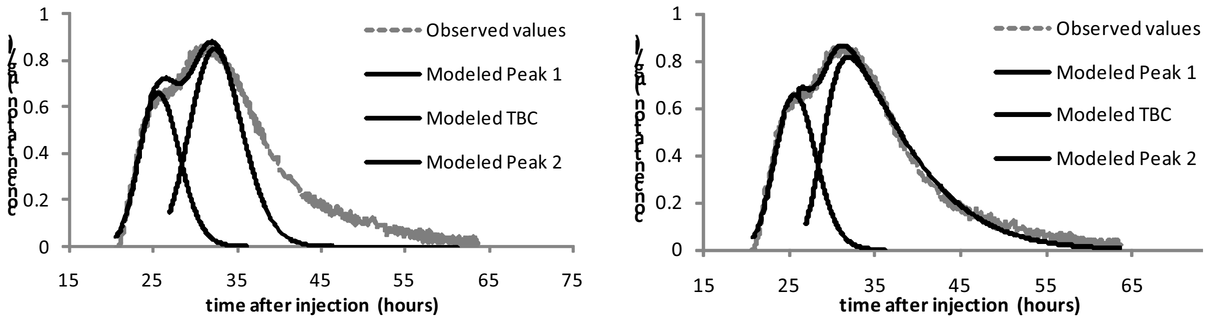


A B

Figure 4-4 Comparison of TBCs of Na-Naphtionate and Amidorhodamine G injected in the Ras El Astar Sinkhole on the 20th of August 2010 retrieved in fluorometers 533(a) and 526 (b)

The TBC portrays two main peaks resulting from two separate groundwater flow pathways. If the TBC is regarded as one curve, the mean velocity is estimated to about 199 m/h.

If the TBC is modeled using a multi peak approach, then the first rapid flow path is characterized by a mean velocity of 250 m/h and a longitudinal dispersivity of 27 m, whereas the second slower pathway is characterized by a mean velocity of 199 m/h and a dispersivity of 30 m. As portrayed by



A b

Figure 4-5 Multi peak modeling with ADM (a), and 2NREM (b) of the TBC resulting from the tracer test performed on the 20th of August 2010

Table 4-2 and 4-3 show the hydrodynamic parameters namely mean velocity and dispersivities resulting from modeling of the TBCs using the ADM and 2NREm models with CXTFIT. In general for all modeled TBCs, Peclet numbers ranges between 200 and 900, reflecting the prevailing advective component of the transport through the karst system. Recovery rates obtained with the CXTFIT fall in the same range of that calculated by manual integration. It is worth noting that AG was retarded with respect to Na-Naphtionate with a factor of retardation estimated at 1.03, i.e., about 1 hour delay over the entire distance.

Table 4-2 **Summary of the Modeling Results of the Tracer Tests Undertaken within the cave in August 2010**

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO (+715M)	JEITA GROTTO (+500M)	JEITA GROTTO (+715M; 525)	JEITA GROTTO (+500M; 533)
SIPHON TERMINAL –JEITA			**TRACER TEST (50 g AG) - 17. AUGUST 2010**		**TRACER TEST (510 g FL) - 17. AUGUST 2010**	
Distance	D	m	4585	4800	4585	4800
Discharge	Q	m^3/sec	1.575	1.655	1.575	1.65
ADVECTION DISPERSION METHOD (ADM)						
Mean Velocity	v	m/hour	**440**	**424**	**454**	**437**
Mean transient time	t_m	hours	10	11	10	11
Dispersion	D	$m^2/hour$	5240	4680	2720	3070
Dispersivity	A	M	11.9	11	6	7
Peclet number	P_D	-	385	435	765	683
Massive Flux	M	µg•h/l	8.8	8.4	0.522	0.624
Restitution Rate	R	%	99.79	99.79	29.60	37.07
Statistical parameters						
Coefficient of Correlation	R^2	-	0.98	0.985	0.98	0.994
Mean Square Error	MSE	µg/l	5.33E-02	3.36E-02	3.95E-04	1.16E-04
TWO REGION NON EQUILIBRIUM MODEL (2NREM)						
Mean Velocity	v	m/hour	**440**	**424**	**454**	**436**
Mean transient time of mobile phase	t_m	hours	10.4	11.3	10.1	11.0
Dispersion	D	$m^2/hour$	5240	4660	2800	2390

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO (+715M)	JEITA GROTTO (+500M)	JEITA GROTTO (+715M; 525)	JEITA GROTTO (+500M; 533)
Partition coefficient	β	-	0.95	0.95	0.921	0.971
Mass transfer coefficient	ω	1/hour	1.8E-01	1.6E-01	0.404	0.47
Dispersivity	α	m	11.9	11	6.2	5.5
Peclet number	P_D	-	385	437	743	876
Massive Flux	M	µg•h/l	8.86	8.45	0.526	0.626
Restitution Rate	R	%	100.47	100.39	29.82	37.18
Statistical parameters						
Coefficient of Correlation	R^2	-	0.98	0.985	0.982	0.995
Root mean Square Error	RMSE	µg/l	5.40E-02	3.37E-02	3.96E-04	9.96E-01
Dilution amount between 525 and 533				80l/s		

Table 4-3 Summary of the Modeling Results of the Tracer Tests Undertaken on August 20th, 2010

