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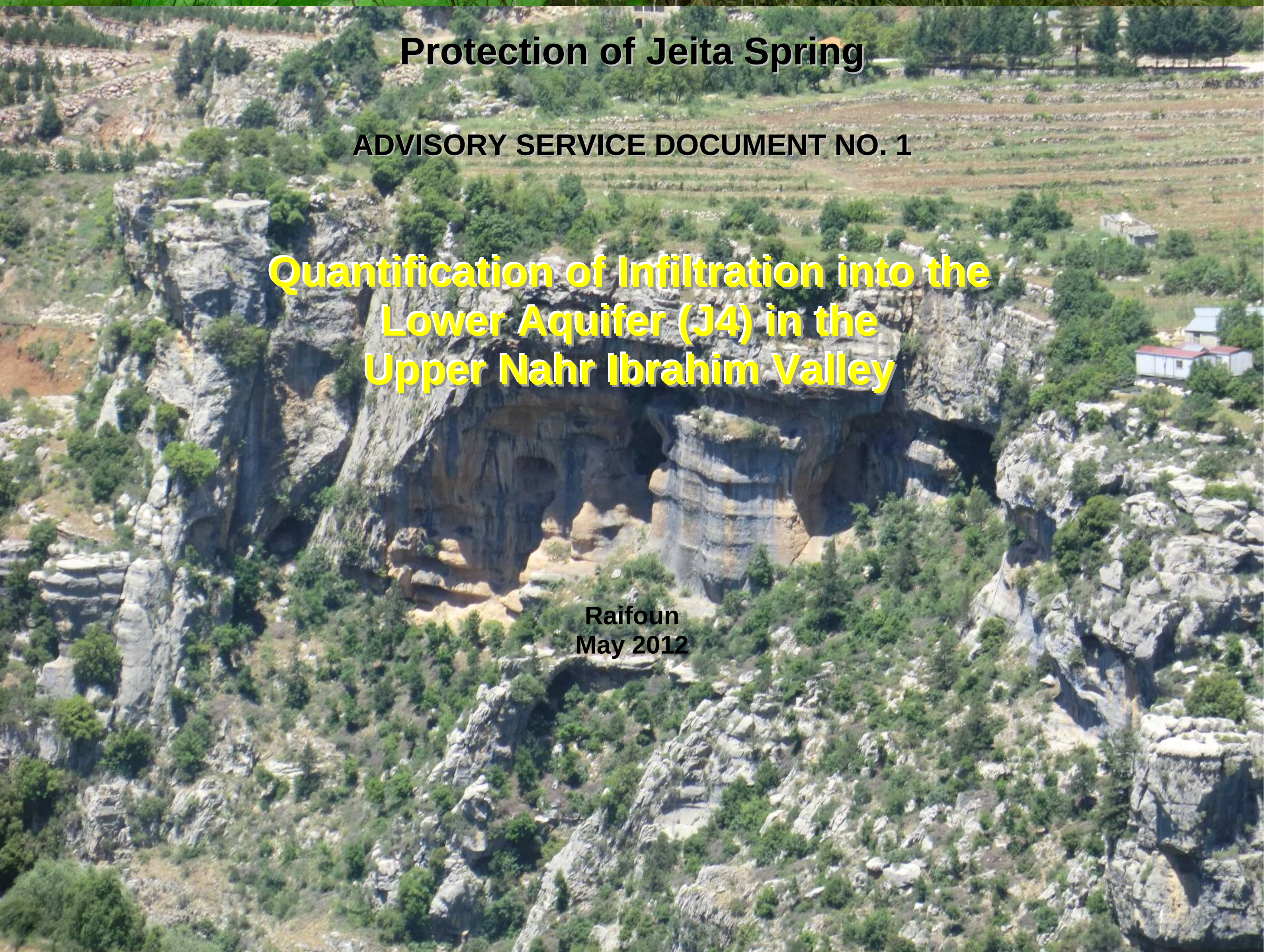

# Protection of Jeita Spring

## ADVISORY SERVICE DOCUMENT NO. 1

# Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley

Raifoun
May 2012

# Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley

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## List of Reports prepared by the Technical Cooperation Project Protection of Jeita Spring

| Report No. | Title | Date Completed |
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| **Technical Reports** | | |
| 1 | Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment – General Recommendations from the Perspective of Groundwater Resources Protection | January 2011 |
| 2 | Best Management Practice Guideline for Wastewater Facilities in Karstic Areas of Lebanon – with special respect to the protection of ground- and surface waters | March 2011 |
| 3 | Guideline for Environmental Impact Assessments for Wastewater Facilities in Lebanon – Recommendations from the Perspective of Groundwater Resources Protection | November 2011 |
| 4 | Geological Map, Tectonics and Karstification in the Groundwater Contribution Zone of Jeita Spring | First Draft September 2011 |
| 5 | Hydrogeology of the Groundwater Contribution Zone of Jeita Spring | In progress |
| 6 | Water Balance for the Groundwater Contribution Zone of Jeita Spring using WEAP including Water Resources Management Options and Scenarios | In progress |
| 7 | Groundwater Vulnerability Mapping in the Jeita Spring Catchment | April 2012 |
| **Special Reports** | | |
| 1 | Artificial Tracer Tests 1 - April 2010 (prepared with University of Goettingen) | July 2010 |
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| 3 | Practice Guide for Tracer Tests | Version 1 January 2011 |
| 4 | Proposed National Standard for Treated Domestic Wastewater Reuse for Irrigation | July 2011 |
| 5 | Artificial Tracer Tests 4B - May 2011 (prepared with University of | September 2011 |

| Report No. | Title | Date Completed |
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| | Goettingen) | |
| 6 | Artificial Tracer Tests 5A - June 2011 (prepared with University of Goettingen) | September 2011 |
| 7 | Mapping of Surface Karst Features in the Jeita Spring Catchment | October 2011 |
| 8 | Monitoring of Spring Discharge and Surface Water Runoff in the Jeita Spring Catchment | In Progress |
| 9 | Soil Survey in the Jeita Spring Catchment | First Draft November 2011 |
| 10 | Mapping of the Irrigation System in the Jeita Catchment | First Draft November 2011 |
| 11 | Artificial Tracer Tests 5C - September 2011<br>(prepared with University of Goettingen) | February 2012 |
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| 14 | Guideline for Gas Stations - Recommendations from the Perspective of Groundwater Resources Protection | May 2012 |
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| 16 | Hazards to Groundwater and Assessment of Pollution Risk in the Jeita Spring Catchment | In Progress |
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| 1 | Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley | May 2012 |
| Reports with KfW Development Bank<br>(jointly prepared and submitted to CDR) | | |
| 1 | Jeita Spring Protection Project Phase I - Regional Sewage Plan | October 2011 |
| 2 | Jeita Spring Protection Project - Feasibility Study - Rehabilitation of Transmission Channel Jeita Spring Intake – Dbaye WTP | May 2012 |
| 3 | Jeita Spring Protection Project - Environmental Impact Assessment for | In Progress |

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## List of Abbreviations

| | |
|---|---|
| asl | Above mean sea level |
| bgl | Below ground level |
| BGR | Federal Institute for Geosciences and Natural Resources www.bgr.bund.de |
| BMZ | German Ministry of Economic Cooperation and Development www.bmz.de |
| C4 | Sannine Formation (limestone; Cretaceous) |
| CAS | Chemical Abstracts Service (www.cas.org) |
| CDR | Council for Development and Reconstruction www.cdr.gov.lb |
| D | deuterium |
| DEM | Digital elevation model |
| GW | Groundwater |
| J4 | Keserwan Fromation (limestone and dolomite; Jurassic) |
| J5 | Bhannes Formation (basalt; Jurassic) |
| LRA | Litani River Authority |
| MAR | Managed aquifer recharge (artificial groundwater recharge) |
| MCM | Million cubic meters |
| MoEW | Ministry of Energy and Water |
| NTU | Nephelometric turbidity units |
| O-18 | Oxygen-18 isotope |
| ppb | Parts per billion |
| TC | Technical Cooperation |
| UTM | Universal Transverse Mercator |
| WEBML | Water Establishment Beirut and Mount Lebanon |

# 0 Executive Summary

The BGR project Protection of Jeita Spring had conducted several tracer tests over the past two years which were providing increasing evidence that the groundwater contribution zone of Jeita spring reaches far into the Nahr Ibrahim surface water catchment. It was proven by hydroisotope analyses that a major share of water discharging at Jeita comes from groundwater recharge at elevations > 2000 m. However most of the water recharged on the Upper Cretaceous plateau discharges at Afqa spring. Therefore there was assumed to be a connection of Afqa spring with Jeita spring. This cannot be through downward leakage as tracer tests have also proven. The only possible explanation was infiltration of the Upper Cretaceous water discharge at Afqa into the Lower Aquifer (J4) in the Upper Nahr Ibrahim.

Due to the difficult access conditions there was, however, until now no possibility to conduct a tracer test in the J4 aquifer in this area. Another possibility to prove the hypothesis of infiltration was to conduct differential discharge measurements in the Upper Nahr Ibrahim Valley. Two such tests were now conducted during high-flow conditions between the area upstream of the outcrop of the J4 Formation and Janneh bridge (30.04.2012 and 16.05.2012). Streamflow was measured at five locations, two measuring separately the discharge in the Rouaiss and Afqa branch before the confluence, three measuring downstream of the confluence, over a total distance of 8 km.

**Both tests prove that a massive infiltration into the J4 aquifer exists in the Upper Nahr Ibrahim Valley.** During the first campaign an infiltration of around 40 % was measured, while it was around 35 % during the second campaign. The main infiltration zone was identified but infiltration may also exist elsewhere. Further tests are needed and will be conducted.

These findings do not just have consequences for the groundwater contribution zone of Jeita spring, which is now extended much further to the north, to E of Tannourine, but also for the planning of water resources infrastructure, which are currently planned in the Upper Nahr Ibrahim Valley. The proposed Janneh dam would extend onto the assumed main infiltration zone so that it must be expected that the dam would rather act as a recharge facility (MAR) than a storage dam.

Principally this would have a positive effect for Jeita spring in so far as it would increase discharge at Jeita spring and would probably result in much shorter deficit periods for water supply in Beirut. Currently discharge of Jeita spring reaches a minimum of 1 m³/s in December. By artificial groundwater recharge at the Janneh dam this minimum discharge could probably be doubled.

However, it would also mean that the original purpose of the dam, storage, can most likely not be met.

# 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 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).

This report presents preliminary results of hydrogeological investigations of the Technical Cooperation (TC) Project Protection of Jeita Spring (implemented by BGR and CDR) related to the delineation of the groundwater catchment of and groundwater protection zones for Jeita spring.

Because some of these results are also relevant for the planning of water resources infrastructure of the Lebanese Government currently ongoing in the Janneh area, the results of differential discharge measurements conducted by the project in the Upper Nahr Ibrahim Valley are documented, upon request of the Ministry of Energy and Water, in this report.

The area investigated until now by the project is shown in Figure 1. Until before these tracer tests were conducted in the Upper Nahr Ibrahim Valley, the assumed groundwater contribution zone of Jeita spring comprised 311 km². A preliminary water balance for this area has been established (SCHULER, 2011). The aquifer system is divided into (Figure 2):

- Upper Aquifer (Sannine Formation; C4);
- Aquitard (J5 to C3 formations);
- Lower Aquifer (Keserwan Formation; J4).

It was assumed since a long time by the project that the major contribution to Jeita spring comes from the Upper Aquifer (C4), discharged at Afqa and Rouaiss springs, which were believed to infiltrate into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley. With the now extended part of the catchment, the groundwater contribution zone of Jeita encompasses 406 km².

The Upper Nahr Ibrahim Valley exhibits a number of major structural geological elements, which are important for the groundwater flow path. Due to the fact that, unlike in other countries of the region, geological investigations have not yet been undertaken in Lebanon, many of these structures have not been described or named until now. The names used in this report are therefore those attributed by the BGR project (MARGANE et al., in progr.; HAHNE et al., in progr.).

This area is at the crossing point of the catchments of five major springs:

- Afqa (E 35.893295°, N 34.067753°, 1280 m asl)
- Rouaiss (E 35.909024°, N 34.108946°, 1335 m asl)
- Yammouneh (E 36.021975°, N 34.126083°, 1400 m asl)
- Jeita (E 35.641960°, N 33.943575°, 60 m asl) and
- Chekka (submarine spring)

The boundaries of these catchments are defined mainly by the dip of geological strata and the following structural geological elements (Figure 9):

- Yammouneh fault (N-S strike; eastern boundary of Beka'a Valley)
- Janneh-Tannourine fault (N-S strike; Figure 1)
- Laqlouk anticline (N-S strike; Figure 2)
- Ariz geological dome (Figure 3)
- Afqa syncline (W-E strike; Figure 4)
- Sannine anticline (Figure 5)
- Afqa fault (W-E strike; Figure 4)
- Qehmez-Nahr ed Dahab fault zone (WSW-ENE strike; partly as basalt dyke; Figure 6)

Other geological factors which play a major role in controlling groundwater flow are:

- secondary dolomitization and
- basalt emplacement and thickness.

In this structurally very complicated area the Lebanese Government is currently planning to build the Janneh dam. The planning of this dam has been reiterated several times over the past 60 years. Initial geological investigations had been conducted but did not touch on the many of the most critical issues:

- the role of the above mentioned structural geological elements,
- the groundwater flow path and specifically the issue of surface water infiltration into the underground at the proposed location of the dam.

Based on numerous field visits in the area and the substantial hydrogeological investigations carried out in the Jeita groundwater catchment by the BGR project it was known that:

- along the Janneh-Tannourine fault a vertical displacement of up to 800 m must be assumed; the eastern block is down-faulted, causing the base of the Jurassic, the Triassic, to be presumably very close to land surface west of the fault (assumed depth to Triassic near Janneh bridge: 100-200 m bgl); because the top of the Triassic is relatively high on the western side, this prominent fault is assumed to act as a hydrogeological barrier, blocking groundwater flow towards W; the Janneh-Tannourine fault acts thus as a groundwater divide; groundwater flow in the half-graben like structure E of this fault can only go towards N and S; a groundwater divide is assumed near the highest point, in the Laqlouk area; N of it GW flow is assumed to be directed towards N, S of it towards S;

- the Qahmez-Nahr ed Dahab fault zone is believed to constitute a compressional fault; basalt (dyke), probably related to the emplacement of the J5 formation, is found along many parts of this fault and is considered the main reason for the blockage of groundwater flow at this fault; this blockage was proven through a tracer test in the Msheti well (DOUMMAR et al., 2012c);
- secondary dolomitization has affected large parts of the Keserwan Formation (J4); dolomites are especially found along the major fault zones mentioned above, especially the Qahmez and Janneh-Tannourine faults; secondary dolomite is present near the proposed Janneh dam but not upstream of it; it is assumed that basalt weathering (J5) and the leaching of magnesium-rich solutions from this process lead to secondary dolomitization in the underlying J4;
- the dolomites ($CaMg(CO_3)_2$) in the J4 are highly friable and when intensively fractured become a sand-like deposit (which unfortunately is often mistaken for sand in the project area); at outcrops it can be observed that in these secondary dolomites there are many voids (Photos 3, 4); this is related to the fact that during secondary dolomitization both, density and porosity increase; dolomitization will therefore principally have an effect of increasing the permeability of the rock; on the other hand dolomite is less soluble compared to limestone so that over time porosity in dolomites will be lower than in the neighboring limestone;
- basalt (J5) thickness varies considerably in the area studied by the BGR project; in the Qartaba area, near the Janneh-Tannourine fault (left-lateral shear fault), it reaches around 200 m, while in some other areas of the project basalt may be completely missing; this basalt thickness depends on the topography of the former land surface and on the areas where basalt was rising up; some of the faults in the Qartaba area may have been activated at that time bringing up these large amounts of basalt;
- the uppermost part of the Keserwan limestone (J4) is commonly highly karstified and usually provides a well developed karst network; it is therefore considered the layer with the highest groundwater recharge in the Jeita catchment (around 75%);

- several caves are found in the Upper Nahr Ibrahim Valley in the upper part of the J4 formation (cover page; Figure 32; Photo 1);
- at the easternmost limit of the J4 outcrop area, i.e. near the junction of the Afqa and Rouaiss branches of Nahr Ibrahim, the dip of strata is towards E - SE (~5°), facilitating infiltration into the J4;
- rocks in this area exhibit an intensive fracturation and presumably dense karst network due to the above mentioned structural geological elements.

Groundwater recharge, not considering return flows, in the Keserwan formation (J4; 87 km²) of the Jeita groundwater catchment reaches only around 60 MCM/a, while discharge of Jeita spring averages 160 MCM/a. Therefore an additional 100 MCM/a must originate from the Upper Aquifer (C4) and/or other sources (surface water). Tracer tests along the northern boundary of the Jeita groundwater contribution zone showed that the most probable explanation would be a considerable infiltration of surface water, most of it coming from the Upper Aquifer (C4), in the Upper Nahr Ibrahim Valley because most other sources (e.g. downward leakage from Upper into Lower Aquifer or inflow from Beka'a Valley through the Yammouneh fault) were ruled out in the course of the groundwater investigations. The BGR project had until now assumed an infiltration of around 50% in the Upper Nahr Ibrahim Valley, which would bring around 60 MCM/a to Jeita. The stable isotope (O-18/D) composition of Jeita spring points to a large contribution from elevations above 2000 m (KOENIGER & MARGANE, in progr.; MARGANE et al., in progr.).


Figure 1A

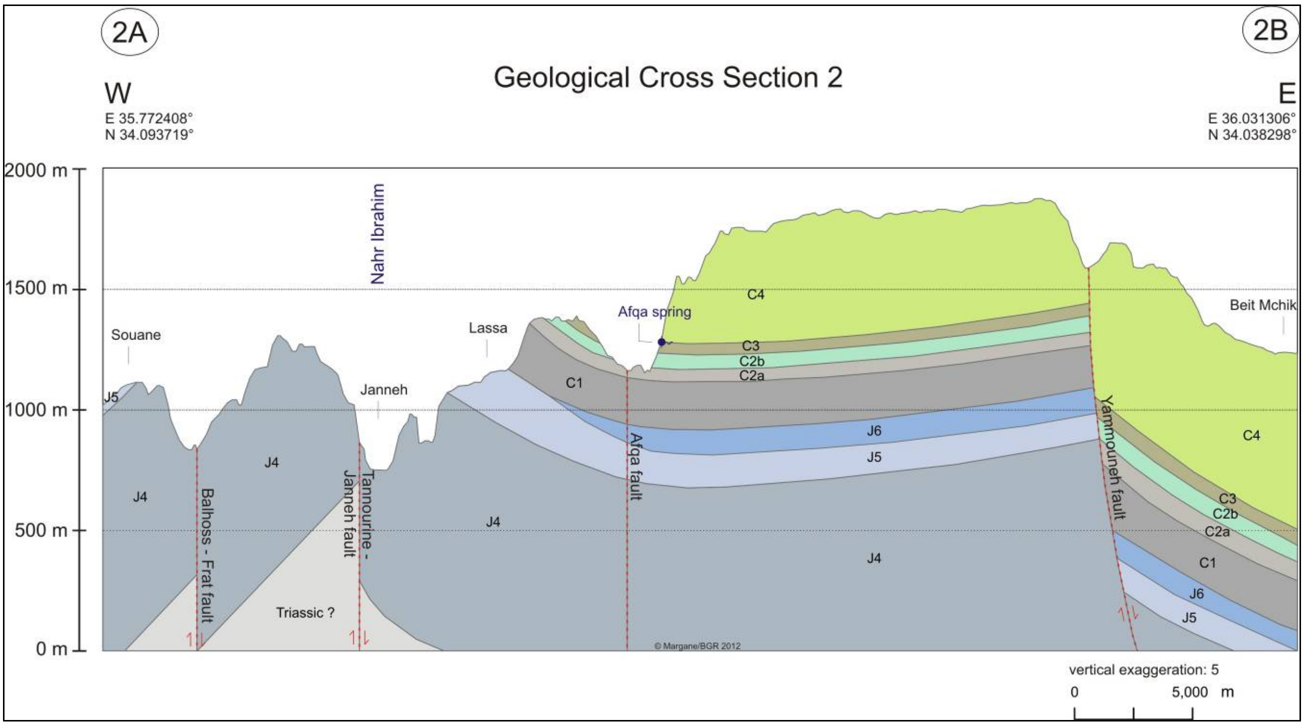


Figure 1B

Figure 1: Janneh-Tanourine Fault with up to 800 m vertical displacement (eastern side down-lifted);
A - View from Laissa towards Qartaba;
B - Geological Cross Section showing the Hydrogeological Function

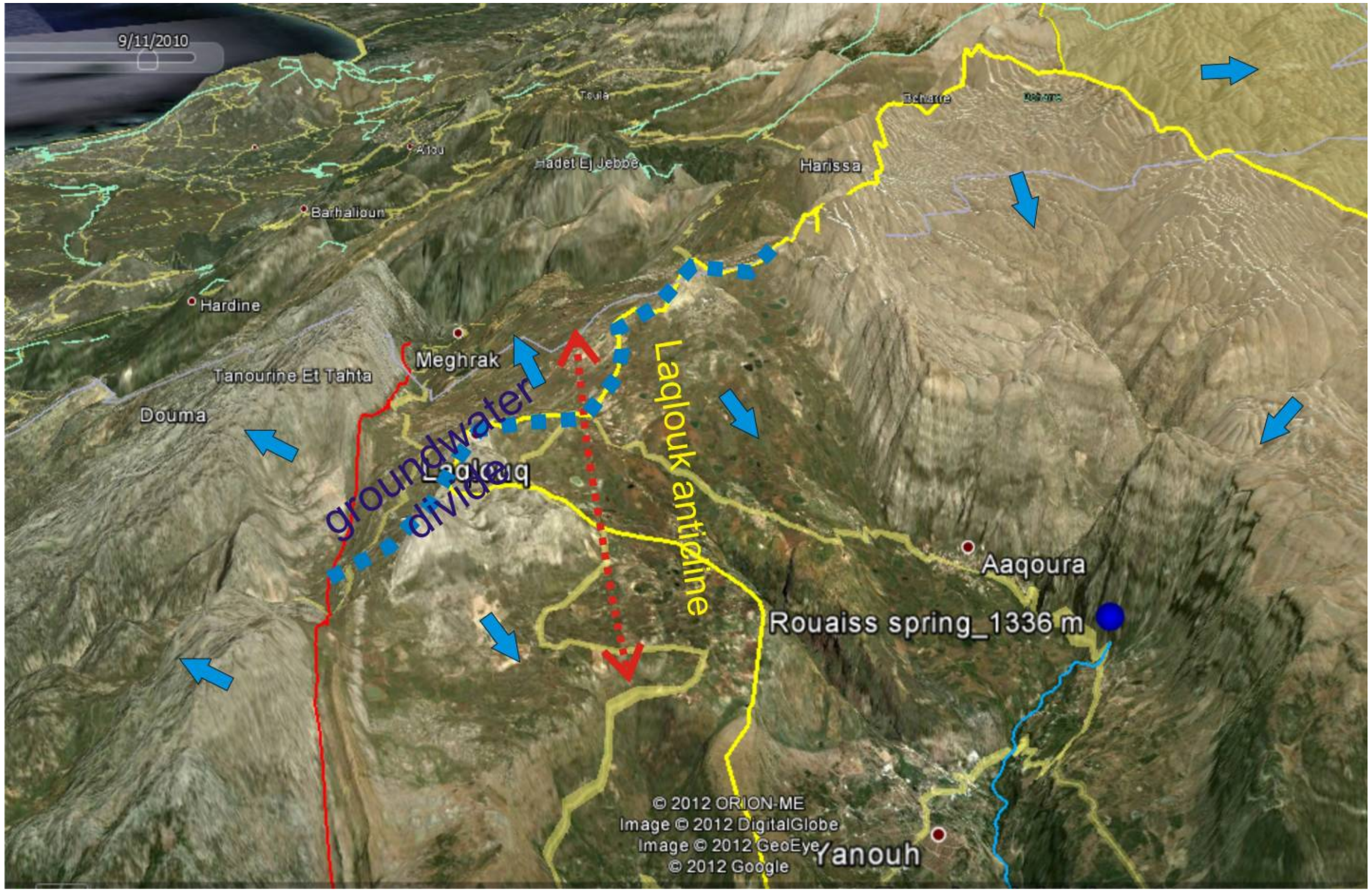


Figure 2: Laqlouk Anticline (3-D view looking N from Nahr Ibrahim)

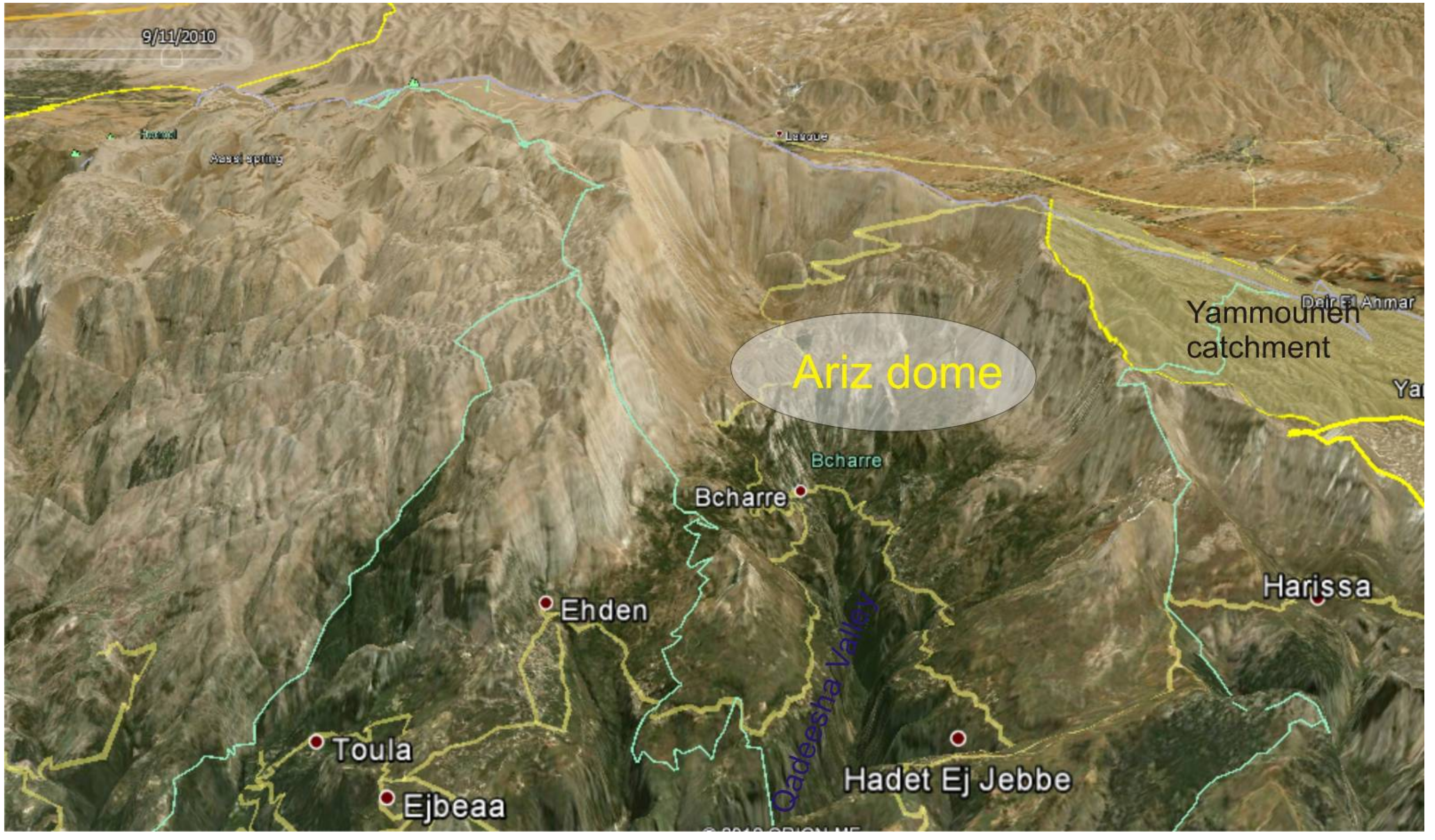


Figure 3: Ariz Geological Dome

Quantification of Infiltration Valley into the J4 Aquifer in the Upper Nahr Ibrahim Valley

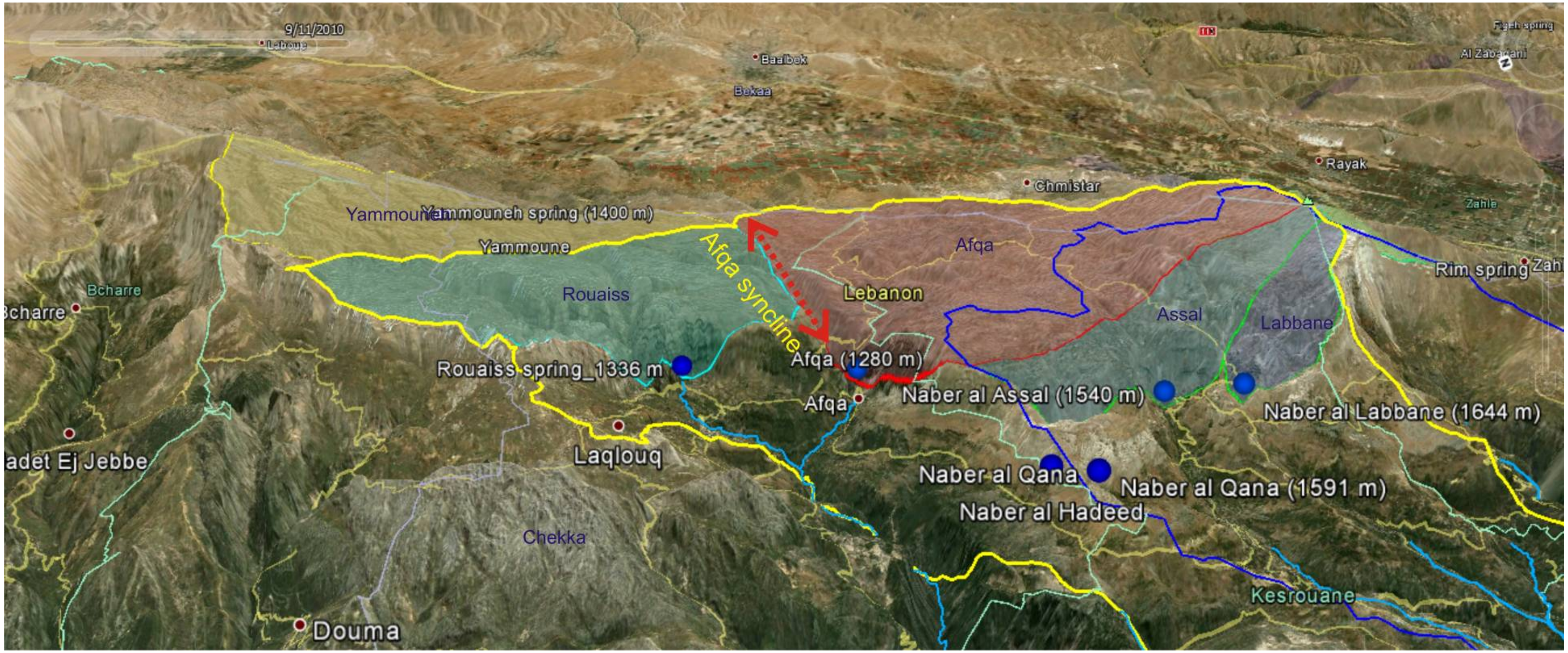


Figure 4: Afqa Syncline and Afqa Fault (compressional fault)

Quantification of Infiltration Valley into the J4 Aquifer in the Upper Nahr Ibrahim Valley

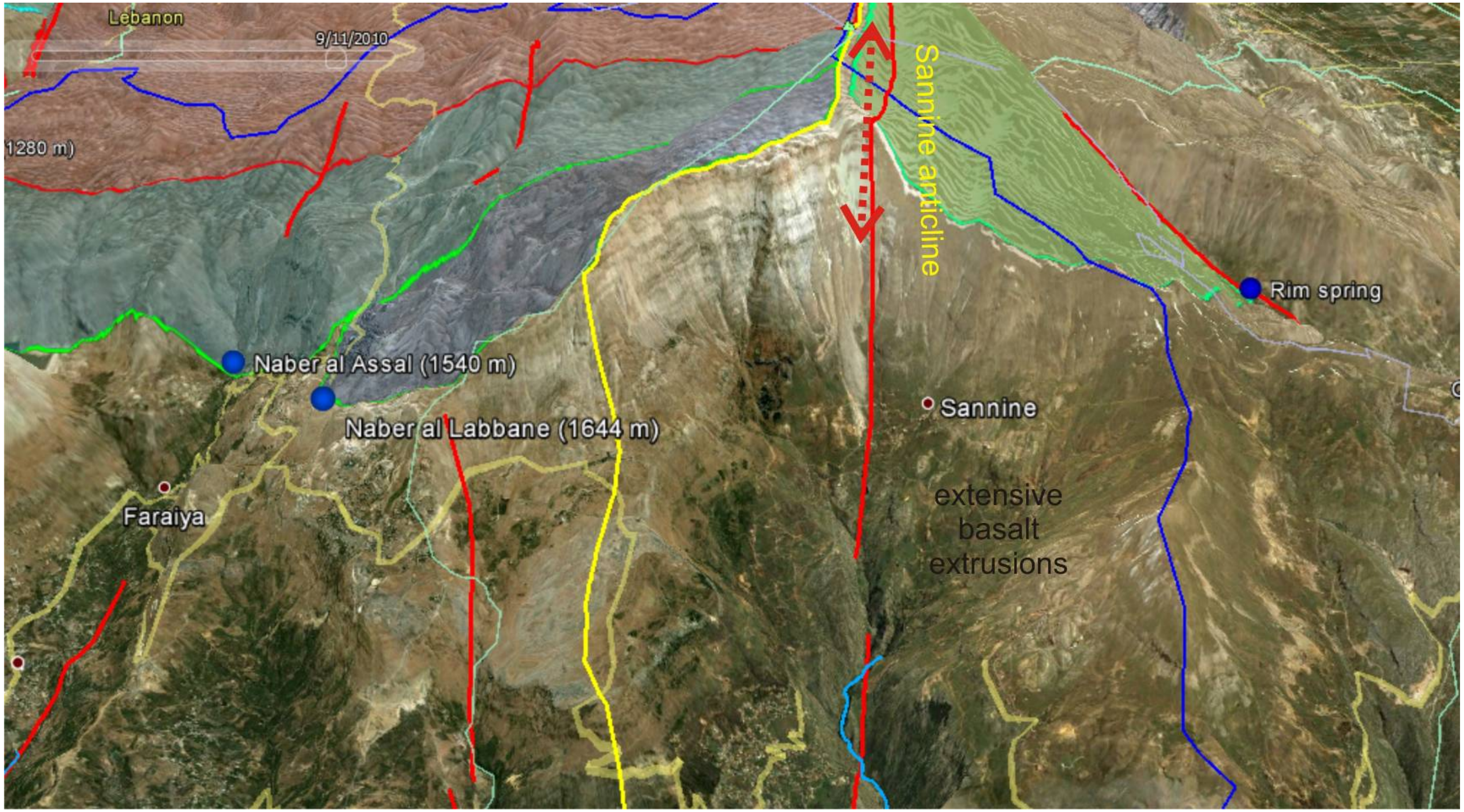


Figure 5: Sannine Anticline

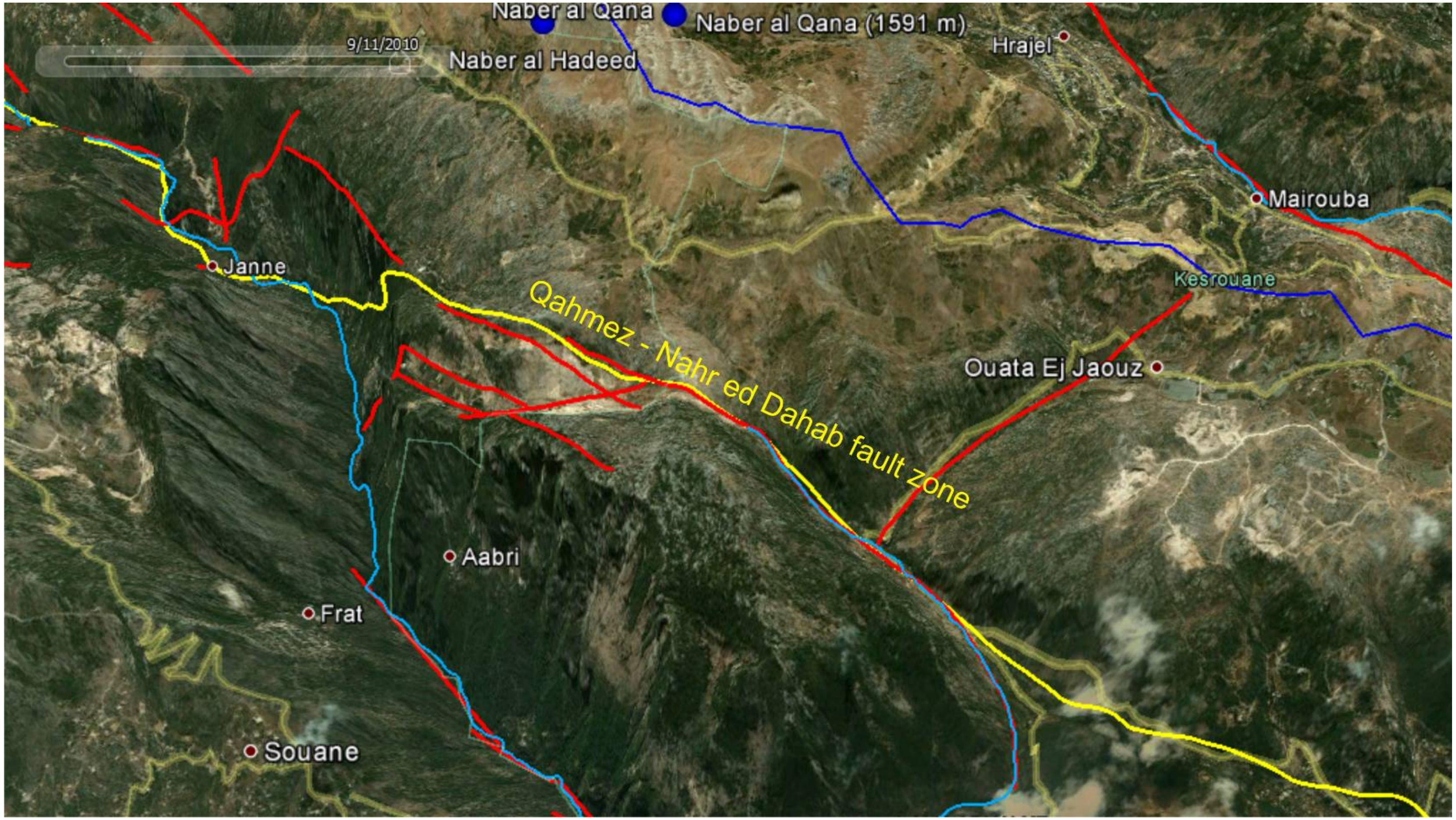


Figure 6: Qahmez - Nahr ed Dahab Fault Zone (compressional fault)

# 2 Characteristics of the Investigated Area

## *2.1 Topography*

Figure 7 displays the topography in the groundwater contribution zone of Jeita spring. The average elevation in the catchment is 1629 m asl, 61 % of the catchment is located at elevations above 1500 m, 20 % at elevations above 2000 m.