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO (+50M; 533;FC)	JEITA GROTTO (+0M; 526;FC)	JEITA GROTTO (+0M; 526;FC)	JEITA GROTTO (+0M; 526; PEAK1)	JEITA GROTTO (+0M; 526; PEAK2)
SIPHON TERMINAL –JEITA			**TRACER TEST (5KG AG- 5KG NA-NAPHTIONATE) - 20. AUGUST 2010**				
Distance	D	m	6000	6500	6500	6500	6500
Discharge	Q	m^3/sec	1.65	1.65	1.65	1.65	1.65
Tracer	-	-	AG	Na-Naphtionate	AG	AG	AG
ADVECTION DISPERSION METHOD (ADM)							
Mean Velocity	v	m/hour	**201**	**204**	**199**	**251**	**199**
Mean transient time	t_m	hours	32	32	33	26	33
Dispersion	D	m^2/hour	35000	35500	30300	6890	6050
Dispersivity	A	M	174.1	174	152.3	27.5	30.4
Peclet number	P_D	-	32	37	43	237	214
Massive Flux	M	µg•h/l	21.8	176	14	22	38
Restitution Rate	R	%	2.49	20.1	1.6	0.44	0.75
Statistical parameters							
Coefficient of Correlation	R^2	-	0.96	0.97	0.98	0.984	0.984
Mean Square Error	MSE	µg/l	3.23 E-03	2.95E-03	1.67E-03	9.51E-04	1.66E-03
TWO REGION NON EQUILIBRIUM MODEL (2NREM)							
Mean Velocity	v	m/hour	**200**	**199**	**194**	**251**	**178**
Mean transient time of mobile phase	t_m	hours	32.5	32.7	33.5	25.9	36.5

PARAMETERS	SYMBOL	UNITS	JEITA GROTTO (+50M; 533;FC)	JEITA GROTTO (+0M; 526;FC)	JEITA GROTTO (+0M; 526;FC)	JEITA GROTTO (+0M; 526; PEAK1)	JEITA GROTTO (+0M; 526; PEAK2)
Dispersion	D	m^2/hour	7240	18900	14300	6890	2470
Partition coefficient	β	-	0.554	0.839	0.833	-	0.833
Mass transfer coefficient	ω	1/hour	0.122E-02	3.1E-04	3.1E-04	-	3.1E-04
Dispersivity	α	m	36.2	95	73.1	27.2	13.9
Peclet number	P_D	-	152	68	237	237	468
Massive Flux	M	µg•h/l	20.3	175	14	22	10.1
Restitution Rate	R	%	1.93	19.97	1.6	0.44	1.15
Statistical parameters							
Coefficient of Correlation	R^2	-	.0.964	0.98	0.98	0.984	0.994
Root mean Square Error	RMSE	µg/l	0.298E-02	2.91E-03	1.18E-03	9.51E-04	4.78E-04

5. CONCLUSIONS

Discharge rates of the Jeita Spring have been estimated at **1.65 m^3/s** (with an error of ±0.2 m^3/s) during the month of August based on various dilution measurements. Discharge rates of the Jeita Spring in Daraya are estimated at about **1 m^3/s** (with an error of ±0.1 m^3/s) as portrayed by dilution tests conducted in August 2010.

Based on the tracer test undertaken on August 20th, 2010, a hydrogeological connection was established between the Ras El Astar Sinkhole (which is believed to have a direct access to the cave) and the Jeita Spring at various points within the cave and at the outlet. Similar hydrodynamic parameters can be deduced from the TBC retrieved in Fluorometers 526 and 533 for both Na-Naphtionate and AG, notably with regards to velocity (about **200 m/h**) and dispersivity (**30 000 m^2/h**). However amounts of AG restitution (**about 2%**) appear to be 10 times less than that of Na-Naphtionate (**about 20 %**), with the AG TBC slightly retarded with respect to that of Na-Naphtionate due to the reactivity of the Amidorhodamine G.

Two main flow paths (modeled using a multi peak approach) can be identified in the retrieved TBC as follows:

1. A flowpath characterized by velocities of about **250 m/h**, diverting about 36% of the tracer retrieved mass with dispersivities of about **33 m**.
2. A flowpath characterized by slower velocities of about **199 m/h**, diverting 54% of the total restituted mass, with dispersivities of about **26 m**.

The tailing in the AG and Na-Naphtionate TBC is prominent due an important portion of immobile phase released with time, the portion of mobile phase is estimated according to 2NREM to be about 0.83.

Velocities within the cave are of the range of **400 m/h** as portrayed by tracer tests using both Fluorescein and AG. The dispersivities within the cave are in the range of **10-12 m**.

Assuming a velocity of 400 m/h over the entire length of the cave (4800 m), the mean transit time of the tracer in the cave is about 10-12 hours. The total transit time of the tracer during the tracer test conducted on August 20. 2010, was about 33 hours. Therefore the transit time of the tracer before reaching the cave can be estimated at 21-23 hours. Velocities in the unsaturated zone (related to a shaft/fast flow pathway) are in the range of 30-40 m/h.

Based on the tracer test undertaken within the cave, no loss of tracer was observed (restitution of the injected 50g AG). However an additional inflow of about **70-90 l/s** (0.07-0.09 m^3/s) can be inferred from the dilution effect depicted between TBC's restituted in 525 and 533 (respectively located at + 715 m and + 500 m from cave entrance).

Even though AG and Fluorescein injected on 02[nd] of August 2010 were not detected in any of the observation point, a hydrogeological connection between the injection point at Abu Mizane and the Jeita spring cannot be ruled out. The tests could have been negative as a result of poor infiltration rates during injection and poor conditions of the injection hole.

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