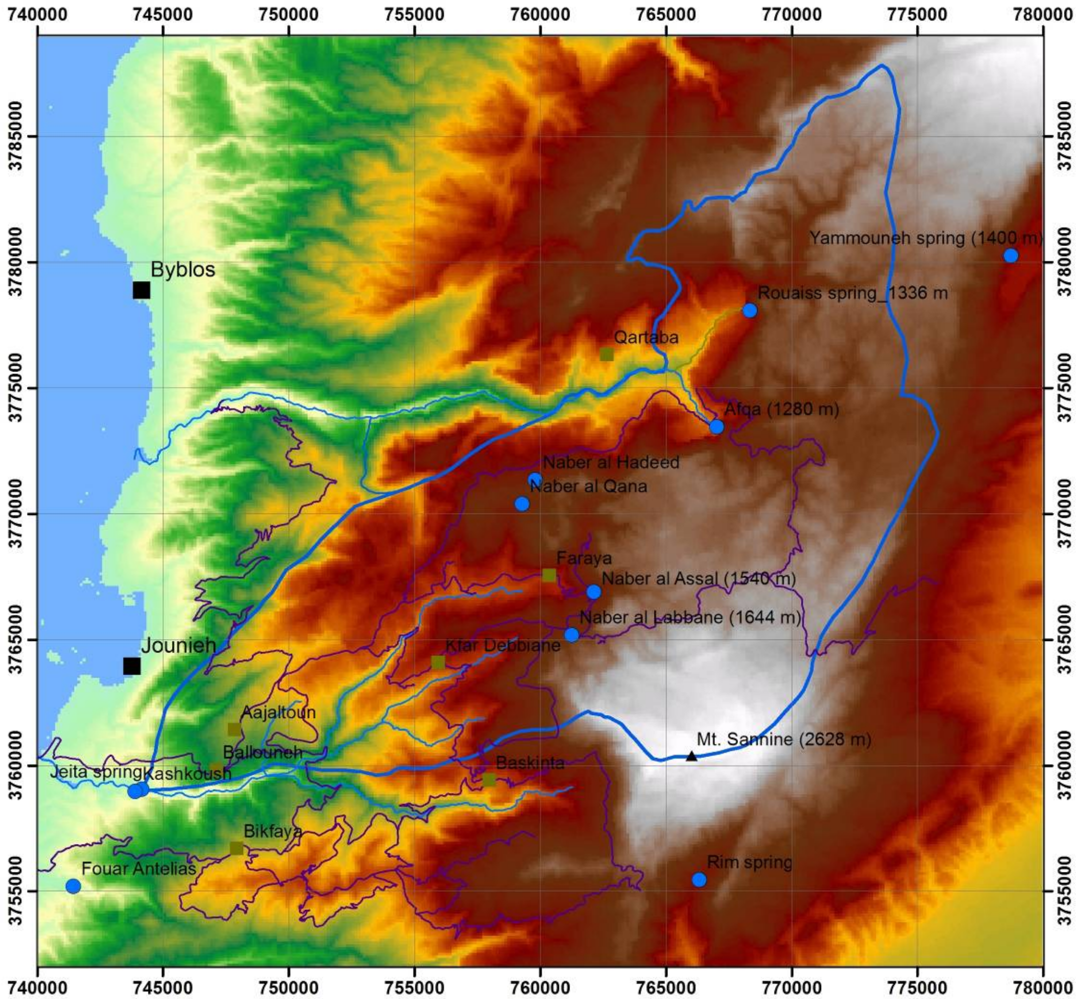


Figure 7: Topography in the Groundwater Contribution Zone of Jeita Spring (based on SRTM data; blue line: newly defined groundwater contribution zone of Jeita spring)

The Topography in the Upper Nahr Ibrahim Valley is shown in Figure 8. The proposed Janneh dam is located at an elevation of around 755 m asl. At the confluence of the two main tributaries, the Afqa and the Rouaiss branch, the valley is at an elevation of around 860 m.

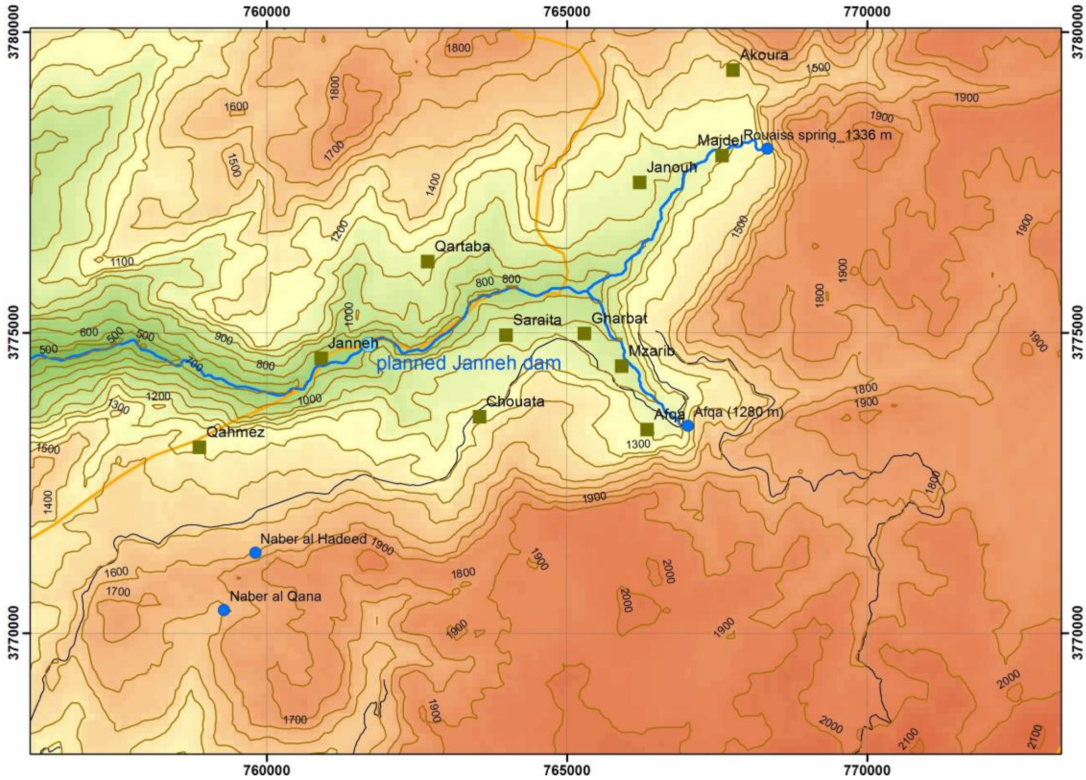


Figure 8: Topography in the Upper Nahr Ibrahim Valley
(based on SRTM data)

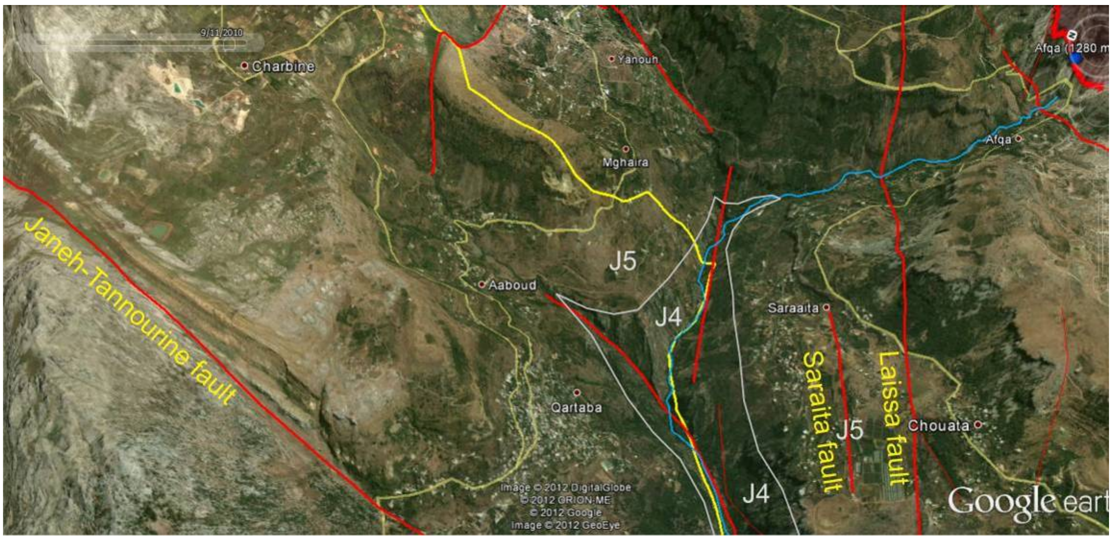


Figure 9: Geological Contact J4/J5 near the Confluence of the Afqa and Rouaiss Branch

Near the Rouaiss - Afqa confluence, then forming Nahr Ibrahaim, the top of the J4 is at around 875 m asl (Figure 9). Between Laissa and the confluence dip of the strata is around 5° towards E to SE.

## 2.2 Hydrological Setup

Discharge of Afqa spring (Figure 10) is monitored by LRA (drum chart recorder). Daily data are available with the project for the time period water year 2000/01 - 2009/10. Average annual discharge during that period is 123 MCM (Table 1). During that period annual discharge varied between 44 and 232 MCM (Figure 13). Average monthly discharge of Afqa spring during the water years 2000/01 - 2009-10 (Figure 14) indicate that peak flow is commonly during July to September. Although discharge of Rouaiss spring is considerable, it not monitored by LRA.

The monitoring station at Afqa, however, is not properly built. There is no straight-line segment with low gradient that would allow measuring a non-turbulent flow. The existing weirs are too large. Principally the larger of the two weirs should be narrower and higher. The same applies for the smaller weir. There is an opening at the southern side allowing a considerable leakage. It would be better having two independent weirs, where the lower and smaller one would record spring flow during low flow and the larger one spring flow during high flow periods. Even peak flow measurements are incorrect because the recorder is located too far from the weir, in a section of very turbulent flow, which does not represent the water level at the weir (Figure 11). Monitoring should be relocated to be closer to the weir. Furthermore, during low flow periods flow cannot be measured correctly because the openings of the weirs are too large.

Since Afqa spring is fairly important, it is proposed to build a completely new spring flow monitoring station.

Also Rouaiss spring (Figure 12) should be monitored. This would require extensive excavations in the section between the two bridges in order to create a long enough straight-line segment with reduced turbulence. Since also here the variation of flow is considerable, two independent sections should allow for measurements during low flow and peak flow periods.

Figure 10: Afqa Spring (during high-flow period in April 2012)

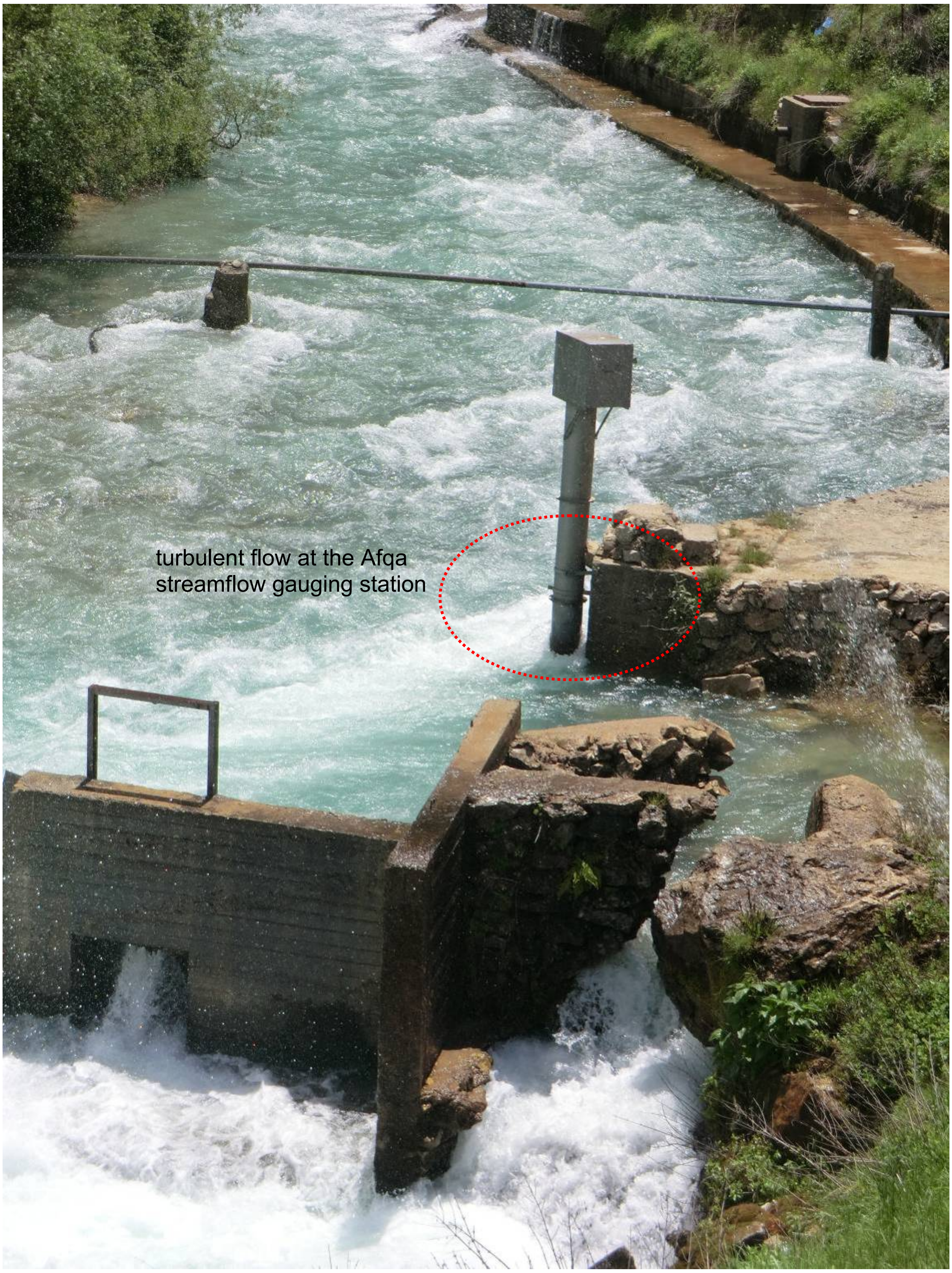


Figure 11: Afqa Spring showing turbulent section at Spring Flow Gauging Station and Leakage

Figure 12: Rouaiss Spring (during high-flow period in April 2012)

Quantification of Infiltration Valley into the J4 Aquifer in the Upper Nahr Ibrahim Valley

Table 1: Discharge of Afqa Spring Monitored by LRA during Water Years 2000/01 - 2009/10

| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2008/09 | 2009/10 | average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.27 | 0.33 | 0.23 | 0.73 | 0.32 | 1.03 | 1.16 | 0.82 | 0.57 | 0.89 | 0.64 |
| February | 0.31 | 0.26 | 0.25 | 0.42 | 0.20 | 0.39 | 1.21 | 0.58 | 0.62 | 0.52 | 0.48 |
| March | 0.26 | 0.64 | 0.26 | 0.39 | 9.26 | 6.63 | 5.14 | 0.42 | 0.94 | 7.39 | 3.13 |
| April | 0.35 | 7.59 | 7.36 | 0.69 | 5.80 | 7.92 | 2.01 | 6.94 | 4.43 | 15.37 | 5.84 |
| May | 0.88 | 2.07 | 9.76 | 3.49 | 6.35 | 13.93 | 2.27 | 2.26 | 7.40 | 13.61 | 6.20 |
| June | 1.46 | 13.24 | 5.18 | 3.43 | 15.17 | 10.43 | 6.70 | 1.76 | 11.84 | 17.45 | 8.67 |
| July | 24.83 | 22.93 | 20.95 | 31.18 | 53.78 | 29.96 | 23.66 | 35.19 | 32.94 | 24.19 | 29.96 |
| August | 11.22 | 44.94 | 66.96 | 36.45 | 43.15 | 38.73 | 28.46 | 20.23 | 77.09 | 8.71 | 37.59 |
| September | 3.52 | 7.89 | 65.14 | 21.99 | 25.38 | 10.73 | 14.03 | 4.71 | 33.38 | 4.06 | 19.08 |
| October | 0.84 | 1.63 | 34.88 | 6.09 | 7.84 | 3.80 | 3.00 | 1.66 | 8.59 | 2.07 | 7.04 |
| November | 0.30 | 0.56 | 13.77 | 1.61 | 2.89 | 3.14 | 2.14 | 1.50 | 3.15 | 1.38 | 3.05 |
| December | 0.32 | 0.32 | 6.89 | 0.54 | 1.13 | 1.59 | 1.62 | 1.13 | 1.13 | 0.78 | 1.55 |
| | 44.55 | 102.40 | 231.63 | 107.03 | 171.26 | 128.27 | 91.39 | 77.21 | 182.08 | 96.43 | 123.22 |

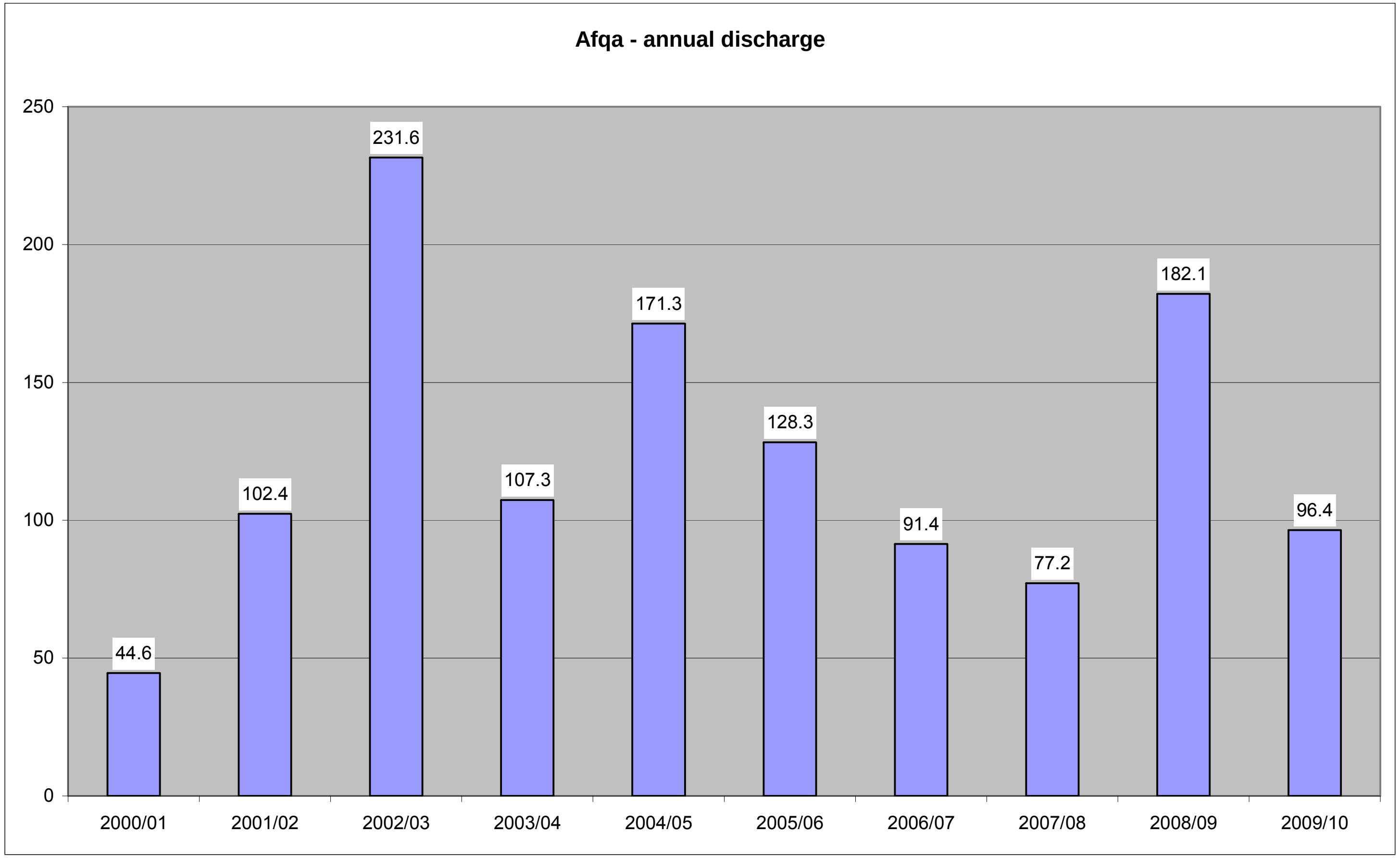


Figure 13: Annual Discharge of Afqa Spring during Water Years 2000/01 - 2009-10

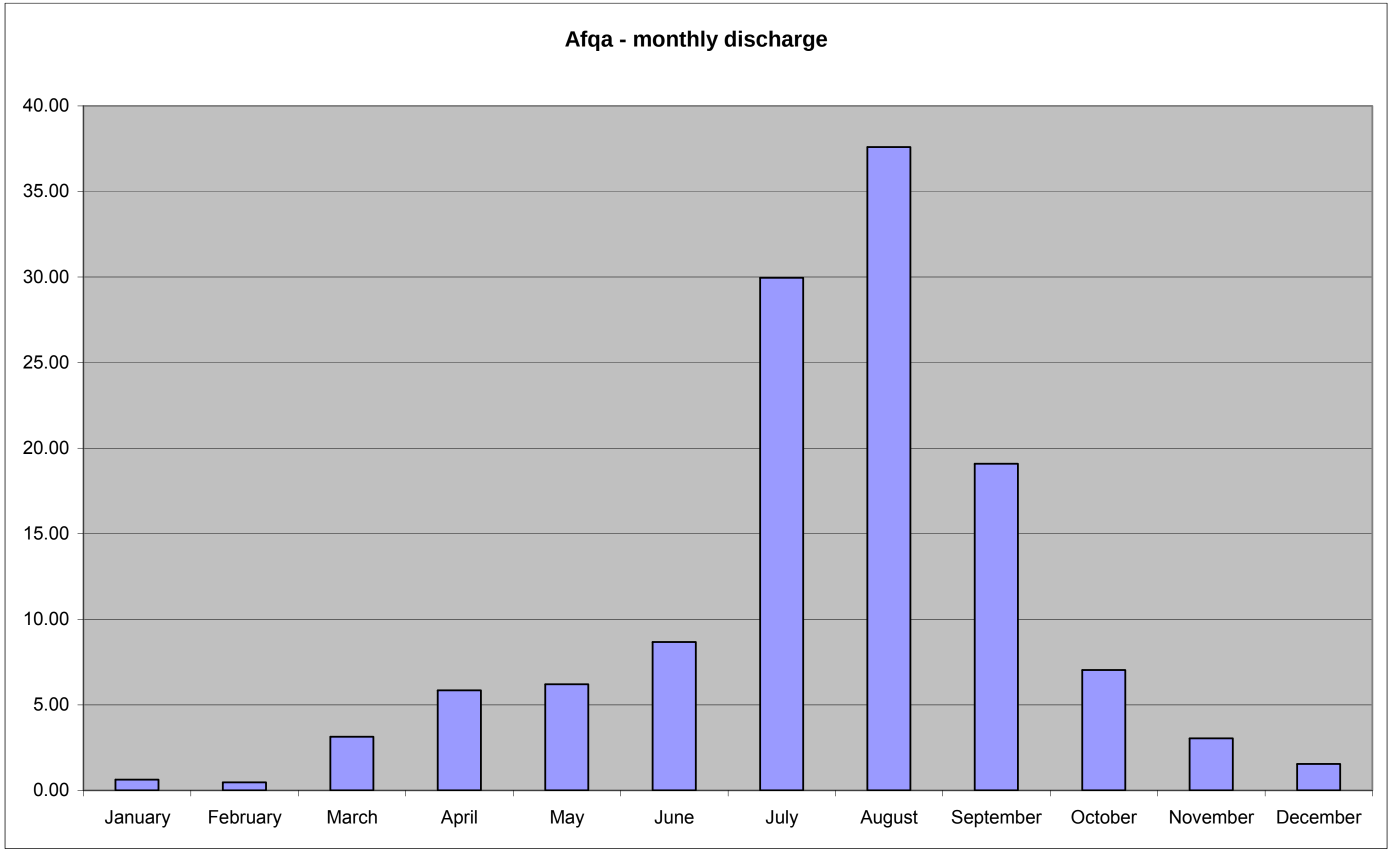


Figure 14: Average Monthly Discharge of Afqa Spring during Water Years 2000/01 - 2009-10

## 2.3 Geological Setup and Tectonic Features

The BGR project has remapped the geology in the Jeita groundwater catchment because it was noticed that the geological maps prepared by DUBERTRET (1944) were not accurate and detailed enough. Mapping started covering the surface water catchment and then, as knowledge about the extent of the Jeita groundwater contribution zone increased, was extended more and more towards north, covering the assumed groundwater catchment.

The currently available geological map is shown in Figure 17. The lithostratigraphy, the hydrogeological classification and the subdivision of the aquifer system is shown in Figure 18. In the Upper Nahr Ibrahim Valley the thickness of the Lower Aquifer (J4) reaches around 1100 m, the aquitard is between 500 and 800 m thick, while the Upper Aquifer (C4) is assumed to be 600-700 m thick.

The main tectonic elements governing groundwater flow in the Jeita catchment and its surrounding are shown in Figure 15. They mainly consist of :

- faults striking 70-90°: related to compression ($\sigma_3$)
- faults striking 20-40°: related to left-lateral shear
- faults striking 140-170°: related to dilatation ($\sigma_1$)

The regional stress field consists of

$\sigma_1$ : ~ 160°

$\sigma_3$ : ~ 70°

Faults related to right-lateral shear (~120°) are much less frequent.

The faults of local importance in the Upper Nahr Ibrahim Valley are shown in Figure 16:

compressional fault type:

- Afqa fault 1
- Rouaiss faults
- Upper Nahr Ibrahim fault
- Qahmez fault zone
- Saraita fault
- Laissa fault

left-lateral shear fault type:

- Janneh-Tannourine fault
- Janneh fault
- Qartaba fault

- Majdel fault
- Afqa fault 2/3

dilatational fault type:

- Laqlouk fault

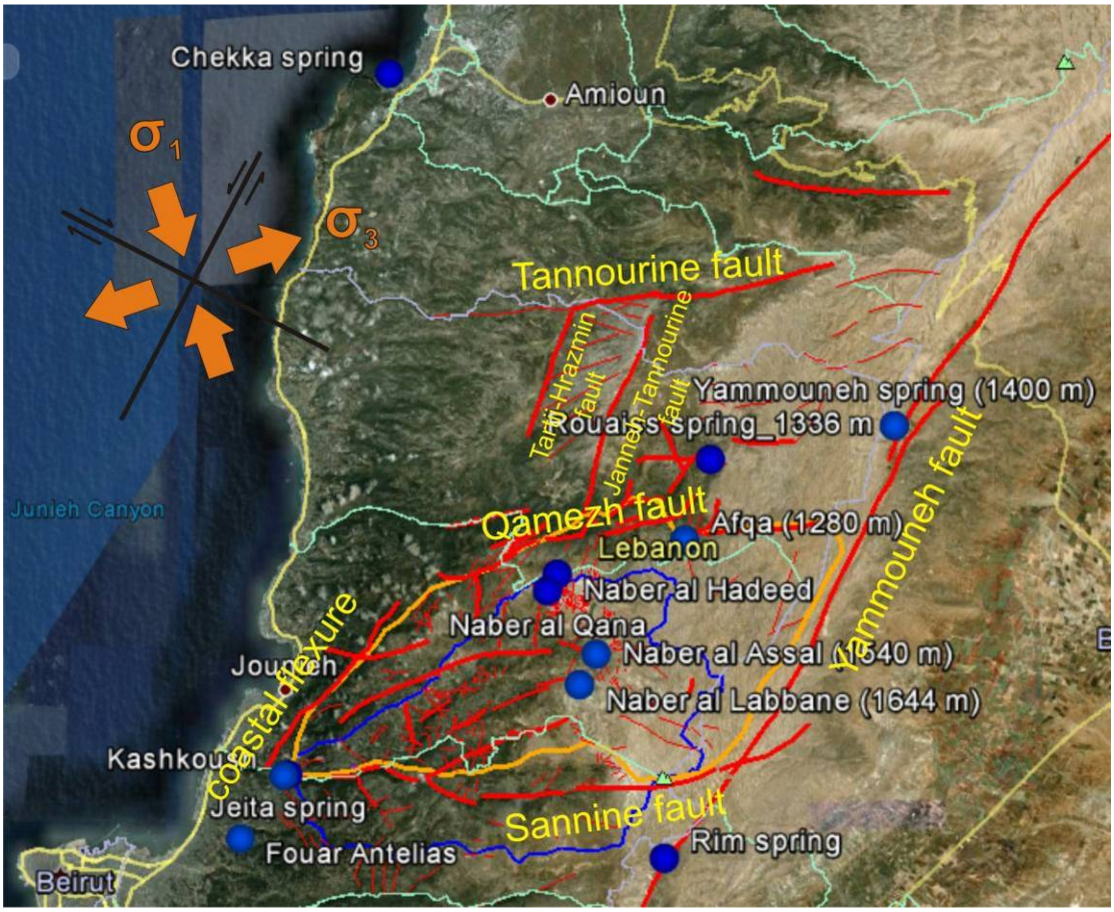


Figure 15: Main Regional Fault Systems governing Groundwater Flow in and surrounding the Jeita Catchment

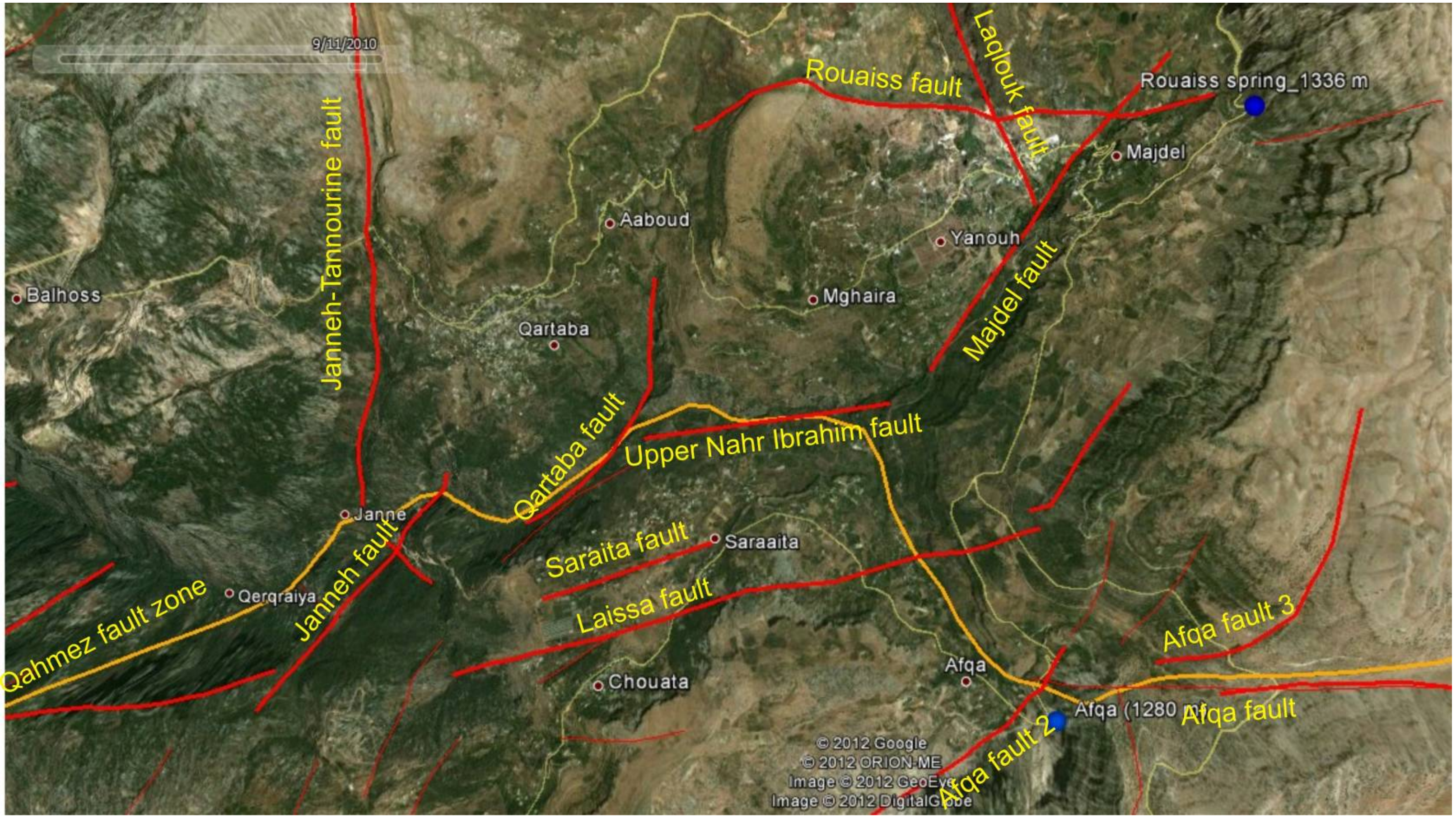


Figure 16: Local Fault Systems in the Upper Nahr Ibrahim Valley

Quantification of Infiltration Valley into the J4 Aquifer in the Upper Nahr Ibrahim Valley

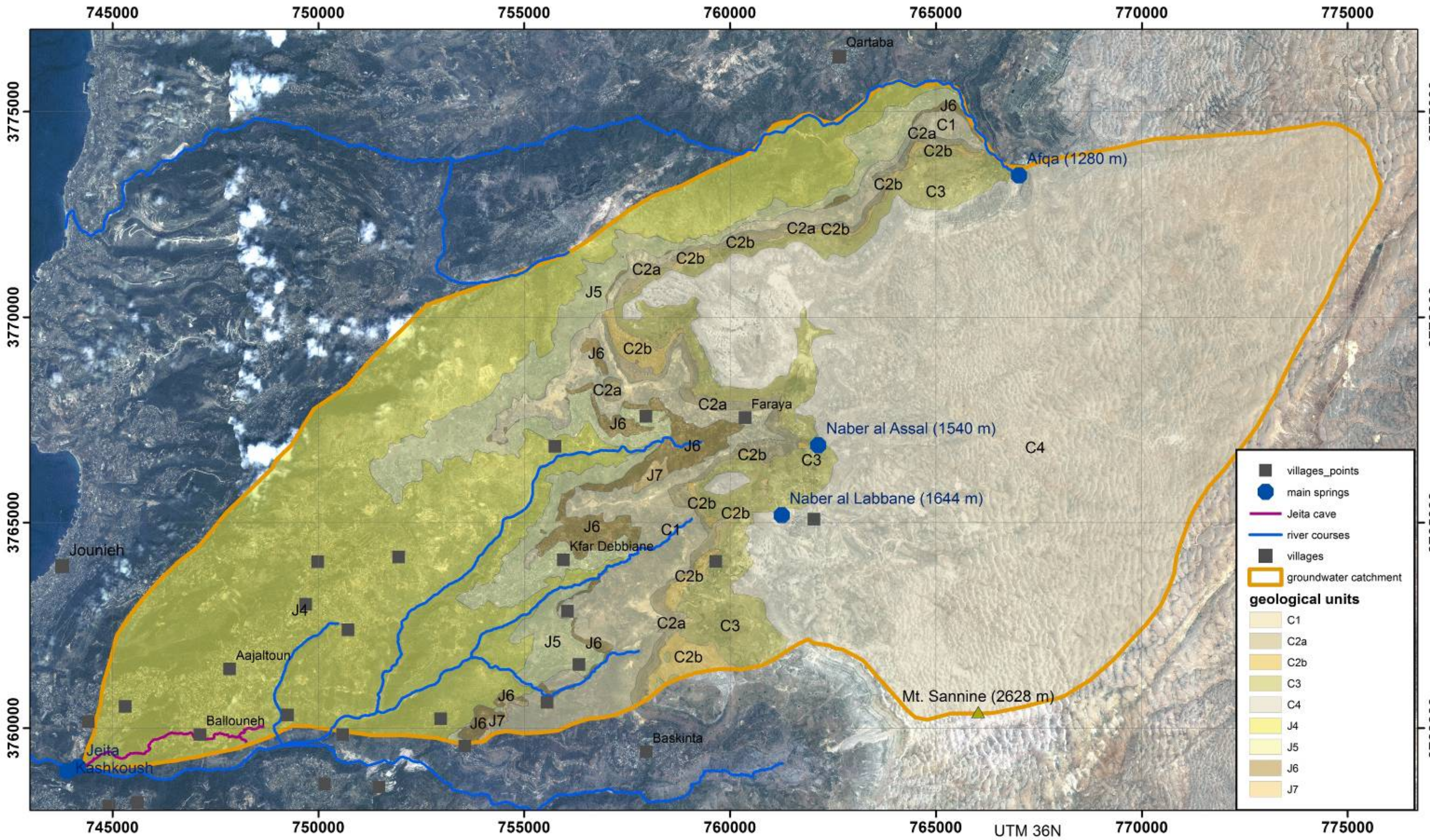


Figure 17: Geological Map prepared by the BGR Project

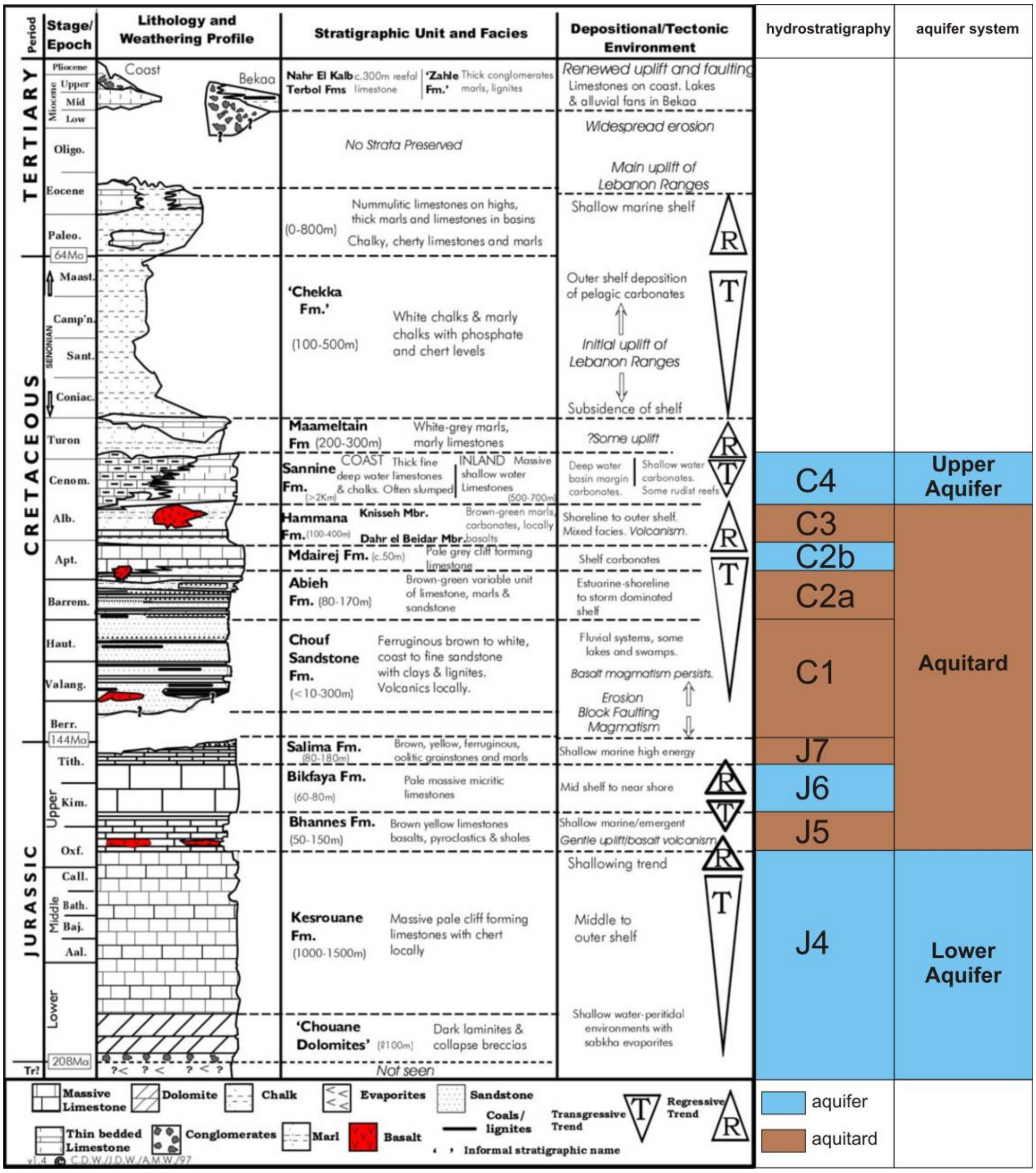


Figure 18: Lithostratigraphy, Hydrostratigraphy and Subdivision of Aquifer System in the Project Area (modified after WALLEY, 2001)

The J4 outcrop area begins near the confluence of the Rouaiss and Afqa branches in the Upper Nahr Ibrahim Valley. At both tributaries there is a water fall at the start of the J4 outcrop area (at the Rouaiss approx. 50 m deep).

## 2.4 Hydrogeological Setup

The subdivision of the aquifer system is based on the results of a tracer test conducted in the Upper Cretaceous plateau in May 2011 (DOUMMAR et al., 2012a), where restitution reached 100 %. It must therefore be assumed that there is very little downward leakage from the Upper Aquifer to the Lower Aquifer. Based on structure contour lines prepared for the base of C4, the BGR project assumes the subdivision of groundwater catchments in the Upper Aquifer (C4) presented in Figure 19. Tracer test 4C, conducted on 04 May 2012 confirmed the northern boundary of the Afqa catchment (MARGANE et al., in progr.).

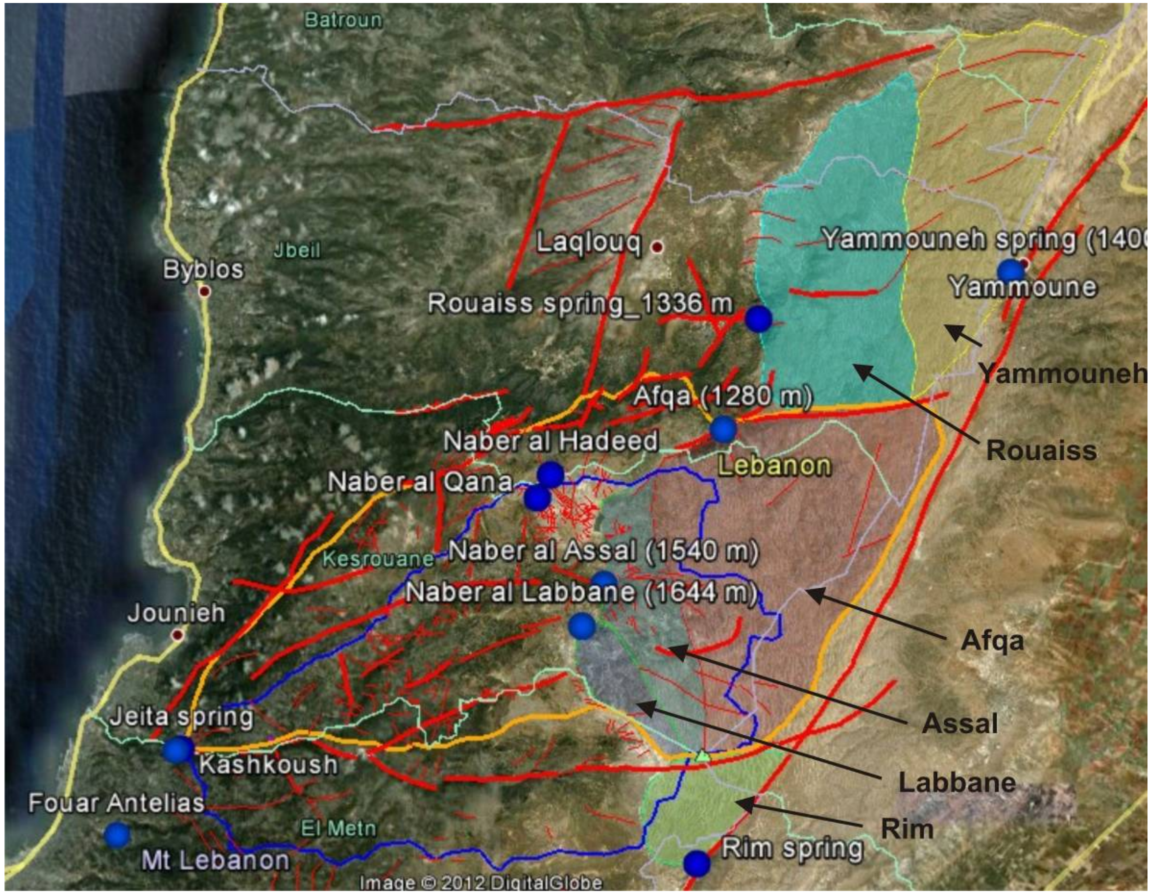


Figure 19: Subdivision of Groundwater Catchments in the Upper Aquifer (C4)

# 3 Description of Discharge Measurements

In order to confirm the assumed infiltration of surface water in the Upper Nahr Ibrahim Valley, two campaigns of discharge measurements were done:

- first discharge measurements: 30 April 2012
- second discharge measurements: 15 May 2012

While discharge of the Rouaiss and Afqa springs where close to its peak during the first campaign, they where about half of that during the second discharge measurements.

## *3.1 Locations of Measurements*

The Upper Nahr Ibrahim Valley is difficult to access and the valley is very steep and narrow so that the possibility of discharge measurements is very limited. The assumption was that infiltration will occur in the upper part of the J4 outcrop area between Janneh and the confluence of the two main tributaries of Nahr Ibrahim, the Rouaiss branch and the Afqa branch. Five locations were chosen at which streamflow was measured (Table 2). Between injection (Table 3) and monitoring locations a distance between of at least 200 m was maintained. During the second campaign distances were increased although breakthrough curves during the first campaign were of a good shape. Monitoring stations remained the same during both campaigns, except for Afqa where monitoring was shifted approximately 650 m in the upstream direction. During the second campaign it was tried to achieve a larger distance between injection and monitoring where possible.

The locations of injection and monitoring are shown in Figures 20 to 27.

Table 2: Location of Monitoring Stations

| Location | LONG (E) | LAT (N) | Distance injection - monitoring 30-04-2012 | Distance injection - monitoring 16-05-2012 |
|---|---|---|---|---|
| Janneh-2 | 35.825932 | 34.078007 | 420 | 420 |
| Janneh-1 | 35.835430 | 34.081150 | 360 | 620 |
| Janouh (Joe Marine) | 35.862059 | 34.089495 | 300 | 300 |
| Rouaiss (restaurant) | 35.884111 | 34.093452 | 220 | 1100 |
| Afqa (Mzarib)<br>30-04-12<br>16-05-12 | <br>35.881746<br>35.884586 | <br>34.080736<br>34.075785 | <br>250 | <br><br>1100 |

Table 3: Location of Injection Stations

| Location | LONG (E) | LAT (N) |
|---|---|---|
| Janneh-2 | 35.830210 | 34.078910 |
| Janneh-1<br>30-04-12<br>16-05-12 | <br>35.838913<br>35.841302 | <br>34.082293<br>34.081215 |
| Janouh<br>(Joe Marine) | 35.864898 | 34.088337 |
| Rouaiss (restaurant)<br>30-04-12<br>16-05-12 | <br>35.885677<br>35.890337 | <br>34.094758<br>34.101255 |
| Afqa (Mzarib)<br>30-04-12<br>16-05-12 | <br>35.882116<br>35.891567 | <br>34.078603<br>34.068454 |

Total distance between Afqa injection and Janneh-2 monitoring was 6700 m (30-04-2012) and 8250 m (16-05-2012), respectively.

Total distance between Rouaiss injection and Janneh-2 monitoring was 6620 m (30-04-2012) and 7500 m (16-05-2012), respectively.

The proposed dam location is at:

| LONG (E) | LAT (N) | Elevation |
|---|---|---|
| 35.836165 | 34.081298 | 755 m asl |

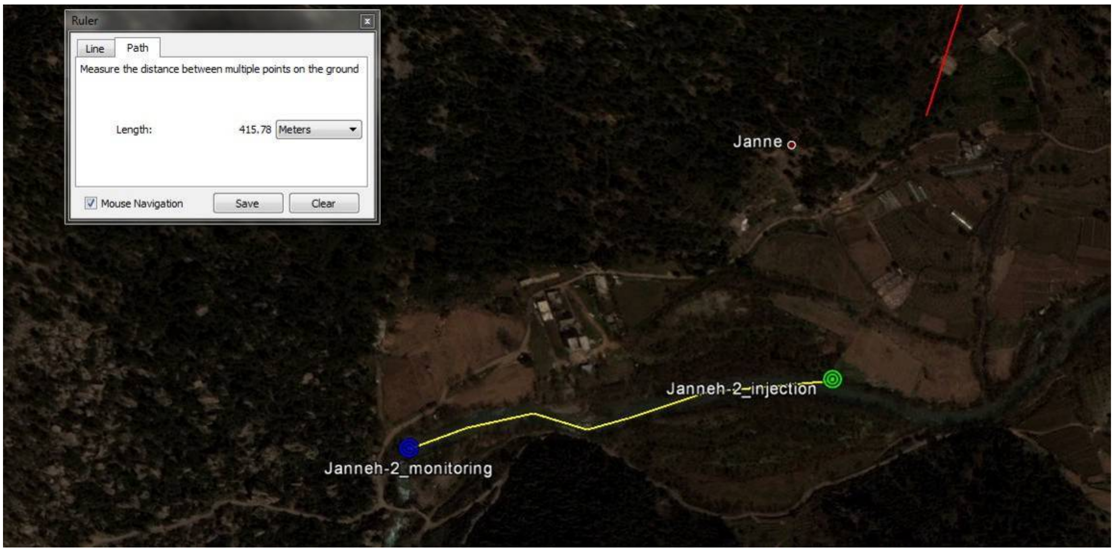


Figure 20: Monitoring and Injection at Janneh-2


Figure 21: Monitoring and Injection at Janneh-1 during the First Campaign

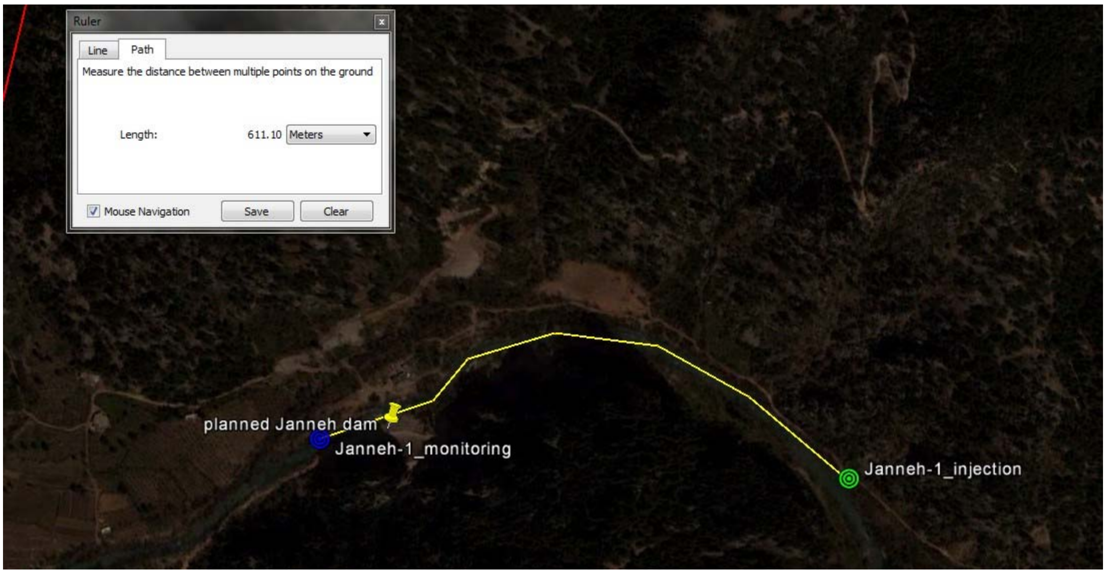


Figure 22: Monitoring and Injection at Janneh-1 during the Second Campaign


Figure 23: Monitoring and Injection at Janouh (Joe Marine)

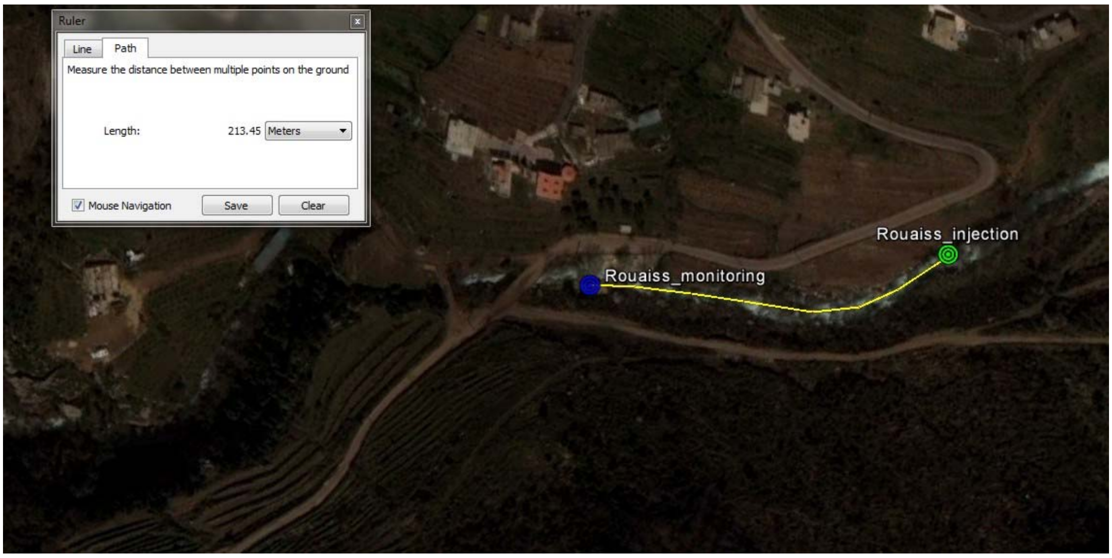


Figure 24: Monitoring and Injection at Rouaiss during the First Second Campaign

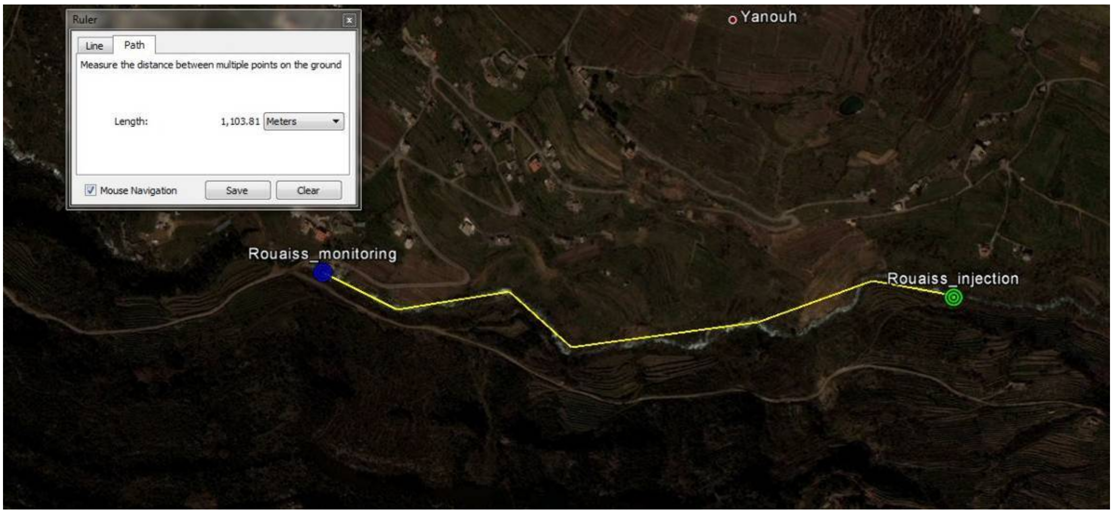


Figure 25: Monitoring and Injection at Rouaiss during the Second Campaign

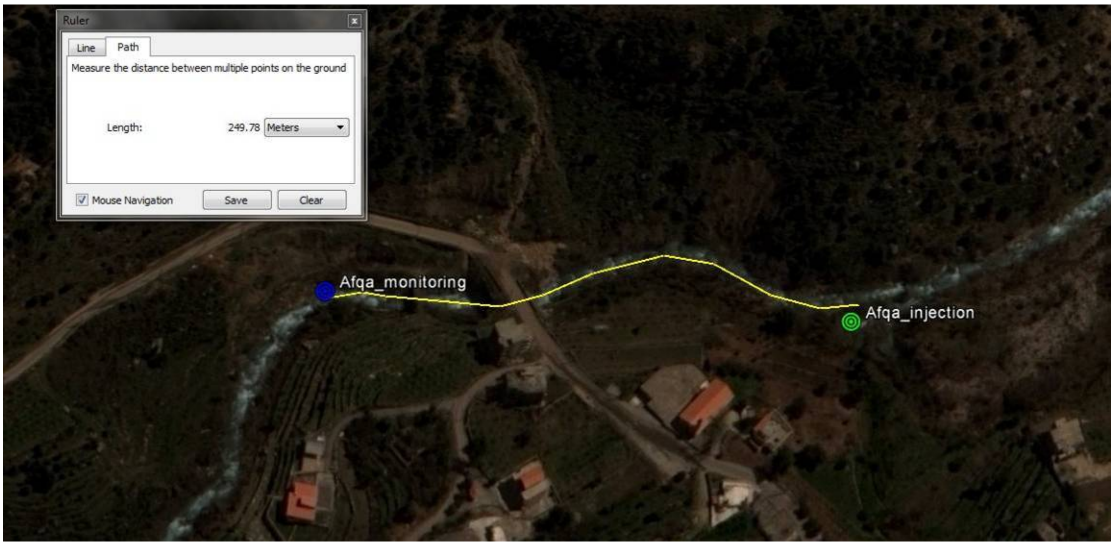


Figure 26: Monitoring and Injection at Afqa during the First Campaign

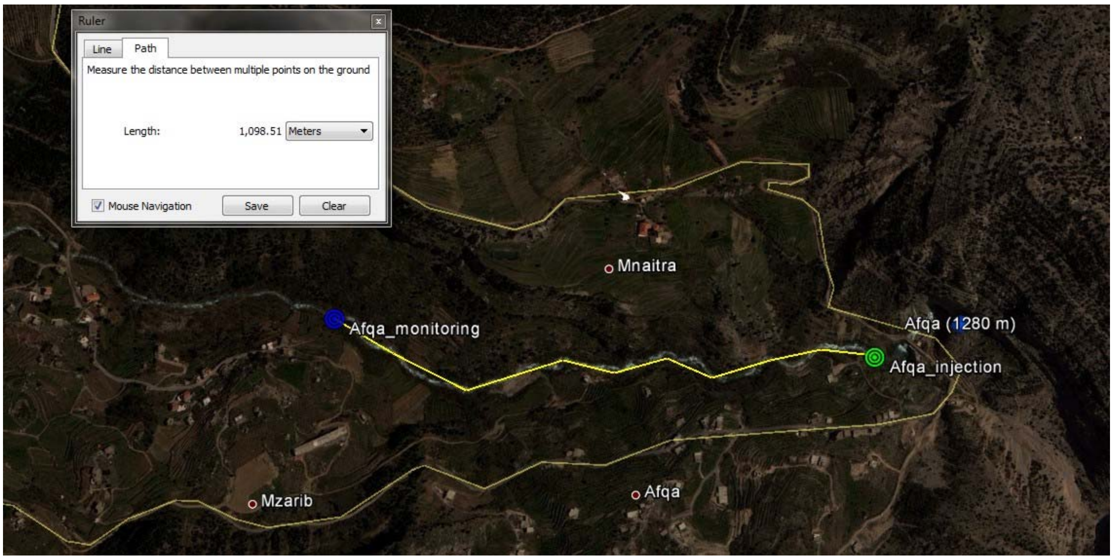


Figure 27: Monitoring and Injection at Afqa during the Second Campaign

## *3.2 Monitoring Equipment*

For tracer detection fluorometers manufactured by Albillia (http://www.albillia.com/FL30e.html), Type GGUN-FL30 (serial numbers 525, 526, 531, 532, 533, 536) were used (Figure 28). Before measurements all instruments were calibrated and synchronized. The detection limit for uranine is 0.002 ppb.

The BGR Project has conduct numerous tracer tests in the Jeita catchment and the instruments have proven to be reliable and durable even under difficult conditions as encountered in the Upper Nahr Ibrahim Valley. Based on the vast experience gathered, the project has prepared a practice guide for tracer tests (MARGANE & ABI RIZK, 2011).


Logger

Fluorometer

Figure 28: GGUN-FL30 Fluorometer for detection of Organic Dyes

### *3.3 Tracer Substance*

For the tracer tests in the Upper Nahr Ibrahim Valley the BGR project used the following tracer, which can (among others) be detected by these instruments at a detection limit of 0.002 ppb:

- uranine (ORCO, 86%; sodium fluorescein, BASF, CAS 518-47-8, $C_{20}H_{10}O_5Na_2$)

Uranine is most commonly used in tracer tests around the world and has no known negative effect on human health (FIELD et al., 1995; GERMAN MINISTRY OF HEALTH, 1997).

The response at the monitoring station should not exceed a concentration of 100 ppb and be higher than 1 ppb. It was expected that during the first campaign there would be a relatively high turbidity which may influence measurements negatively. However, water during both tests was relatively clear and turbidity did not exceed 10 NTU (as measured by the fluorometer).

Before conducting the first campaign the discharge, flow velocity, distances between points and thus the optimal amount of tracer to be used was not known. However, in all cases the response of the breakthrough curves was good (Figures 29-37).

During the first campaign 20 and 40 g of tracer was used per injection, while 50 g was used during all injections of the second campaign.

# 4 Tracer Tests

The concept behind dilution tests with organic dye tracer substances is to easily carry out discharge measurements at almost any discharge rate, as the detection limits is fairly small. Such tests are also common in rivers, such as the Rhine in Germany. Accuracy of the measurements depends on:

- turbidity in the measured water;
- distance between injection and monitoring (whether concentration is equally distributed over the section); this depends on gradient and turbulence;
- whether there are segments of stagnant flow between injection and monitoring where some tracer substance might get lost;
- whether there are losses or inflows between injection and monitoring (those can be detected by establishing several stations along a profile, such as was done here).

Under the conditions encountered during both campaigns (high-flow) accuracy of measurements is assumed to be 10-15 % during the first and 5-10 % during the second campaign.

## *4.1 First Campaign*

The first discharge measurements were conducted on 30 April 2012. At this time flow at Rouaiss and Afqa springs was relatively high due to snowmelt arriving not just at those springs but also via surface water in the Rouaiss branch.

The following injections were conducted (three at each station):

Table 4: Tracer Injections during First Campaign

| Site | Time | Amount of Tracer (g) | Discharge ($m^3/s$) |
|---|---|---|---|
| Janneh-2 | 10:48 | 30 | 48.8 |
| Janneh-2 | 10:56 | 30 | 43.9 |
| *average* | | | *46.4* |
| *inflow correction* | *-0.3* | | *46.1* |
| Janneh-1 | 11:47:30 | 30 | section inappropriate |
| Janneh-1 | 12:07:30 | 30 | |
| discharge measurement not feasible | | | |
| Janouh | 14:35:30 | 20 | - |
| Janouh | 14:45 | 200 | 40.3 |
| *average* | | | *40.3* |
| Rouaiss | 15:43 | 20 | cable malfunction |
| Rouaiss | 15:53 | 400 | |
| *average* | | | - |
| Afqa | 16:57 | 200 | 26.9 |
| Afqa | 17:05 | 200 | 26.5 |
| *average* | | | *26.7* |
| Rouaiss | 17:45 | 20 | - |
| Rouaiss | 17:52 | 200 | 47.0 |
| *average* | | | *47.0* |
| *Rouaiss + Afqa* | | | *73.7* |

Table 5: Infiltration Measured during First Campaign

| Segment | Infiltration ($m^3/s$) | Infiltration (%) |
|---|---|---|
| Confluence - Janouh | 33.4 | **45** |
| Confluence - Janneh-2 | 27.6 | **37** |

All measurements were conducted using the following fluorometers (all calibrated before use):

- Janneh-2: 526
- Janneh-1: 536
- Janouh: 532
- Rouaiss: 533
- Afqa: 533

The arriving tracer was observed in all downstream stations in order to observe tracer recovery and travel times between stations. Different amounts of tracer (20, 40, 200 g) were used.

Injections were done starting downstream and going up in the catchment. Time interval between injections at one station varied between 7 and 10 minutes. In order to be able to separate upstream injections at downstream monitoring sites, commonly between one and two hours had to elapse before starting injections at the next station.

Table 6 shows that mean flow velocities in the monitored segment of the Upper Nahr Ibrahim Valley were similar (1.7 - 2.1 m/s).

## Table 6: Mean Travel Times in the Upper Nahr Ibrahim during First Campaign

Travel times

| | Injection-1 | Injection-2 | Injection-3 | Injection-4 | Injection-5 | Injection-6 | Injection-7 | Injection-8 | Injection-9 | Injection-10 | Injection-11 | Injection-12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Janneh-2 | Janneh-2 | Janneh-1 | Janneh-1 | Janouh | Janouh | Rouaiss | Rouaiss | Afqa | Afqa | Rouaiss | Rouaiss |
| | 30 | 30 | 40 | 40 | 20 | 200 | 20 | 400 | 200 | 200 | 20 | 200 |
| | 10:48 | 10:56 | 11:47:30 | 12:07:30 | 14:35:30 | 14:45 | 15:43 | 15:53 | 16:57 | 17:05 | 17:45 | 17:52 |
| Janneh-2 (arrival time) | | | 12:00:10 | 12:20:00 | | 15:18:35 | | 16:48:45 | | 17:59:50 | | 18:47:25 |
| Janneh-2 (travel min) | | | 12.67 | 12.50 | | 33.58 | | 55.75 | | 54.83 | | 55.42 |
| Janneh-2 (distance) | | | 1412 | 1412 | | 4310 | | 6618 | | 6712 | | 6618 |
| Janneh-2 (velocity) | | | 1.86 | 1.88 | | 2.14 | | 1.98 | | 2.04 | | 1.99 |
| Janneh-1 (arrival time) | | | | | 15:01:35 | 15:10:55 | | 16:40:45 | | 17:53:15 | | 18:40:00 |
| Janneh-1 (travel min) | | | | | 26.08 | 25.92 | | 47.75 | | 48.25 | | 48.00 |
| Janneh-1 (distance) | | | | | 3307 | 3307 | | 5611 | | 5709 | | 5611 |
| Janneh-1 (velocity) | | | | | 2.11 | 2.13 | | 1.96 | | 1.97 | | 1.95 |
| Janouh (arrival time) | | | | | | | 16:07:50 | 16:17:10 | 17:22:25 | 17:30:15 | 18:08:50 | 18:16:20 |
| Janouh (travel min) | | | | | | | 24.83 | 24.17 | 25.42 | 25.25 | 23.83 | 24.33 |
| Janouh (distance) | | | | | | | 2575.00 | 2575.00 | 2669.00 | 2669.00 | 2575.00 | 2575.00 |
| Janouh (velocity) | | | | | | | 1.73 | 1.78 | 1.75 | 1.76 | 1.80 | 1.76 |

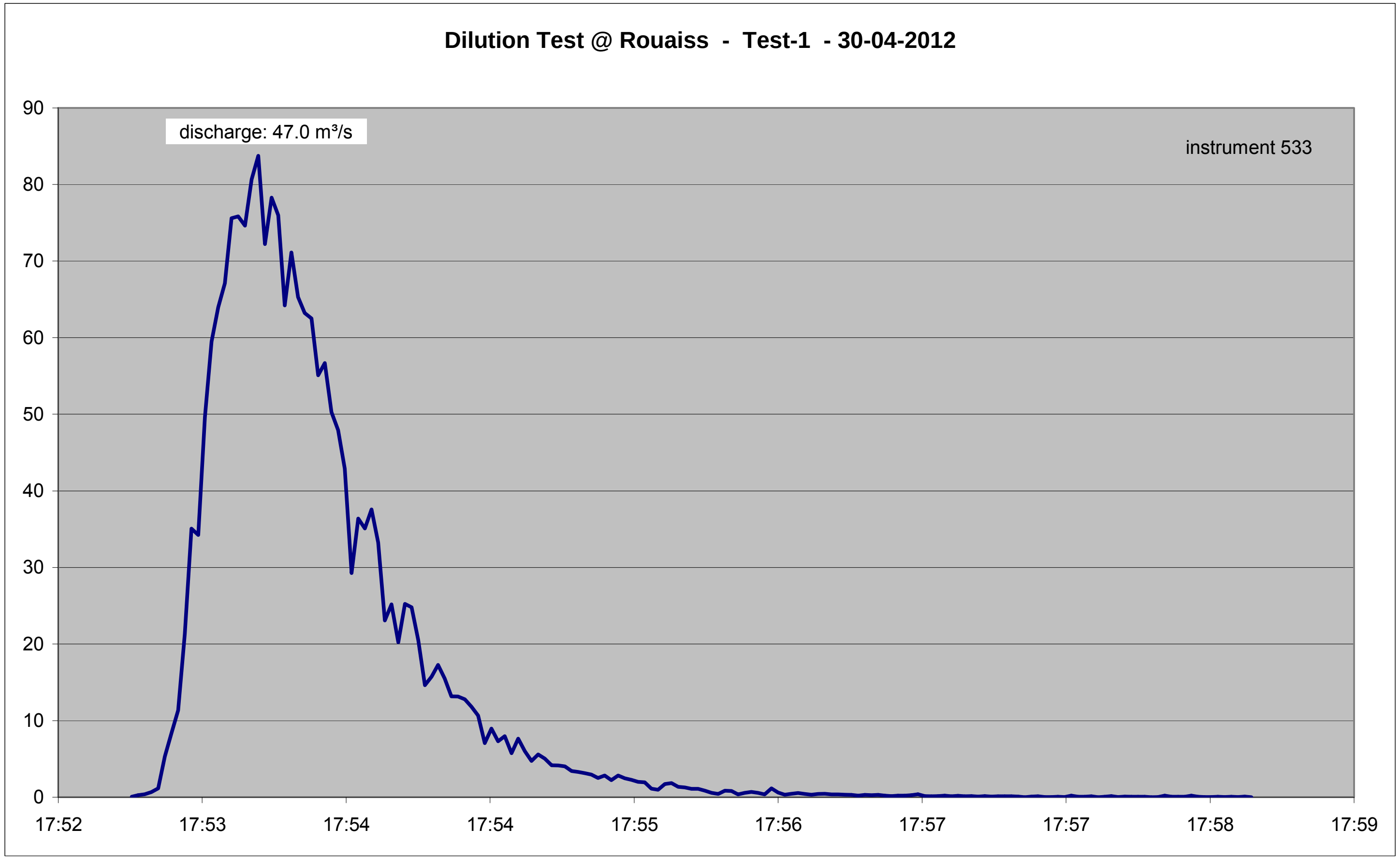


Figure 29: Determination of Discharge at the Rouaiss branch of Nahr Ibrahim during First Campaign

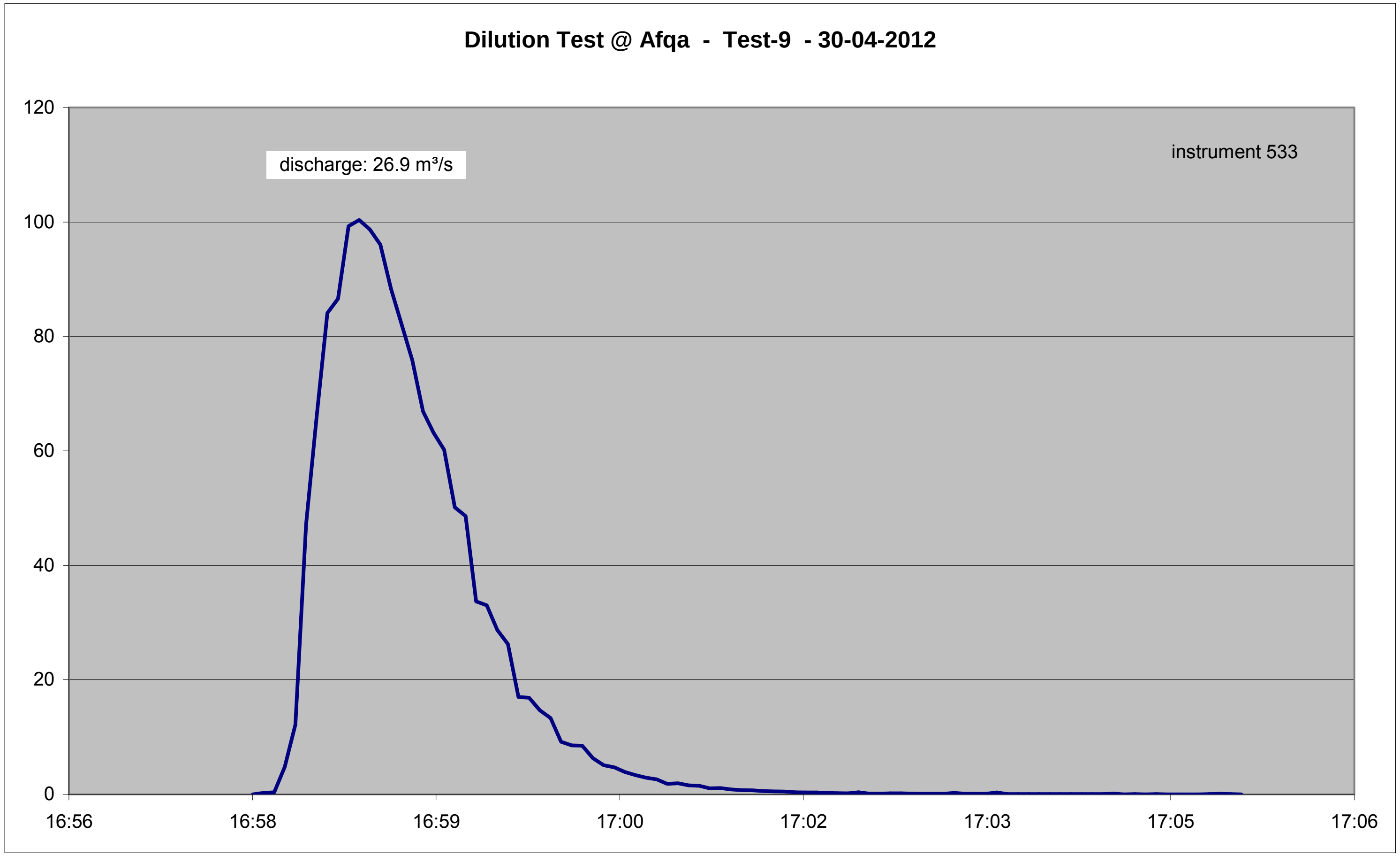


Figure 30: Determination of Discharge at the Afqa branch of Nahr Ibrahim during First Campaign

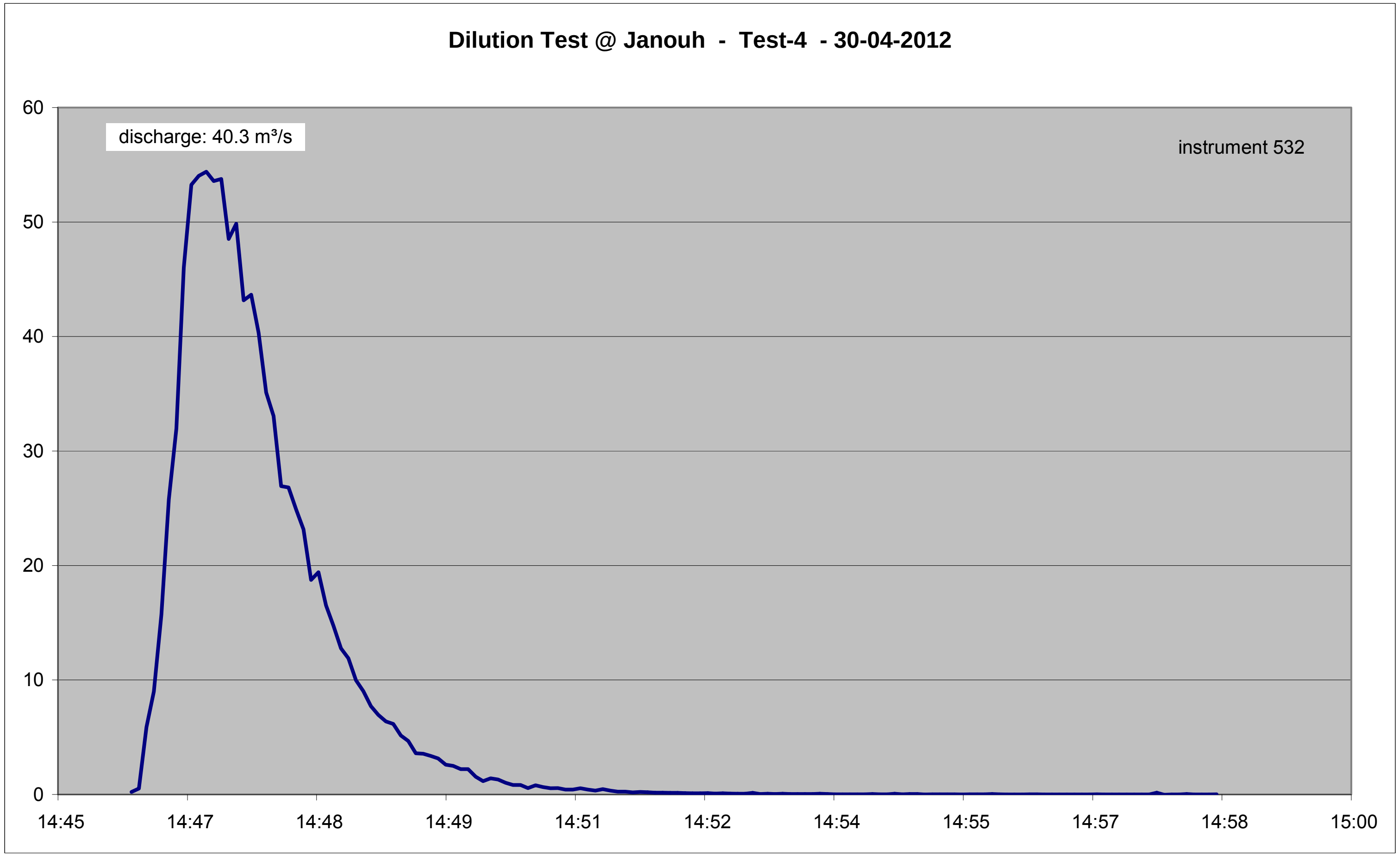


Figure 31: Determination of Discharge at Janouh (approx. 1250 m downstream of confluence) during First Campaign

Quantification of Infiltration Valley into the J4 Aquifer in the Upper Nahr Ibrahim Valley

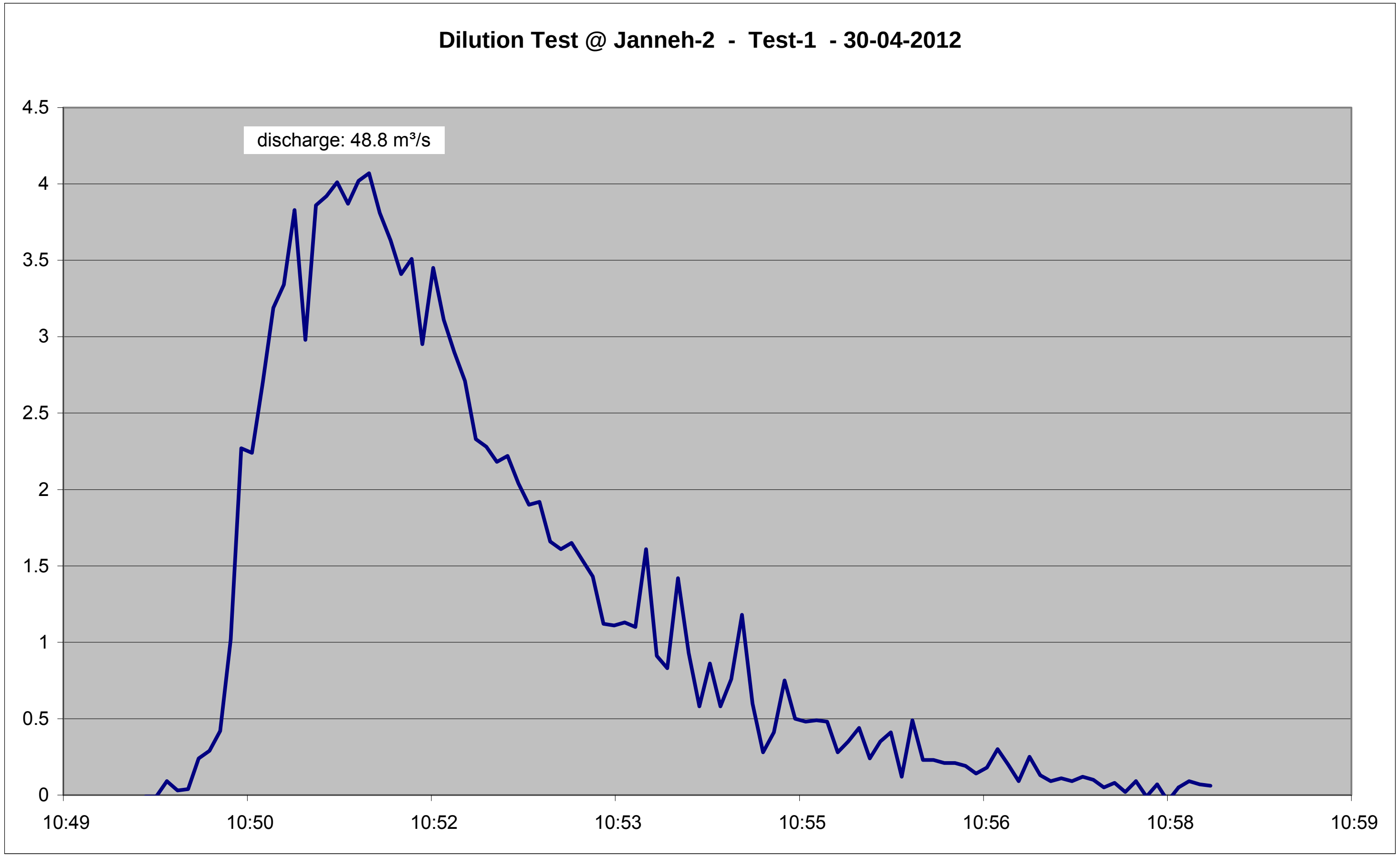


Figure 32: Determination of Discharge at Janneh-2 (approx. 5400 m downstream of confluence) during First Campaign

During the first campaign the following surface water inflows between stations were observed:

Table 7: Inflows during First Campaign

| Between stations | LONG (E) | LAT (N) | Flow ($m^3/s$) |
|---|---|---|---|
| Janneh-2 - Janneh-1 | 35.832467 | 34.079295 | 0.1 |
| Jannouh - Janneh-1 | 35.856117 | 34.087800 | 0.2 |
| Total inflow | | | 0.3 |

These inflows are insignificant compared to the total flow and have no influence on the determination of flows at the individual stations because they were not located between injection and monitoring of the same station. However, for calculation of total infiltration it has to be considered for station Janneh-2.

## *4.2 Second Campaign*

The second discharge measurements were conducted on 16 May 2012. The following injections were conducted (three at each station):

Table 8: Tracer Injections during Second Campaign

| Site | Time | Amount of Tracer (g) | Discharge ($m^3/s$) |
|---|---|---|---|
| Janneh-2 | 09:16 | 50 | 30.1 |
| Janneh-2 | 09:26 | 50 | 28.3 |
| *average* | | | *29.2* |
| *inflow correction* | *0.0* | | *29.2* |
| Janneh-1 | 10:34 | 50 | section inappropriate |
| Janneh-1 | 10:50 | 50 | |
| discharge measurement not feasible | | | |
| Janouh | 12:28 | 50 | 29.3 |
| Janouh | 12:45 | 50 | 28.3 |
| *average* | | | *28.8* |
| Rouaiss | 14:14 | 50 | 21.7 |
| Rouaiss | 14:29 | 50 | 21.5 |
| *average* | | | *21.6* |
| Afqa | 16:00 | 50 | 22.8 |
| Afqa | 16:15 | 50 | 22.6 |
| *average* | | | *22.7* |
| *Rouaiss + Afqa* | | | *44.3* |

Table 9: Infiltration Measured during Second Campaign

| Segment | Infiltration ($m^3/s$) | Infiltration (%) |
|---|---|---|
| Confluence - Janouh | 15.5 | **35** |
| Confluence - Janneh-2 | 15.1 | **34** |

All measurements were conducted with the same instrument (533). The arriving tracer was observed in all downstream stations by other instruments in order to observe tracer recovery and travel times between stations. In all stations the same amount of tracer (50 g) was used in order to make results easily comparable. Injections of 100 g after the first two injections were only done for control purposes at downstream stations.

Injections were done starting downstream and going up in the catchment. Time interval between injections at one station was commonly 15 minutes. In order to be able to separate upstream injections at downstream monitoring sites, commonly between one and two hours had to elapse before starting injections at the next station.

Table 10 shows that mean flow velocities in the upper part of the monitored segment of the Upper Nahr Ibrahim Valley between Rouaiss and Janouh (Joe

Marine) and between Afqa and Janouh are much smaller (1.3 m/s and 1.0 m/s, respectively) than in the lower part (Janouh to Janneh-1: 1.7 m/s; Janneh-1 to Janneh-2: 1.9 m/s). Since the upper sections between injection and monitoring at Rouaiss and Afqa and between monitoring and water falls (beginning of outcrop area) are relatively steep, flow velocities in the segment downstream much be much lower. Especially in the area of the assumed J4 outcrop (Figure 38), where geological dip is towards E to SE, i.e. against the direction of flow in the river, flow velocity must be considerably reduced (probably < 0.5 m/s) because the gradient in the valley is very low.

Quantification of Infiltration Valley into the J4 Aquifer in the Upper Nahr Ibrahim Valley

## Table 10: Mean Travel Times in the Upper Nahr Ibrahim during Second Campaign

Travel times

| | Injection-1 | Injection-2 | Injection-3 | Injection-4 | Injection-5 | Injection-6 | Injection-7 | Injection-8 | Injection-9 | Injection-10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Janneh-2 | Janneh-2 | Janneh-1 | Janneh-1 | Janouh | Janouh | Rouaiss | Rouaiss | Afqa | Afqa |
| | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 9:16 | 9:26 | 10:34:00 | 10:50:00 | 12:28:00 | 12:45 | 14:14 | 14:29 | 16:00 | 16:15 |
| Janneh-2 (arrival time) | | | 10:48:20 | 11:04:50 | 13:08:50 | 13:26:10 | fluorometer defect | | | |
| Janneh-2 (travel min) | | | 14.33 | 14.83 | 40.83 | 41.17 | | | | |
| Janneh-2 (distance) | | | 1670 | 1670 | 4310 | 4310 | | | | |
| Janneh-2 (velocity) | | | 1.94 | 1.88 | 1.76 | 1.74 | | | | |
| Janneh-1 (arrival time) | | | | | 13:00:30 | 13:17:20 | 15:27:10 | 15:41:20 | 17:26:20 | 17:41:30 |
| Janneh-1 (travel min) | | | | | 32.50 | 32.33 | 73.17 | 72.33 | 86.33 | 86.50 |
| Janneh-1 (distance) | | | | | 3307 | 3307 | 6430 | 6430 | 6560 | 6560 |
| Janneh-1 (velocity) | | | | | 1.70 | 1.70 | 1.46 | 1.48 | 1.27 | 1.26 |
| Janouh (arrival time) | | | | | | | 14:56:00 | 15:11:30 | 16:55:10 | 17:10:50 |
| Janouh (travel min) | | | | | | | 42.00 | 42.50 | 55.17 | 55.83 |
| Janouh (distance) | | | | | | | 3400.00 | 3400.00 | 3520.00 | 3520.00 |
| Janouh (velocity) | | | | | | | 1.35 | 1.33 | 1.06 | 1.05 |

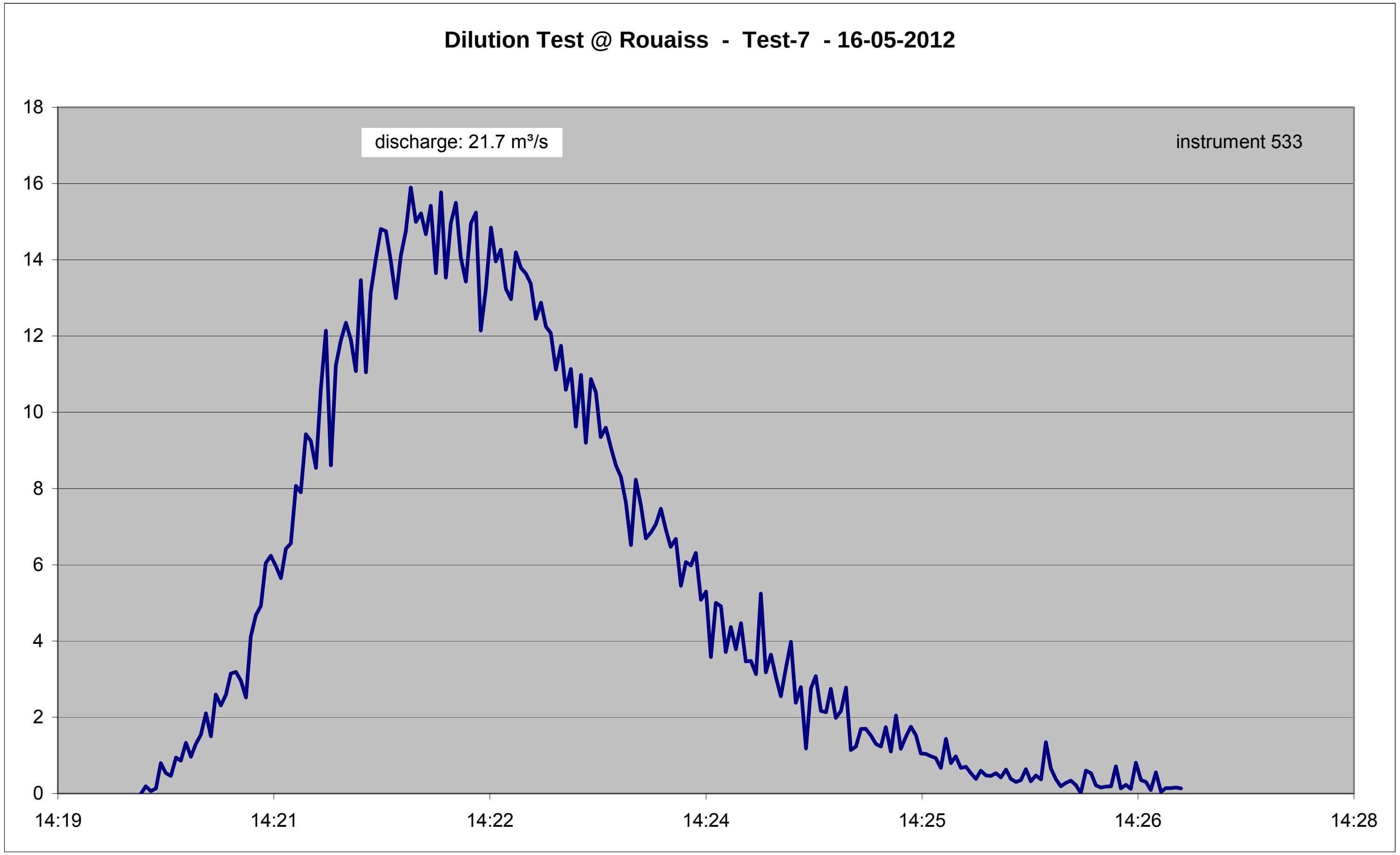


Figure 33: Determination of Discharge at the Rouaiss branch of Nahr Ibrahim during Second Campaign

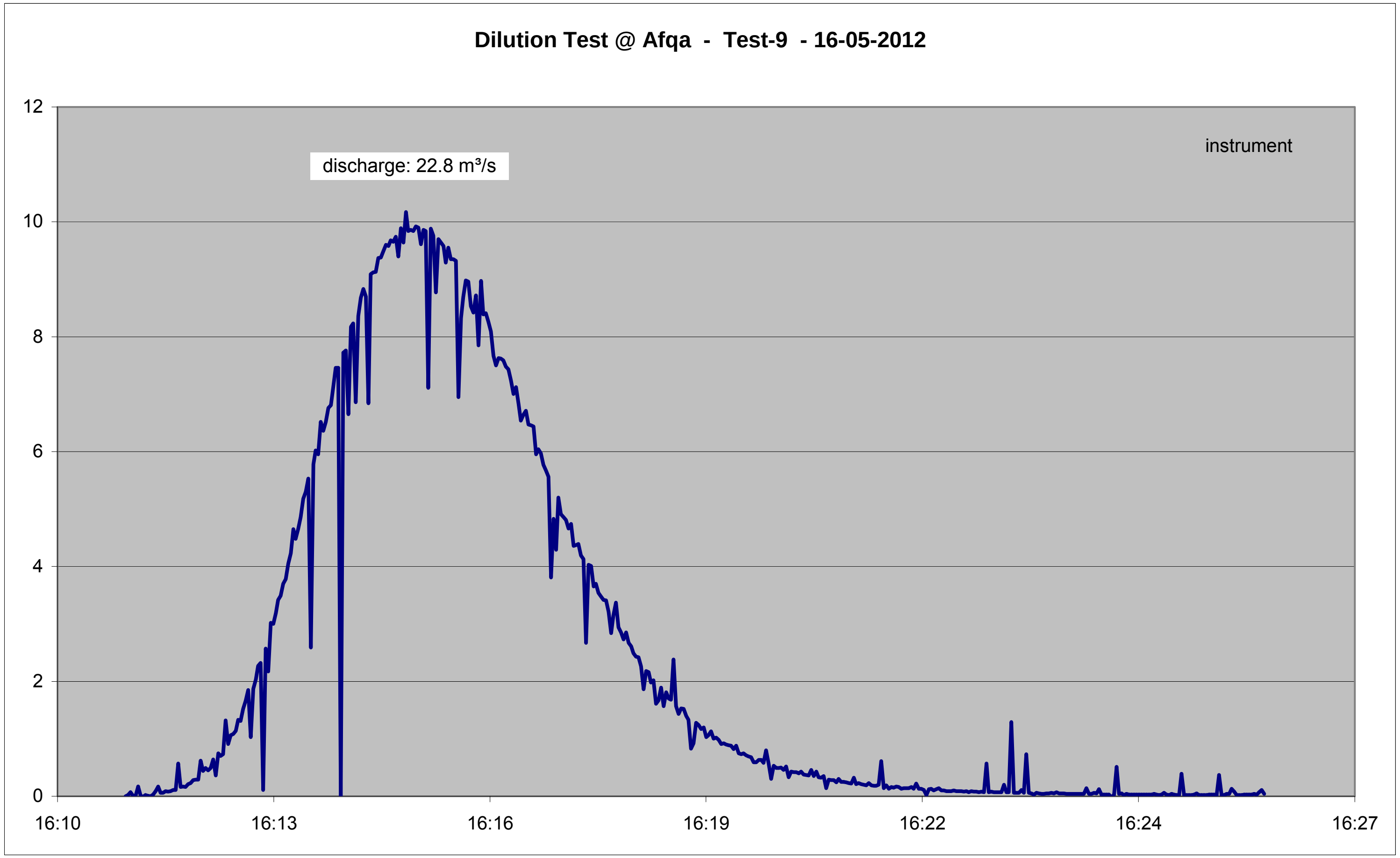


Figure 34: Determination of Discharge at the Afqa branch of Nahr Ibrahim during Second Campaign

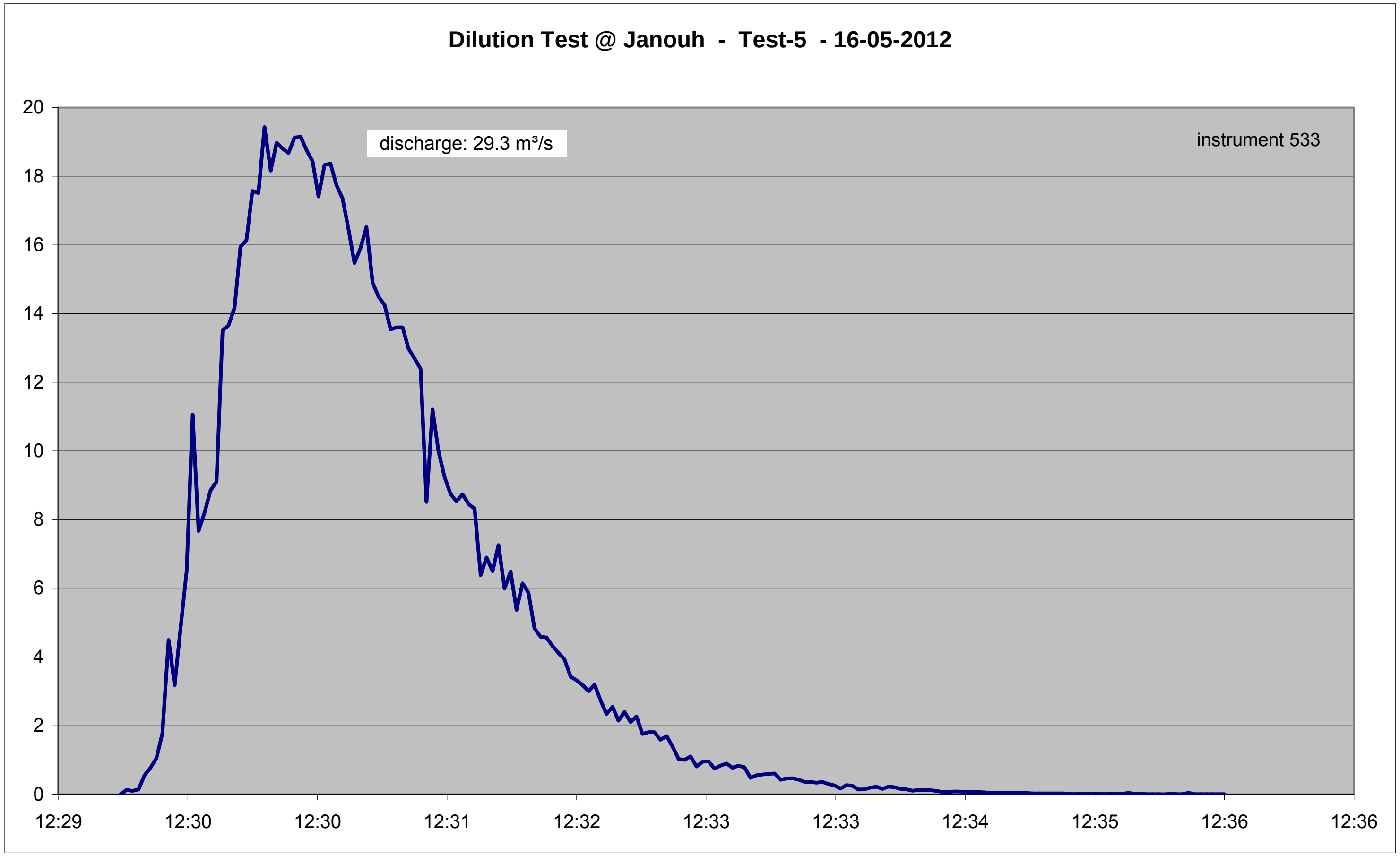


Figure 35: Determination of Discharge at Janouh (approx. 1250 m downstream of confluence) during Second Campaign

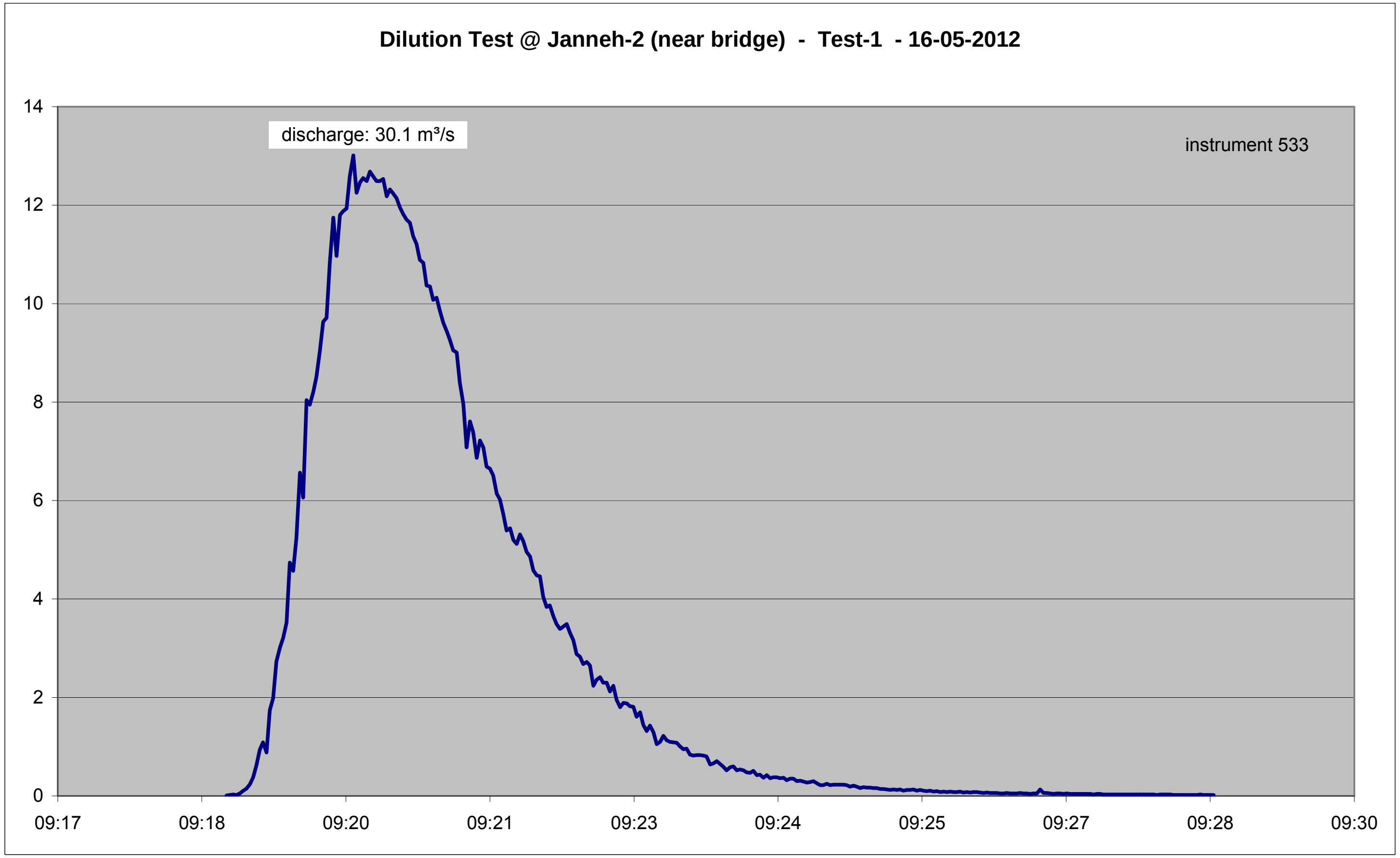


Figure 36: Determination of Discharge at Janneh-2 (approx. 5400 m downstream of confluence) during Second Campaign

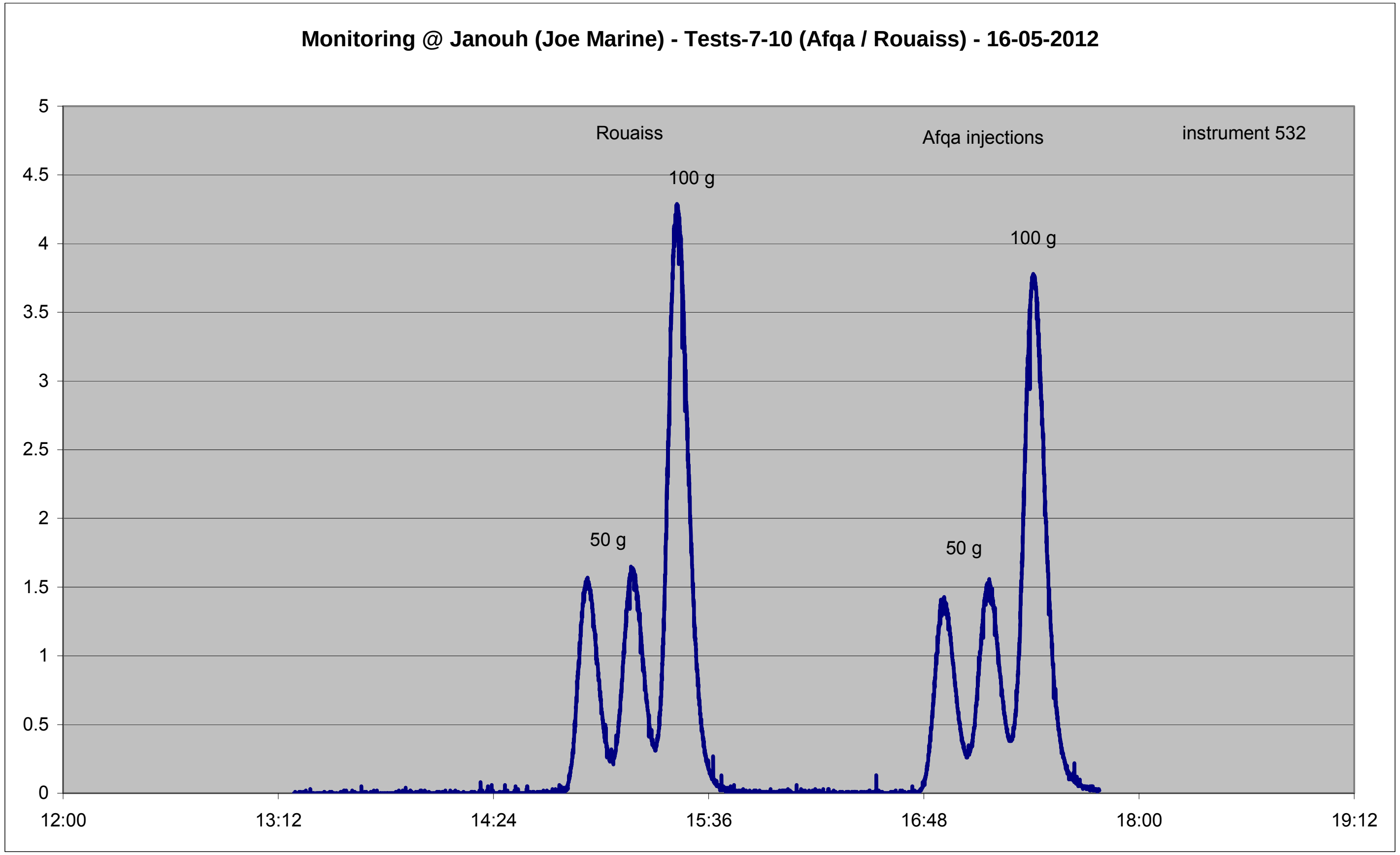


Figure 37: Monitoring of Rouaiss / Afqa Injections @ Janouh (Joe Marine) (approx. 1250 m downstream of confluence) during Second Campaign

## *4.3 Results*

The discharge measurements conducted by the BGR project show that **a very significant infiltration into the Lower Aquifer (J4, Keserwan Formation) occurred during both campaigns in the Upper Nahr Ibrahim Valley** (Table 11). During the first campaign infiltration reached around **40 %**, while it was around **35 %** during the second campaign (Table 12).

No clear statement concerning infiltration between the stations Janouh and Janneh-2 can be made yet. This would require more precise measurements. Using organic dye tracers, those are only possible during low-flow periods.

Further measurements are required during periods of lower flow. The BGR project intends to conduct two more discharge monitoring campaigns for this purpose.

Table 11: Discharge Measured during First and Second Campaign

| | First Campaign Discharge ($m^3/s$) | Second Campaign Discharge ($m^3/s$) |
|---|---|---|
| Rouaiss | 47.0 | 21.6 |
| Afqa | 26.7 | 22.7 |
| Rouaiss + Afqa | 73.7 | 44.3 |
| Janouh | 46.4 | 28.8 |
| Janneh-2 | 40.3 | 29.2 |

Table 12: Infiltration Measured during First and Second Campaign

| Segment | First Campaign Infiltration ($m^3/s$) | Second Campaign Infiltration (%) |
|---|---|---|
| Confluence - Janouh | **45** | **35** |
| Confluence - Janneh-2 | **37** | **34** |

The flow during the first campaign was near its peak. Total flow during the second campaign was 40 % less. Flow velocities during the first campaign (1.7 - 2.2 m/s) were higher and more uniform than during the second campaign (1.0 - 2.1 m/s). It is noted that a **zone of low flow velocity exists near the confluence of the Rouaiss and Afqa branch**, then forming Nahr Ibrahim. In this zone caves are observed and it is clearly identified as an area of high karstification. It stretches from the water falls at the J4 cliff almost to the station Janouh (Joe Marine) **over more than 1 km** (Figure 38) and must be the zone where most of the observed infiltration occurs.

Accuracy of effected discharge measurements was around 10-15 % during the first campaign and 5-10 % during the second campaign.

During the first campaign there was some surface water inflow between stations, while during the second campaign (16-05-2012) inflow was almost zero. There is no influence on the discharge measurements at the stations and only a negligible influence on the monitoring between stations during the first campaign. For calculation of infiltration, measurements were corrected for inflow.

# 5 Conclusions and Recommendations

The results of these measurements proving a massive infiltration into the J4 aquifer in the Upper Nahr Ibrahim Valley (Chapter 4.3) have mayor implications for the currently ongoing planning of the Janneh dam which extends well into the assumed zone of high infiltration. As such measurements are usually conducted in the framework of the planning of dams it is incomprehensible why this infiltration risk was not noticed and investigated before. There are several facts which were not noticed during the investigations for the planning of Janneh dam but clearly identified by the BGR project:

- The uppermost part of the Keserwan Formation (J4) is highly karstified (as almost everywhere in Lebanon);
- There are many caves in the assumed zone of high infiltration;
- Geological dip of strata is towards ESE, i.e. against the direction of surface water flow; water having the chance to infiltrate here would thus foremost be flowing with the dip of the strata, except if major karst conduits allow for a different direction of flow; it is assumed that such large karst conduits have developed here;
- There are numerous major faults in the Upper Nahr Ibrahim Valley; the role of these faults had not been investigated before; at the Janneh-Tannourine fault (left-lateral shear fault) a vertical displacement of up to 800 m is observed, it acts as a hydrogeological barrier because the base of the J4 must be close to the bottom of the valley; the Qahmez fault zone (compressional fault; basalt dyke) also acts a hydrogeological barrier;
- The above mentioned hydrogeological barriers force groundwater in the J4 to flow towards the only area where it can go, towards SW, i.e. towards Jeita.

**In view of the current findings, it is proposed to soundly reevaluate the planning for Janneh dam.**

There is a surprising tremendous lack even of the most fundamental of data in the Nahr Ibrahim Valley, which are commonly a prerequisite for any water resources planning. It is amazing how planning of the Janneh dam could be done without such data.

The existing spring discharge monitoring station at Afqa is not providing useful results because its construction was not correctly done and maintenance was completely neglected. There is no spring flow monitoring station at Rouaiss spring. Thus the potential inflow to Janneh dam could not reasonably be calculated.

It is recommended to establish a completely new monitoring of spring flow at Afqa and Rouaiss springs.

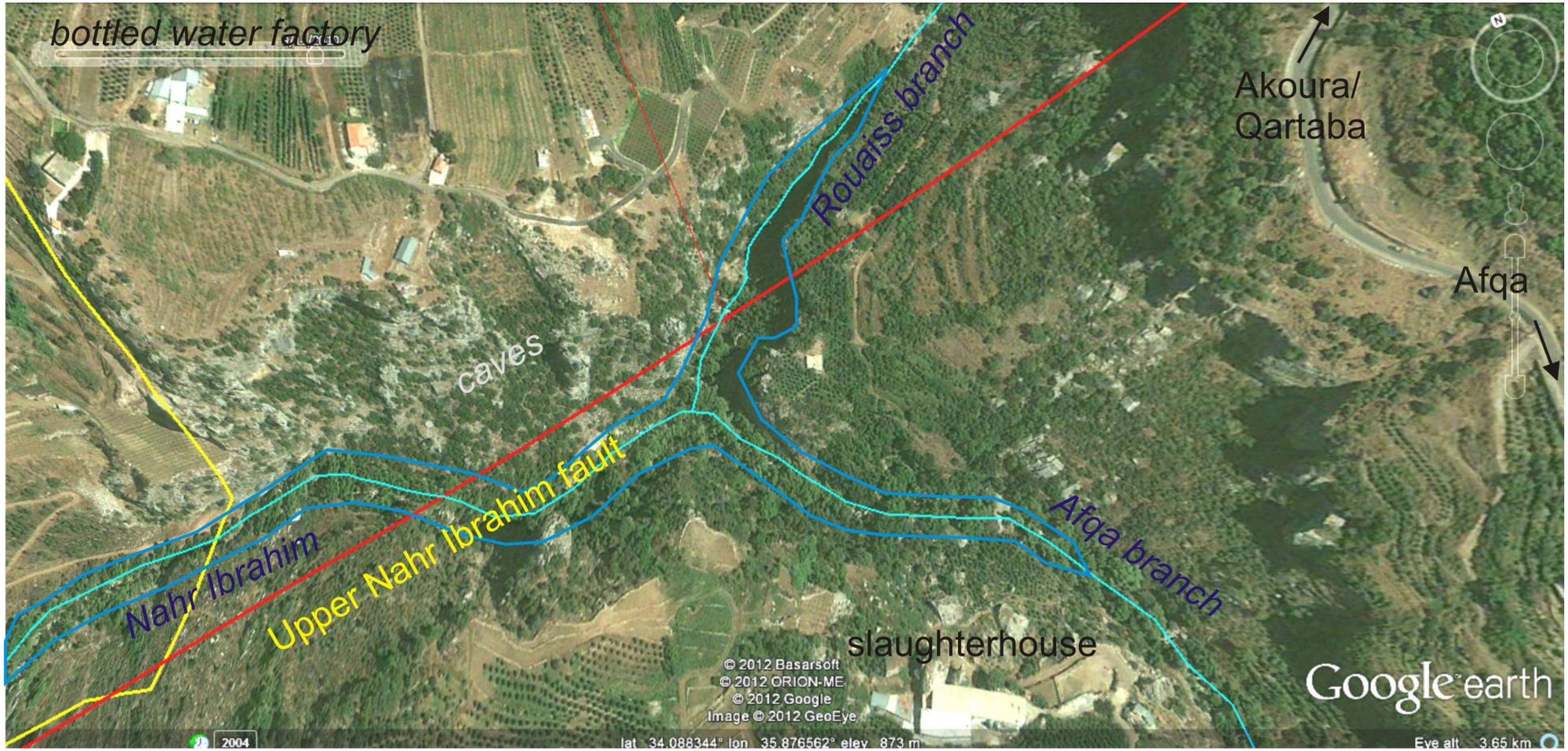


Figure 38: Assumed Main Infiltration Area in the Upper Nahr Ibrahim Valley (near Confluence)

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# Annex: Photos

Photo 1: Caves near the Rouaiss / Afqa confluence (view from Mzarib - Janouh road)

Photo 2: Rouaiss Water Fall near Rouaiss / Afqa confluence (approx. 40 m deep)

Photo 3: Secondary Dolomite near Planned Janneh Dam showing extensive Porosity

Photo 4: Secondary Dolomite near Planned Janneh Dam

Photo 5: Location of Proposed Janneh Dam (view from road to Qartaba)

Photo 6: Intensive Karstification in Uppermost J4 south of Qartaba

Photo 7: Tracer Injection at Afqa Spring